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USING MOHID GIS TO AID HYDRODYNAMIC MODELING IN THE GUADIANA ESTUARY

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Abstract

Hydrodynamic models usually require the management of large quantities of georeferenced information. GIS can help to prepare, manage, analyze and display these data. This work shows how open-source GIS tools can improve the setup of hydrodynamic models. Hydrodynamics and salinity dynamics of the Guadiana Estuary were simulated using the MOHID system. MOHID is an open-source three-dimensional water modeling system. It includes MOHID GIS, which handles spatial and temporal data using specific input and output formats of MOHID numerical models. MOHID GIS also helps to display georeferenced images, convert shapefiles to MOHID ASCII format, produce computational grids (Cartesian and boundary-fitted curvilinear) and interpolate data into a grid. MOHID GIS was used to create and preprocess the model inputs, such as the interpolated bathymetric grid and the time series locations. The curvilinear grid was generated in MOHID GIS for the branched estuary polygon. Python open-source programming language (with GDAL and OGR libraries) was used to preprocess bathymetry data points using extraction of information from orthophoto maps. MOHID GIS was also useful for visualization of temporary variable model results. The model was run under different scenarios, was calibrated and validated using measured data. The calibration and validation process shows that good quality of the spatial input data is critical for having good model results and proves the suitability of the methods proposed to improve the model results.

Keywords: MOHID GIS, Python, hydrodynamic modeling, curvilinear grid, bathymetry, Guadiana Estuary.

1. INTRODUCTION

Estuarine hydrodynamic models usually require management of large quantities of georeferenced information. A Geographic Information System (GIS) can help to store, manage, analyze and display all these data, during the input and the output phases. Many attempts have been made recently to integrate hydrodynamic and pollution transport models with GIS (Sandy, 2009; Tsanis, 2001). GIS is considered to be a very useful tool to help spatial discretization, input data processing and results visualization (Naoum, 2005; Merwade, 2008). However, none of the previous works prove the benefit of using GIS by model validation on real measurements.

The main objective of this presentation is to show how open-source GIS tools can aid the setup of hydrodynamic models and to improve model results. The simulations were performed in a real domain, the Guadiana Estuary. Hydrodynamics and salinity dynamics of this estuary were simulated using a 2D configuration in MOHID Water Modelling System, based on a boundary fitted curvilinear grid.

The Guadiana Estuary is a rock-bound estuary located at the southern Iberian Peninsula, between Portugal and Spain (figure 1). The estuary extends for about 80 km upstream from the mouth and is prolonged offshore by a submerged delta. The estuary has an average depth of about 5 m (Garel et al., 2009a).

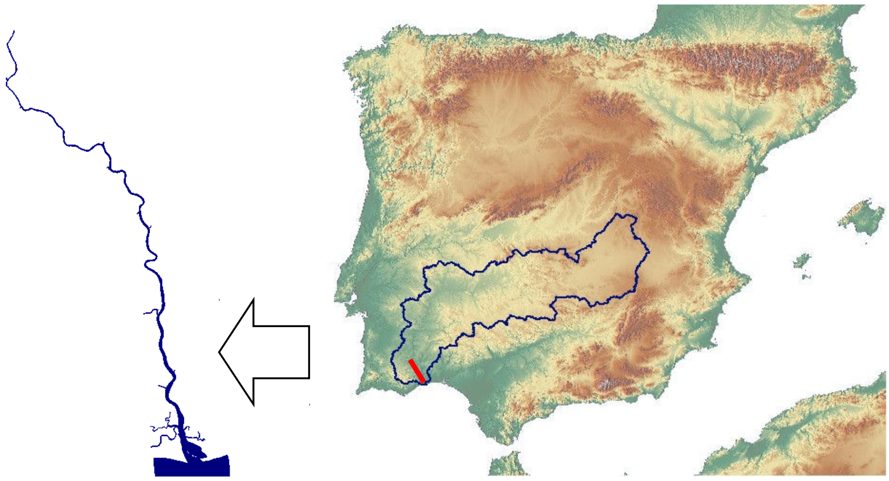

Figure 1. Guadiana Estuary.

MOHID is an open-source three-dimensional water modeling system developed in the Technical University of Lisbon[1]. The MOHID package includes a GIS software, MOHID GIS (figure 2), which handles spatial and temporal data in specific input and output formats of MOHID numerical programs (Braunschweig, 2005). MOHID GIS is written in Microsoft Visual Basic .NET and uses some executable extensions written in Fortran.

2. MODEL SPATIAL DATA

In particular, MOHID GIS helps to display georeferenced images, convert shapefiles to MOHID ASCII format, produce computational grids and interpolate data into a grid. It allows creating and editing vector data. MOHID GIS requires all the data to be in the same coordinate system.

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[1] *http://www.mohid.com*

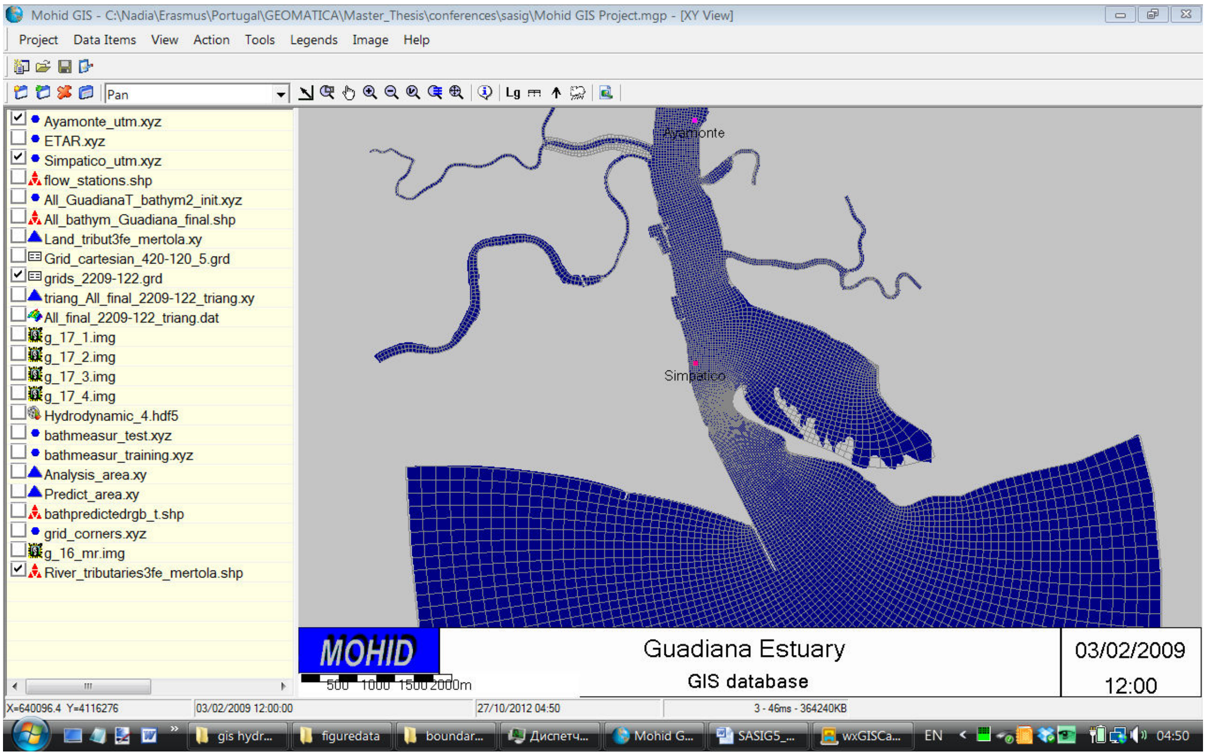

Figure 2. MOHID GIS general window.

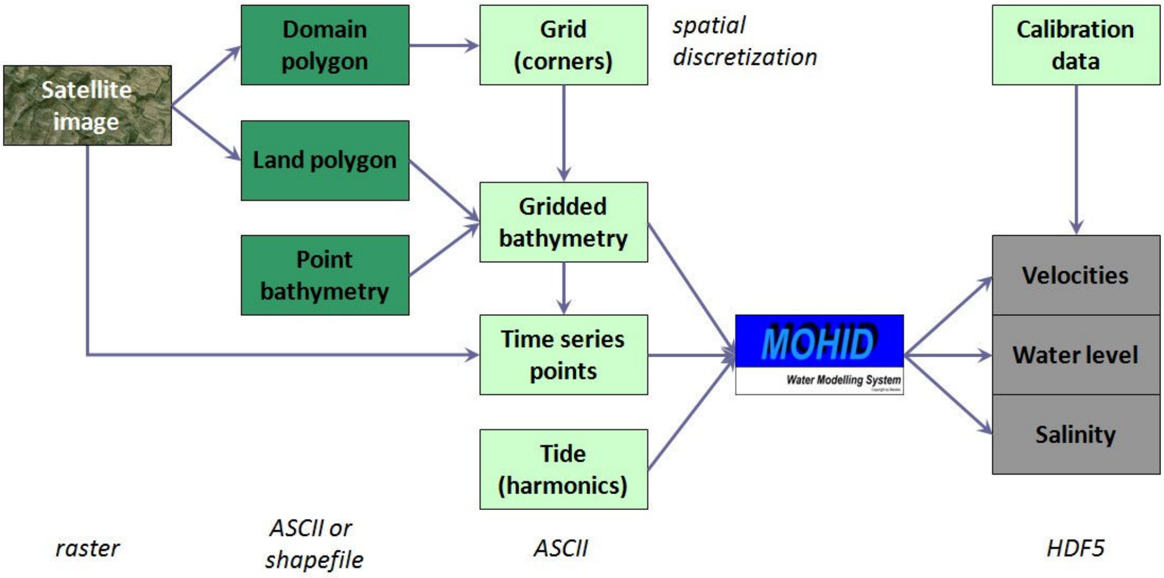

Figure 3. Model spatial data structure.

MOHID spatial inputs and outputs are schematically presented on the figure 3. The figure presents only spatial inputs for a simple hydrodynamic model forced by tide and river flow.

River flow values are temporal data, but located in the certain grid cells. Tidal input is not really spatial in case of one tidal gauge when it is applied to all model boundary, however in case of large areas in the ocean several tidal gauges will be needed in different locations and a spatiotemporal treatment of the data is needed.

Basically, GIS can help in processing all these input datasets. Ususally inputs are gridded field, such as bathymetriesrequiring spatial data of high quality. MOHID GIS can interpolate bathymetry point data into a computational grid, using land polygon presenting non-computing areas.

3. CURVILINEAR GRID GENERATION

A numerical model requires the discretization of the continuous space using a computational grid. Grid orthogonality is important for minimizing computational error. In estuarine models the correct description of the shoreline is a major issue because it influences strongly the results. In the traditional Cartesian grid the shoreline is discretized by steps producing a very rough description of the real geometry. In addition a large number of inactive cells are always present occupying the computer memory and increasing computational time. On the other hand, boundary-fitted curvilinear grids fit the coastline precisely, have few unused grid cells and allow higher precision in narrow parts of the domain and lower precision in the parts of less interest (figure 4). This type of grid is particularly well suited for long and narrow meandering rivers like Guadiana.

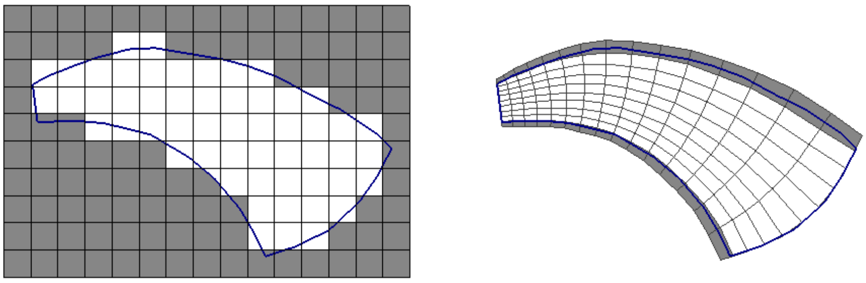

Figure 4. Cartesian grid 15x10 cells and curvilinear grid 15x10 cells.

MOHID GIS contains a grid generator that produces structured nearly-orthogonal boundary-fitted curvilinear grids, based on the cross-ratios of the Delaunay triangulation (CRDT) algorithm (Driscoll and Stephen, 1998). Producing such grid requires a meshing domain polygon, which must follow the shoreline shape. Data for domain polygon can be obtained from the open data archives like NOAA's National Geophysical Data Center, or can be created manually as a vector feature over satellite images. MOHID GIS allows displaying satellite images as a background, and to create and edit vector data (lines, points, polygons) in MOHID ASCII format. This format presents a list of X,Y coordinates with a specific keyword in the beginning and at the end. A curvilinear grid file contains the list of cell corner coordinates (in the sequential order with the code -9.9e+15 for unexisting vertices), information about georeference and the number of rows and columns (figure 5).

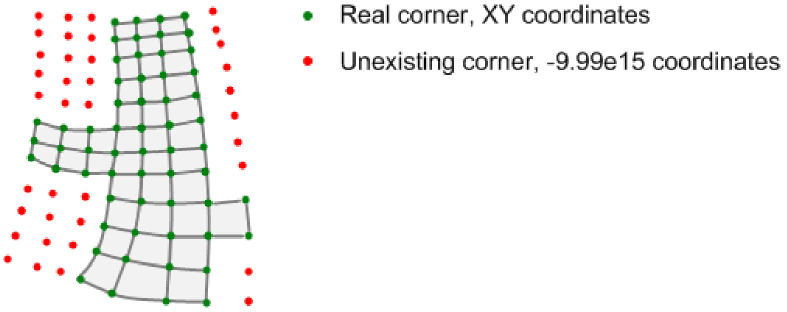

Figure 5. Curvilinear grid structure.

To generate a curvilinear grid the boundary polygon must have a defined topology, namely marked vertices of the polygon representing “corners”. Vertices can be Right turn or Left turn, and the number of marked vertices in each part of the polygon must be equal to the number of corners of the corresponding rectangle (figure 6). Therefore`, simple river channel must have only four Right corners, but a branched estuary should have a very complicated corner definition. Islands are not allowed for grid generation.

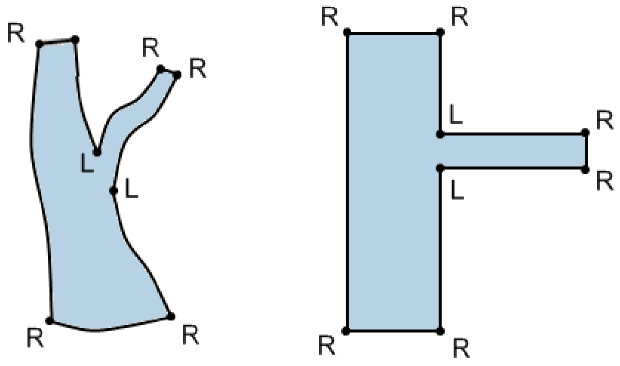

Figure 6. Domain polygon topology.

The Guadiana Estuary has a very complex branched shape. MOHID GIS provides the tools for editing and defining corners of the domain polygon, but the decision on how to define these corners to obtain a grid which will perfectly represent the geometry of the estuary is more of an art than a science.

Many attempts were performed and many issues resolved before an acceptable good curvilinear grid was obtained for the Guadiana Estuary. The biggest problem was the breakwater at the mouth of the estuary. For correct modeling the grid cells covering the breakwater must be marked as land, but it is very narrow and prolonged far offshore, and the grid needs to describe it precisely. Figure 7 shows the main steps of improving the domain polygon and the resulting grid. The first grids described the breakwater shape very roughly, and only the last attempt produced the cell size comparable to its width and the grid direction following it.

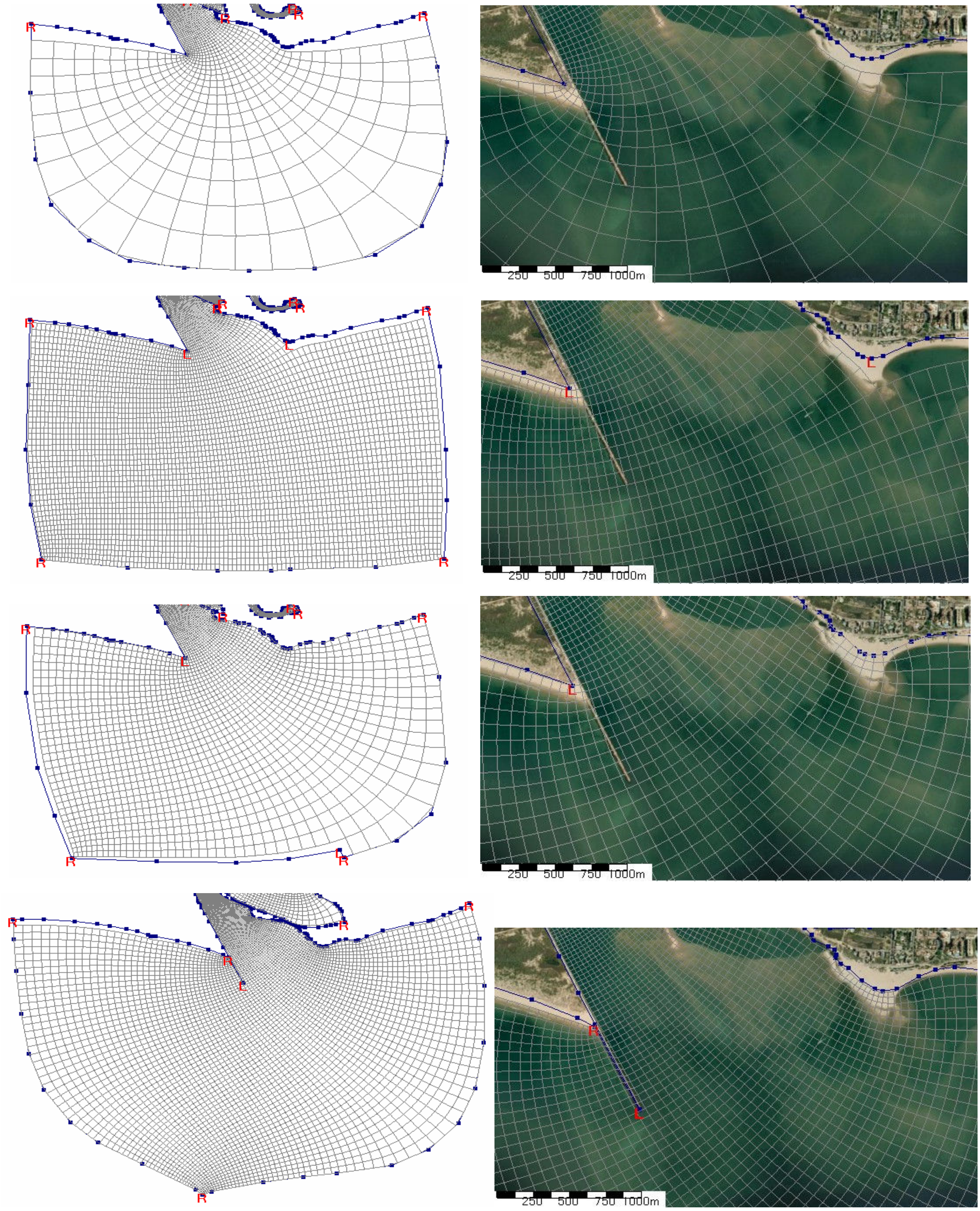

Figure 7. Domain polygons and grids.

Other difficulties were representation of tributaries, ports and tidal flats (figures 8, 9).

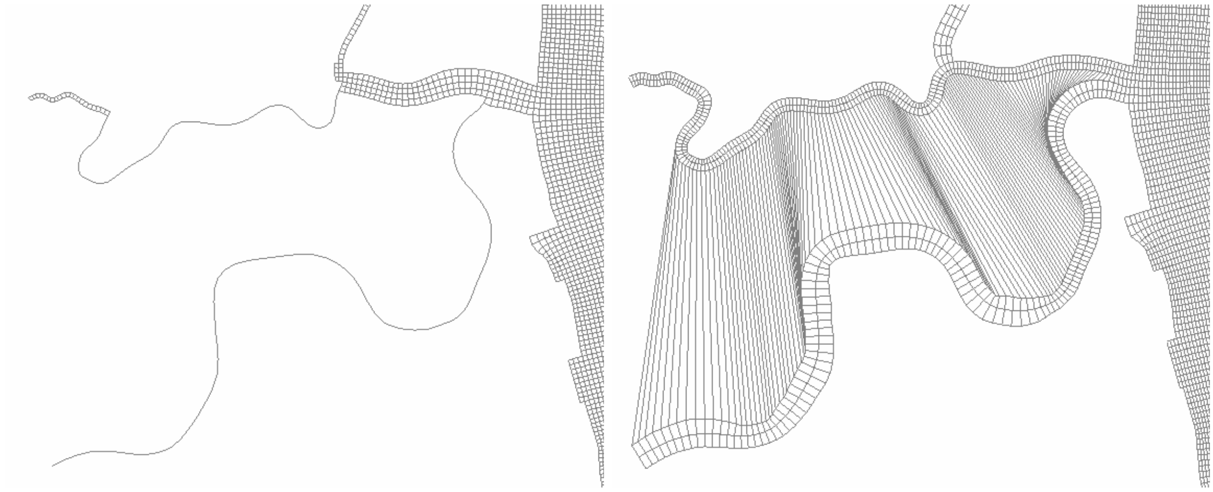

Figure 8. Errors in tributaries.

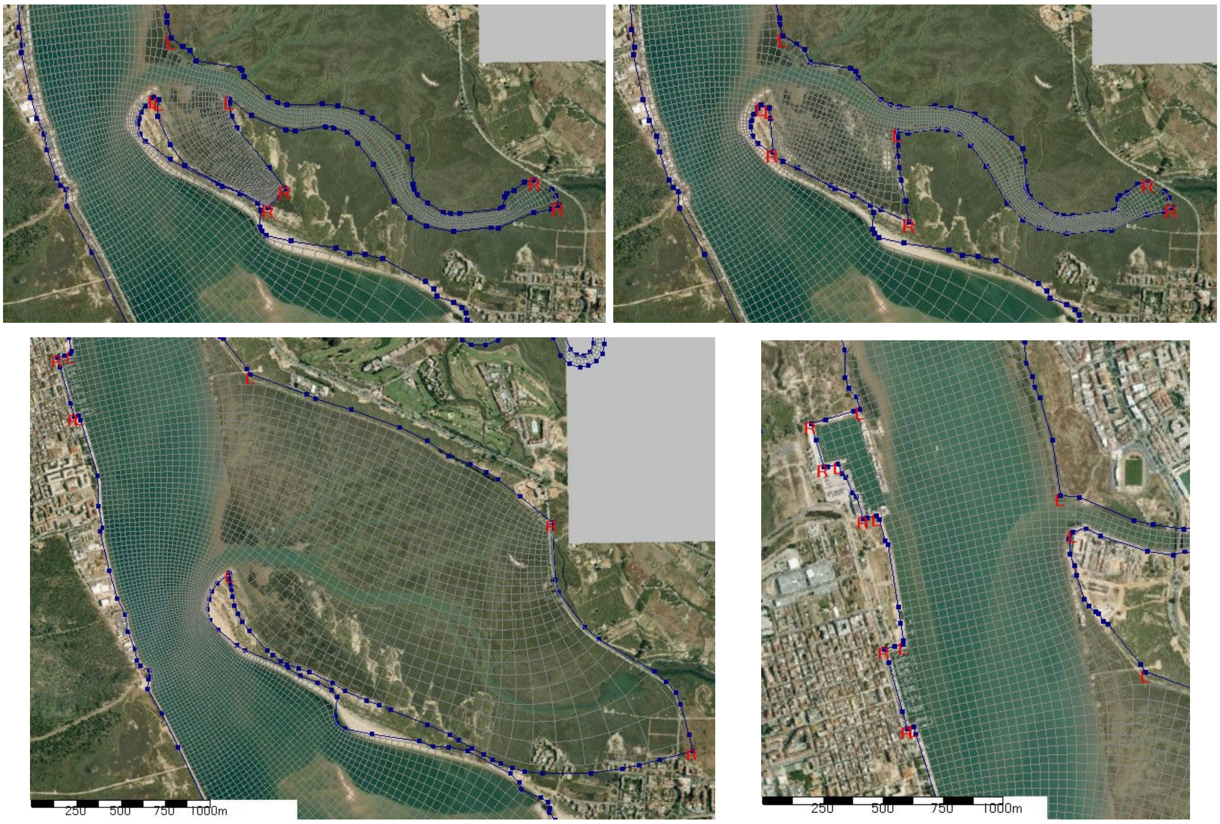

Figure 9. Tidal flat and ports.

The final curvilinear grid is presented on figure 10.

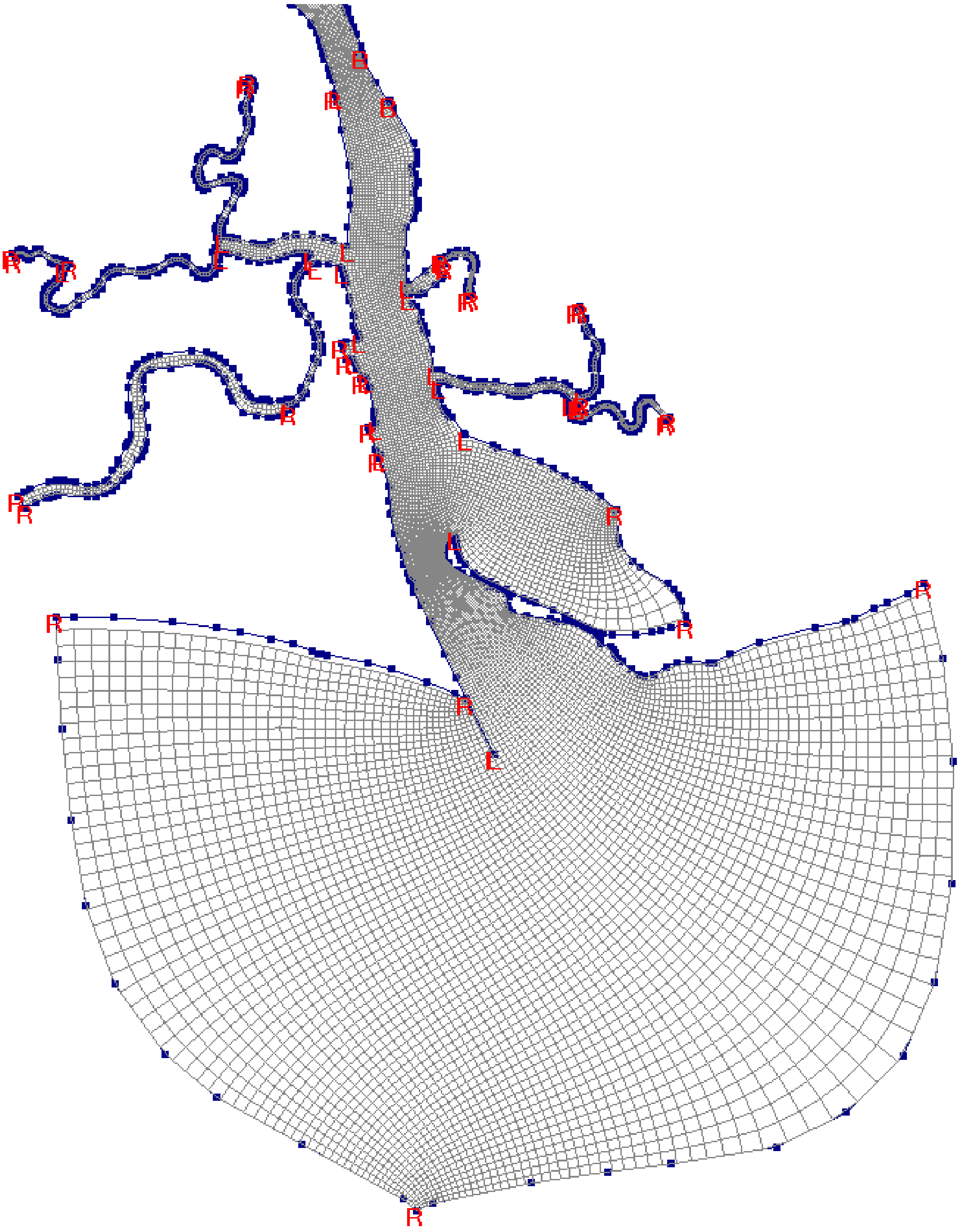

Figure 10. The final grid.

4. BATHYMETRY PREPROCESSING

4.1 ESTIMATING BATHYMETRY

Python open-source programming language (with GDAL and OGR libraries) was used to preprocess bathymetry point data using extraction of information from orthophoto maps.

Sonar surveys always display gaps in the shallowest parts of the coastal waters. Such areas are very dynamic and often experience quick and significant changes in bottom shape, so acquired data become old rather quickly. Since the water is usually clear and the depth is small in those areas, sunlight reflected from the bottom can be detected by a satellite or aircraft. The recorded light intensity depends mainly on the water depth, attenuation coefficient for its wavelength in this water, and the reflection coefficient of the bottom. Thus it is possible to extract water depth information from orthophoto maps of clear shallow areas. This possibility has been examined by many authors for about 40 years (Lyzenga, 1978). Most of the authors prefer determining water depth from multispectral satellite imagery by complicated equations based on optical laws. However, all those equations have several parameters to be tuned empirically using known bathymetry points. These tunable coefficients partially represent attenuation and other local water properties. Generally, the relationships between depth and optical signal are sensor and site specific (Stumpf, 2003). So, in this work bathymetry was estimated from the orthophoto maps by simple statistical method using correlations between existing data and spectral band values. Image obtained from Google Maps was selected due to high water clarity. The bathymetry points for the analysis were chosen in the clean shallow area, with values shallower than 8 m depth, where the relation between bathymetry and color was strong (figures 11, 12). A script in Python (using GDAL and OGR libraries) was developed to read georeferenced raster cell values correspondent to the bathymetry points. Light attenuation exponentially growths with increasing depth. So, the log-transformation for the bathymetry values is used to achieve the linear relationship between bathymetry and bottom reflectance (Lyzenga, 1978).
A multiple linear regression was performed for the three bands in the form of the following equation using R program (R Development Core Team, 2010).

$$\textit{Transformed bathymetry} = a + b * R + c * G + d * B$$

where: R, G, B – red, green and blue digital numbers of pixels, a, b, c, d – coefficients.

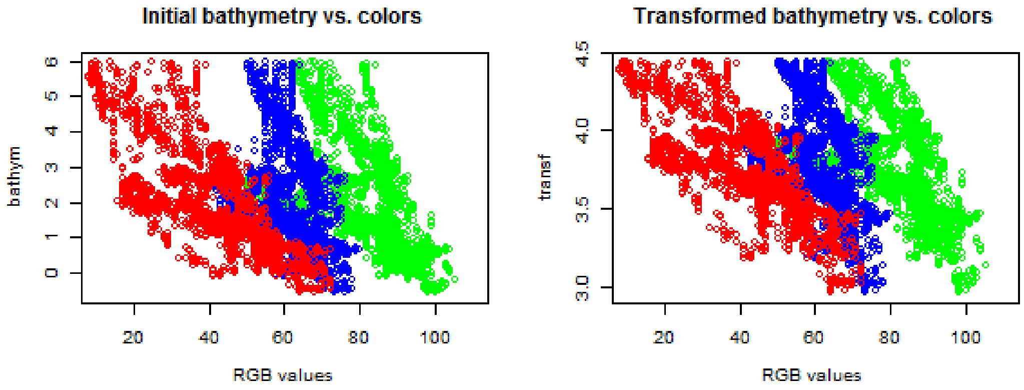
Initial bathymetry vs. colors
Transformed bathymetry vs. colors

Figure 11. Relationships between bathymetry and color intensity.

Then the result was returned to the normal bathymetry scale by inverting the transformation.

The bathymetry data were separated into two subsets: 75% for regression and 25% for accuracy evaluation. R-squared of the regression was 0.73 and RMSE was 0.6 m. The regression result was used for determining bathymetry in the data-missing areas. The point locations for bathymetry estimation, shown in figure 12, were selected in very clean shallow areas (marked by the pink outline) at the centers and corners of cells of the computational grid.

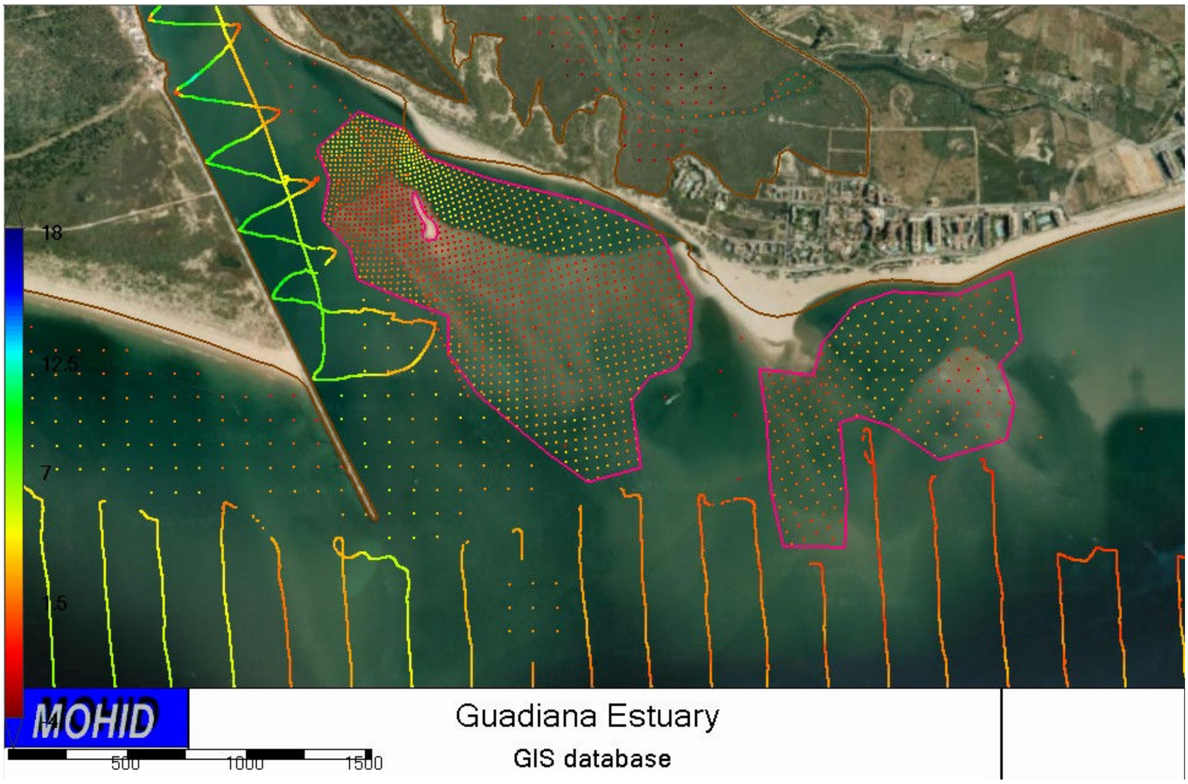

Figure 12. Estimated bathymetry.

The values of estimated bathymetry are very close to the topographic zero at the points located almost on the shoreline, increasing the confidence in the method.

4.2 INPUT GRIDDED BATHYMETRY

MOHID GIS was used to create and preprocess the model inputs in the required format, such as the interpolated bathymetric grid and the time series locations.

The final computational gridded bathymetry was interpolated by triangulation in MOHID GIS (figure 13) from the bathymetry points into the curvilinear grid. Points on the shoreline were added into the final bathymetry dataset to keep the interpolation until the land.

The time series point locations were created at the locations of real measurements in the estuary, such as Sympatico (Garel, 2009b), based on the correspondent cells of the gridded bathymetry.

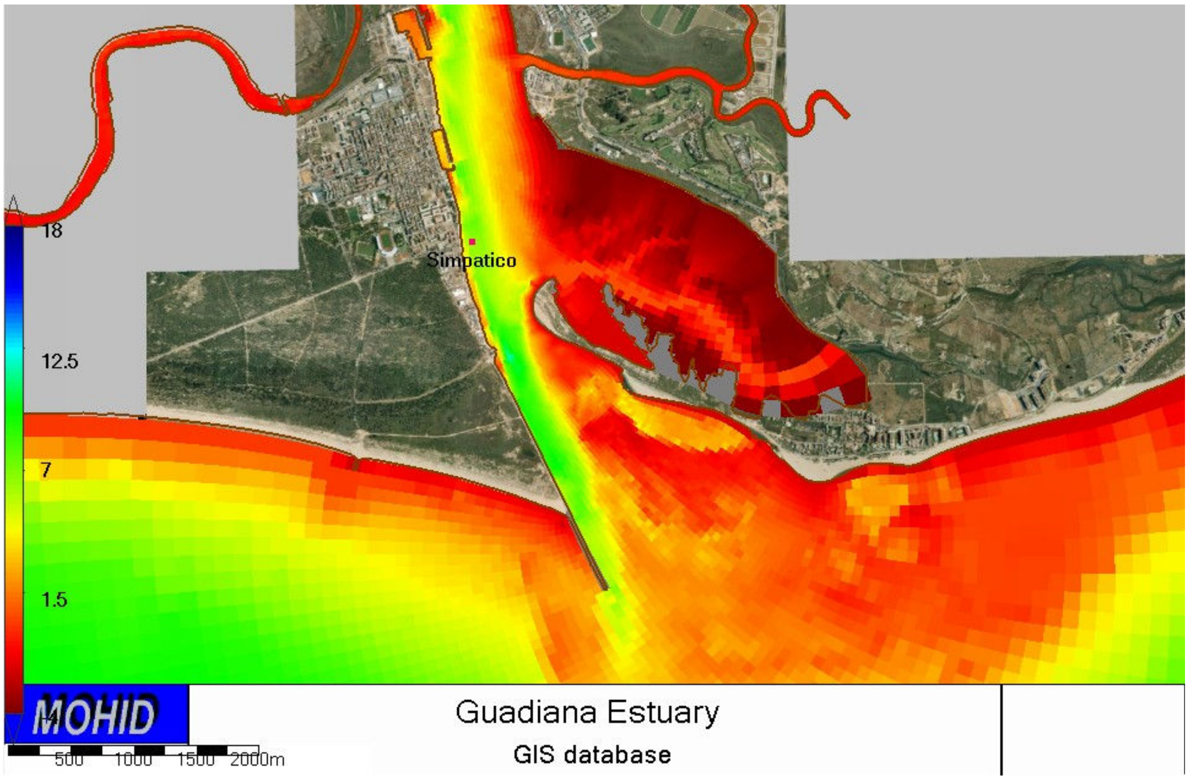

Figure 13. Gridded bathymetry.

Finally the interpolated bathymetric grid was corrected in several locations in a try-and-error process to produce better model results. This was done using MOHID GIS which has the advantage of allowing manual change of values of particular grid cells, which is not possible in many other GIS programs.

5. MODEL RESULTS

5.1 VISUALIZATION

MOHID GIS was also useful for visualization of temporary variable model results. It allows to see animated maps of the time-dependent spatial variables in HDF5 format. Figure 14 shows velocity modulus for the ebbing and flooding parts of the tidal cycle.

The low tide picture shows some cells getting dry in the mouth at the top of the sandy bank. It proves the benefit of the estimation of bathymetry over this bank, because old and sparse data points for this place resulted in wrong location of drying in that old model result.

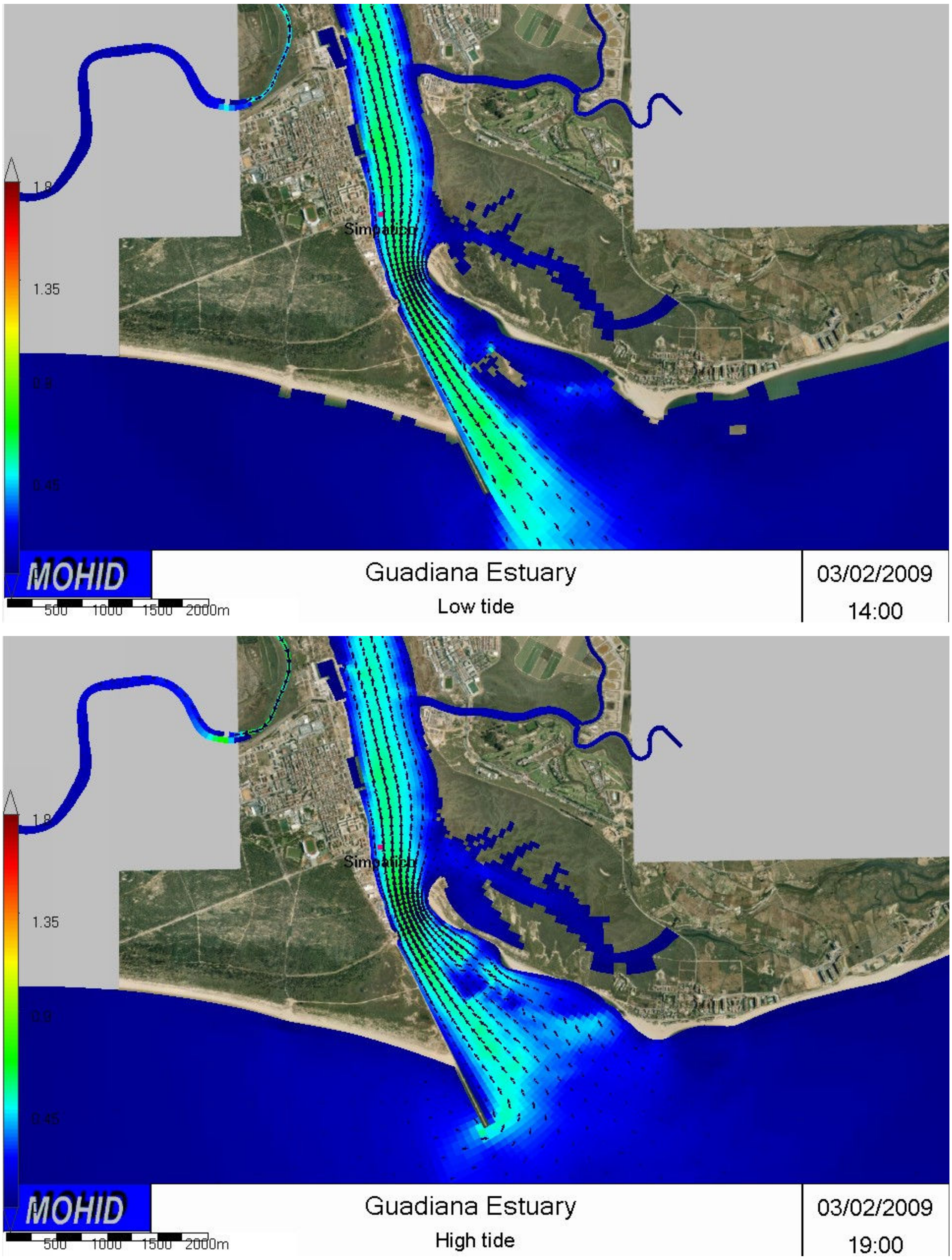

Figure 14. Model results.

5.2 VALIDATION

The model was calibrated using the time series of the variables produced at the several locations of real measurements in the estuary.

The model was run under different scenarios and then validated using the measurements at the point location of the Sympatico system (Garel, 2009b). The results were in the good agreement with the measurements (figure 15), and there was some visible improvement for the GIS-processed model comparing to the simple model, despite of the location of the Sympatico is rather far from the mouth.

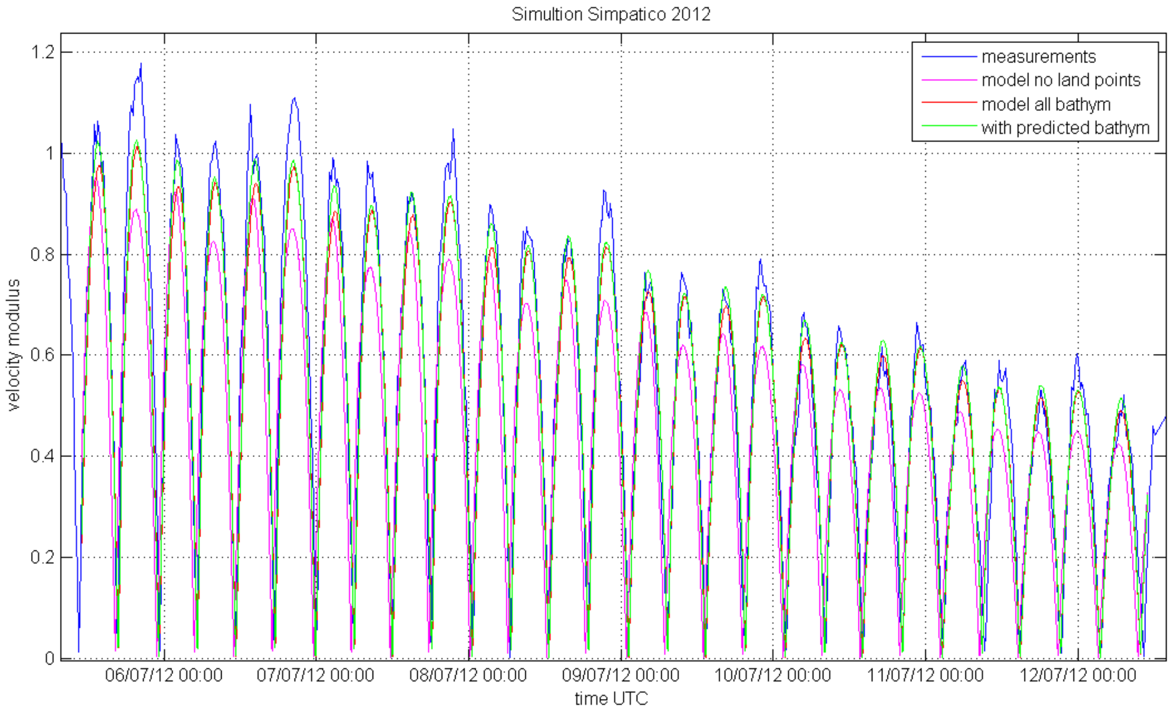

Figure 15. Validation plot.

6. CONCLUSIONS

Open-source MOHID GIS is very useful for handling the hydrodynamic model data, in particular for creating and preprocessing the model spatial inputs. And it is also useful for visualization of temporary variable model results. MOHID GIS has several specific functions strongly needed for modeling activities and not available in many proprietary GIS softwares. Programming in open-source languages also offers great opportunities for improving the model inputs.

The validation process showed that good quality of the spatial input data is critical for having good model results and proves the suitability of the methods proposed to improve the model results.

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