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Study of ocean circulation by coupling with global ocean model

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***Abstract*—Most of the marine coastal models represent only the tidal currents. However, in many parts of the world, the coastal circulation is also driven by the global currents which are linked to climatology and atmospheric circulation. s. Through various studies around the world, and step by step, ARTELIA has developed a methodology to integrate the global circulation in TELEMAC numerical models; this methodology has evolved progressively according to data available and the requirements of the studies: port facilities, coastal development, cooling water systems, maritime renewable energy....This paper describes the methods and their evolution.**

I. Introduction

At the beginning, the global currents were only integrated as a flow rate at the TELEMAC model lateral boundaries. Then, a coupling with global ocean models has been implemented. This coupling involves the currents but also the salinity and the temperature. To have a good representation of the surface phenomena, the atmospheric forcing (wind stress, pressure field…) had to be added. The description of these developments is presented below in the context of the study site and its specificity.

II. Surface Flux

The model has been developed in the framework of the construction and exploitation of a large scale transhipment containers terminal in the Republic of São Tomé e Príncipe. The area of the project has been selected by taking into account from one side, the existence of the deep-sea canyon which allows large draughts vessels to call and from the other side, the natural protection constituted by the island of São Tomé from major oceanic swells from SW and SE.

Currents in São Tomé, and more generally in the Gulf of Guinea, are marked by a variability occurring over wide ranges of time and space. The São Tomé island is located at the boundary area between the South-West Guinea current at the North and the West-North-West equatorial current at the South. Due to some seasonal fluctuations, this boundary is not constant. The variability of the current is due to the fact that it is essentially driven by atmospheric forcing and by seasonal changes in equatorial wind stress fields. Wind fields are directly related to the position and the intensity of the semi-permanent high pressure system in the South.

The study of the ocean circulation is based on the use and evaluation of a 3D local model of the Sao Tomé island. Boundary conditions of this local model have been determined by other models built on a regional scale.

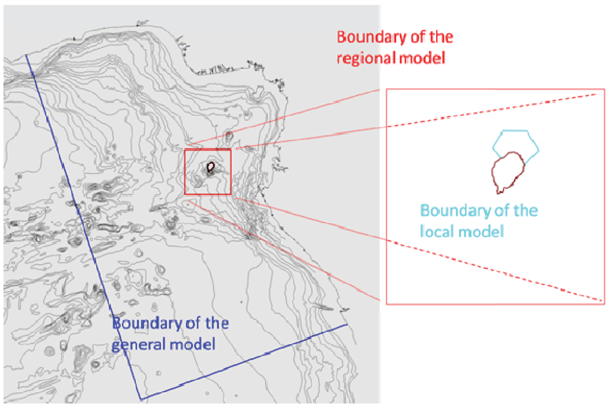


Figure 1 - Boundary of the general and regional model

To represent seasonal scenarios, combining the tidal effects to the global and local wind-driven currents, the sea level variations and tidal currents are computed by a specifically developed tidal hydrodynamic model. In order to add the global circulation currents to the tidal sea surface variations and currents, another model with nested grid has been built. This intermediate model integrates all the phenomena at these boundaries. This model, firstly build in 3D, has been simplified in 2D.

Finally, the local 3D model integrates the bathymetric data established from the survey around the site of the project and in particular those which describe the canyon and the water level and fluxes boundary conditions for the local model are transferred from the output of the intermediate model.

For the thermal and salt transport, only the local model is used. The initial and boundary conditions are based on the surveys and the wind data of the in-situ measurements in "Ilheu das Cabras" are applied as boundary conditions over the whole sea surface.

We have calibrated the hydrodynamic model on the results of measurements by tuning the bed resistance (which is not the dominating parameter for these depths), the eddy viscosity and the wind friction factor. We have put damping functions inside the vertical viscosities, for the velocity and the tracers, to take into account of the impact of the stratification (thermal and saline stratification) on the results.

The time series of surface and bottom currents simulated by the model are calibrated against available in-situ measurements obtained from three stations (Figure 2). At the end of the tuning process, we may conclude that, in spite of some minor deviations, the agreement between the simulation results and the measurements is very good in general. So, we have assessed that the local model is calibrated successfully on the week of measurements and that the selected calibration parameters are the best compromise to reproduce the various hydro-meteorological situations simulated.

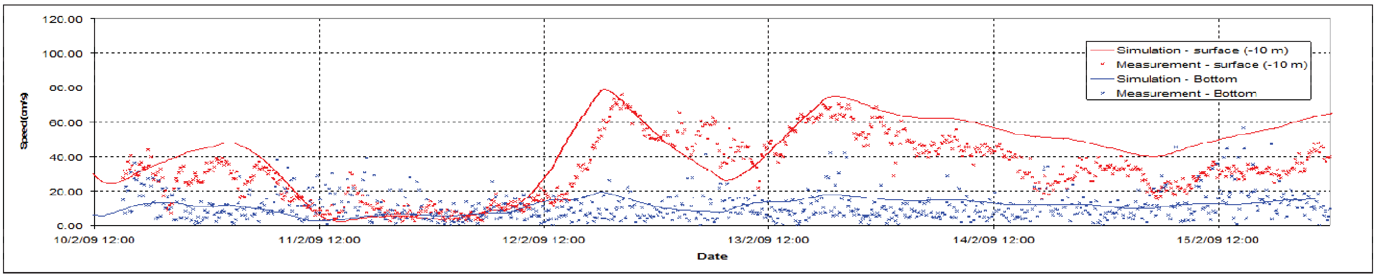


Figure 2 - Comparison model/measurement at surface (red) and bottom (blue)

III. Global currents

A. General description

In order to have a better representation of the currents in the areas where the global currents are predominant, it was decided to take them into account as input in the hydrodynamic model.

An ocean current is a continuous, directed movement of seawater generated by forces acting upon this mean flow, such as breaking waves, wind, the Coriolis effect, cabbeling, temperature and salinity differences, while tides are caused by the gravitational forces of the Sun and Moon. Depth contours, shoreline configurations, and interactions with other currents influence a current's direction and strength.

Since 2010, ARTELIA has fulfilled several hydrodynamic study in the Guinea gulf area. Thus global currents have been investigated in order to understand the circulation around the study area and then to provide input data into the model. Indeed, currents along the Guinea gulf coast are mainly driven by these complex global currents.

Analysis of currents implies a preliminary study of global currents in the Guinea Gulf. Indeed, even if these big ocean currents evolve offshore, they create global currents which can affect the local hydrodynamic at the superficial layers (0-100m).

In this area, global flows are complex and closely linked to climatology. On the one hand, atmospheric circulation (wind, rain, heat exchanges, anticyclonic cells …) generates currents, on the other hand, heat accumulated by the ocean in this area influence climate through marine currents.

B. Global currents in the Guinea Gulf

Main global currents, offshore the study area, are showed on Figure 3.

- The **South Equatorial Current (SEC)** is directly created by trade winds. It is a warm current going from east to west with a velocity between 0.2 to 1 m/s. Its maximum value appears during austral winter because of the Saint Helens anticyclone. It is found near the equator but its situation can move. The South Subtropical Current (parallel to the SEC) goes in the same direction (through the west) and is situated lightly south. The difference between these 2 currents is not clear.
- The **North Equatorial UnderCurrent (CCEN)** is situated on the north side of the equator. It evolves according to the Intertropical Convergence Zone (ITCZ) which corresponds to the part of the earth near the equator where atmospheric flows of the 2 hemispheres come together. Structure and position of this area evolves every day. It is stronger during austral winter.
- At the east, the North Equatorial Undercurrent gives birth to the main current of the Guinea Gulf: the **Guinea Current (GC)**; it flows easterly along the Guinea coast of the West Africa. Its mean speed is about 0.6 m/s, with a minimum value of about 0.25 m/s during austral summer (January - February), and a maximum value able to reach 1.5 m/s in austral winter (June – July). At the end of the Biafra Bay, it goes south to be partially integrated in the South Equatorial Current. Its extent is about 150 miles offshore with a thickness around 20 to 30m. Strong winds from North-East to East can create a switch of this current.

The limit between the Guinea Current and the South Equatorial Current is an area where; whirls, eddies appear.

- At the level of sub surface layers, complex circulations exist. The **Equatorial UnderCurrent (EUC)** is the main flow; it goes easterly in the opposite direction of the SEC (bellow 100m depth). In the Guinea gulf, it divides into 2 branches: one through the south (which supplies the Congo-Gabon UnderCurrent) and the second one through the north towards the Biafra Bay which leads to the **Guinea UnderCurrent (GUC)** heading to the west. The size of these 2 branches is not well known because it depends on the position of EUC and its whirls near Sao Tome which evolve. During austral winter, EUC velocity reaches its maximum.

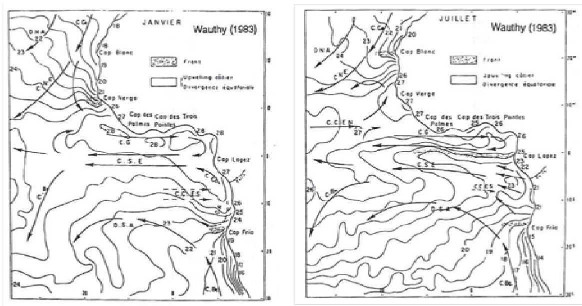


Figure 3 - Temperature and surface flow in January (austral summer) and July (austral winter)

C. Global model

Global Currents in the Gulf, which is one of the input data for the local hydrodynamic TELEMAC-3D model, have been derived from the MyOcean Products.

The MyOcean services provide information of currents, temperature, salinity on the Global Ocean, based on a combination of space and in situ observations and their assimilation into models.

For the present study, daily data of currents, temperature and salinity have been downloaded at a large scale and at various depth. They come from an operational Mercator global model analysis and forecast system which spatial resolution is at 1/12 degree horizontally and temporal resolution daily. The vertical discretization is composed of 50 layers (22 levels for the upper 100m).

Once the analysis is done, some of these data have been used as boundaries conditions for the hydrodynamic model.

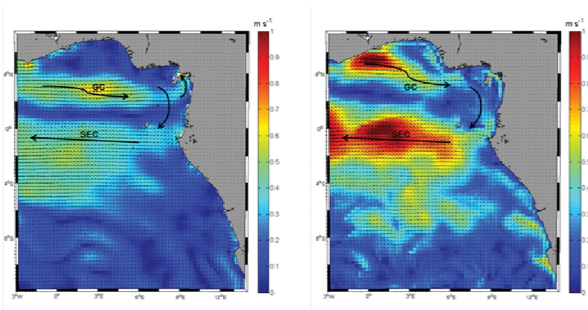


Figure 4 - Maps of global currents in the Guinea Gulf in February (left side) and July (right side)

Figure 4 shows the 2 main global currents at 2 different periods. As described previously, the Guinea Current is directed easterly whereas the South Equatorial Current goes toward the west. During the austral summer, the Guinea Current remains low because of the weakness of the North Equatorial Undercurrent; the South Equatorial Current, is also weak.

IV. GLOBAL CURRENTS AT THE SURFACE

In 2011, a study was conducted in Gabon in order to adress the issues of major coastal developments. A hydrodynamic model was built in order to reproduce the ocean circulation off Cap Lopez.

Maritime boundaries were controlled by water level (tide) and currents from the large-scale ocean model MERCATOR. The model proved to be unsatisfactory because it was unstable. This phenomenon is well known in modelling and is induced by a mismatch between the two sources of external data the Mercator model and the tidal model of the Gulf of Guinea) and the local model. These incompatibilities are usually of two types, namely differences in bathymetry and other source of external forcing such as wind.

To overcome this, it is necessary to bring this type of modelling to a number of degree of freedom to the limits that allow the model to adjust while integrating the external forcing provided at the boundary. Here, the flow is directed mainly to the north / south, thus the western boundary has been modified to only impose water levels. This change has resulted in some stability to the overall scale of the local model and modelled currents consistent with observations on the outskirts of Cap Lopez.

Despite this, the overall dynamics was not satisfactory, especially on the eastern boundary with the presence of a flux too important compared to the information available in the literature or from Mercator. In turn, this border has partially been modified to take into account only the water levels.

Finally, for each boundary, these forcing data have been implemented (Figure 5):

- Boundary 1: water level
- Boundary 2: water level and global current
- Boundary 3: water level
- Boundary 4; water level and global current

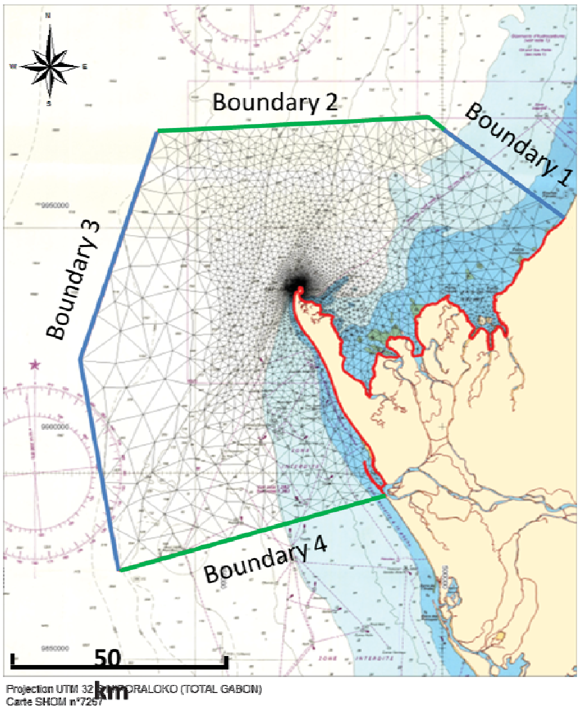
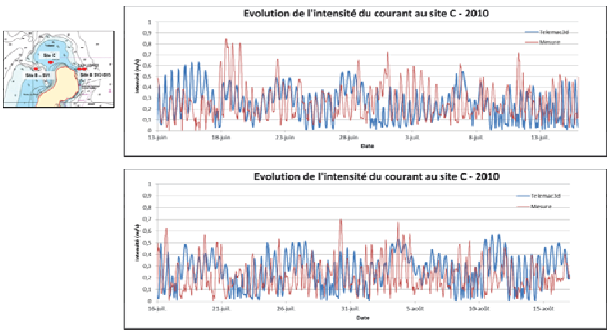


Figure 5 - Boundaries conditions

The energies involved in the model are consistent with the measurements. Indeed, the model alternates periods when the intensity is low (less than 0,2 m / s) and periods where the intensity is higher (several days around 0.30 to 0.40 m / s, which translates general currents supplied by the Mercator model) so that the measured velocity intensity is constant over the whole period. However, statistically, the model provides an average surface speed of about 13.5 cm / s compared with 14.5cm/ s for the observations. It is the same further with an average speed measured on the order of 13.1 cm / s 11,7cm / s speed modelled.



	Mesures (cm/s)	Telemac (cm/s)
Moyenne	24,1	23,6
Ecart type Moyen	10,9	11,7

Figure 6 - Comparison between model/measurements

In summary, for this study, only global currents at the surface are imposed. And then it's propagated on the vertical by using a Soulsby profile. So there no real 3D global current imposed. In order to have a better representation of the currents, 3D global currents must be taken into account. And to keep the 3D stratification, temperature and salinity have to be used in the model.

V. 3D Global currents, temperature and salinity

In 2014, ARTELIA has developed a model in order to develop the basis of design of a CLNG terminal project, which is located in an industrial/port development at about 30km South of the town of Kribi in Cameroon

Three maritime boundaries are considered (Figure 7).

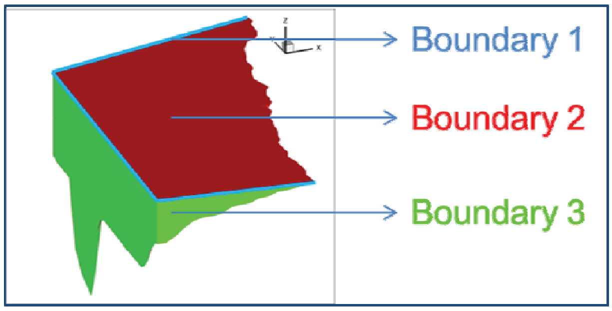


Figure 7 - The 3 hydrodynamic model boundaries

For each boundary, various forcing data have been implemented during the calibration step.

- Boundary 1 is the contours of the model at the surface, where tidal data are imposed as input.
- Boundary 2 corresponds to the surface layer where daily currents, temperature and salinity may be imposed as input data.
- Boundary 3 represents the 3D lateral conditions where daily currents, temperature and salinity may be imposed along the water column.

Then, during calibration process different input conditions have been imposed to the 3 boundaries, until a satisfactory reproduction of the measured current has been achieved.

This has been done in three steps (during each step, various tests have been realised). Finally, to improve model results, temperature and salinity are added, it is synthetized in Table 1.

TABLE 1 CALIBRATION CASES

Case	Boundaries						
	Boundary 1	Boundary 2			Boundary 3		
	Tide	Currents	Temperature	Salinity	Currents	Temperature	Salinity
Calibration Case 15	x	x			x		
Calibration Case 17	x	x			x		
Calibration Case 22	x		x	x	x	x	x
Calibration Case 23 (Final one)	x	x	x	x	x	x	x

The next figure shows the integral of speed amplitude for the different tests cases.

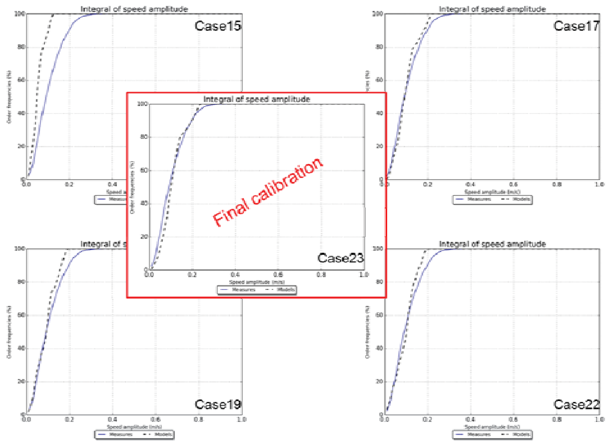


Figure 8 - Comparison between different tests cases

The statistical analyses show that the model is consistent with measurements both at the subsurface and the mid depth. Energy levels in the model are good. Local hydrodynamic circulation is correct even if sometimes the energy peaks are slightly weaker. It is worth noting that strong intensities represent a weak weight in global value of velocity. Distributions of speed amplitude (model and measures) are close.

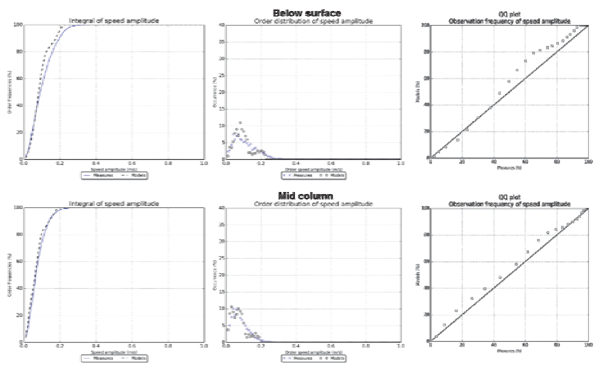


Figure 9 - Comparison model/measurements at the surface and mid column

This study shows how important it is to take into account all the parameters (global currents, temperature, salinity) when global currents are predominant.

VI. LONG TERM

In 2016, for an offshore project near the Martinique island, we have developed a three-dimensional model in order to model 20 years of currents, temperature and salinity. The size of the edges of the mesh is ¼° at the boundary for less than 200 m near the project. This size on the periphery is equivalent to the one of the structured grid of the NEMO model which is used to impose currents, temperature and salinity at the meso-scale and for the entire water column (boundary 3 in the figure below). TPXO is used for forcing the water depth with the tidal signal. Atmospheric conditions with air temperature, pressure, wind and evaporation are also imposed at the free surface.

In order to avoid a slow derive on the results, data assimilation is used on the bulk water for the two parameters salinity and temperature. The result of temperature evolution at different depth can be seen on Figure 10.

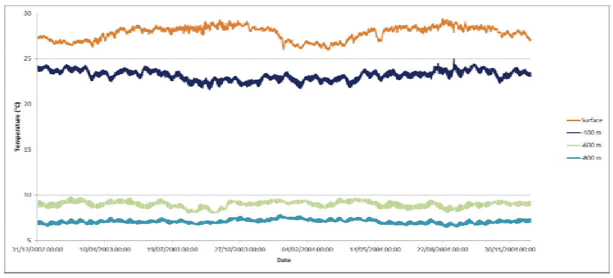


Figure 10 - Temperature evolution during 1 year