Modelling tidal currents on the coast of Portugal

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Abstract

A tide circulation model of the Atlantic coast of the Iberian Peninsula has been constructed. This regional numerical model covers the whole continental shelf. The finite element computational grid is made of some 16,300 triangular elements with sizes ranging between 13 km (on the offshore boundary) and 1 km (near the coast), with local refinements on the continental shelf and in the area of Figueira da Foz. This site was selected as experimental site for the study of waves and currents in the frame of the MAST2/WAVEMOD research project.

Boundary conditions along the three oceanic limits of this widely open domain are obtained from the North-Atlantic component of a World Ocean tidal numerical model known as FES94 [Le Provost, C., Genco, M.L., Lyard, F., Vincent, P. and Canceil, P. (1994) Spectroscopy of the world ocean tides from a finite element hydrodynamic model, Journal of Geophysical Research, Topex-Poseidon Special Issue]. A new radiation-like boundary condition has been introduced in the modelling system used (Telemac-2D), which solves the Shallow Water Equations (SWE), in order to interface the two models and to allow for the tidal wave to leave the northern limit without reflection. Model calibration has been performed on the dominating M 2 constituent. The introduction of the astral static potential generating the tide in the SWE improved this regional model.

A long duration run (1 month) has been performed, the model being forced by the eight major tide constituents. Harmonic analysis of results has been performed on 17 tide constituents, due to non-linear interactions of constituents on the continental shelf. Comparisons with the FES94 model on one hand, and with a set of coastal tide gauges on the other hand, are good. A database of tidal harmonics is now available for forecasting sea levels and currents in this area.
This work has shown that diurnal shelf trapped tide waves exist in some places along the Portuguese continental shelf, which induce diurnal dominant tidal currents in these places (North of Figueira da Foz). © 2000 Elsevier Science B.V. All rights reserved.

**Keywords:** Coastal oceanography; Tide; Shelf; Hydrodynamic modelling; Finite elements; Harmonic analysis

1. Introduction

A good knowledge of current conditions is generally the basis of any study in the coastal marine environment. For more than 20 years now, scientists and engineers have developed in this aim efficient numerical schemes allowing to solve the 2D shallow water flow equations (Benqué et al., 1982; Hervouet, 1998), which are governing the dynamics of shallow and well-mixed water bodies. However, up to the recent past, the numerical model of a coastal domain had to be forced along its open boundaries, thanks to the analysis of good quality current and sea level simultaneous data records. These were generally collected during a field survey preceding the modelling work, thus increasing the global cost of the study.

Good quality models predicting tides over the World Ocean have appeared (Le Provost et al., 1995). The oceanic tides generated by astral influence generally constitute the main source of barotropic flow in coastal waters because the tidal wave is amplified over continental shelves. Although field data remain indispensable for tuning a coastal numerical model, a World Ocean tide model can be used to force a coastal circulation model along its open boundaries. Presently, even when unstructured grids with refined mesh over the continental shelf are used, the typical space resolution of a model predicting tides over the World Ocean is not smaller than 10 km near the coast. On the other hand, coastal environmental studies often need a space resolution of a few tens of metres, for instance, to study dispersion of an effluent by currents near a sea outfall. A model computing tidal currents at the intermediate regional scale is therefore necessary to interface the World Ocean and coastal circulation models.

The construction of such regional model has been undertaken for the Atlantic coast of Portugal. The methodology and the analysis of the resulting database of tidal sea levels and currents are presented here after. This general-purpose regional model has been used in the project to study the influence of currents on the transformation of ocean surface waves for the site of Figueira da Foz. This site was selected as experimental site for the study of waves and currents in the European research project MAST-2/WAVEMOD.

2. The Portuguese continental shelf

The Portuguese coast is oriented North–South along the meridian 9°W in average and around the latitude 40°N. North of the Tagus estuary, rocky coasts of Estremadura are the Western point of continental Europe. North of Estremadura, rectilinear sandy beaches surrounding Figueira da Foz over long distances receive North–West Atlantic waves directly. The domain considered for current modelling covers the coast of...
Portugal from Cape São Vincente in the South to Cape Finistere in the North. In the East–West direction, it extends from the coastline up to meridian 12°W. This area is approximately 670 km S–N by 260 km E–W.

The continental shelf along Portugal is relatively narrow (50 km in average) and its border is steep. The main irregularity is the canyon of Nazaré, immediately North of Extremadura. Bathymetry (Fig. 1) has been obtained from the ETOPO-V world database,
which covers the domain 5° by 5° in latitude and longitude and from a denser data set supplied by the Hydrographic Centre of Portugal for 300 km of the continental shelf North of Peniche (Estremadura).

Tides are dominated by the M\textsubscript{2} semi-diurnal constituent and mainly modulated over one moon cycle by the S\textsubscript{2} semi-diurnal constituent. The M\textsubscript{2} amplitude is close to 1 m over the whole domain, with a small amplification occurring along the continental shelf in the northern part of Portugal. The tidal wave is propagating from South to North in a direction almost parallel to the shoreline, the M\textsubscript{2} phase lag between South and North of our domain corresponding to a time difference of about 1 h. The amplitude of the highest astronomical tide, which is the value obtained by addition of amplitudes of all harmonic constituents, does not exceed 2 m (see Fig. 2a). The maximum current of the highest astronomical tide, which is the value obtained by algebraic addition of the maximum current of all harmonic constituents, shows local amplification in front of Estremadura with local values above 0.5 m/s (Fig. 2b). In other parts of the continental shelf, this parameter is rarely above 0.2 m/s. Although the flow is mainly barotropic under the influence of tides, significant three-dimensional hydrodynamic features can be induced (1) by the interaction of the tidal wave with the continental shelf, (2) by internal tides of the thermocline created in intermediate waters during summer and possibly (3)

![Fig. 2. Amplitude and maximum current of highest astronomical tide.](image-url)
by the inflow of deep denser salted water coming from the Mediterranean Sea through the Strait of Gibraltar South of this area.

3. Numerical modelling of tidal flows

3.1. Governing equations and solution techniques

The hydrodynamic numerical model of the study domain has been constructed on the basis of TELEMAC-2D, which is a software developed by EDF-DER, France. This code solves the depth-averaged free surface and time-dependent shallow water flow equations. These equations express the conservation of water mass and momentum under the hypothesis of hydrostaticity. Written in spherical coordinates and projected in a Mercator plane \((x, y)\), these equations read:

\[
\begin{align*}
\frac{\partial \eta}{\partial t} + \frac{1}{\cos \lambda} \text{div} \left( \eta \frac{\mathbf{Q}}{h} \right) &= \frac{g h}{\cos \lambda} \frac{\partial \eta}{\partial x} + \frac{K}{\cos^2 \lambda} \text{div} \left( \kappa \nabla \eta \right) + \frac{\tan \lambda}{R} \frac{Q_x}{h} + S_x, \\
\frac{\partial Q_x}{\partial t} + \frac{1}{\cos \lambda} \text{div} \left( Q_y \frac{\mathbf{Q}}{h} \right) &= - \frac{g h}{\cos \lambda} \frac{\partial \eta}{\partial x} + \frac{K}{\cos^2 \lambda} \text{div} \left( \kappa \nabla \eta \right) + \frac{\tan \lambda}{R} \frac{Q_x^2}{h} + S_x,
\end{align*}
\]

with: \( g \) (m/s²), gravity; \( h \) (m), water depth; \( K \) (m²/s), water viscosity; \( \lambda \) (degree), latitude; \( R \) (m), radius of the earth; \( t \) (s), time; \( z \) (m), elevation of the free surface; \( \mathbf{Q} = (Q_x, Q_y) \), (m³/s) discharge by unit width; and \( \mathbf{S} = (S_x, S_y) \), (m²/s²) external forces.

The source term of external forces \( \mathbf{S} \) is the summation of:
- the Coriolis force, \( \mathbf{S}_c = -2 \Omega \times \mathbf{Q} \), \( \Omega \) being the vector of earth rotation;
- bottom friction \( \mathbf{S}_f = -(g/C_h h^2) \mathbf{Q} \| \mathbf{Q} \|, C_h \) being the Chezy friction coefficient

Remark. This type of oceanic tide flow problem is not dominated by friction, as confirmed by the study of orders of magnitude and an analysis of the sensitivity of results to the friction parameter. A constant value of the Chezy coefficient (\( C_h = 65 \)) was finally adopted.

- astral potential of heavenly bodies \( S_g \), see Section 4.3 for a detailed discussion on this matter
- wind shear stress on the free surface, \( S_v = -(\rho_a/\rho_w) K_F W^2 \| W \|, \rho_a \) and \( \rho_w \) being the specific weights of air and water, respectively, \( W \) the wind speed at 10 m above the sea level and \( K_F \) the wind shear coefficient.
The governing equations are solved thanks to a two-step procedure in each time step. The hyperbolic advective terms are solved first: in this application, the method of characteristics was used for the advective term of the continuity equation and the Streamline Upwind Petrov–Galerkin (SUPG) method, as presented by Brooks and Hughes (1982), for the advective terms of the momentum equations. When applying the method of characteristics, two sub-iterations in each time step allow to consider a time-centred advective field. In a second step, all other terms are solved simultaneously thanks to a finite element discretisation with linear shape function (P1). Discretized equations are assembled element-by-Element (see Winget and Hughes (1985)). The global system is solved using an iterative conjugate gradient algorithm with diagonal preconditioning. Although a simplification of the bottom gradient term on partly covered elements allows consideration of tidal flats in TELEMAC-2D, the possibility was excluded in order to limit the computational time of long duration simulations. Bottom elevation along the coastline was therefore modified in order to impose a minimum 3-m water depth with no overall hydrodynamic consequences. The analysis of orders of magnitude shows that the diffusion terms are negligible for a domain with this size. They have been eliminated. For a complete presentation of the TELEMAC modelling system, see Laboratoire d’Hydraulique de France (LHF), (1997).

3.2. Mesh design

The finite element method allows a great flexibility in the definition of the computational mesh. In order to solve better non-linear effects occurring on the continental shelf, mesh sizes have been reduced on steep slopes of its border and near the coastline, the characteristic size of elements there varying linearly with the water depth. The final mesh shown on Fig. 3 is made of some 8300 nodes and 16,100 triangles of variable sizes and shapes. Triangle sizes range from 13 km along the offshore boundary to 1.5 km near the coast. They were reduced up to 1 km around Figueira da Foz, the site of interest to the project.

3.3. Tidal forcing along the open boundaries

Modelling the World Ocean tides has been a major concern for 3 decades. Schwiderski (1983) proposed a numerical model for the computation of World Ocean tides with an average accuracy of the order of 6 cm. This model is based on data assimilation-like techniques from a set of available gauge records. Its accuracy is therefore greater in areas where a denser recording network exists. More recently, Le Provost et al. (1994, 1995) have published the results of their FES94 finite element spectral model for the computation of World Ocean tides. This model has an average accuracy of 3 cm (RMS of the error between the computed sea level and observations over long time periods). They have produced a world atlas of ocean tides for 13 constituents. The main advantages of this model are (1) to have an accuracy independent of the predicted location and (2) to take advantage of unstructured grids of triangles authorised by finite elements. This allows a resolution up to 10 km along the continent coastlines to model energy dissipation mechanisms and non-linear transfers of energy between the different
Fig. 3. Computational mesh of the FE regional model.

tidal constituents. The results supplied by the North-Atlantic component of this model (Genco, 1993) have been used to force the present regional hydrodynamic model along its open boundaries.

A harmonic analysis of a 1-year tide gauge record at Leixões (North part of our domain) is shown on Fig. 4. Constituents with an amplitude above a threshold of 3 cm are the semi-diurnal constituents $M_2$, $S_2$, $N_2$, $K_2$, $m_2$, $n_2$, $2N_2$ and the diurnal constituents $O_1$ and $K_1$. The contribution of constituents with very close periods can be distinguished in the harmonic analysis only if the duration of records exceeds $T_A^{-1} - B = T_A T_B / (T_B - T_A)$, $T_A$ and $T_B = T_A + e$, $e \ll 1$ being the periods of the two constituents A and B.

In order to avoid long simulation duration, the technique commonly used is to group the constituents with close periods and to carry out the harmonic analysis on the dominating constituent only within this group. In order to deduce the amplitude and phase of all constituents within one group, a linear dependency between these con-
Fig. 4. Amplitude of sea level for different constituents after harmonic analysis of a one year record at Leixões.

...tuisents is generally adopted. This technique, however, does not allow to study non-linear transfers of energy between constituents belonging to the same group.

Amongst the main constituents identified at Leixões, the \((S_2, K_2)\) couple imposes the more severe constraint: \(T_{S_2-K_2} = 183\) days (about 6 months). One month is a critical period to separate the effects of other couples of important constituents: \(T_{N_2-M_2} = 32\) days and \(T_{M_2-N_2} = 28\) days. As a compromise between the accuracy of this analysis and CPU time of exploitation runs, the simulations were limited to about 40 days. Applying the grouping technique to \((S_2, K_2)\) and other couples of constituents, the regional model was finally forced by eight constituents, as shown in Table 1. Associated constituents are also presented in the same table. Therefore, all constituents with amplitude above a threshold of 0.005 m at Leixões are considered in the simulation.

Furthermore, transfer of energy to other constituents (third-diurnal and quarter-diurnal in particular) may occur on the continental shelf by non-linear interaction. Therefore, the harmonic analysis of the simulation results was not limited to forcing constituents but eight other constituents important for non-linear effects were considered as also shown in Table 1. Including the average sea level and currents \((M_0\) constituent), 17 tide constituents are taken into consideration in total.

3.4. Boundary conditions

The study domain is widely opened on the Atlantic Ocean. It has roughly the shape of a rectangle with three open boundaries and one closed one. South and North boundaries are transects to the shoreline along which sea bottom varies importantly —
Table 1
Constituents considered in the exploitation runs

<table>
<thead>
<tr>
<th>Dominating constituent</th>
<th>Associated constituent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Period</td>
</tr>
<tr>
<td>Q1</td>
<td>26 h 52 min 04 s</td>
</tr>
<tr>
<td>O1</td>
<td>25 h 49 min 10 s</td>
</tr>
<tr>
<td>K1</td>
<td>23 h 56 min 04 s</td>
</tr>
<tr>
<td>μ2</td>
<td>12 h 52 min 18 s</td>
</tr>
<tr>
<td>N2</td>
<td>12 h 39 min 30 s</td>
</tr>
<tr>
<td>M2</td>
<td>12 h 25 min 14 s</td>
</tr>
<tr>
<td>L2</td>
<td>12 h 11 min 30 s</td>
</tr>
<tr>
<td>S2</td>
<td>12 h</td>
</tr>
</tbody>
</table>

Complementary constituents considered for the harmonic analysis of results

<table>
<thead>
<tr>
<th>Name</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS0</td>
<td>14 days 18 h 19 min 51 s</td>
</tr>
<tr>
<td>MQ1</td>
<td>23 h 5 min 57 s</td>
</tr>
<tr>
<td>2MK3</td>
<td>8 h 23 min 11 s</td>
</tr>
<tr>
<td>MK4</td>
<td>8 h 10 min 38 s</td>
</tr>
<tr>
<td>N4</td>
<td>6 h 19 min 45 s</td>
</tr>
<tr>
<td>M4</td>
<td>6 h 12 min 37 s</td>
</tr>
<tr>
<td>MS4</td>
<td>6 h 06 min 12 s</td>
</tr>
<tr>
<td>Ms</td>
<td>4 h 08 min 25 s</td>
</tr>
</tbody>
</table>

from 3 m at the coast to 5000 m offshore — with steep gradient along the border of the continental shelf.

At the beginning of this work, as commonly made in coastal hydrodynamic modelling, prescribed sea level variations and free velocities along open boundaries were used. This revealed unstable, although a time-centred velocity field was used in the advection step as recommended by Janin and Galland (1992). The radiation-like incident wave condition, which allows free progression of a wave normal to the boundary with celerity $\sqrt{gh}$, was also used on the North boundary without success. The main problem was encountered along the North boundary during ebb flow: when the tidal wave is leaving the computational domain in its progression to the North, currents are directed into the domain. It should be noticed that, in this situation, the specification of the boundary condition should include information “from outside the domain.”

The presence of the continental shelf along the North–East open boundary leads to important variations of the free surface, which are poorly resolved by a World Ocean model. Prescribing directly sea levels supplied by such model over-stresses the regional model, which resulted in an accumulation of energy and instabilities, mainly at the end of the ebb, in the North–East corner of the domain. These instabilities took long time to disappear during the following tide cycle, which was not satisfactory.

Therefore, another way of prescribing boundary conditions had to be adopted. The solution was found in the adaptation to SWE of a numerical scheme initially proposed
for compressible flows by Thompson (1987, 1990). Basically, this scheme is based on the following principles.

1. For each boundary, the SWEs are written in a transformed system of axis normal and parallel to the boundary (lower magnitude diffusion terms are omitted in this transformation).

2. Eigenvalues and Riemann invariants of this hyperbolic system are computed.

3. A split operator technique is then used: along the boundary, the standard finite element scheme is applied, whereas in the normal direction, the three wave equations constructed on the eigenvalues and Riemann invariants are considered.

4. These three wave equations are integrated successively over the time step by considering constant eigenvalues. This integration results in estimates of Riemann invariants on boundary points, from which dependent variables \( h, u, v \) are derived.

5. Values “at the foot of the characteristics” are needed for this integration. When the characteristic curve falls in the computational domain, computed values are adopted. When the characteristic leaves the domain, values supplied by the World Ocean model at the beginning of the time step are taken as external source of information.

This method has been applied to water levels and to velocity components along the three open boundaries. It revealed to be flexible enough for interfacing the regional hydrodynamic model to the World Ocean tidal model. Finally, in order to ensure a smooth progression towards the fully established tidal regime, prescribed variables were increased linearly from zero to their real values during the first 2 h of the simulation, the initial state being an ocean at rest.

4. Exploitation of the model

4.1. \( M_2 \) constituent

The calibration was carried out first by forcing the model with the \( M_2 \) constituent only, mainly because this allows to put in evidence and solve the main difficulties within a simulation with short duration. Seven tide periods were used to perform the harmonic decomposition of results produced by calibration runs. This analysis considered \( M_2 \) and its sub-harmonics \( M_4, M_6, M_8 \) and \( M_{10} \) to which energy is transferred. Final calibration run showed very few differences on \( M_2 \) with the simulation performed over 1 month with all constituents. Therefore, only these complete results are presented.

Fig. 5 shows the amplitude and phase of sea levels over the domain (graphs a and b). Isovalues of these two variables are regularly spaced. The concentration of energy of \( M_2 \) over Estremadura appears clearly. Maximum amplitude (1.05 m) is reached as expected in the North of the domain.

Velocity patterns are also presented on Fig. 5 through four parameters (graphs c to f):

- the maximum current (averaged value over all analysed tide cycles),
- the angle between the direction of maximum current and the reference East direction,
- the ellipticity of the current hodograph over one tide period (ratio between the maximum and minimum currents in percent), and
- the phase of the current maximum.

...
Fig. 5. Sea level and current patterns of the $M_2$ constituent.
M₂ currents on the continental shelf are mainly alternating (ellipticity < 25%), oriented South–North and lower than 0.25 m/s. They are generally between 0.04 and 0.06 m/s in deep areas. Alternate structure of maximum current direction along the shelf is created by canyons in the edge of the continental shelf. Currents in front of Figueira da Foz have locally a circular hodograph (ellipticity close to 100%).

Energy transferred to sub-harmonics of M₂ is very small everywhere. The highest — very localised — amplitude value of these sub-harmonics is found for M₄ in front of Extremadura (1.6 mm). The space-averaged amplitude is about 0.1 mm for each sub-harmonic of M₂. M₀ results show that tide residual currents are lower than 0.02 m/s flowing in the Northward direction.

An alongshore development of M₂ tide amplitudes and phases is compared with observations and Schwiderski and FES94 solutions in Fig. 6. The average error of the present model is less than 1.35 cm for the M₂ amplitude and 1.4° for the phase. A comparison of current ellipses produced by the model with observations was also satisfying for points located offshore the continental shelf.

4.2. Other constituents

The overall behaviour of other analysed semi-diurnal waves (six last lines of forcing constituents in Table 1) is similar to M₂. In the studied area, the amplitude of S₂ ranges between 0.33 and 0.40 m, and the one of N₂ ranges between 0.20 and 0.25 m.

However, the current pattern of diurnal constituents is totally different. As an example, graphs showing the sea level and current patterns for the K₁ constituent are presented in Fig. 7.

Between the coastline and the border of the continental shelf and between 39°5N and 42°5N (i.e. in the area including Figueira da Foz) there are topography trapped waves, also called Rossby waves. Such topography wave can occur at latitudes higher than 70°, as far as semi-diurnal waves are concerned, and at latitudes higher than 30° for diurnal waves. These waves generated by topography effects have a shorter wavelength than gravity waves. The relatively large sea level gradients associated to these waves generate important currents, which may become dominant over those of semi-diurnal constituents. To examine this effect, Fig. 8 shows the ratio of the summation of maximum current values of all analysed diurnal constituents over the summation of maximum current values of all semi-diurnal constituents. When this ratio is greater than 1, currents have an overall diurnal behaviour; they have an overall semi-diurnal behaviour in the contrary. It can be observed that this ratio is greater than 1 over a long distance of the continental shelf North of Figueira da Foz.

4.3. Importance of the tide generating potential

The tide generating potential of heavenly bodies is generally omitted in coastal hydrodynamics modelling because of its very small effect when small domains are considered. The first part of this study, including the long duration simulation, was
performed without this internal forcing. Computation of orders of magnitude in the global energy balance of the domain we consider revealed the importance of this term, which is greater than the friction dissipation rate by a factor 10 (friction is low in particular because the continental shelf in front of Portugal is narrow).

The tide potential is made of a static and a dynamic part. The dynamic part depends on the solution itself. Its inclusion in the governing equations is a heavy task, although it
can reach 40% to 50% of the total tide potential in this area. The static part itself is made of different contributions: the influence of heavenly bodies (moon and sun) on water masses $S_H$, the Earth tides, ocean tide loading and self attraction. The three last contributions are taken into account as corrections to the first one through Love numbers (Love, 1911):

$$S_T \text{ (tide potential)} = 0.69S_H.$$ 

$S_H$ is a direct function of moon and sun positions with respect to the Earth obtained from heavenly bodies' mechanics (see Shureman (1958)).

The static tide generating potential was introduced in the model and the 1-month simulation was run again. Results obtained for $M_2$ were very similar to those without

Fig. 7. Sea level and current patterns of the $K_1$ constituent.
the static tide generating force, as well as for other semi-diurnal constituents. However, the pattern of diurnal constituents amplitude was modified quite importantly over the whole continental shelf (as an example, the maximum amplitude of $K_1$ is 0.075 m without astronomical forcing, whereas it is 0.093 m with this forcing). The overall solution was improved as illustrated by Table 2 giving two specific locations where we have reliable long term observations.

Table 2
Comparison between observations and modelling results of $K_1$ for two locations, with and without the static tide generating potential

<table>
<thead>
<tr>
<th>Location</th>
<th>Observations</th>
<th>Without static tide generating terms</th>
<th>With static tide generating terms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude</td>
<td>Phase (deg)</td>
<td>Amplitude</td>
</tr>
<tr>
<td></td>
<td>(m)</td>
<td></td>
<td>(m)</td>
</tr>
<tr>
<td>Peniche, 39.35°N–9.37°W</td>
<td>0.077</td>
<td>57</td>
<td>0.0725</td>
</tr>
<tr>
<td>Leixões, 41.18°N–8.7°W</td>
<td>0.070</td>
<td>58</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Fig. 8. Ratio of diurnal constituent currents over semi-diurnal constituent currents.
5. Synthesis and concluding remark

An efficient methodology has been designed to interface a World Ocean spectral model and a regional hydrodynamic model solving SWE. Both models are based on finite element schemes using unstructured computational grids of triangular elements. The regional model takes into account all non-linear effects (advection terms, bottom friction, and wind shear stress) as well as internal forcing by the static tide potential. It was calibrated by existing long-term sea-level gauge measurements and some current observations. Tide forcing along the open boundary conditions of the regional model is based on the distribution of eight major constituents given by the North-Atlantic Ocean model. This study revealed the existence of shelf trapped diurnal waves along the Portuguese continental shelf North of Figueira da Foz which, to our knowledge, was not known before. These waves produce dominant diurnal currents.

The six parameters characterising each of the 17 analysed constituents (amplitude/phase of the sea level, module/direction/phase of the maximum velocity and ellipticity of the current hodograph) produced by a long run simulation have been mapped and stored in a database. A prediction software was developed to give tide sea level and current evolution for a given time interval at any point in the studied domain. This is a valuable predictive tool in itself but, more interestingly, it can be used as a basis for defining the boundary conditions of a local coastal hydrodynamic numerical model along the Portuguese coastline designed for engineering purposes: environmental impact assessment, design of harbour equipment, etc. The regional model was used as a basis for the computation of combined tide and wind currents for different spatially constant wind speeds and directions over the area of Figueira da Foz. This model can also be used for the computation of long-term residual currents for ecological purposes.

6. Uncited references

David et al., (1995)

Acknowledgements

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References


