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Numerical computation of the Residence Time Related to the Water Renewal in the Nador Lagoon

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Abstract. In this work, an unstructured finite volume solver is used to compute the residence time in the Nador lagoon (Morocco). The modeling system consists of the well-established shallow water system including the bathymetric forces, friction terms, Coriolis forces, wind stress, and momentum diffusion terms. To model the passive tracer transport an advection-diffusion equation is used. The solver is based on a Non-Homogeneous Riemann solver that can handle topography variations. The objective of this study is to compute the mean residence time in the Nador lagoon considering several scenarios with respect to the pass between the Mediterranean Sea and the Nador lagoon. In particular, we propose a new inlet that can substantially reduce the water residence time in the lagoon.

INTRODUCTION

The Nador Lagoon (or Marchica) is an ecosystem located in the northeastern part of the Mediterranean coast of Morocco, which extends over $25km$ in length and 0.3 to $1.7km$ in width. Before 2011, the lagoon was connected with the sea intermittently, through a natural pass. Subsequently, and since 2011, as part of the lagoon development plan to improve its environmental quality, the communication was closed and replaced by a new, wider channel. Just as an activated sludge-type treatment plant has been set up to serve the Nador region with the aim of reducing pollution in the lagoon. The Nador lagoon is considered as a site of great biological and ecological interest. This site is also the seat of several economic activities including fishing, aquaculture, tourism, and agriculture. As a result, it is subject to strong anthropogenic pressure. Before 2011, the situation was further aggravated by the discharges of raw urban and industrial wastewater in the face of a low renewal rate and following regular clogging of the only pass that communicated with the sea. Even if the new pass is opened for more exchange with the Mediterranean it is not enough, in this study we measured the residence time of the lagoon when it connected with the sea by the new pass, and also we proposed a new pass location to reduce the water residence time in the Nador lagoon.

Using the concepts of the Constituent-oriented Age and Residence time Theory [1], [2] (CART, www.climate.be/cart), we compute timescales related to the water renewal in Nador lagoon. The modeling system is based on an Eulerian approach [1] and consists of two coupled model components, the shallow-water equations for the hydrodynamical model and the advection-diffusion equation for the passive tracer transport. The full system is incorporated into a high-order finite volume solver on unstructured meshes. Advection is approximated by a Non-Homogeneous Riemann Solver (SRNH) which can handle topography complexity and its variations [3]. Our objective is to measure the residence time of water inside the lagoon. A suitable numerical analysis would establish the need for additional passes between the lagoon and the Mediterranean that would shorten a given tracer's residence time, as well as their eventual location.

The structure of this study is as follows. First, we present the mathematical equations of the hydrodynamics and the transport of the passive tracer then the formulation of the problem of the residence time. The formulation of the finite volume method and the non-homogeneous Riemann solver are detailed. The last section is devoted to the numerical results and discussion. Finally, we give some concluding remarks.

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MATHEMATICAL MODEL

The two-dimensional shallow water equations are a type of mathematical model that describes the conservation of mass and momentum in water flows influenced by gravity. This model is based on the assumption that the vertical scale of the flow is much smaller than the horizontal scale, and it can be derived from the incompressible Navier–Stokes equations under the hydrostatic pressure, impermeability of the bottom and the free surface and the hypothesis of boussinesq see [4].

$$\begin{cases} \dfrac{\partial h}{\partial t}+\dfrac{\partial (hu)}{\partial x}+\dfrac{\partial (hv)}{\partial y}=0 \\ \dfrac{\partial (hu)}{\partial t}+\dfrac{\partial \left(hu^2+\frac{gh^2}{2}\right)}{\partial x}+\dfrac{\partial (huv)}{\partial y}=-gh\left(\dfrac{\partial Z}{\partial x}-S_{fx}\right)+\dfrac{\tau_{wx}}{\rho_w}+\Omega hv+\mathscr{D}_{xx}(h,u,v) \\ \dfrac{\partial (hv)}{\partial t}+\dfrac{\partial (huv)}{\partial x}+\dfrac{\partial \left(hv^2+\frac{gh^2}{2}\right)}{\partial y}=-gh\left(\dfrac{\partial Z}{\partial y}-S_{fy}\right)+\dfrac{\tau_{wy}}{\rho_w}-\Omega hu+\mathscr{D}_{yy}(h,u,v) \end{cases} \tag{1}$$

where g is the gravitational acceleration, $h(t,x,y)$ is the water height, and $u(t,x,y)$ and $v(t,x,y)$ are the flow velocity components in the respective x and y directions. $\frac{\partial Z}{\partial x}$ and $\frac{\partial Z}{\partial y}$ are the slopes of the bottom in the respective directions x and y and Z designates the slope of the bottom of the domain. Ω is the Coriolis parameter defined by $\Omega = 2\omega\sin(\phi)$ with ω is the angular velocity of the earth and ϕ is the geographic latitude. ρ_w the water density. S_{fy} and S_{fy} are the friction terms in both directions x and y.

$$S_{fx}=-N^2\frac{u\sqrt{u^2+v^2}}{h^{\frac{4}{3}}},\quad S_{fy}=-N^2\frac{v\sqrt{u^2+v^2}}{h^{\frac{4}{3}}}$$

The wind stresses τ_{w_x} and τ_{w_y} are expressed using a quadratic function of the wind speed (w_x, w_y):

$$\tau_{w_x}=\rho_a C_w w_x\sqrt{w_x^2+w_y^2},\qquad \tau_{w_y}=\rho_a C_w w_y\sqrt{w_x^2+w_y^2} \tag{2}$$

where ρ_a is the air density, C_w is the coefficient of wind friction and $(w_x, w_y)^T$ is the wind speed at 10 meters above the water's surface. Usually, it is described by

$$C_w=\left(0.75+0.067\sqrt{w_x^2+w_y^2}\right)10^{-3}$$

$\mathscr{D}_{xx}$ and $\mathscr{D}_{yy}$, are the momentum diffusion terms, we used the parameterizations of [5].

Residence time

The residence time of a lagoon, or a segment of it, is often referred to as the average time that a parcel of water or an introduced substance remains in the system. In this work an Eulerian approach is used to estimate detailed spatial and temporal distributions of particle concentrations and the time of residence of the particles. The Eulerian approach models the particle phase as a continuous phase and treats the particles as passive pollutants. The simplicity of this approach stems from the use of the advection-diffusion equation to calculate the spatio-temporal distribution of particle concentrations [6].

$$\begin{cases} \dfrac{\partial (hC)}{\partial t}+\nabla\cdot(hC\mathbf{u})=\nabla\cdot(h\mathbf{K}\nabla C) \\ C(t_0,\mathbf{x}\in\Omega')=1 \\ C(t_0,\mathbf{x}\in\Omega\setminus\Omega')=0 \end{cases} \tag{3}$$

where $\mathbf{u}$ denotes the depth-averaged velocity vector, C particle concentrations, and $\mathbf{K}$ is the diffusivity tensor of the tracer. The water entering the region of interest after t_0 must be prescribed to contain no tracer, and once the tracer leaves through one of the open boundaries it is lost forever. Then, the mean residence time in the subdomain Ω' is given by

$$\overline{\theta}(t_0) = \frac{\int_{t_0}^{\infty}\int_{\Omega} h(t,\mathbf{x})C(t,\mathbf{x}|t_0)\mathrm{d}\mathbf{x}\mathrm{d}t}{\int_{\Omega} h(t_0,\mathbf{x})C(t_0,\mathbf{x}|t_0)\mathrm{d}\mathbf{x}} \tag{4}$$

In terms of flow variables $\mathbf{W} = (h, hu, hv)$, the Saint-Venant equations coupled with the advection-diffusion equation can be written as

$$\frac{\partial \mathbf{W}}{\partial t} + \frac{\partial}{\partial x}\left(\mathbf{F}(\mathbf{W}) - \widetilde{\mathbf{F}}(\mathbf{W})\right) + \frac{\partial}{\partial y}\left(\mathbf{G}(\mathbf{W}) - \widetilde{\mathbf{G}}(\mathbf{W})\right) = \mathbf{S}_1(\mathbf{W}) + \mathbf{S}_2(\mathbf{W}) \tag{5}$$

where $\mathbf{W}$ is the conserved variable's vector, $\mathbf{F}$ and $\mathbf{G}$ are the advective tensor fluxes, $\widetilde{\mathbf{F}}$ and $\widetilde{\mathbf{G}}$ are the diffusion tensor fluxes, $\mathbf{S}_1$ is the source term representing the slope variation. The source term $\mathbf{S}_2$ accounts for Coriolis forces, friction losses and wind effects.

$$\mathbf{W} = \begin{pmatrix} h \\ hu \\ hv \\ hC \end{pmatrix}, \quad \mathbf{F}(\mathbf{W}) = \begin{pmatrix} hu \\ hu^2 + \frac{1}{2}gh^2 \\ huv \\ huC \end{pmatrix}, \quad \mathbf{G}(\mathbf{W}) = \begin{pmatrix} hv \\ huv \\ hv^2 + \frac{1}{2}gh^2 \\ hvC \end{pmatrix}, \quad \mathbf{S}_1(\mathbf{W}) = \begin{pmatrix} 0 \\ -gh\frac{\partial Z}{\partial x} \\ -gh\frac{\partial Z}{\partial y} \\ 0 \end{pmatrix},$$

$$\mathbf{S}_2(\mathbf{W}) = \begin{pmatrix} 0 \\ hgS_{fx} + \Omega hv + \frac{\tau_{wx}}{\rho_w} \\ hgS_{fy} - \Omega hu + \frac{\tau_{wy}}{\rho_w} \\ 0 \end{pmatrix}, \quad \widetilde{\mathbf{F}}(\mathbf{W}) = \begin{pmatrix} 0 \\ 0 \\ 0 \\ hK_x\frac{\partial C}{\partial x} \end{pmatrix}, \quad \widetilde{\mathbf{G}}(\mathbf{W}) = \begin{pmatrix} 0 \\ 0 \\ 0 \\ hK_y\frac{\partial C}{\partial y} \end{pmatrix},$$

The system (5) is hyperbolic. The eigenvalues of the Jacobian matrix of the flux function are given by:

$$\lambda_1 = u - \sqrt{gh}, \quad ,\lambda_2 = u, \quad \lambda_3 = u, \quad \lambda_4 = u + \sqrt{gh}$$

$$\mu_1 = v - \sqrt{gh}, \quad ,\mu_2 = v, \quad \mu_3 = v \quad ,\mu_4 = v + \sqrt{gh}$$

NUMERICAL METHODS

The Saint-Venant system is a system of nonlinear and hyperbolic partial differential equations. It is impossible to solve this system analytically in the general case. Therefore, a numerical resolution of this system is needed. Simulating free surface flow amounts to solving the Saint-Venant system using a robust numerical scheme, i.e. capable of giving a numerical solution close to reality whatever the particularities of the flow. The finite volume method is nowadays the most widely used method for numerically solving the Saint-Venant equations. This method is based on the integral discretization of the equations and requires the subdivision of the domain into a finite number of cells called control volumes. The integral is applicable locally on each volume and keeps the same value in each calculation cell. The finite volume technique has been used in many applications as a systematic approach for efficient discretization of equations modeling fluid flows ([7], [8]). The advantage of this method lies in its ease of adaptation to complex geometries. Its conservation property, which comes from the approximation of the integral form of conservation laws, is very important for the accuracy of simulations of complicated physical processes on relatively coarse meshes.

Finite volume discretization

The finite volume method involves dividing the computational domain into a finite number of control volumes. In this case, we are using a cell-centered formulation, which means that the variables of interest are defined at the center of each control volume. By integrating (5) over the volume of each control volume T_i and applying Green's divergence formula, we obtain the following integral system

$$\begin{aligned}\mathbf{W}_i^{n+1} = \mathbf{W}_i^n - \frac{\Delta t}{|T_i|}\sum_{j\in N(i)}\int_{\Gamma_{ij}}\mathscr{F}(\mathbf{W}^n;\mathbf{n})\,\mathrm{d}\sigma + \frac{\Delta t}{|T_i|}\sum_{j\in N(i)}\int_{\Gamma_{ij}}\widetilde{\mathscr{F}}(\mathbf{W}^n;\mathbf{n})\,\mathrm{d}\sigma \\ + \frac{\Delta t}{|T_i|}\int_{T_i}\mathbf{S}_1(\mathbf{W}^n)\,\mathrm{d}V + \frac{\Delta t}{|T_i|}\int_{T_i}\mathbf{S}_2(\mathbf{W}^n)\,\mathrm{d}V\end{aligned} \tag{6}$$

where $\mathbf{W}_i^n$ is the mean value of the solution $\mathbf{W}$ in the control volume T_i at time t_n, $|T_i|$ represents the area of T_i and $N(i)$ is the set of triangles surrounding the cell T_i,

$$\mathscr{F}(\mathbf{W};\mathbf{n}) = \mathbf{F}(\mathbf{W})n_x + \mathbf{G}(\mathbf{W})n_y \qquad \widetilde{\mathscr{F}}(\mathbf{W};\mathbf{n}) = \widetilde{\mathbf{F}}(\mathbf{W})n_x + \widetilde{\mathbf{G}}(\mathbf{W})n_y$$

$$\mathbf{W}_i^n = \frac{1}{|T_i|}\int_{T_i}\mathbf{W}^n\,\mathrm{d}V$$

The SRNH scheme

The finite volume scheme consists of predictor stage and corrector stage. The scheme considers only the source term containing slope variations and the advection part. These equations are firstly projected on the local cell outward normal and tangential. Then, for this projection, the predictor stage is written as follows

$$\mathbf{U}_{ij}^n = \frac{1}{2}\left(\mathbf{U}_i^n + \mathbf{U}_j^n\right) - \frac{1}{2}sgn\left[\nabla\mathbf{F}_\eta(\overline{\mathbf{U}}_{ij}^n)\right]\left(\mathbf{U}_j^n - \mathbf{U}_i^n\right) + \frac{1}{2}|\nabla\mathbf{F}_\eta(\overline{\mathbf{U}}_{ij}^n)^{-1}|\mathbf{S}_{1ij}^n \tag{7}$$

$$\mathbf{U} = \begin{pmatrix} h \\ hu_\eta \\ hu_\tau \\ hC \end{pmatrix}, \qquad \mathbf{F}_\eta(\mathbf{U}) = \begin{pmatrix} hu_\eta \\ hu_\eta^2 + \frac{g}{2}h^2 \\ hu_\eta u_\tau \\ hu_\eta C \end{pmatrix}, \qquad \mathbf{S}_{1ij} = -g\frac{h_i + h_j}{2}(Z_j - Z_i)\begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$$

where $u_\eta = (u,v).\eta$ is the normal velocity, $u_\tau = (u,v).\tau$ is the tangential one and $\overline{\mathbf{U}}_{ij}^n$ is denoted the Roe-averaged value associated to the states $\mathbf{U}_i$ and $\mathbf{U}_j$ on triangles T_i and T_j. The Jacobian's matrix is denotes by $\nabla\mathbf{F}_\eta(\overline{\mathbf{U}}_{ij}^n)$.

Once the state $\mathbf{U}_{ij}^n$ is computed, the conservative state $\mathbf{W}_{ij}^n$ is recovered by using the transformation $u = (u_\tau, v_\eta).\tau$ and $u = (u_\tau, v_\eta).\eta$, the corrector is then formulated using the conservative, non-projected states as follows

$$\mathbf{W}_i^{n+1} = \mathbf{W}_i^n - \frac{\Delta t}{|T_i|}\sum_{j\in N(i)}\mathscr{F}\left(\mathbf{W}_{ij}^n;\mathbf{n}_{ij}\right)|\Gamma_{ij}| + \Delta t\mathbf{S}_{1i}^n$$

where

$$\mathbf{W}_{ij}^n = \frac{1}{2}\left(\mathbf{W}_i^n + \mathbf{W}_j^n\right) - \frac{1}{2}sgn\left[\nabla\mathscr{F}(\overline{\mathbf{W}}_{ij}^n,\mathbf{n}_{ij})\right]\left(\mathbf{W}_j^n - \mathbf{W}_i^n\right) + \frac{1}{2}|\nabla\mathscr{F}(\overline{\mathbf{W}}_{ij}^n,\mathbf{n}_{ij})^{-1}|\mathbf{S}_{1ij}^n \tag{8}$$

$$\mathbf{S}_{1i}^n = \frac{1}{|T_i|}\int_{T_i}\mathbf{S}_1(\mathbf{W}^n)\,dV$$

$sgn[\mathbf{A}]$ represents the sign matrix of $\mathbf{A}$ and $\overline{\mathbf{W}}_{ij}^n$ is an averaged state that can be roughly approximated by the mean state or the Roe's average state.

$$\overline{\mathbf{W}}_{ij}^n = \frac{1}{2}\left(\mathbf{W}_i^n + \mathbf{W}_j^n\right)$$

The state $\mathbf{W}_{ij}^n$ is determined by projecting the equations (1) onto the outward normal and tangential coordinates of the local cell, as described in the next section. The source term approximation is designed to achieve a well-balanced scheme that preserves steady state at rest. This is achieved through a specific reconstruction process, as described in([3]).

Second order extension in space (MUSCL)

The MUSCL reconstruction (Monotonic Upwind-Schemes for Conservation Laws) was proposed by Van Leer in 1977. This method consists in assuming that the state variables $\mathbf{W}$ are no longer constant in each cell but vary linearly in the cell. The problem is thus to reconstruct values at the interface starting from the discrete mean values $\mathbf{W}_i^n$. We use for that a development of the second order of variables to have the slope of its variables. We define a new approximation space, where we approximate the physical state $\mathbf{W}$ by a piecewise linear distribution, which is the space of affine functions per cell. Furthermore, we apply an approach which was used by I. Elmahi [9] which breaks down into two stages of limitation of the gradients in order to avoid oscillations. The first step is the linear reconstruction of the states on both sides of the interface as follows:

$$\begin{cases} \mathbf{W}_{ij} = \mathbf{W}_i + \dfrac{1}{2}\left(\beta \nabla \mathbf{W}_i . \overrightarrow{X_i X_j} + (1-\beta)(\mathbf{W}_j - \mathbf{W}_i)\right) \\ \mathbf{W}_{ji} = \mathbf{W}_j - \dfrac{1}{2}\left(\beta \nabla \mathbf{W}_j . \overrightarrow{X_i X_j} + (1-\beta)(\mathbf{W}_j - \mathbf{W}_i)\right) \end{cases} \tag{9}$$

β is a parameter between 0 and 1. In practice, we take $\beta = \frac{1}{2}$. The resulting scheme is second order in space but is not necessarily monotonic and non-physical oscillations may appear. To attenuate these oscillations, we incorporate slope limiters into the reconstruction (9) as

$$\begin{cases} \mathbf{W}_{ij} = \mathbf{W}_i + \dfrac{1}{2} Lim\left(\beta \nabla \mathbf{W}_i . \overrightarrow{X_i X_j} + (1-\beta)(\mathbf{W}_j - \mathbf{W}_i), \mathbf{W}_j - \mathbf{W}_i\right) \\ \mathbf{W}_{ji} = \mathbf{W}_j - \dfrac{1}{2} Lim\left(\beta \nabla \mathbf{W}_j . \overrightarrow{X_i X_j} + (1-\beta)(\mathbf{W}_j - \mathbf{W}_i), \mathbf{W}_j - \mathbf{W}_i\right) \end{cases} \tag{10}$$

As examples of slope limiter functions, We present two limiters used in the two-dimensional case on unstructured meshes. The MinMod limiter function given by

$$Lim(a,b) = \max\left(0, \min\left(1, \frac{a}{b}\right)\right) \tag{11}$$

and the Van Albada limiter function given by

$$\begin{cases} Lim(a,b) = \dfrac{(a^2+\varepsilon)\, b + (b^2+\varepsilon)\, a}{a^2+b^2+2\varepsilon} \quad \text{if} \quad ab > 0 \\ Lim(a,b) = 0 \quad \text{otherwise} \end{cases} \tag{12}$$

where $0 < \varepsilon < 1$. With this limitation, we obtain a second monotone reconstruction for the hyperbolic part. To construct an equilibrium scheme, we also consider a linear approximation of the bottom Z and reconstruct the values of Z_{ij} and Z_{ji} on both sides of the interface, as was done previously for the other variables.

NUMERICAL SETUP AND RESULTS

The Nador lagoon is situated on the Mediterranean coast of Morocco, at about 35° N, (see Figure 1). It covers an area of $120Km^2$ and a volume of about $5.4.10^8 m^3$. Figure 2 shows the mesh of the computational domain. This mesh consists of 35241 elements and 20148 nodes, the density of nodes at the lagoon level is high. The interest is to have enough points between the two borders of the sea and the land, therefore to be able to process the boundary conditions correctly. Two types of boundary conditions are applied at the boundary between the Mediterranean Sea and the lagoon, referred to as the 'pass' Γ^p, and at the Nador lagoon coastlines Γ^c. The resulting boundary conditions are: At the Nador lagoon coastlines a No-slip conditions for the velocity flow ($\overrightarrow{V} = \overrightarrow{0}$) and Neumann condition on

h, in Γ^p a Neumann conditions on u and v and a tidal condition for h. The initial assumption for the flow is that it is at rest and has a constant free surface. It is important to note that the initial conditions were generated by modeling the hydrodynamic for one year in physical time until the flow is established. the water height and velocity field are recorded and used as the initial conditions for the study. At this time, the tracer in the Nador lagoon is fully released, and its concentration is set to 1. This study considers two scenarios: the first one is to connect the Nador lagoon and the sea with the new pass (Boukhana) and the second one is adding to the Nador lagoon two small passes near Beni-Ansar and Kariat-Arekmane. Figure(2) shows the location of those two passes. This figure shows also the bathymetry of the lagoon which was reconstructed from a cloud of points recovered from a topographic map.

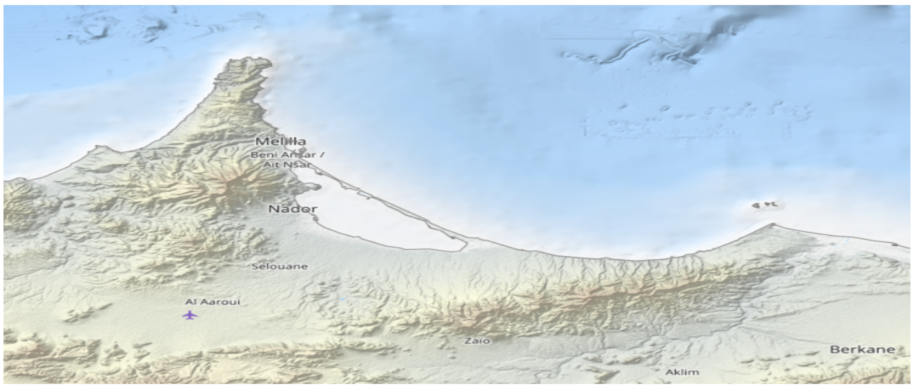

FIGURE 1. Schematic definition of the Nador lagoon.

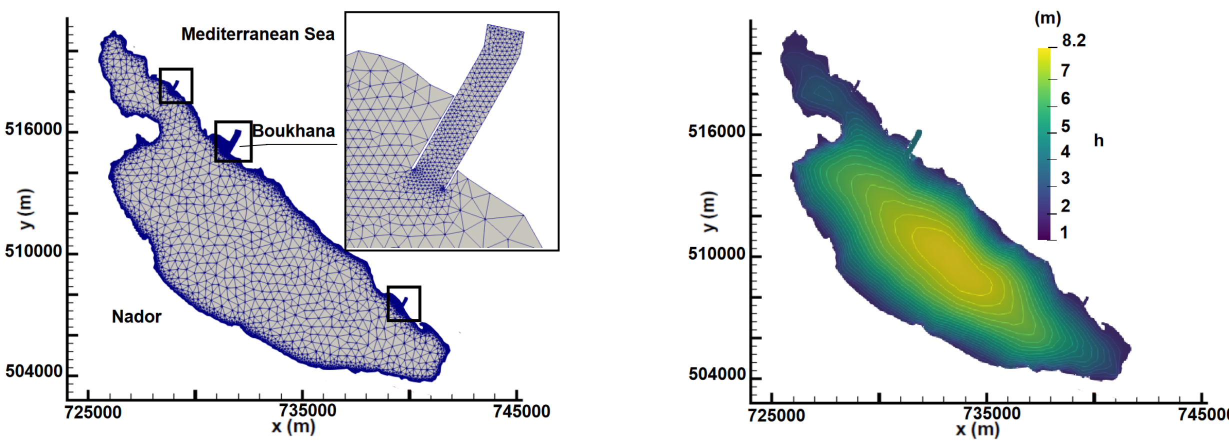

FIGURE 2. The computation unstructured mesh (left) and Bathymetry of the Nador lagoon (right) with its new entrance pass.

The model being used to simulate the flow of water in a lagoon has several physical parameters that can affect the flow. The bathymetry of the lagoon, which is the shape of the underwater terrain, is very irregular with different spatial scales that require careful treatment in order to accurately model the flow see [3]. The bottom friction coefficient, also known as the Manning coefficient, is According to [3] set to 0.0025 $v = 10m^2/s$, and the kinematic viscosity of the water is $v = 10m^2/s$. The flow is being forced by the main semidiurnal $M2$, $S2$, $N2$, and $K1$ tides, which have an amplitude of 12 cm and produce a maximum current of approximately 1 m/s through the inlet of the lagoon. These tides correspond to the annual mean of the Mediterranean input flux. The model is fitted at the open boundary with boundary conditions that simulate these tides using the concept of fictitious cells. At the start of the simulation, the water is assumed to be still and the level of the water is constant.

The numerical computation has been carried out with a wind direction and intensities taken from two different locations established over the period from January 1 to December 31, 2021 (Data source: https://power.larc.nasa.gov/)

FIGURE 3. Wind rose over the period from January 1 to December 31, 2021, Beni-Ansar (right) and Kariat-Arekmane (Left)

Results and discussion

The computations are performed with a physical time step Δt chosen so that the stability condition listed below is satisfied:

$$\Delta t_{conv} = \min_{\Gamma_{ij}} \left(\frac{|T_i| + |T_j|}{2|\Gamma_{ij}| \max_p |\lambda_{ij}^p|} \right), \quad \Delta t_{diff} = \min_{T_i} \left(\frac{|T_i|}{2\max(K_x, K_y)} \right) \tag{13}$$

with

$$\Delta t = Cr. \min(\Delta t_{conv}, \Delta t_{diff}) \tag{14}$$

where λ_{ij}^p is the eigenvalue calculated at the interface Γ_{ij} between the two cells T_i and T_j , and Cr is the current number set to 0.7 to ensure stability of the numerical scheme. The implementation of this work is done by using Manapy (https://github.com /pyccel/manapy). It's a parallel unstructured finite-volume based solver for the solution of partial differential equations, and it's object oriented, written in Python, and structured in a way that makes it simple to comprehend and modify see [10].

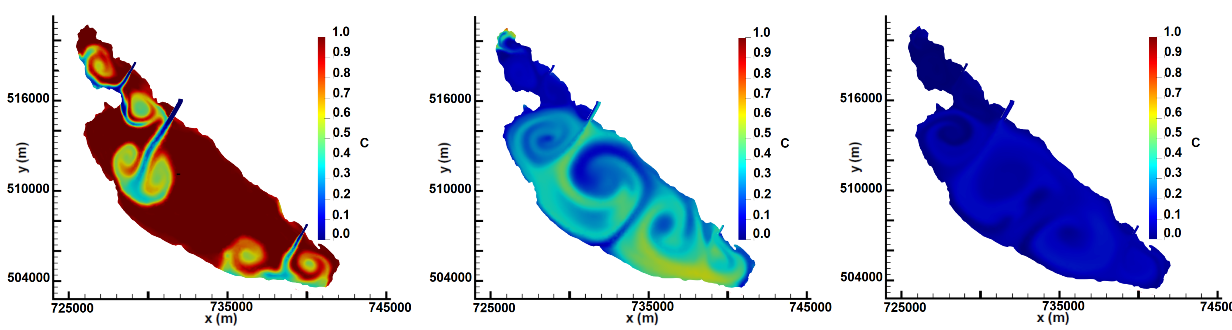

FIGURE 4. Tracer concentration in Nador lagoon with the three pass at physical times 0.5, 5, 15 (day).

Through the results obtained, which represent transport of the passive tracer in the Nador lagoon see Figure 4 and 5, it becomes clear that the addition of the two small passes to connect the lagoon to the Mediterranean sea near Beni-Ansar and Kariat-Arekmane increases the rate of water exchange between the lagoon and Mediterranean sea. This can be seen in the tracer that leaves the lagoon through the three passes, it only takes 15 days in physical time. As a result of this rapid exchange, the residence time of the Nador lagoon's water has been reduced from about 15 days in the case of the new pass to about 4 days for the three passes.

The results obtained showed the necessity of adding the two small passages to the lagoon in order to achieve a comprehensive and rapid cleaning in a period of 4 days. As a result, the lagoon will witness a wide prosperity in terms of fisheries, the quality of the lagoon's water will improve, as well as the recovery of the tourism sector in the region.

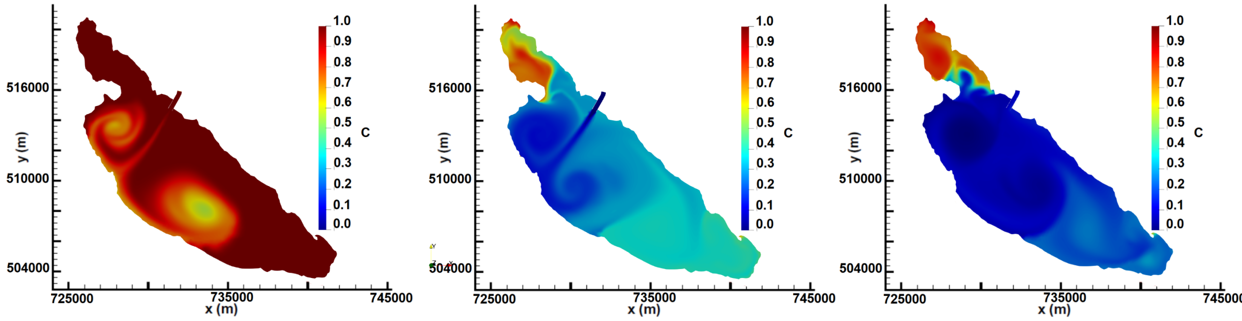

FIGURE 5. Tracer concentration in Nador lagoon with the new pass at physical times $2, 17, 30$ (day).

CONCLUSION

In this study, the residence time of water in the Nador lagoon (Morocco) was calculated using an unstructured finite volume solver that is robust and well-balanced. The numerical simulation was conducted under realistic conditions, including the effects of tides, winds, bottom friction, Coriolis forces, and momentum diffusion. These factors can significantly influence the flow of water in the lagoon and are important to consider in order to accurately model the residence time. The simulation showed that the residence time is reduced about three times when the three passes (the new pass and two small incoming passes) are considered, compared to just the new pass. This result suggests that the additional passes play a significant role in the residence time of water in the lagoon. Further analysis may be necessary to understand the full impact of the passes on the water flow and residence time in the lagoon.

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