A TIDAL FLOW MODEL OF THE WESTERN COAST OF LIBYA

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ABSTRACT: This paper presents the hydrodynamics on the western coast of Libya. The investigated area, which is a part of the Mediterranean Sea, is one of the most critical and active coastal regions in the country. A 2DH process-based model for flow based on the Delft3D modelling system from Deltares is constructed for the study area. Extensive field data concerning the tidal constituents were used. The flow model that is necessary to understand the hydrodynamics of the area was calibrated and validated using field measurements. In this paper, only the water levels and tidal components for the astronomical tide are presented. Calibration and validation of the numerical flow model show that the results of the water level represent the field conditions well. The present study gives insight into the basic hydrodynamic processes of the investigated area. It should help designers and the decision-makers maintain the region for any other economic and social activities. The flow model for the investigated area can be also coupled with any other models like wave, sediment transport, morphodynamic and water quality.

Keywords: Western coast Libya, Hydrodynamics, Astronomical tide, and Process-based model.

نموذج رقمي للتيارات المائية للساحل الغربي - ليبيا

طلال عاشور العتري و أحمد فرج قديرة و عبد الرحمن عثمان العطا حمزة

الملخص: تعرض هذه الورقة هايدروديناميكية الساحل الغربي لليبيا. حيث تعد منطقة الدراسة جزء من البحر الأبيض المتوسط وواحدة من أكثر المناطق الساحلية نشاطًا في البلاد. تم إنشاء نموذج للمحاكاة الرقمية ثنائي الابعاد (2DH) لمنطقة الدراسة لدراسة التيارات المائية باستخدام نظام النمذجة Delft3D من Deltares. تم استخدام قياسات ميدانية واسعة النطاق تتعلق بمكونات المد والجزر للتيارات المائية. ولفهم هذه التيارات المائية في منطقة الدراسة تم معايرة النموذج الرقمي والتحقق من صحته بمقارنتها بالقياسات الميدانية. في هذه الدراسة، تم دراسة مستويات المياه ومكونات المد والجزر فقط بدون الاخذ في الاعتبار تأثير الرياح. تُظهر معايرة النموذج أن نتائج مستوى الماء المتحصل عليها متطابقة بشكل جيد مع القياسات الميدانية. ومن أهم استخدامات نتائج هذه الدراسة أنها تعطي نظرة أكثر دقة على العمليات الهيدروديناميكية الأساسية للمنطقة التي تم فحصها والمتمثلة في التيارات المائية للمد والجز. هذه النتائج يمكن أن تساعد المصممين وصناع القرار في الحفاظ على المنطقة في حالة التوسع لأي أنشطة اقتصادية واجتماعية أخرى. كذلك يمكن أن يقترن نموذج التدفق الرقمي المستخدم بأي من نماذج المحاكاة الأخرى لدراسة تأثير التيارات المائية الناتجة عن الأمواج أو تلك التي تسبب في نقل الرواسب وتغيير طبوغرافية قاع البحر بالإضافة الى دراسة مدى جودة المياه في منطقة الدراسة.

الكلمات المفتاحية: الساحل الغربي لليبيا؛ هايدروديناميكية؛ التيارات المائية؛ تيارات المد والجز؛ نماذج المحاكاة الرقمية الحديثة.

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1. INTRODUCTION

The Libyan coast is of great importance to the population. Approximately 90% of the population lives in an area of only 10% of the total area of the country (World Bank, 2012). Most of the people are living on the Mediterranean coast, providing the use of many commercial, industrial and tourist activities. Tripoli, as the capital of Libya and is located on the western coast, represents an important research area. This considers the activities built on it from the port of Tripoli, sea and many of the investment, which is the destination of the local population. Also added facilities such as conference centre, luxury hotels and a cruise station. where the area was reclaimed from the coast of Andalusia to establish the Marina within the luxury tourist facilities. The small harbour is located near outlet pipes of wastewater and the fall of a valley. Moreover, heavy traffic and pollution close to the sea give extra importance to the study area. All these factors make the modelling of the tide as a primary database an essential work. It is also critical to identify some biological and ecological aspects in the region.

Therefore, the Tripoli coast is extremely important to both the economy and the ecology of the region. At the same time, the model, which is based on free source code Delft3D from Deltares, and freely available data sets, will support researchers, scientists and institutions to understand the coastal processes. This kind of numerical model would give a good understanding not only of the hydrodynamics of the region but also of the environment. This will lead to help in making decisions that will affect the ecology of the study area.

To achieve a good understanding of the biological and water quality in the region, a very well-calibrated and validated hydrodynamic model is required. This includes the information on the velocity, water level, and fluxes for each grid cell within the domain under discussion. Then the quantitative analysis of the water quality would be easy to perform by the researchers. It also provides an understanding of the behaviour of the environment, including determining the fate of different compounds.

In this paper, a hydrodynamic flow model using Delft3D software developed by Deltares in Delft, the Netherlands is set up. The modelling used the tidal movement in Tripoli station. Moreover, the modelling will be evaluated and calibrated for a one-year evaluation. However, the grid was conducted and distributed by 14 monitoring stations. The Tripoli tidal station was with high concern in the study area.

The data has taken from Delft Dashboard (DDB), which provided the Open-source Project for a Network Data Access Protocol. Also, the topography of the bed and the open boundary is defined by the general bathymetric chart of the ocean from the General Bathymetric Charts of the Ocean (GEBCO 08 Grid). The hydrodynamic flow model was validated, calibrated and evaluated with observations, which is reliable and useful for further model studies.

The goal of this paper is to develop a high-resolution model that can describe the hydrodynamics of the Tripoli Marina located in western coastal Libya using Delft3D. This model should be able to predict the tidal and water level as appropriately as possible.

It should also be able to deal with wet and dry computations. In other words, the model can handle the wet/drylands concerning the water depth.

2. AREA OF STUDY

The Andalusia marina is a luxury hotel and cruise station. It is situated in Tripoli on the west coast of Libya. The study area is a part and is located at the southern of the Mediterranean Sea (Fig. 1). The Mediterranean Sea is a semi-enclosed sea that leads to high salinities, temperatures, and densities. The only connection to the Atlantic Ocean in the west is through about 13km wide Gibraltar strait. The other connection in the northeast is through the Dardanelles to the Sea of Marmara and Black sea. The rivers from the northern shores are bringing about 92% (15000 m^3/s) of the input water (Bryden *et al.*, 1994). On the southern shore, the Nile River drains water where most of the water evaporates. On the other hand, the drainage basin of the southern-eastern Mediterranean, including a big part of the Libyan coast, is mostly desert with low water inputs (Ludwig *et al.* 2009).

This amount of water is about one-third of the amount of water that it loses by evaporation. The water balance will have approximately 3250 km^3/year losses but also the Atlantic waters (Bryden *et al.*, 1994). This also will not have a significant effect on the hydrology of the study area. Close to the study area, the exchange will be limited due to the shallow Sicily Stairs which has a depth of about 500m (Crise *et al.*, 1999).

In the study area (arid and semi-arid) is common to have floods due to lasting rainfall during spring and fall, affecting small coastal catchments (UNEP/MAP/MED POL, 2003).

3. PURPOSE AND METHODOLOGY OF THE PRESENT STUDY

Studies of hydrodynamics in the western Libyan coast so far have been exploratory and detailed study is required for the functioning of the Andalusia marina. This paper presents a 2DH model for flow based on Delft3D software developed by Deltares.

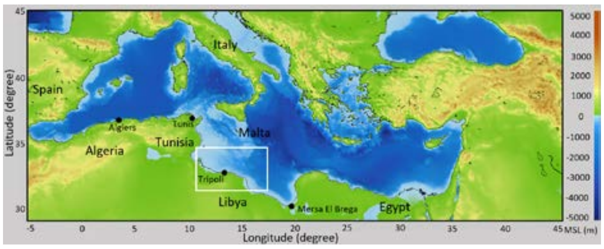

Figure 1. Area of study.

The flow model was used to compute current velocities, water levels at several locations on the western coast of Libya. The flow model was set up for astronomical conditions, calibrated and validated using relevant tide gauges′ measurements at different locations in the area.

This paper confines itself to the presentation of results relevant to the flow field in the area of investigation.

The flow model when it is completed should be useful to set up sediment transport, morphodynamic, and water quality models in arriving at decisions pertaining to the Andalusia marina operation.

4. DELFT3D FLOW MODEL

The use of the FLOW model is to simulate the multidimensional hydrodynamic flow and transport phenomena, including sediments (Deltares, 2018). Delft3D flow model solves the two-dimensional (depth-averaged or 2DH) or three-dimensional (3D) unsteady shallow water equations by applying the hydrostatic pressure assumption.

Transport and deposition of sediments are computed simultaneously with the hydrodynamics, creating direct feedback between hydro- and morphodynamics (Deltares, 2018).

Delft3D flow model calculates non-steady flow resulting from tidal and meteorological forcing. The main purpose is the two-dimensional (2DH, depth-averaged) and three-dimensional (3D) simulation of tidal and wind-driven flow by solving the unsteady shallow water equations.

Usually, the purpose of the model affects the choice of the grid and the bathymetry resolutions, and the period of the simulation. The model designed in this research is to link data and model in real-time.

The Delft3D modelling system is designed to simulate wind shear, wave forces, tidal forces, density-driven flows and stratification due to salinity and temperature gradients and atmospheric pressure changes in coastal, river and estuarine areas (Lesser G.R., *et al.*, 2004).

Delft3D flow model is suited with a flooding and drying algorithm. Grid cells are activated when water levels exceed a flooding threshold, while grid cells are de-activated when local water levels drop below half this threshold (Deltares, 2018). The flow model equations could be normally solved on a Cartesian or spherical staggered grid. It is using the Generalized Lagrangian Mean (GLM) in the same way as the Eulerian equations (Lesser G.R., *et al.*, 2004).

Lesser G.R., *et al.*, 2004 described the governing equations of the flow model as the following:

$$\left.\begin{aligned} U &= u + u_s \\ V &= v + v_s \end{aligned}\right\} \tag{1}$$

where U and V are GLM velocity components, u and v are Eulerian velocity components and *we* and v_s are the Stokes' drift components (Lesser G.R., *et al.*, 2004).

The hydrostatic pressure is based on the assumption of shallow water equations where the vertical momentum equation is expressed only with the hydrostatic pressure. At the same time, the vertical component for the acceleration will be neglected. Therefore, the final description for the hydrostatic pressure will be

$$\frac{\partial P}{\partial \sigma} = -\rho g h \tag{2}$$

where σ is the vertical layer thickness as a ratio of total depth, *h*is the total depth, and ρ is the local fluid density (including salinity, temperature and sediment).

The horizontal momentum equations can be described in two equations

$$\left.\begin{aligned} &\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + v\frac{\partial U}{\partial y} + \frac{\omega}{h}\frac{\partial U}{\partial \sigma} - fV \\ &= -\frac{1}{\rho_o}P_x + F_x + M_x + \frac{1}{h^2}\frac{\partial}{\partial \sigma}\left(v_V\frac{\partial u}{\partial \sigma}\right) \\ &\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y} + \frac{\omega}{h}\frac{\partial V}{\partial \sigma} - fU \\ &= -\frac{1}{\rho_o}P_y + F_y + M_y + \frac{1}{h^2}\frac{\partial}{\partial \sigma}\left(v_V\frac{\partial v}{\partial \sigma}\right) \end{aligned}\right\} \tag{3}$$

where ω is the vertical velocity, f is Coriolis parameter, v_U and v_V are the Eulerian velocity components in Cartesian coordinates (*x* and *y*), M_x and M_y are the external sources or sinks of momentum, and the horizontal pressure P_x and P_y are given by using Boussinesq approximations

$$\left.\begin{aligned} \frac{1}{\rho_o}P_x &= g\frac{\partial \zeta}{\partial x} + g\frac{h}{\partial \rho_o}\int_\sigma^0\left(\frac{\partial \rho}{\partial x} + \frac{\partial \sigma'}{\partial x} + \frac{\partial \rho}{\partial \sigma'}\right)d\sigma' \\ \frac{1}{\rho_o}P_y &= g\frac{\partial \zeta}{\partial y} + g\frac{h}{\partial \rho_o}\int_\sigma^0\left(\frac{\partial \rho}{\partial y} + \frac{\partial \sigma'}{\partial y} + \frac{\partial \rho}{\partial \sigma'}\right)d\sigma' \end{aligned}\right\} \tag{4}$$

where ρ_o is the reference density of water, σ' is the scaled vertical coordinate, and the horizontal Reynold's stress F_x and F_y are determined by the eddy viscosity concept with simplification, as shown in Eqn. (5).

$$\left.\begin{aligned} F_x &= v_H\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2}\right) \\ F_y &= v_H\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2}\right) \end{aligned}\right\} \tag{5}$$

M_x and M_y are describing any external sources or subside of momentum like external forces due to hydraulic structures, discharge or withdrawal of water waves stress, etc.

The continuity equation will be defined as depth-averaged in Eqn. (6).

$$S = \frac{\partial \zeta}{\partial t} + \frac{\partial[h\bar{U}]}{\partial x} + \frac{\partial[h\bar{V}]}{\partial y} \tag{6}$$

where S is the discharge or withdrawal of water, evaporation and precipitation per unit area, ζ is the water level above some horizontal plane, and t is the time. For details and verification of the described equation, it is better to refer to the paper from Walstra et. al., 2000.

To solve the continuity and momentum equations for the Flow model from Delft3D, the alternating direction implicit (ADI) is used (Leendertse, 1987).

The most important advantage form the ADI method is that a system of equations with a small bandwidth will be developed. Many improvements have been done by Stelling and Leendertse, 1991 makes the method used to solve the equations computationally efficiently. This stability can be seen at a courant number of up to about ten and most the second-order accurate (Lesser G.R., *et al.*, 2004).

5. FLOW MODEL SET UP

The domain definition is the first and the most important step for the model setup. It should be taken into account the area of interest and the location of the open sea boundaries.

On the other hand, the computational requirements in terms of stability should be fulfilled. Figure 1 shows the entire western Libyan coast and also the area of interest.

The open sea boundaries have been selected away from the area of interest to ensure that the hydrodynamics is well captured. Moreover, any fluctuations will not affect the area of interest.

To set up the flow model, the tool Delft Dashboard (DDB) from Deltares is used. The DDB is a MATLAB based tool and several open-source datasets are embedded. These datasets include tidal information in many locations around the world (including the area of interest). It is also including the General Bathymetric Chart of the Ocean (GEBCO) bathymetric dataset. This dataset is controlled by the support of the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO (van Ormondt *et al.*, 2020). The grid for the domain is generated also using the mentioned DDB tool.

The numerical model domain, as it is shown in Figure 2, is about 472976 km^2. It consists of a rectangular grid with about 564 km cross-shore by about 1204 km longshore at the western coast of Libya. The upper boundary is located just south of Italy and the lower boundary is West of Tunisia from the study area in Libya.

The grid spacing is about 4 km, in both directions, with about 32164 total number of active cells (301×141 cells total cells).

The bathymetry, that has been used for the flow model was generated using the DDB tool with GEBCO bathymetric dataset. The maximum depth is about 4000 m close to the north open boundary (the deepest point in the Mediterranean Sea is about 5267 m) and about 500 m in the area of interest.

Two main open boundaries have been defined for the flow model. The West open boundary is located between the southern part of Italian and the Tunisian coast (West boundary).

The northern open boundary is located between southern Italy and the eastern Libyan coast (Northboundary) (Fig. 2). Thirteen astronomical components, from the DDB tool, have been applied along the open boundaries using the TPXO tide model. The TPXO models include complex amplitudes of MSL relative sea surface elevations and transports/currents for eight primaries (M_2, S_2, N_2, K_2, K_1, O_1, P_1 and Q_1), two long periods (M_f and M_m) and 3 non-linear (M_4, MS_4 and MN_4) harmonic constituents (Egbert and Erofeeva, 2002). Where M_2 is the main semi-diurnal component, S_2 is the main solar semidiurnal component, N_2 is the Lunar component due to monthly variation in moon's distance from the earth, K_2 is the Soil-lunar constituent due to changes in declination of sun and moon throughout their orbital cycle, K_1 is the Soil-lunar component, O_1 is the main lunar diurnal component, P_1 is the main solar diurnal component, Q_1 is the larger lunar elliptic component, M_f is Moon's biweekly component, M_m is Lunar monthly component, M_4, MS_4 and MN_4 are the non-linear tidal components described as functions of M_2, S_2, and N_2.

All the tidal components along the open boundaries have been modified, the amplitude and the phase, to improve the flow model performance (more details will be described in detail in the calibration section).

6. EVALUATING THE PERFORMANCE OF THE FLOW MODEL

Any numerical model requires several sequential input parameters tuning steps (numerical and physical). These steps should lead to an acceptable and trusted model.

To ensure a good model performance, sensitivity, validation and calibration processes should be taken place. The sensitivity studies for the flow model is dealing with input parameters and their degree of effect on the model results. Any tuned parameters will not be included in the evaluation concerning the model quality. The importance of this stage is in the definition of the parameters to be calibrated.

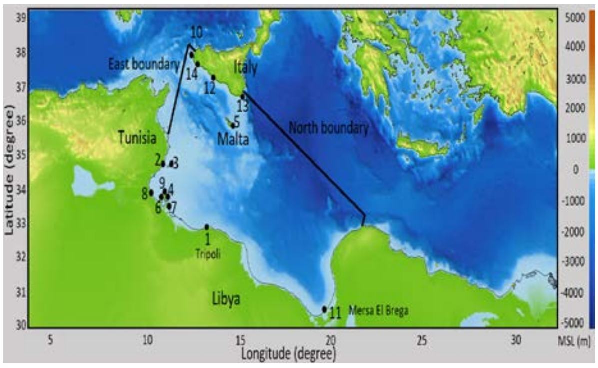

Figure 2. Domain, open boundaries, and observation points.

The calibration procedure includes the defined parameters during the sensitivity analysis. These parameters will be tuned again within the physical limits to get a better agreement between the model results and measured data.

The last step of the model evaluation is the validation for the model concerning different data sets in terms of time. This includes longer and different simulation periods but without changing any of the calibrated parameters.

To evaluate the model performance properly, 14 observation stations will be used during the sensitivity, calibration, and validation processes (Fig. 2).

For the sensitivity analysis, no model quality will be investigated but only the water levels as time series will be considered. From the above-described evaluation performance steps, the grid spacing, time step, bottom roughness parameters have been investigated for the sensitivity study of the one month (spring and neap tide) during June 2016. This period has been used to avoid the effect of the wave due to wind (calm wind conditions, no storms no high waves and no wave-induced currents).

Three grid sets, 2×2 km, 4×4 km, and 6×6 km (fine, medium, and coarse) have been investigated. The model results for the three conditions do not show major differences in terms of water level. The only difference that has been noted is the computational time. The finer grid set makes the longer computational time. Therefore, the medium grid set will be the optimal choice. It will have reasonable computing time and a good representation of the domain and observation stations.

Five-time steps 5, 10, 20, 60 and 120 minutes have been tested. All of them showed small differences in the water level results with longer computation time for the 5 minutes time step and less for the coarse one.

In this study, a 10 minutes time step will be used to have reasonable computation time with fewer numerical errors.

The bottom roughness for the flow model has been taken into account using Chezy formula, uniform across the domain. Also, three sets of uniform values of the bottom roughness (55, 65, and 70) are investigated. The results showed no effect would be observed with changing the bottom roughness. Therefore, the value set 65 (default from Deltars flow model) is used. Table 1 concludes the final setting for the model sensitivity study, which will be used during the calibration and the validation procedures.

The simulation period for the calibration has also been chosen like the sensitivity analysis. The sensitivity analysis showed that the most significant parameter, which should be taken in detail during the calibration study, is the open boundaries. Therefore, the calibration procedure will only be focusing on the modification of the tidal components in terms of amplitude and phase.

June 2016 will be considered for the calibration study (the comparison between the model results and the measurements).

In this study, the quality of the flow model simulations was evaluated by using the mean square error (MSE) and mean absolute error (MAE), as shown in Eqns. (7) and (8). The MAE is more suitable and practical to evaluate the hydrodynamic models (Sutherland *et al.*, 2004). Therefore, the MAE will be used mainly in this paper to evaluate the model performance and the MSE with the scatter diagrams will be used to assist the evaluations.

$$MAE = \langle |H_c - H_m| \rangle \tag{7}$$

$$MSE = \langle (H_c - H_m)^2 \rangle \tag{8}$$

where, H_c is computed (modelled) water level, and H_m is measured water level.

As a result of the sensitivity analysis, the calibration analysis will focus on the modification of the open boundaries in terms of phase and amplitude. Since it is difficult to adjust the two open boundaries at the same time, the modification by several attempts of both boundaries will take place. These modifications will be by using different percentages (increase or decrease) of the amplitude and the phase till the model results, and the measurements in most of the observation points will have a good agreement.

To simplify the adjustment of the open boundaries, an increase and decrease in the phase with a different percentage for each tidal component (Semi-diurnal and diurnal components only) are applied.

Table 2 shows a summary of the modified open boundaries. It can be seen that the adjustments for the amplitude (meter) were required only by adding 10 to 35% to the open boundaries. But less modification for the phase (degree) is required (between 6 to 17%).

The simulations also showed that the modification of the semi-diurnal and diurnal tidal components have major effects on the simulated water level.

This is because the tide in the area of interest is a semi-diurnal tide (M_2, S_2, N_2 and K_2 components).

On the other hand, less influence from the remaining tidal components has been seen.

Table 1. Flow model settings.

Parameter	value	Description
Δt	10	Computational time step (minute)
ρ_w	1025	Water density (kg/m^3)
ρ_{air}	1	Air density (kg/m^3)
g	9.81	Gravitational acceleration (m/s^2)
ν	1	Horizontal eddy viscosity (m^2/s)
C	65	Chezy roughness coefficient
Threshold depth	0.1	Threshold depth for exposure and flooding (m)

Table 2. Adjustment of the northern open boundary.

	Component	Amplitude (%)	Phase (%)
Semi-diurnal	M_2	+35	+9
	S_2	+35	+8
	N_2	+35	+9
	K_2	+35	+8
Diurnal	K_1	+10	+11
	O_1	+10	+17
	P_1	+10	+11
	Q_1	+10	+6

In this study, the evaluation for the model performances during the calibration period will be only for the time series, the model qualification using MAE and MSE (Eqns. (7) and (8)), and the scatter diagrams for water levels from the model results and the measurements. The comparison between the modelled and measured tidal components (semi-diurnal and diurnal) will be inefficient for one month (too short).

The model results for the 14 observation stations (Fig. 2) showed a very good agreement with the measurements in most of the stations. Table 3 shows the quality of the model results using the MSE and MAE qualifications described before using Eqns. (7) and (8).

The results from the modelled and the measured water level in most of the observation stations showed good quality. But in some observation points (Adjim, Gabs, and humtsuk) some differences in the results between the modelled and the measured water levels can be seen. This could be due to the location of the observation points, where the three stations are located in a protected and relatively shallow area (1.4 to 5.6m water depth).

On the other hand, the observation points close to the open boundaries showed very good agreements (like Capopassero and Mazzaradelvallo). The results showed for these observation points MAE is in the order of a few millimetres. Moreover, the results in the area of interest (Tripoli station) showed clear excellent model results compared to the measurements in terms of water level, where the MAE is about 11mm MAE and no phase lag.

In this paper, only four observation stations will be shown including Tripoli station and three close stations (Sfax, El Abassia and Turgoenssmarsa).

Figure 3 shows the comparison between the modelled and measured water levels in the four stations and Fig. 4 shows the scatter diagrams for the same stations. From both of the mentioned figures, it can be seen that Tripoli station showed very good agreements without phase lag with MAE about 11 mm and MSE almost zero (Fig. 3 and Table 3).

At the same time for the same station, the scatter diagram showed a high to the perfect correlation between the modelled and the measured water levels (Fig. 4).

The same conclusion can be conducted for the observation point Turgoenessmarsa (185 km west from Tripoli station) where the MAE and MSE are about 27 mm and 0.0008 m^2, respectively.

Sfax and El Abassia stations are located about 250 and 220 km west of Tripoli station, respectively. Both of the stations showed fewer results in an agreement between the modelled and the measured water levels, but still acceptable for the MAE 94 mm for Sfax and 58 mm for El Abassia.

From the scatter diagram, the Sfax observation station showed some deviation in the model results for high and low tides. About 38% less deviation at the El Abassia observation station have been seen. Moreover, the deviation in El Abassia station has been observed in the low tide more than in the high tide. The possible reason for these observed results in Sfax and El Abassia could be due to the locations of the two stations where both of them are located in a protected coastal region.

This reveals that the more open sea stations have fewer errors to the more protected stations. The results for the stations close to the open boundaries, as is expected, have very good agreements between the model and the measurements. In some of them, the calculated MAE and MSE were about 1mm and zero, respectively (Table 3 and Figure 2). This leads to that the model is well-calibrated and no more improvements are required.

Table 3. Quality of the flow model during the calibration period.

Station No.	Station	MAE (m)	MSE (m^2)
1	Tripoli	0.011	0.0001
2	Sfax	0.094	0.0089
3	El Abassia	0.057	0.0033
4	Turgoenessmarsa	0.027	0.0008
5	Valetta Harbour	0.002	0.0000
6	Adjim	0.284	0.0808
7	Zarzis	0.030	0.0009
8	Gabs	0.127	0.0162
9	Humtsuk	0.104	0.0110
10	Marsala	0.025	0.0006
11	Mersaelbrega	0.013	0.0002
12	Porto Empedocle	0.014	0.0002
13	Capopassero	0.001	0.0000
14	Mazzaradelvallo	0.008	0.0001

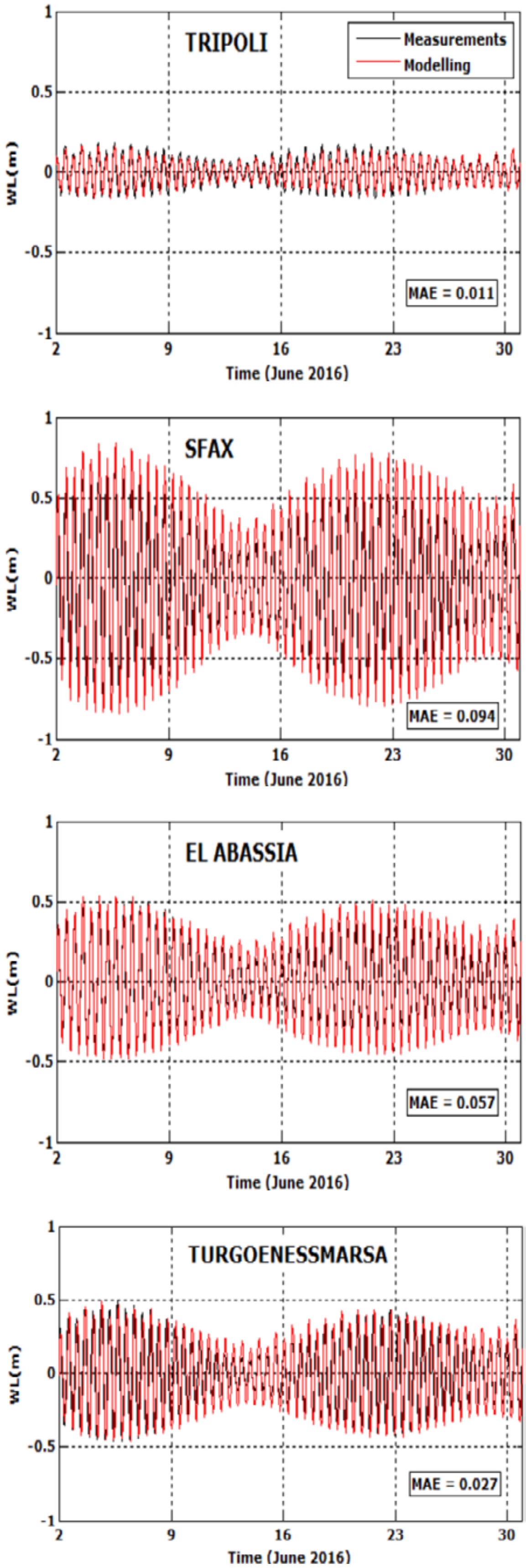

Figure 3. Modelled vs measured water level.

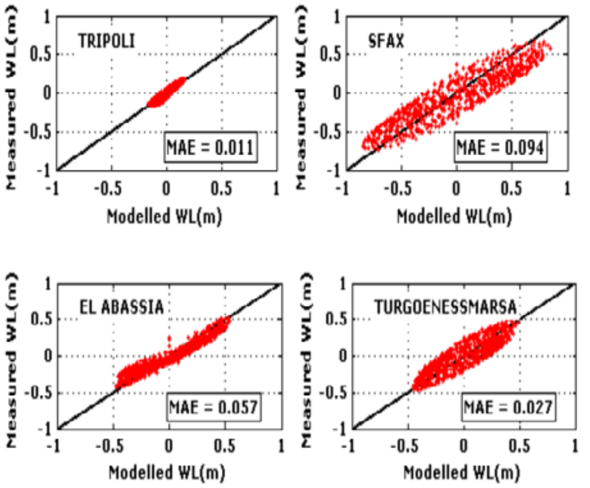

Figure 4. Scatter diagram for modelled and measured water level.

To understand the possible errors in the model results due to the effect of the spring-neap tides for different months in one year, simulation for one year (2016) has been taken place.

Moreover, a longer simulation period will minimize the effect of the wind on the model results. These simulations have been conducted using the well-calibrated model. This process is defined as the validation of the model.

Since the simulation is for one year, the evaluation of the model will be for measured and the modelled tidal constituents (diurnal and semi-diurnal components) in Tripoli station only (area of interest).

Therefore, the time series evaluation using MAE or MSE will not be applicable.

The tidal components for the model results have been generated using the tool Tide from (Deltares systems) where this tool is a major part of the Delft3D from Deltares.

Figure 5 shows the results for the validated model for 2016 (January till December) in terms of tidal components at the Tripoli observation point.

The agreement between the modelled and the measured tidal components are very good for both the amplitude and the phase. This good agreement can be seen for the semi-diurnal tidal constituents (M_2, S_2, N_2 and K_2) for both tide amplitude and phase. The differences in the amplitude for measured and modelled semi-diurnal components were in the order of 1cm for one-year model results.

Also, the phase results showed the same conclusion, where the differences were in the order of 2 to 4 degrees except N_2, the Lunar component due to monthly variation in the moon's distance from the earth tidal component (20 degrees). But it is still in the acceptable range. The results, for the semi-diurnal tidal constituents, clearly show that the considered calibration period is much better than the diurnal tidal constituents.

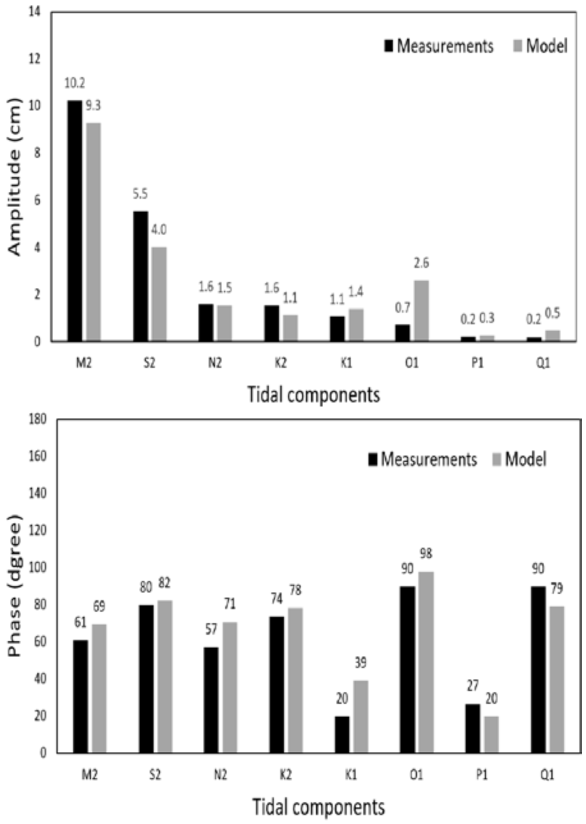

Figure 5. Modelled and measured Tidal components for Tripoli station (the year 2016).

This can be seen in the same figure for the diurnal tidal constituents (K_1, O1, P1 and Q_1) without omission the fact that the tide in the area of interest is semi-diurnal tide. Although of these results, the model showed generally good agreement between the measured and the modelled results. But for some tidal components, the model results showed slightly overestimated amplitude and phase compared to the measurements. On the other hand, the overestimated results will not have a significant effect on the semi-diurnal tidal components.

7. CONCLUSION

The 2DH flow model of Delft3D from Deltares was set up in conjunction with field measurements for tidal constituents on the western coast of Libya. The model simulations account for the tides to compute hydrodynamics in the area of interest.

Sensitivity and calibration studies show that the effect of wind during the calm periods on the hydrodynamics in the area of interest is not very important. Where the results for the modelled water level were very close and identical in some locations for calm periods (June 2016). Results of the validation of the model over a longer period (the year 2016) showed that the flow model is capable of predicting the hydrodynamics agreeably with the observations. Some adjustments to the derived tidal components were found necessary to account for calm meteorological conditions.

The results of the simulations serve to improve our understating of the underlying physical processes in the area of interest due to tides. Although a good understanding of hydrodynamics was achieved, the application of the model to the wind from different years and different seasons may help to improve our understanding of storm effects on the hydrodynamic and morphological evolution.

Although it was found that the 2DH approximation seems to be appropriate for describing the water level, comparisons of the results for the current velocities with those using a 3D approximation and field measurements are recommended.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding this publication.

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