A ZOOMED 3D CIRCULATION MODEL FOR THE MONASTIR BAY: COMPARISON TO OPERATIONAL ANALYSES

Sana CHAOUCH[1,2] and A. HARZALLAH[1*]
[1] Institut National des Sciences et Technologies de la Mer, 28 rue du 2 mars 1934, 2025 Salammbô - Tunisie
[2] Département des mathématiques, Faculté des Sciences de Monastir, 5000 Monastir, Tunisie
*Corresponding Author *: Ali Harzallah. ali.harzallah@instm.rnrt.tn*

ملخص

تهدف هذه الدراسة إلى تطوير نموذج هيدروديناميكي ثلاثي الأبعاد مكثف يحاكي دوران الكتل المائية للمنطقة التي تغطي السواحل الشرقية الوسطى لتونس (نابل إلى الشابة) و في الوسط خليج المنستير.تزداد دقة النموذج تدريجياً من الحواف (حوالي 1100 م) باتجاه خليج المنستير حيث تبلغ حوالي 300 م. تم إجبار النموذج على سطح البحر عن طريق بيانات الغلاف الجوي من محطة أرصاد جوية قريبة و بيانات معاد تحليلها. نقدم هنا مقارنة بين نتائج النموذج وبيانات معاد تحليلها لمحاكاة سنة 2008. تظهر مخرجات النموذج دورة موسمية مهمة مع برودة الشتاء وحرارة الصيف و ذلك بشكل أكبر بالقرب من السواحل، يتم تعديل ملوحة السطح باختراق وريد مياه المحيط الأطلسي في خليج الحمامات، وهو أكثر أهمية في الصيف بالقرب من المناطق الساحلية الضحلة، تكون الملوحة مرتفعة نسبيًا خاصة داخل الخليج وتزداد حدة في الصيف. وتتميز الدورة بالتيارات المتجهة إلى الجنوب الشرقي في الشتاء والغرب والشمال الغربي في الصيف. نتائج المحاكاة هذه مشابهة لتلك الخاصة بالبيانات المعاد تحليلها في الشتاء في حين أن التيارات البحرية تتجه نحو الجنوب الغربي في الصيف. تظهر مقارنة المقاطع الرأسية لدرجة الحرارة والملوحة اتفاقًا قويًا مع وجود أثر لوريد مياه المحيط الأطلسي على عمق حوالي 50 إلى 60 مترًا.

كلمات المفاتيح: نموذج هيدروديناميكي ، خليج المنستير ، بيانات معاد تحليلها

RESUME

Un Modèle Tridimensionnel et à Résolution Variable pour la circulation marine dans la Baie de Monastir: Comparaison aux Analyses Opérationnelles: Le présent travail consiste à développer un modèle hydrodynamique 3D zoomé simulant la circulation des masses d'eau pour la région couvrant les côtes centre-est de la Tunisie (Nabeul à Chebba) avec au centre la baie de Monastir. La résolution du modèle augmente progressivement des bords (~ 1100 m) vers la baie de Monastir où elle est de l'ordre de 300 m. Le modèle est forcé à la surface de la mer par les données atmosphériques d'une station météorologique voisine et par des ré-analyses. Nous présentons ici une comparaison entre les résultats du modèle et les ré-analyses pour l'année simulée 2008. Les sorties du modèle montrent un cycle saisonnier important avec un refroidissement hivernal et un réchauffement estival plus accentués près des côtes. La salinité de surface est modulée par la pénétration de la veine d'eau Atlantique dans le golfe d'Hammamet, plus importante en été. Près des zones côtières peu profondes, la salinité est relativement élevée surtout à l'intérieur de la baie et de façon plus accentuée en été. La circulation est caractérisée par des courants dirigés vers le sud-est en hiver et l'ouest et le nord-ouest en été. Ces résultats de simulations sont assez similaires à ceux des ré-analyses. Les courants au large montrés par les ré-analyses sont cependant orientés vers le sud-ouest en été. Une comparaison des coupes verticales de température et de salinité montre une forte concordance avec la présence de la trace de la veine d'eau Atlantique à une profondeur d'environ 50 à 60 m.

***Mots clés*:** modèle hydrodynamique, baie de Monastir, ré-analyses CMEMS

ABSTRACT

The present work aims at developing a zoomed 3D hydrodynamic model that simulates the circulation of water masses for the central-eastern coasts of Tunisia (Nabeul to Chebba) with the bay of Monastir in the center. The resolution of the model gradually increases from the edges (~ 1100 m) towards the bay of Monastir where it is of the order of 300 m. The model is forced at the sea surface by atmospheric data from a neighboring weather station and by ocean re-analyses. We present here a comparison between the results of the model and the re-analyses for the simulated year 2008. The outputs of the model show a strong seasonal cycle with winter cooling and summer warming more accentuated near the coasts. The surface salinity is modulated by the penetration of the Atlantic water vein in the Gulf of Hammamet, more important in summer. Near shallow coastal areas, the salinity is relatively high especially in the bay interior and is more accentuated in summer. The circulation is characterized by currents directed towards the southeast in winter and the west and northwest in summer. These simulation results are similar to those of the re-analyses. The re-analyses offshore currents are, however, oriented towards the southwest in summer. A comparison of vertical sections of temperature and salinity shows high agreement with the presence of the trace of the Atlantic water vein at a depth of about 50 to 60 m.

Key words: hydrodynamic model, Monastir Bay, re-analyses CMEMS

INTRODUCTION

Very few studies have been conducted in the central region of the east coast of Tunisia despite being subjected to pressures of various origins. This area is located on the south of Cap Bon that forms the southern tip of the Strait of Sicily boarded by the Gulf of Gabes in the south. It is therefore an intermediate zone between low salinity and relatively cold waters in the North and high salinity and relatively warm waters in the south. Depending on the seasons and the daily weather conditions, marine dynamics are more or less intense with a varying intrusion of the Atlantic water vein (Alioua and Harzallah, 2008; Poulain and Zambianchi, 2007; Ben Ismail et al., 2014). Several observational and modelling studies have shown that the Atlantic water vein reaches large parts of the Gulf in summer whereas it is mostly directly towards the south-east in winter (Brandhorst, 1977; Alioua et al., 2008; Poulain and Zambianchi, 2007). Water masses in the Atlantic vein are shown to circulate in the subsurface layers in summer and reach the surface winter due to higher vertical water mixing in winter (Brandhorst, 1977; Ben Ismail et al., 2010). Whereas some features of the water circulation in the Gulf of Hammamet were elucidated, a detailed view is still missing in particular in the Gulf interior and along the Gulf coasts.

The bay of Monastir, located within this region, constitutes an area of major interest due to its high coastal population density (URAM, 2003). It is a very important economic activity zone (industry, fishing, aquaculture, tourism …) that have created very strong pressures on the marine environment of this bay. Indeed, the bay is an area of recurrent episodes of algae proliferation, eutrophication, red colour appearance or even fish mortality. Land-based discharges, which have increased sharply in recent years, have surely contributed to the occurrence of these crises. Climate change is expected to reinforce them. The morphology of the bay, a shallow area surrounded by shoals, constitutes a receptacle very vulnerable to any material that is poured into it. The bay is bounded to the south-east by the Teboulba shoals which extend to the Kuriat Islands, to the north-west by the Monastir peninsula and by the coastal coastline to the south-west.

A detailed study was carried out in 2010 to understand the state of health of the Bay of Monastir and to propose development solutions (APAL, 2010). This multidisciplinary study made use of typical atmospheric conditions to simulate the associated marine circulation and sediment transport, providing information on the possible modes of circulation of water masses. It is however based on a closed domain and a permanent mode modelling approach. Following the recommendations of this study, a modification of the banks of the bay at the level of the main stream (west Khniss et Oued Khniss) was carried out in order to minimize the zones of stagnation. Souissi et al. (2014) carried out a series of simulations with a wave propagation model and showed that the series of shoals and sand bars between Ras Dimass and Kuriat Islands form a barrier which generates a reduction in energy and contributes to the concentration of pollution. Sassi et al. (1998) showed fattening in the Khniss–KsibetMediouni zone and the presence of both organic and mineral pollution in relation to the inputs of Oued Khniss. The ecosystem was shown not to be affected significantly by aquaculture activity east of Monastir (Challouf et al., 2017).

The present work is based on the hydrodynamic modelling of the Monsatir Bay. The objective is to set up a numerical model that reproduces the marine circulation in the bay as well as its hydrographic characteristics. In this article we will present a comparison between the outputs of the model with the analyses from the CMEMS general circulation operational model (Simoncelli et al., 2019). In section 2, we will present the model and the analysis used in the comparison. The results will be present in section 3. The article ends with a conclusion.

MATERIAL AND METHODS

a. The INSTMBMZ model

The INSTMBMZ model of the bay of Monastir is an improved version compared to the INSTMBM previous one which was developed to simulate the marine dynamics in the bay of Monastir (Jazzar, 2016). The model is based on the POM model (Princeton Ocean Model; Mellor and Yamada, 1982; Mellor and Blumberg, 1985). It is a finite difference model with a vertical sigma coordinate; Jazzar (2016) has already applied a first version to the region covering the central-eastern coasts of Tunisia (Nabeul to Chebba) with the bay of Monastir in the centre using a regular grid (Figure 1). This version has included a progressive zoom towards the bay. The resolution increases from about 1100 m at the edges to about 300 m in the bay. On the vertical, the model has 15 vertical levels. The model bathymetry is based on available marine charts for the region. The model solves the three-dimensional primitive Navier Stokes equations, the heat and salt conservation equations as well as a turbulence closure sub-model (Mellor and Yamada, 1982) to provide the vertical turbulent mixing coefficients and a tracer transport equation coupled with momentum equations to study the propagation of any dissolved matter in the area. The model is forced at the sea surface by atmospheric conditions every 3 hours (wind stress, precipitation, evaporation and heat flux) from the Skanes weather station (60740, see www.meteomanz.com). At the

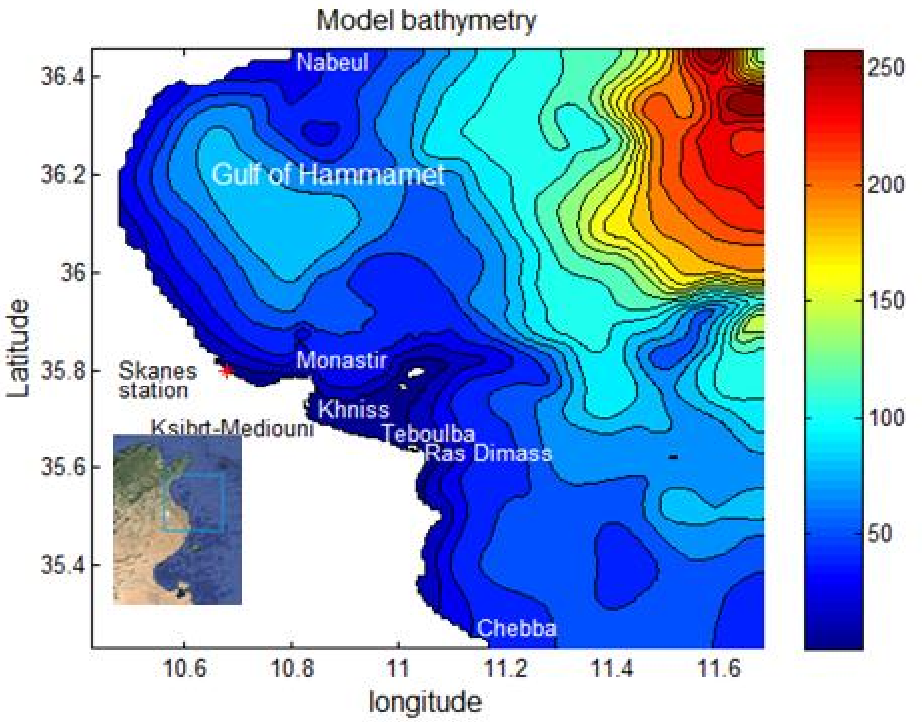

Figure 1. Bathymetry used in the model.
Inner map: geographical location of the model domain.

lateral edges the model is forced by the daily data of water temperature, salinity and velocity using the CMEMS operational reanalyses.

In this study, the model uses atmospheric and oceanic forcing fields for the year 2008. First, a spin-up simulation is performed using data from the CMEMS January 1st, 2008 as initial conditions; the model is then run again for the year 2008 from the state reached by this spin-up simulation. The model includes a land-based water supply but it is not used in the present study. The outputs of the model, calculated on the model sigma coordinates are transformed to the Z coordinates for output processing.

b. The CMEMS data

CMEMS (Copernicus - Marine environment monitoring service) data are based on the NEMO model (Nucleous for European Modeling of the Ocean), a hydrodynamic model based on a variational data assimilation scheme (OceanVAR) for vertical temperature and salinity profiles and satellite sea level anomaly along trajectories data. The horizontal resolution of the model grid is of the order of 6 to 7 km and unevenly spaced 72 vertical levels. The NEMO model uses the Z coordinate.

c. Comparison approach

The model results are compared to the CMEMS re-analyses. For comparison consistency, the NEMO fields are horizontally interpolated on the model grid. Horizontal distributions of surface temperature, salinity and currents are first compared. Those comparisons are made for winter (December, January, February) and summer (June, July, August) averages. The temperature and salinity values averaged over June 2008 are also compared along two vertical sections. The first is directed North-South (at the longitude 11.37°E) and the second one is directed East-West (at the latitude 35.91°N).

RESULTS

The surface salinities simulated by the model and obtained from the CMEMS re-analyses are shown in Figure 2. During the winter of 2008, the salinity minimum of around 37.4 psu is found in the northern part of the Gulf of Hammamet and extends to the south-east, gradually diminishing. This is most likely the trace of low salinity Atlantic water entering the Gulf of Hammamet; they are slightly higher than in CMEMS, in the order of 37.5 psu. The model also shows a secondary extension to the south less pronounced in CMEMS.

Likewise, during summer, the minimum salinity vein is closer to the northern coasts of the Gulf of Hammamet in relation to the southwest orientation of the winds during this season. This behavior is noticed in the CMEMS re-analyses and in the model. The noticeable relationship between the seasonal

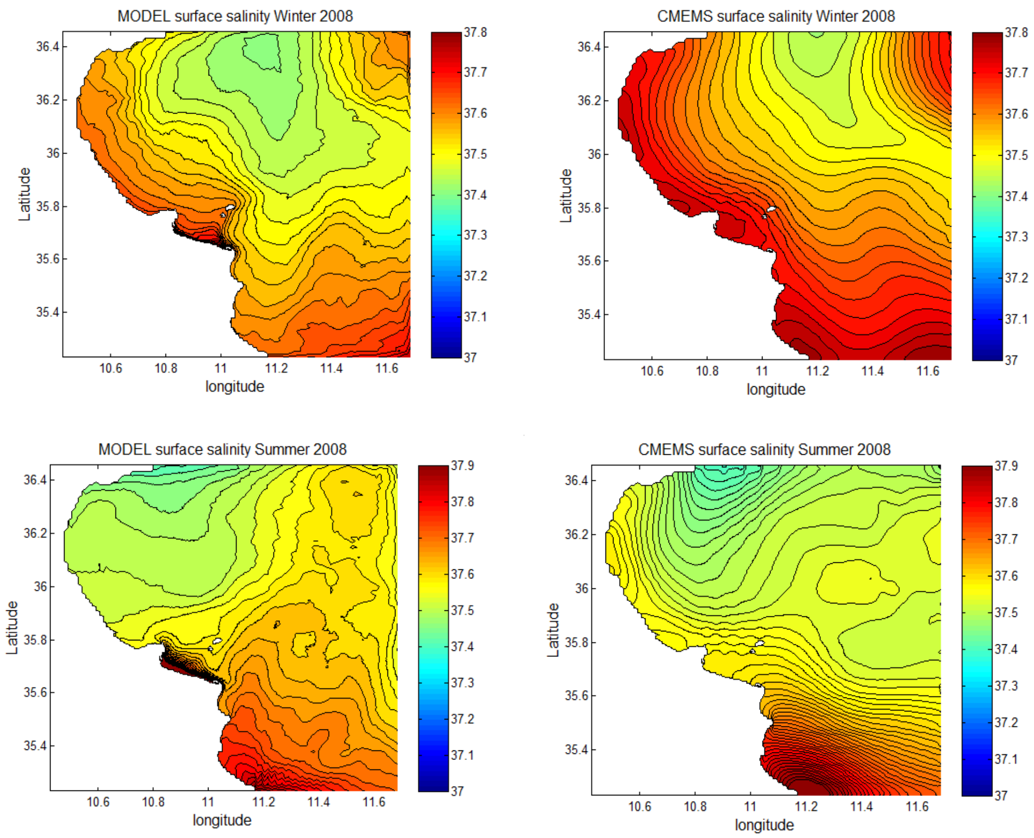

Figure 2: Spatial distribution of surface salinity (in psu) in winter (top) and summer (bottom) from the outputs of the INSTMBMZ model (left) and CMEMS re-analyses (right).

variability of the wind conditions and the surface circulation in the central Mediterranean has been shown by Poulain and Zambianchi (2007). The patterns they obtained based on a compilation of drifters clearly indicate modified Atlantic water directed towards the Tunisia coasts along the Gulf of Hammamet in summer. The salinity reaches a maximum in the southern part of the domain under consideration (off Chebba). Note that the strong salinities in the coastal areas of the bay of Monastir are in the INSTMBMZ model but not in CMEMS, due to the relative low resolution of the latter. Indeed, the shallow area of the Monastir bay surrounded by shoals is better reproduced in the INSTMBMZ high resolution model compared to that in CMEMS. Moreover, the bathymetry minimum being only 1 meter in the INSTMBMZ model, whereas its few meters in CMEMS, induces stronger responses to the atmospheric forcing in the sallow areas.

The winter and summer distributions of the sea surface temperature are represented in Figure 3. The distributions of CMEMS and INSTMBMZ are quite similar with relatively low winter values of around 16.5 °C, reaching 15.5 °C near the ribs. In summer, temperatures are around 25 °C and reach 26.5 °C near the coasts. Unlike CMEMS, the INSTMBMZ model shows a particular behaviour in the bay of Monastir with increased winter cooling and summer warming (14.8 °C and 29 °C respectively). The finer resolution of INSTMBMZ allows taking into account fairly low bathymetries (of the order of a meter) and again explains the ability to reproduce this strong variation within the bay.

Regarding marine currents (Figure 4), INSTMBMZ and CMEMS show similar structures with a circulation directed from northwest to southeast in winter. The structures in INSTMBMZ are less smooth than in CMEMS due to the stronger bathymetry effect. In summer, the INSTMBMZ model shows different currents from those of CMEMS in the offshore area; they are directed northwest in INSTMBMZ while southwest in CMEMS. The weak currents and the frequent changes of their orientation could partly explain these differences.

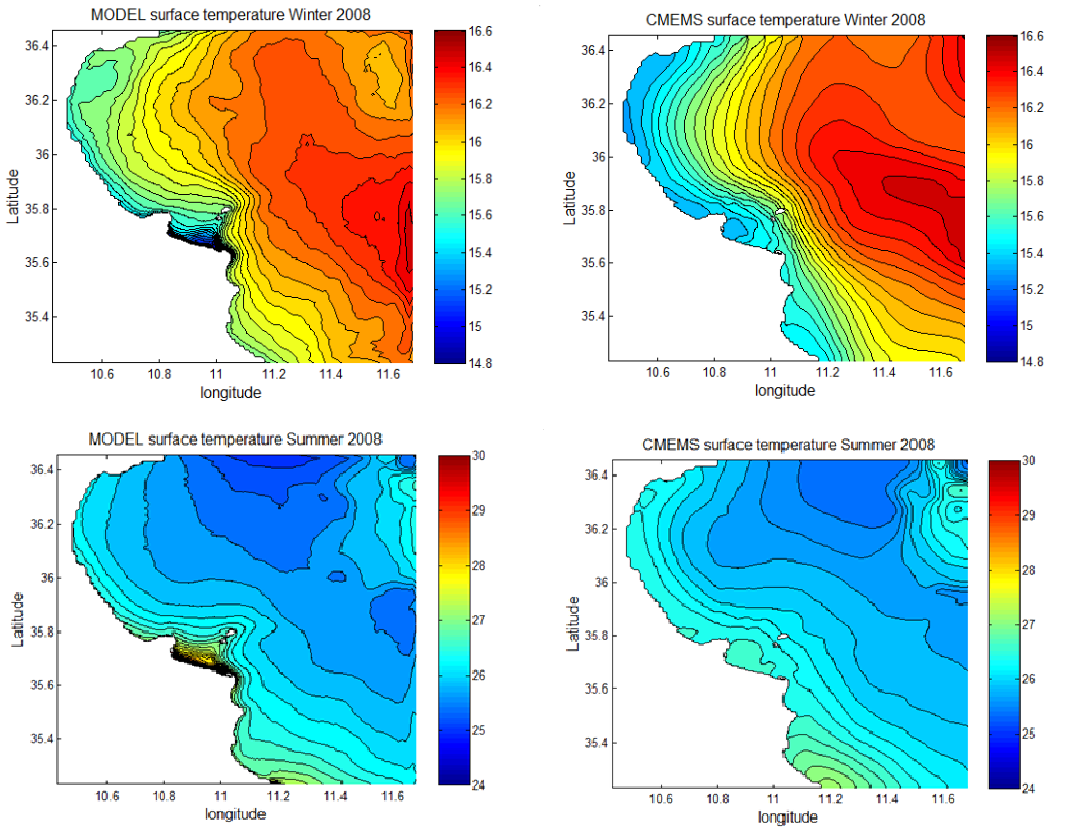

Figure 3: As Figure 2 but for the surface temperature, in°C.

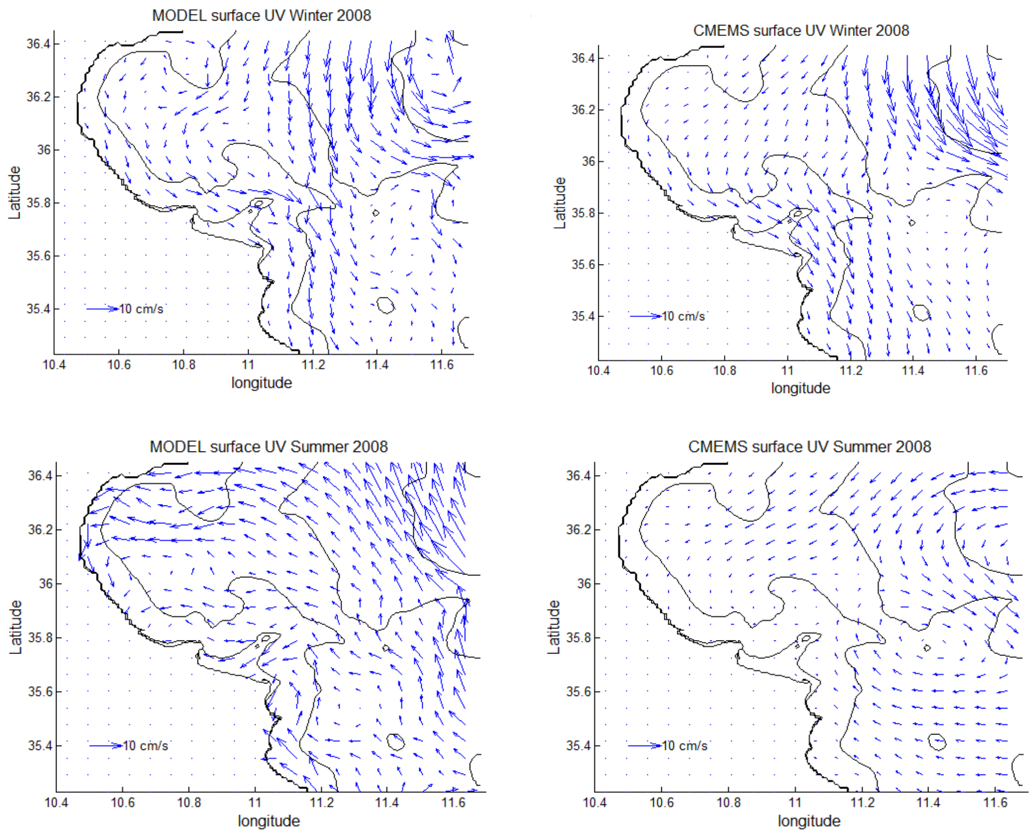

Figure 4: As Figure 2 but for the speed vector of the current (see scale in the figures).

The North-South (at longitude 11.37°E) and East-West (at latitude 35.91°N) vertical sections of Junetemperature are shown in Figure 5. We note a high resemblance between INSTMBMZ and CMEMS with vertical gradients ranging from 23 °C at the surface to 15 °C at the bottom. Stronger temperatures are shown in the shallow areas in the western (East-West section) and southern (North-South section) in both products. The vertical gradients are tilted downward in those zones. The Junesalinity sections (Figure 6) also show similarity between INSTMBMZ and CMEMS. A minimum salinity layer (37.2 psu) is found at a depth of approximately 50 m in both sections. As mentioned above, it is the signature of the Atlantic vein penetrating into the interior of the Gulf of Hammamet. The salinity also shows a deepening of the minimum salinity layer towards the southwestern zones mainly along the North-South section. This behaviour actually translates the penetration of the Atlantic vein into the Gulf. The water vein is directed in June towards the southwest when entering the Gulf. The minimum salinity core follows a vein directed towards the south in the inner part of the Gulf and then towards the east/south-east in the southern Gulf.

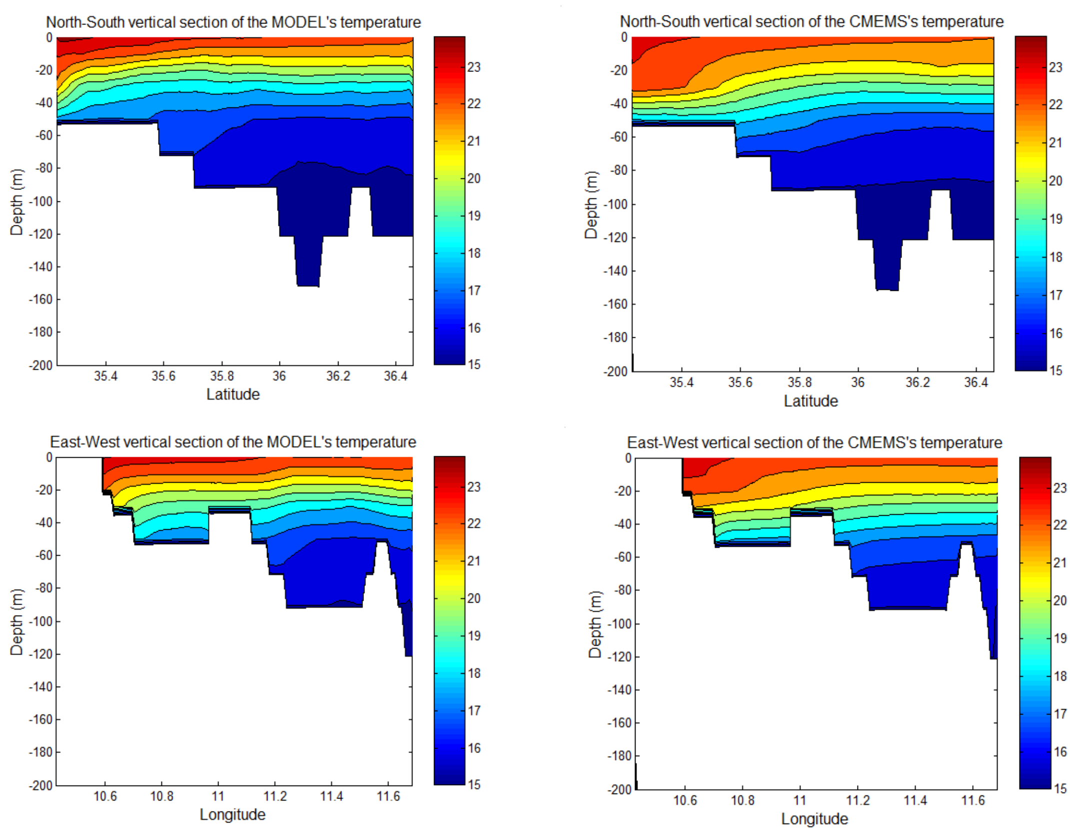

Figure 5: Vertical sections of the North-South (top) and East-West (bottom) temperature (in °C) from the outputs of the INSTMBMZ model (left) and CMEMS re-analyses (right).

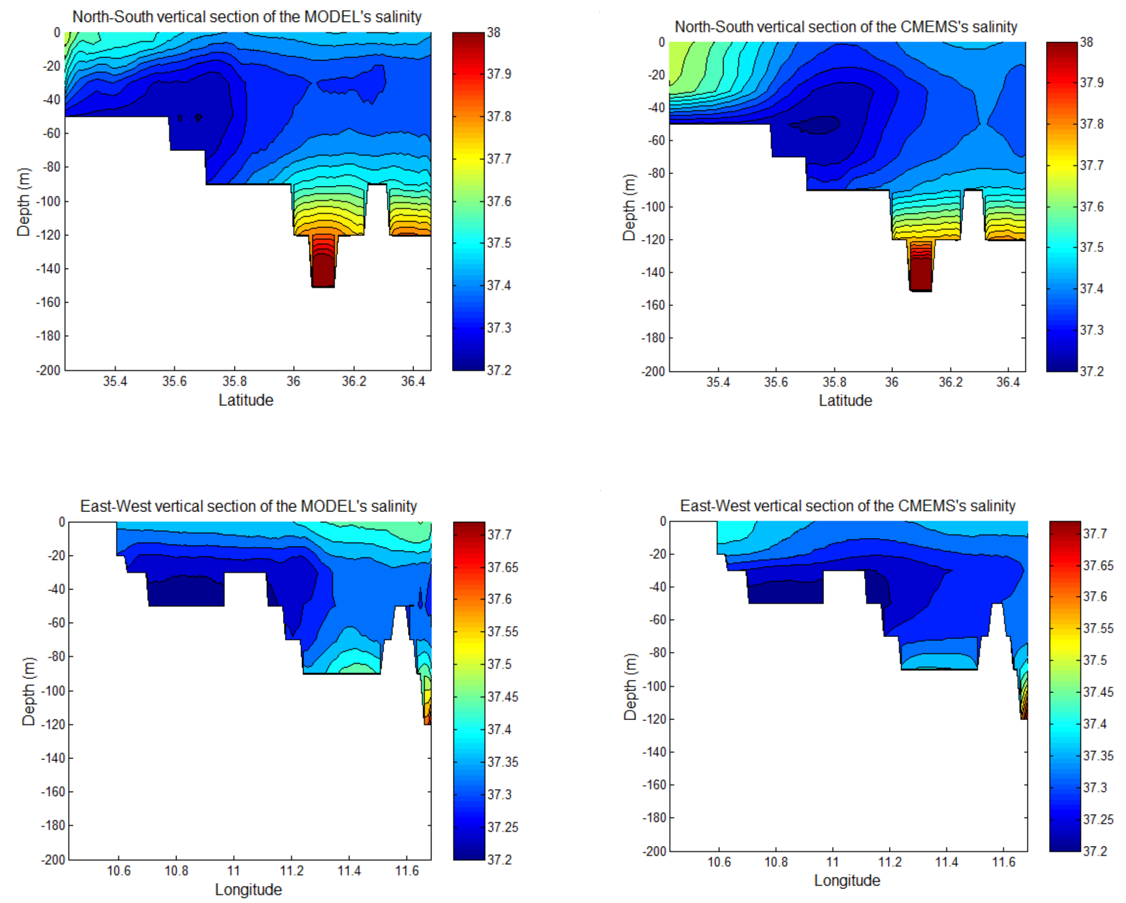

Figure 6: As Figure 5 but for vertical sections of salinity (in psu)

CONCLUSION

This study has shown that the 3D circulation model zoomed on the bay of Monastir reproduces the temperature, salinity in a very similar way to those shown in CMEMS re-analyses. The surface water circulation is found similar in the winter season but not in summer. In this season INSTMBMZ shows northwestward circulation contrasting the southwestward one in CMEMS. Based on both products water masses move on average from north to south-east along the coasts under the effect of the prevailing winds but also carried by the vein of low salinity of Atlantic origin. This vein is located at a depth of about fifty meters in the Gulf of Hammamet and is an important characteristic of the waters of the area since almost continuously bringing relatively low salinity water (37.3 to 37.4 psu) to a zone where water salinity is relatively high (around 37.7psu). In summer, under the effect of the anticyclonic atmospheric circulation, the currents penetrate more into the Gulf. The surface water temperature shows an important seasonal cycle with cooling in winter and warming in summer more accentuated near the coasts and in particular in the bay interior.

The higher resolution of the INSTMBMZ model, especially in the zoomed area inside the bay, permitted to simulate larger temperature variations that reach a minimum of 14.8°C in winter and exceed 29 °C in summer. This is also seen for salinity fields for which shallow depths induce high salinities (exceeding 37.9 psu in summer). The strong evaporation in the shallow areas along the coast of the bay and its confinement explain this particular behavior.

The comparison shown in this study is made against the CMEMS re-analyses to highlight the benefits of using a higher resolution model with a zoon in a confined region (the bay of Monastir) and being able to account for very low bathymetry areas. This work would be completed by validations to observations and by taking into account the terrestrial water inputs which are already incorporated in the model but not used here. Those aspects will be addressed in a forthcoming paper.

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