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Wave and hydrodynamics modelling in coastal areas with TELEMAC and MIKE21

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***Abstract*—Wave and hydrodynamics modelling in coastal areas is nowadays an indispensable tool for both research and engineering/environmental design. The selection among the various available models is equally essential and should be done cautiously, taking into consideration both the models' capabilities and the actual modelling needs. In the above context, results of ongoing research on the comparison between TELEMAC and MIKE21 are presented in this work. The test study area is located near the Port of Brindisi in South Italy. TELEMAC simulations were performed using TOMAWAC for wave propagation and TELEMAC-2D for the hydrodynamics; MIKE21 simulations were performed using the MIKE21-SW and MIKE21-HD modules respectively. Model output is compared on the basis of wave/current fields and wave propagation along linear trajectories from the offshore to the shoreline; analysis shows an overall satisfactory agreement between the two models.**

I. INTRODUCTION

Accurate predictions of wave climate, current patterns and sea level variations are essential for a wide range of research and operational applications, as they govern sediment and pollutant transport, coastal morphology evolution and interactions with structures in the coastal field. Accordingly, numerical models that can serve the above purposes have become the main tool for researchers, engineers and policy planners around the world. The range of available models is wide; the selection of the most suitable for each application should be based on models' evaluation with regard to the case-specific modelling needs.

In the present work, the open-source TELEMAC suite is compared with the well-known MIKE21 commercial software (developed by DHI Group) in a fundamental wave and hydrodynamics modelling application. The study area is located near the Port of Brindisi in South Italy; the models used are briefly described, as are the steps of their setup for the final applications. Results are compared on the basis of wave/current fields and wave propagation along linear trajectories from the offshore to the shoreline. Analysis shows an overall satisfactory agreement between the two models and is deemed to provide a useful insight on their comparative evaluation, setting the basis for future work in this direction.

II. MATERIALS AND METHODS

A. Grid Generation

Blue Kenue is a data preparation, analysis, and visualization tool for hydraulic modellers developed by the Canadian Hydraulics Centre (National Research Council). In the present work it was used to create the variable-density triangular mesh of the study area. The respective work for MIKE21 was done using MIKE Zero, the DHI tool for managing MIKE projects.

The bathymetric and shoreline data of the wider study area resulted from the digitization of nautical charts acquired from the Italian National Hydrographic Military Service ("Istituto Idrografico della Marina Militare").

B. Wave Propagation

Wave propagation with TELEMAC was modelled using TOMAWAC. By means of a finite-element type method, TOMAWAC solves a simplified equation for the spectro-angular density of wave action. The physical processes modelled comprise [1]: (a) energy source/dissipation processes (wind driven interactions with atmosphere, dissipation through wave breaking / whitecapping / wave-blocking due to strong opposing currents, bottom friction-induced dissipation), (b) non-linear energy transfer conservative processes (resonant quadruplet interactions, triad interactions), and (c) wave propagation-related processes (wave propagation due to the wave group / current velocity, depth-/current-induced refraction, shoaling, interactions with unsteady currents).

Wave propagation with MIKE21 was modelled using MIKE21-SW. MIKE 21-SW is a third generation spectral wind-wave model that simulates the growth, decay and transformation of wind-generated waves and swells. The discretisation of the governing equation in geographical and spectral space is performed using a cell-centred finite volume method, while in the geographical domain is discretized by unstructured triangular meshes [2]. MIKE-SW models the same physical processes as TOMAWAC, offering however less options for their parametrization.

C. Hydrodynamics

Hydrodynamics with TELEMAC were modelled using TELEMAC-2D. TELEMAC-2D solves the Saint-Venant equations using the finite-element or finite-volume method, and is able to perform simulations for both transient and permanent conditions [3]. Due to its capabilities, the model is widely used in free-surface maritime and river hydraulics; in the present work, the objective was to test the simulation of wave-current interactions through its direct coupling with TOMAWAC.

Hydrodynamics with MIKE21 were modelled using MIKE21-HD. MIKE21-HD simulates unsteady flow taking into account density variations, bathymetry and external forcings; it is based on the numerical solution of the two-dimensional incompressible Reynolds averaged Navier-Stokes equations, subject to the assumptions of Boussinesq and of hydrostatic pressure. The spatial discretisation of the primitive equations is performed using a cell-centred finite volume method [4]. As mentioned in the previous section for TOMAWAC and MIKE21-SW, MIKE21-HD also offers less parametrization options than TELEMAC-2D.

III. MODEL SETUP

A. Study area

The study area is located northwest of the city and port of Brindisi (Puglia region, South Italy). The selected rectangular outline of the test field for the model applications, also shown in Fig. 1, measures about 21km in the longshore and 8km in the cross-shore direction.

B. Grid Generation

The triangular mesh in Blue Kenue was created defining two density zones: the one below 10m of depth where the "default edge length" was set to 20m, and the rest of the field where the respective value was set to 250m. The "edge growth ratio" parameter that governs the transition between the two in the meshing algorithm was set to 1.2. The resulted mesh, presented in Figure 2a, consists of 55,521 nodes forming 109,490 elements. The same approach was followed using MIKE Zero as well, with the two density zones divided by the 10m depth isoline. However, due to the fact that in MIKE Zero the generation of mesh elements is based on element area rather than "edge length" (as in Blue Kenue), repetitive testing resulted to a mesh of 61,861 nodes forming 122,110 elements (see Fig. 2b) which for this case was considered satisfactory. The effect of the mesh differences on the results will be the subject of future evaluation.

C. Coupled Wave and Hydrodynamics Simulations

Both TELEMAC and MIKE21 were set-up to run coupled wave and hydrodynamics simulations through the direct coupling of TOMAWAC – TELEMAC-2D and MIKE21-SW – MIKE21-HD respectively. Based on previous analysis of the wave regime for the wider area (wave data from the buoy of Monopoli, part of the Italian wave metric network "RON" [5, 6]), the test simulation in this work was selected to run for an extreme NE wave of significant wave height H_s=4m and peak period T_p=8sec imposed to the upper field boundary (see Fig. 2).

Figure 1. Wider study area and outline of the test field for the model applications (base images from Google Earth; privately processed).

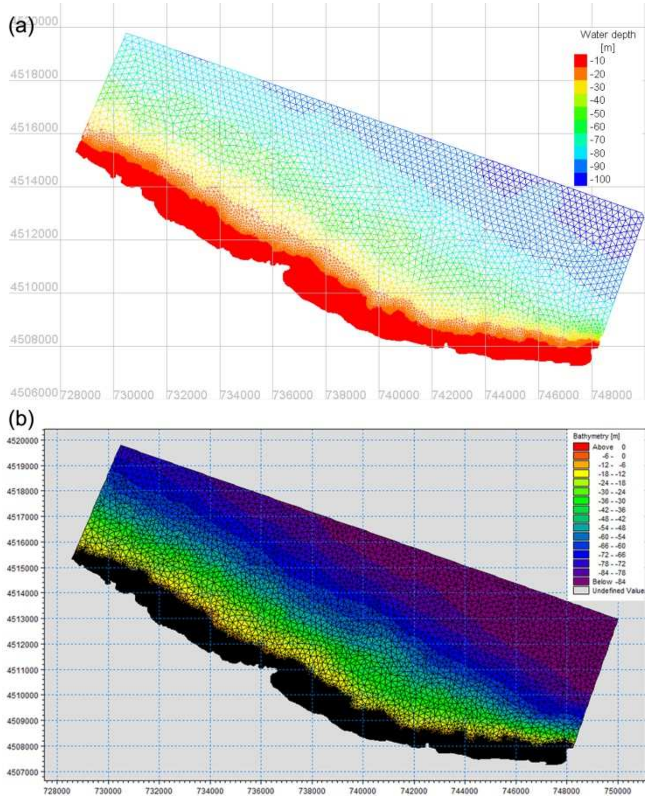

Figure 2. Triangular mesh and bathymetry for the test field as resulted from: (a) Blue Kenue and (b) MIKE Zero.

For the TOMAWAC – TELEMAC-2D simulation, the keywords that were modified in the steering files of the models are presented in Tables I and II respectively. For the MIKE21-SW – MIKE21-HD simulation, basic model parameters are presented in Table III.

TABLE I. MODIFIED KEYWORDS IN TOMAWAC

Keyword	Value
TIME STEP	6
NUMBER OF TIME STEPS	450
TYPE OF BOUNDARY DIRECTIONAL SPECTRUM	6
BOUNDARY SIGNIFICANT WAVE HEIGHT	4
BOUNDARY PEAK FREQUENCY	0.125
MINIMAL FREQUENCY	0.067
NUMBER OF FREQUENCIES	16
BOUNDARY MAIN DIRECTION	225
BOUNDARY DIRECTIONAL SPREAD	5
NUMBER OF DIRECTIONS	16
CONSIDERATION OF SOURCE TERMS	TRUE
DEPTH-INDUCED BREAKING DISSIPATION	1

TABLE II. MODIFIED KEYWORDS IN TELEMAC-2D

Keyword	Value
TIME STEP	3
NUMBER OF TIME STEPS	900
COUPLING WITH	TOMAWAC
COUPLING PERIOD FOR TOMAWAC	2
SOLVER	1 (conjugate gradient)
TREATMENT OF THE LINEAR SYSTEM	2 (wave equation)
WAVE DRIVEN CURRENTS	TRUE

TABLE III. MODEL PARAMETERS IN MIKE21-SW AND MIKE21-HD

Keyword	Value
Duration time [s]	2700
Wave	
Mode	2
EQUATION / Formulation	2
EQUATION / Time Formulation	2
SPECTRAL / Type of frequency discretization	2
SPECTRAL / Number of frequencies	15[a]
SPECTRAL / Minimum frequency	0.067
SPECTRAL / Frequency factor	1.1
SPECTRAL / Type of directional discretization	1
SPECTRAL / Number of directions	16
BOUNDARY CONDITIONS / Type	4
BOUNDARY CONDITIONS / Wave Height	4
BOUNDARY CONDITIONS / Peak period	8
BOUNDARY CONDITIONS / Wave direction	45
BOUNDARY CONDITIONS / Directional spread	5
WAVE BREAKING / Type	1
WAVE BREAKING / Type of gamma	1
WAVE BREAKING / Alpha	1
Hydrodynamics	
EQUATION / Formulation	2
EQUATION / Time Formulation	2
RADIATION STRESSES / Type	2
SOLUTION / Scheme of time integration	1
SOLUTION / Scheme of space discretization	1
SOLUTION / Type of entropy fix	1
SOLUTION / CFL critical HD	0.8
SOLUTION / CFL critical AD	0.8

a. The difference form the respective value in Table I is explained by the different definition of frequency distribution in TOMAWAC and MIKE-SW [1, 2].

IV. RESULTS AND DISCUSSION

Fig. 3a shows the wave height distribution and wave direction vectors over the entire field, as resulted from the coupled TOMAWAC – TELEMAC-2D run; Fig. 3b shows a detail of these results for a particular area of interest. The respective results of the coupled MIKE21-SW – MIKE21-HD run are presented in Figs. 4a and 4b. Model estimates are quite close for both wave height magnitude and distribution, focusing especially in the surf zone. The difference depicted in MIKE21 results (Fig. 4) for the onshore propagating waves is in fact not significant; all the values exceeding 4m in this area are below 4.1m, while the respective ones for TOMAWAC (Fig. 3) are only slightly smaller than 4m. Local peaks of wave height close to the breaker line reach ~4.2m in both models' results.

Fig. 6a shows the current speed distribution and current direction vectors over the entire field, as resulted from the coupled TOMAWAC – TELEMAC-2D run; Fig. 6b shows a detail of these results for the particular area of interest (same as in Figs. 3b and 4b). The respective results of the coupled MIKE21-SW – MIKE21-HD run are presented in Figs. 5a and 5b. In Figs. 5 and 6 insignificant current direction vectors (for speeds lower than 0.1 m/s) were omitted to enhance figures' clarity. Current circulation patterns and magnitude agree satisfactorily between model runs, with the prevailing longshore current (E-SE to W-NW direction) affected by shoreline morphology and local bathymetry. Current speed peaks appear in the same areas in both Figs. 5 and 6, approaching 2.5m/sec for the TOMAWAC – TELEMAC-2D run and reaching 2.8m/sec for the MIKE21-SW – MIKE21-HD run.

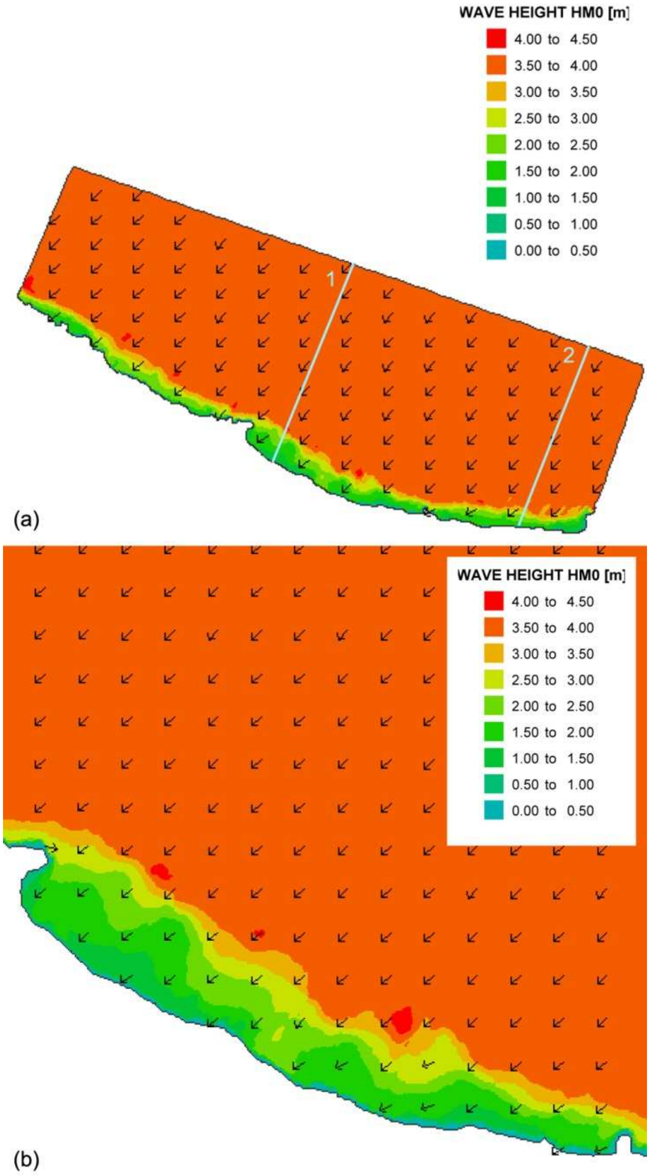

Figure 3. Wave height distribution and wave direction vectors as resulted from the coupled TOMAWAC – TELEMAC-2D run: (a) over the entire field and (b) for a particular area of interest. Wave height evolution along the line trajectories depicted in the upper figure, is presented in Fig. 7.

Figs. 7a and 7b show wave height evolution results of both the coupled TOMAWAC – TELEMAC-2D and MIKE21-SW – MIKE21-HD runs, along two linear trajectories from the offshore field boundary to the shoreline. Wave height profiles for Trajectory 2 (Fig. 7b) practically overlap inside the surf zone, with minor differences for the onshore-propagating wave behind the breaker line (located at ~5800m along the trajectory). On the other hand, results for Trajectory 1 (Fig. 7a) show differences regarding wave breaking and height evolution inside the surf zone. As the underlying theory is similar in both models, these can be attributed to differences in the triangular meshes (see Section III.B) and local anomalies in nearshore water depth interpolation (also affected by mesh properties). The aforementioned issues are undoubtedly among the ones to be further investigated in future research.

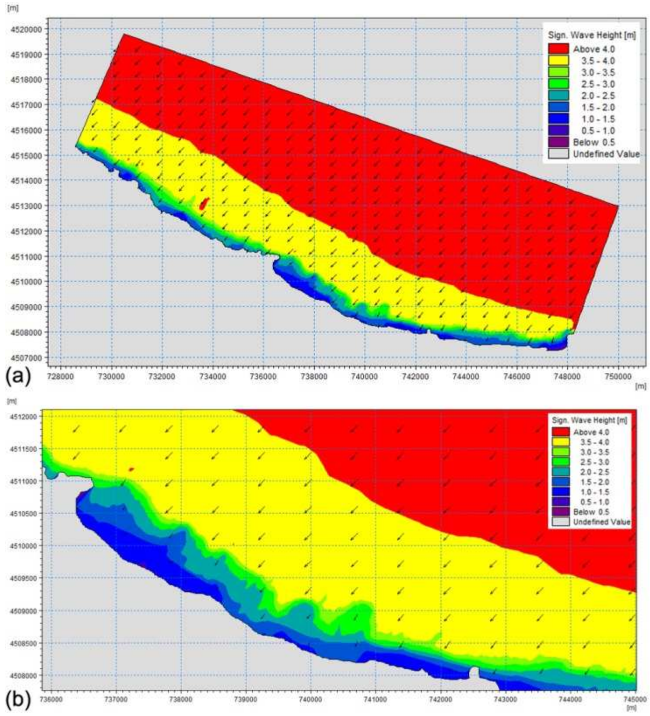

Figure 4. Wave height distribution and wave direction vectors as resulted from the coupled MIKE21-SW – MIKE21-HD run: (a) over the entire field and (b) for a particular area of interest.

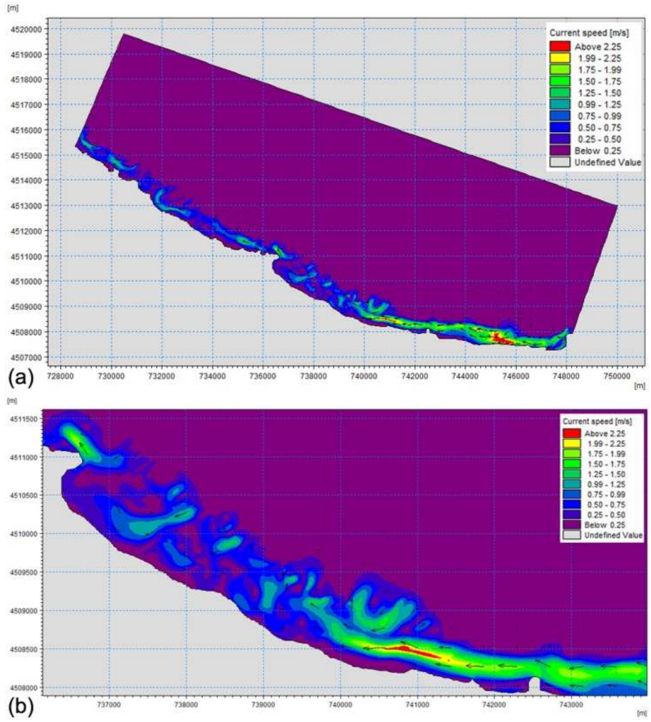

Figure 5. Current speed distribution and current direction vectors as resulted from the coupled MIKE21-SW – MIKE21-HD run: (a) over the entire field and (b) for a particular area of interest.

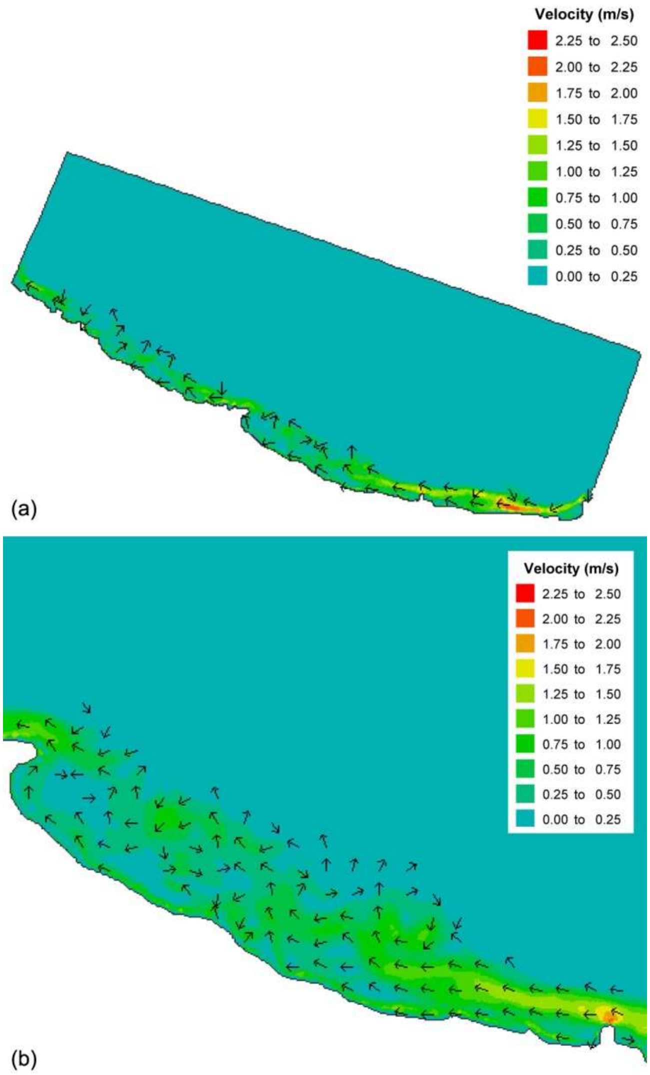

Figure 6. Current speed distribution and current direction vectors as resulted from the coupled TOMAWAC – TELEMAC-2D run: (a) over the entire field and (b) for a particular area of interest.

V. CONCLUSIONS

The present work was the first authors' step towards a comprehensive comparison of TELEMAC and MIKE21 on wave and hydrodynamics modelling. The results of the fundamental applications presented above show a satisfactory agreement between the two models. Having overcome some of the main obstacles in model setup, ongoing research comprises the investigation of the effect of all the wave- and current- related processes – modelled by TELEMAC and MIKE21 – on wave-current interaction. In future work, focus will be also given to identifying and implementing methods of analytical comparison of the models' results.

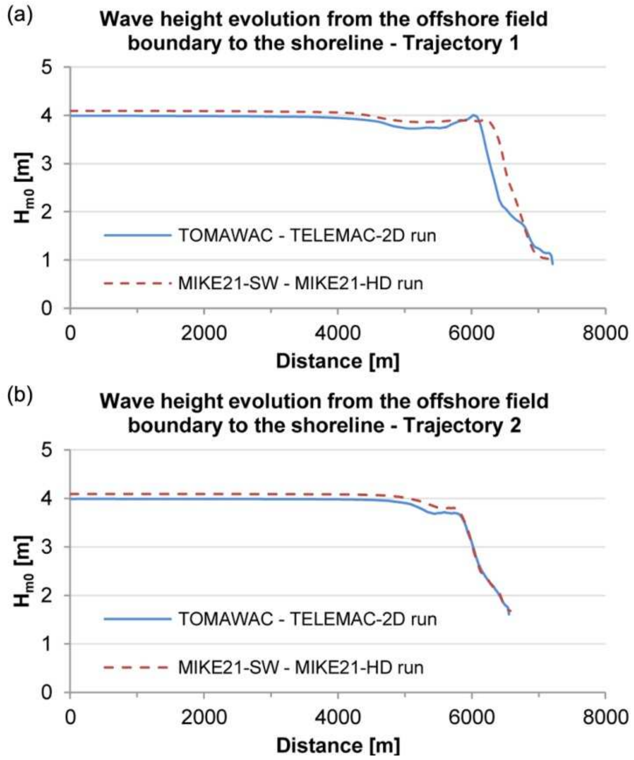

Figure 7. Wave height evolution along two linear trajectories from the offshore field boundary to the shoreline (see Fig. 3, (a) = Trajectory 1 and (b) = Trajectory 2), as resulted from both the coupled TOMAWAC – TELEMAC-2D and MIKE21-SW – MIKE21-HD runs.

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