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Investigation of the current circulation offshore Taranto by using field Measurements and numerical model

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INTRODUCTION

The present work deals with the field measurements and the analysis of sea currents and velocity profiles assessed offshore Taranto, at the open North-Eastern area of the Ionian Sea in Southern Italy. The analysis of current patterns in the area is a very interesting topic due to the highly extensive pollutant discharge in the same region because of the presence of extensive industrial activity into the area. The quantity of undesirable physical, chemical and biological products, discharged into the coastal areas, may affect the local marine ecosystem through advection, diffusion as well as chemical and biological reactions.

For this reason, a worthwhile study is the analysis of the current circulation in the interested zone, considering the main engine forces driving the current patterns, such as tides, winds and salinity and temperature gradients. The main goal of this work is to configure the velocity magnitudes and directions of the marine current in the target area.

This objective may be achieved with both field measurements and numerical model results: the obvious technical and economic difficulties in collecting a large quantity of data along a very extended zone suggest to refer to numerical modelling, which allow to reproduce the field of motion throughout a greater area. To reach such a goal, a proper calibration of the used model must be performed.

DESCRIPTION OF THE INVESTIGATED AREA AND OF THE FIELD MEASUREMENTS

The domain under investigation is a zone offshore Taranto at the open North-Eastern area of the Ionian Sea in Southern Italy (Fig. 1). Indeed, this location is known to be highly polluted due to extensive industrial activity. The choice of this region was based on the need to understand the water-mass exchange between the open sea and the Mar Grande (Fig. 1), which is an area subject to pollution risk. In addition to urban and industrial discharge, the Mar Grande includes two very large harbours where accidental discharge of crude oil, gas and chemical products could take place. It is well-known that the spread of oil and buoyant chemical products depends largely upon the motion of the current. Consequently, an understanding of the overall features of the circulation system between the Mar Grande and the Ionian Sea is needed ([1], [2],[3], [4], [5]). In addition, despite previous studies on the Mar Piccolo (e.g. [6], [7], [8], [9]), it was found that there was a lack of data on the hydrodynamic mechanism driving the fluxes between the Mar Grande and the Ionian Sea. The Mar Grande is joined with the Gulf of Taranto by means of two gaps: the Rondinella gap, in its North-Western part, which is about 100m long, and a longer gap in the Southern part of about 1400m (Fig. 1).

Its total surface area is of about 35km^2, its maximum depth is 35m near the Southern connection to the Gulf of Taranto and its mean depth is 25m. Along the external boundary of the Mar Grande there are two small islands called Cheradi Isles (Fig. 1), joined together by means a long breakwater. The innermost basin is named Mar Piccolo (Fig. 1). It has a total surface area of about 20km^2 (8 km^2 for the I Inlet and 12 km^2 for the II Inlet), its maximum depth is about 12m into the I Inlet and 9m into the II Inlet. The Mar Piccolo is characterized by the presence of a large number of submarine springs and of two small open channels, called Galeso, into the I Inlet, and Ajedda, into the II Inlet. The total inflows coming from springs and channels are very poor, and they are subjected to seasonal fluctuations [10]. Field data were collected on 29 December 2006 between 9:30 and 13:00 (GMT) by the research group of the Department of Civil, Environmental, Building Engineering and Chemistry of the Technical University of Bari (Italy) in the frame of the Integrated Monitoring of Coastal Areas (IMCA) project, a service for the monitoring of the coastal areas based on the integration of satellite data, numerical models and on-site sensed data, in which some public and private corporations were involved.

A Nortek AWAC Vessel Mounted Acoustic Doppler Current Profiler (VM-ADCP) allowed the measurements of the three components of the seawater velocity along the water depth at nine selected stationing points. Most of them were located in the open North-Eastern area of the Ionian Sea. Fig. 2 illustrates their location. The VM-ADCP was connected to a gyro and a DGPS to take into account the vessel velocity in filtering the water current speed thus deducing the sea water velocity components and to provide the coordinates of the stationing points. The time acquisition of the velocity profiler ranged from 5 minutes to almost 10 minutes, to reach a stationary condition. At each station the measurements where acquired every one meter, starting from 4m below the seawater level. The measurements of the flow were carried out with an acquisition frequency of 0.5Hz, while the acoustic frequency of the pulse beam of the ADCP is of 600KHz. The main features of the AWAC current meter are shown in Table I. The velocity vectors were analyzed along the first 20m of the water column (or less, depending on the bathymetry), below the free surface (z = 0m). The first velocity vector map was obtained at z = -4m, while the successive ones were acquired at a vertical interval of 2m. Table II reports the main data acquired at the various stationing point.

FIGURE 1. Target area, including both Mar Piccolo and Mar Grande basins

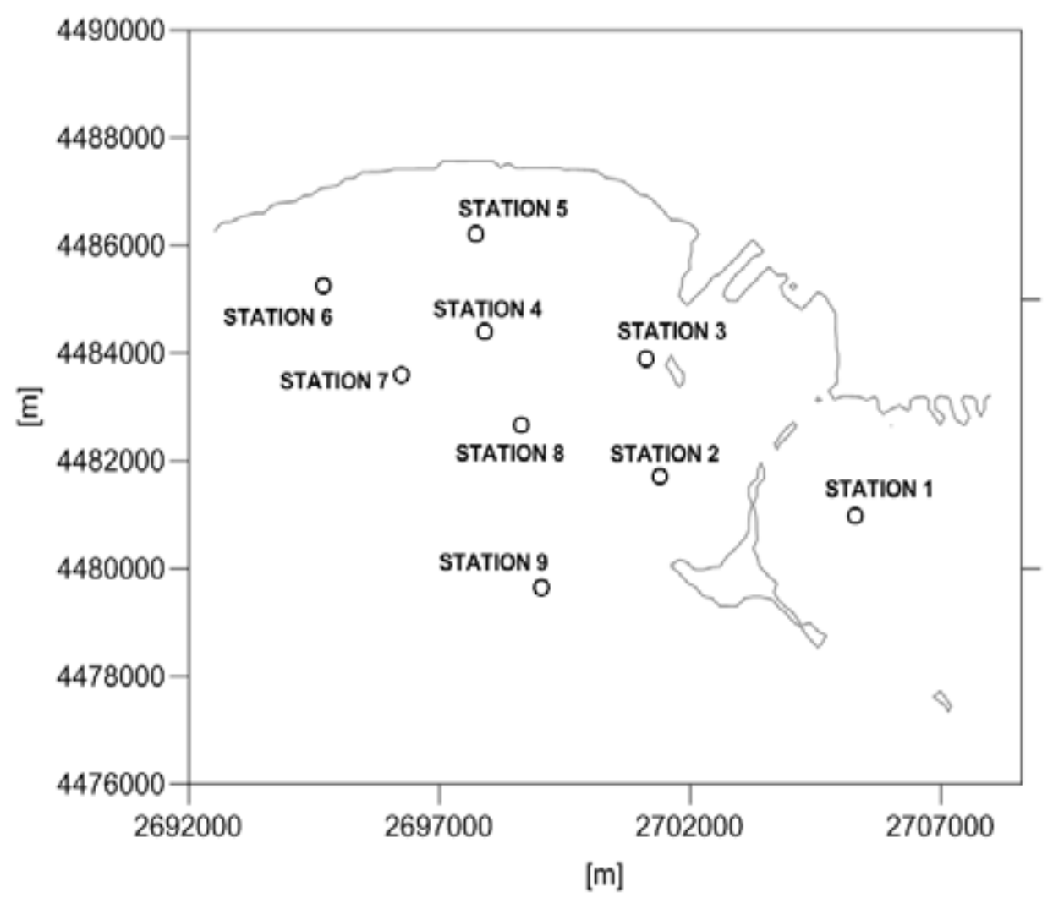

FIGURE 2. Displacement of the stationing points

Quantities	***value***
Acoustic frequency	600 KHz
velocity range	± 10 m/s horizontal ± 5 m/s vertical
accuracy	1% of measured value ± 0.5 cm/s
maximum profiling range	20÷30 m
DGPS velocity accuracy	0.05 m/s or better
gyro accuracy	> 1°

TABLE I. MAIN CHARACTERISTICS OF THE NORTEK AWAC SYSTEM

Station	***Water Depth [m]***	***Time [h:min]***	***Depth and time averaged sea current speed [m/s]***	***Depth and time averaged sea current direction [°]***	***σ Standard deviation of sea current speed [m/s]***
1	-7	10:20	0.031	207	0.0004
2	-13	11:11	0.046	179	0.029
3	-12	14:52	0.025	198	0.038
4	-20	14:21	0.063	164	0.041
5	-20	13:54	0.112	107	0.050
6	-8	13.24	0.130	83	0.031
7	-16	12:55	0.081	163	0.024
8	-24	12:26	0.025	135	0.019
9	-45	11:48	0.067	209	0.029

TABLE II. MAIN QUANTITIES AT STATIONING POINTS

NUMERICAL SIMULATION DESCRIPTION AND RESULTS

Numerical simulations were performed by means of the MIKE 3 FM Flow Model which is largely used in coastal hydrodynamics and oceanography [11]. It solves the three-dimensional time-dependent conservation equations of mass and momentum (the Reynolds-Averaged Navier-Stokes equations) adopting the explicit finite difference method, with the Courant-Friedrichs-Lewy stability condition. The basic characteristics, numerical formulation and process equations of the model MIKE 3 FM are provided by [11]. Simulations were performed for a period of one month starting from 01 December 2006 at 00:00 UTC, in order to allow the spin up of the model itself. The bathymetry was divided into a finite mesh of 3283 triangular elements with 13 combined sigma/z-level (Fig. 3). Previous modelling studies of the current circulation in the Gulf of Taranto (e.g. [7], [8], [9]) were considered as a basic starting point. To improve the numerical approach and results and to model more realistic conditions, the simulations were carried out in baroclinic mode, with temperature and salinity vertical profiles provided by the Mediterranean Sea Physics Reanalysis model, characterized by a horizontal grid resolution of 1/16˚ (that is near 6-7 km) and by 72 unevenly spaced vertical levels. Wind and tidal data forcing the model were temporally varying and were constant in space. They were provided the Oceanographic Station of Taranto. The turbulent closure model used within MIKE 3 FM HD model relies on the k-ε formulation for the vertical direction [12] and on the Smagorinsky formulation for the horizontal direction [13]. The Smagorinsky coefficient was assumed uniform in space and temporally constant, equal to 0.6. A sensitivity analysis was performed to assess the influence of the wind stress factor and the seabed roughness on the numerical results. Four simulation runs, denoted as T1, T2, T3 and T4, were carried out. The wind friction coefficient varied between 0.001 and 0.002 and the seabed roughness was chosen in the range from 0.01m and 0.1m, as summarized in Table III.

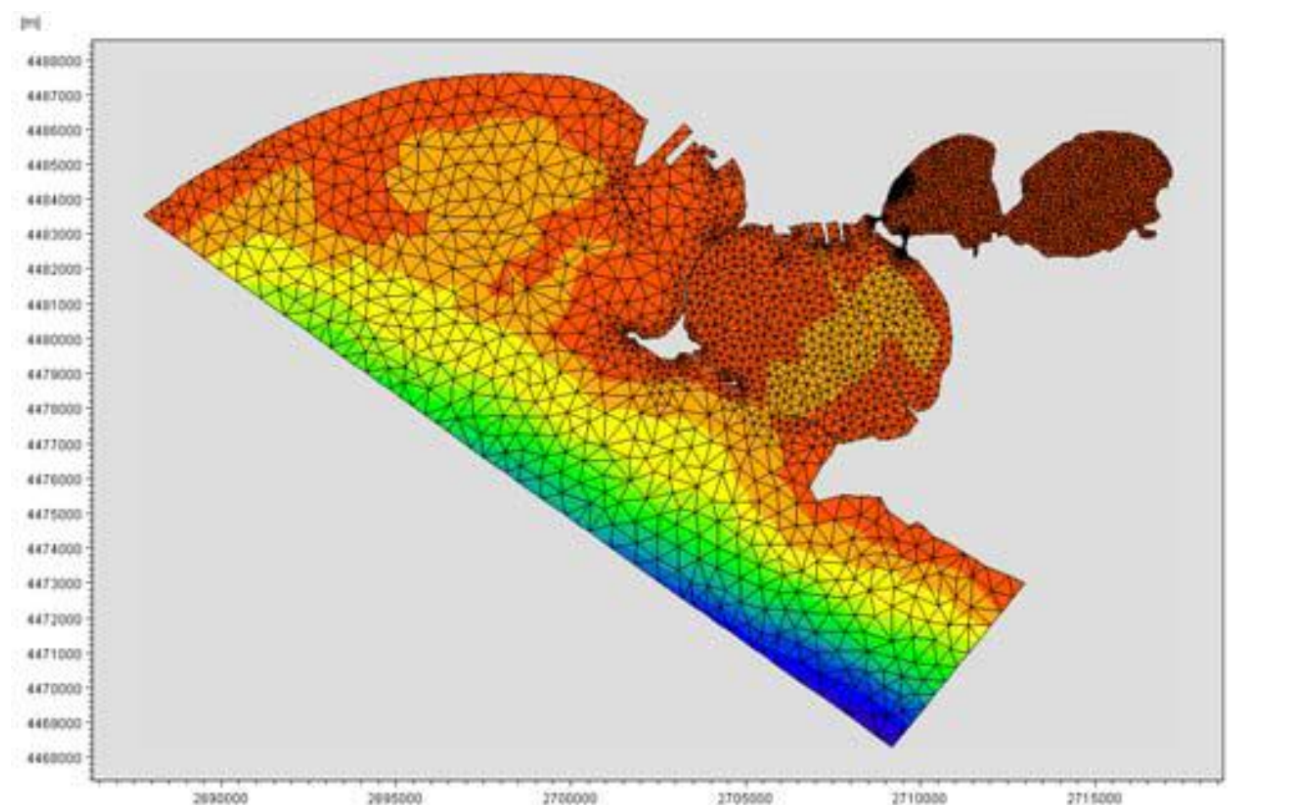

FIGURE 3. Computational domain used for the simulations

Test	Wind drift factor	Seabed roughness [m]
T1	0.002	0.1
T2	0.001	0.1
T3	0.001	0.05
T4	0.001	0.01

TABLE III. PARAMETER VALUES USED IN THE CALIBRATION PHASE

The model data were calibrated using the current speed and direction collected at each stationing point. For a quantitative evaluation, we computed the index proposed by [14]

$$I_W = 1 - \frac{\sum_{k=1}^{N}\left(X_{C_k} - X_{m_k}\right)^2}{\sum_{k=1}^{N}\left[\left|X_{C_k} - \overline{X}_m\right| + \left|X_{m_k} - \overline{X}_m\right|\right]^2} \qquad (1)$$

where X_c and X_m are the computed and measured values respectively, while the overbar denotes the time averaged values. The index I_W assumes a value of 1 when a perfect agreement exists between measured and modelled values, while values close to 0 denote strong discrepancy between the numerical and measured results.

In the present case, the subscript N refers to 9, i.e. the numbers of the investigated stationing points. In this way, the ability of the model to reproduce the circulation in the area of interest in a global mode is checked.

The computed values of I_W for the horizontal current speed at -4 m are equal to 0.43, 0.71, 0.50 and 0.46 in test T1, T2, T3 and T4, respectively. The analogous values for the current speed at -6 m are equal to 0.59, 0.70, 0.58 and 0.58 in test T1, T2, T3 and T4, respectively. For the current speed at -8 m, I_W is equal to 0.52, 0.60, 0.48 and 0.49 in test T1, T2, T3 and T4, respectively. Therefore, the results of the simulation T2 showed the better response of the model to the field data, when the wind friction coefficient and the seabed roughness are equal to 0.001 and 0.1 m respectively.

For each measurement station, Fig. 4 shows the current vectors computed by test T2 (black vectors) superimposed to the corresponding measured one (red vectors). For the sake of brevity, only three selected depths are shown, i.e. -4m (Fig. 4a), -6m (Fig. 4b) and -8m (Fig. 4c).

As previously written, in each station, data were assessed at a specific instant time, during the temporal frame 9:30÷13:00.

Thus, to allow a proper comparison, the numerical velocities plotted in Fig. 4 in each location are the ones extrapolated from the T2 run at the exact time in which the measure was assessed. A general good agreement between the numerical and the measured data can be observed. It is evident that, except for station 9, the direction of the current is generally well reproduced. Slight deviations between measured and modelled directions can be noted in stations 5 and 7 at all depths, even if the anticyclonic trend, visible in the measured coastal flow, is always preserved in the simulation. Some local effects could be the reason of worse matchings. As an example, at the most superficial depth (Fig. 4a), the computed current in station 3 results opposite to the acquired one. It should be noted that station 3 is located near a breakwater, which probably is not adequately reproduced by the model, thus affecting the result. In terms of magnitude, the model seems to provide good estimates of current intensities at all depths.

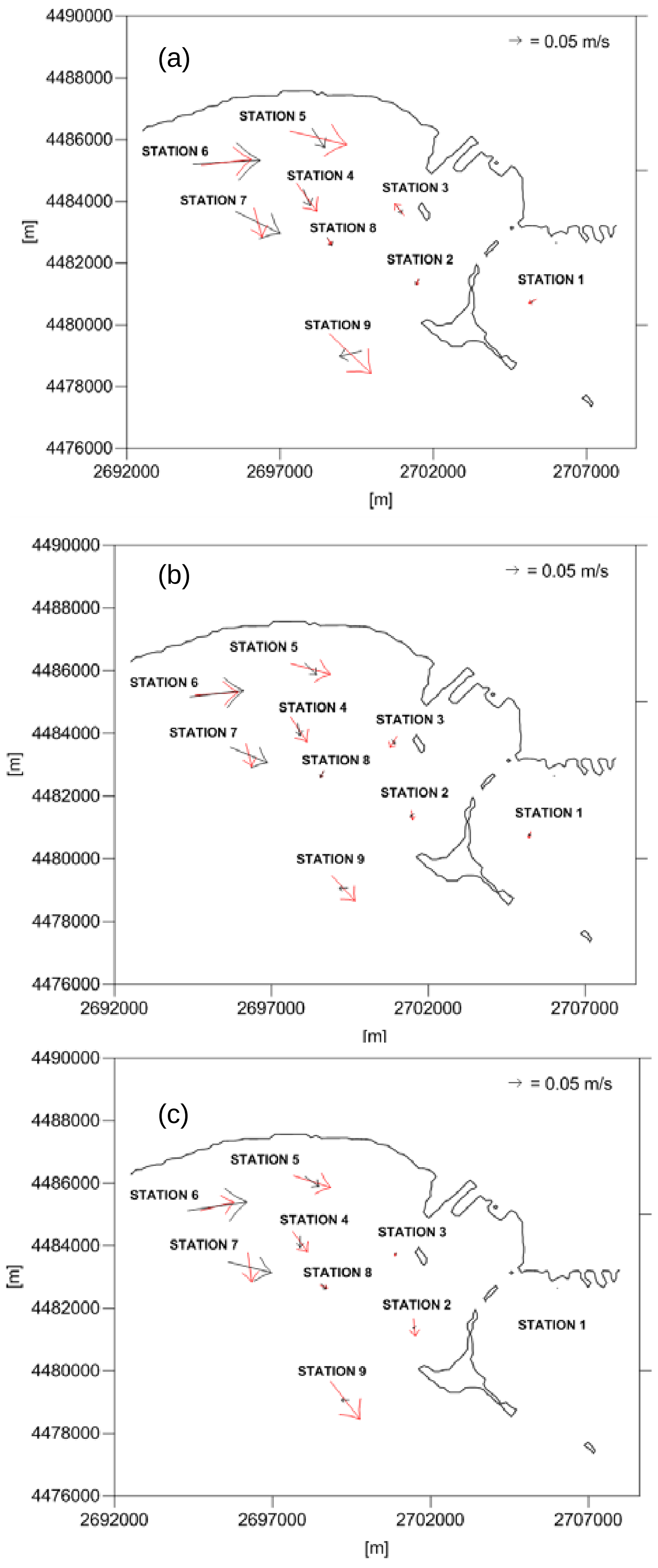

FIGURE 4. Comparison between the horizontal velocity vectors computed by test T2 (black) and the measured ones (red) at depths (a) z=-4 m; (b) z=-6 m and (c) z=-8 m.

Successively, the motion field over the whole domain was examined to evaluate the pattern of the flow in a global perspective.

We noted that, in all the simulations, a quasi-steady circulation occurred in the Gulf of Taranto for the time frame of interest (i.e. the survey duration). Indeed, the current pattern varied very slowly in this region in the examined hours.

Consequently, we decided to use the output of the numerical run T2 and selected the hour 12.00 a.m. of 29 December 2006 as a reference circulation pattern. This behaviour was also representative of a condition of high tide (HT), as recorded at the wave meter of Taranto during the survey time. Fig. 5 shows the comparison between the field of motion computed from test T2 and chosen as reference and the measurements. The depth-averaged vectors are displayed for both modelled results and assessed measurements (represented by black and red arrows respectively). Examining this figure, the dynamic structures resulting from the measurements are reproduced by the model with a satisfactory level of detail. Fig. 5 shows, in depth-averaged terms, that the coastal flow entering the domain from NW principally bends towards SE, while a small branch feeds a cyclonic vortex along the Northern coast. A flux from the NE border, outside the Mar Grande, spreads toward the center of the domain. In the central part, the flow increases its strength and bends toward NW, inducing a clockwise trend.

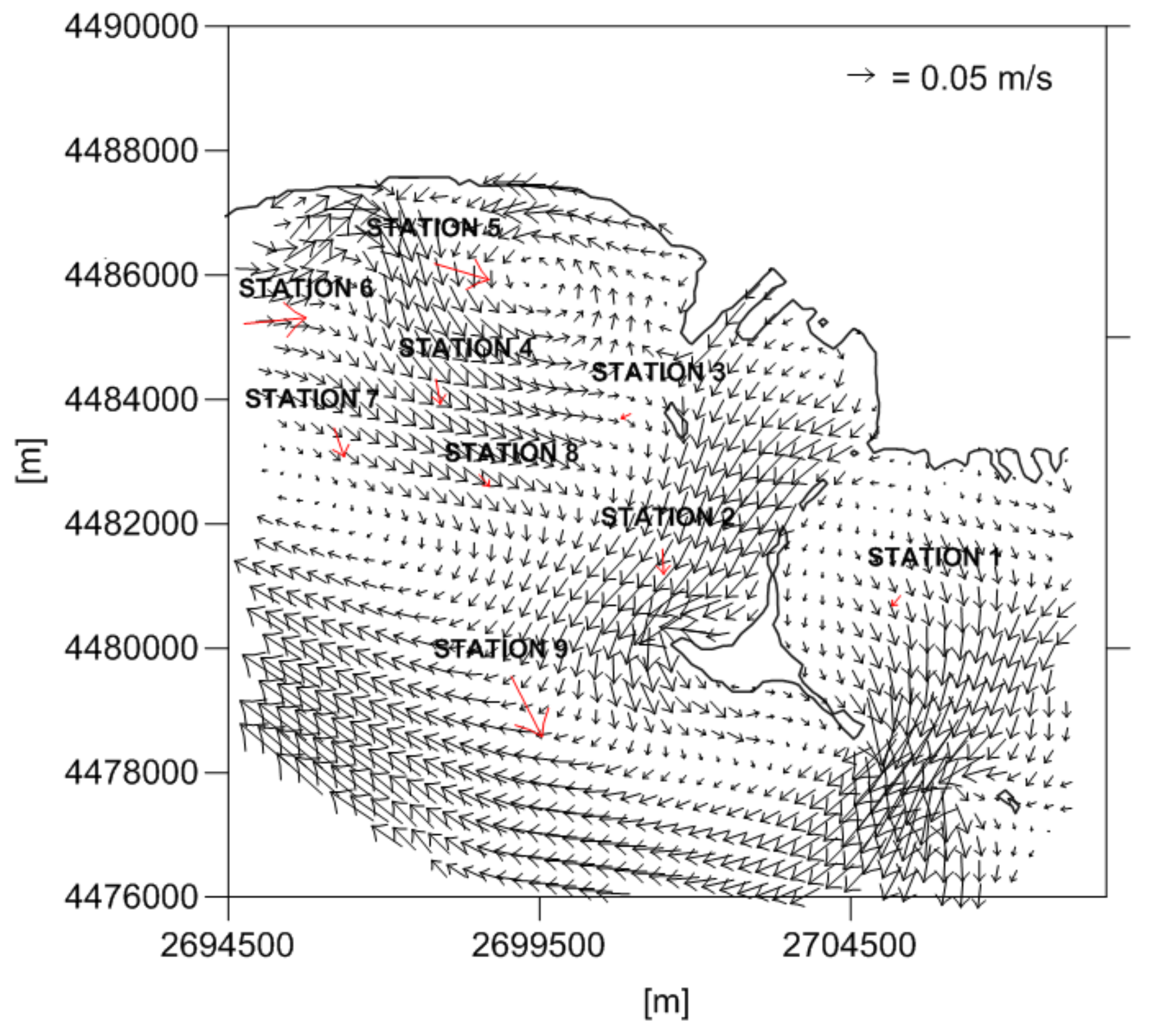

FIGURE 5. Comparison between the numerical and the measured field of motion near the city of Taranto at 12.00 a.m. on 29 December 2006. Red vectors are the measured velocities, while the black ones are the modelled velocities.

Referring to the inflow and outflow of the water-masses from the open sea to the Mar Grande and vice versa, we note Fig. 5) that a very limited inflow occurs through the Western gap connecting the Mar Grande to the open sea, whereas a strong outflow occurs through the Southern gap. Consequently, a Southward flow seems to dominate the Mar Grande basin. The exchange of water-masses, represented here for a specific situation, plays an important role in regulating the biodynamics of the ecosystem in this area. The above written description resulted from the horizontal vector map used as a reference case, which in any way well fitted the measured data. Some consideration must be made about the comparisons between modelling results and measured data [15], [16]. It is not reasonable to expect a perfect match between predicted and assessed values in each investigated point due to i) the selection of forcing actions imposed to the model in the input phase; ii) the real and complex conditions under which data were collected, which greatly differ from the controlled and stationary conditions of a research laboratory. Indeed, in literature, this kind of punctual comparison is generally limited to few investigated points [17], [18] and not to a large target area [19], [20]. Considering all the previous concerns, we can conclude that the used model was able to keep and reproduce the principal features of the circulation structure in the target area.

CONCLUSION

The main goal of the present work is to illustrate how a set of field measurements could be used to improve the use of numerical models. Field data assessed during a survey in the Gulf of Taranto and results of the numerical simulations run with MIKE 3FM model were compared. In this way the model was firstly calibrated, by tuning two main input coefficients such as the wind stress factor and the seabed roughness. Successively, a reference condition was considered, representative of depth-averaged current patterns. Simulated results well agree with the depth-averaged measured data, specifically referring to the principal circulation features observed during the HT phase. Considering all the limits of such a comparison, the magnitudes of the modelled velocities very closely resembled the measured data, as well as the modelled directions. The hydrodynamic mechanism of the water-mass exchange between the Mar Grande and the Ionian Sea was also evident.

The achieved result could be considered as the starting point for further simulations and as the necessary step for using future ecological model in such a sensitive area.

References

[1] MOSSA M., DE SERIO F. (2016). RETHINKING THE PROCESS OF DETRAINMENT: JETS IN OBSTRUCTED NATURAL FLOWS, SCIENTIFIC REPORTS, SCIENTIFIC REPORTS, 6, 39103.

[2] DE SERIO F., MOSSA M. (2015). ANALYSIS OF MEAN VELOCITY AND TURBULENCE MEASUREMENTS WITH ADCPS. ADVANCES IN WATER RESOURCES, VOL. 81, P. 172-185.

[3] DE SERIO F., MOSSA M. (2014). STREAMWISE VELOCITY PROFILES IN COASTAL CURRENTS. ENVIRONMENTAL FLUID MECHANICS, VOL. 14, P. 895-918.

[4] DE CAROLIS G., ADAMO M., PASQUARIELLO G., DE PADOVA D., MOSSA M. (2013). QUANTITATIVE CHARACTERIZATION OF MARINE OIL SLICK BY SATELLITE NEAR-INFRARED IMAGERY AND OIL DRIFT MODELLING: THE FUN SHAI HAI CASE STUDY. INTERNATIONAL JOURNAL OF REMOTE SENSING, VOL. 34, P. 1838-1854

[5] MOSSA M. (2006). FIELD MEASUREMENTS AND MONITORING OF WASTEWATER DISCHARGE IN SEA WATER. ESTUARINE, COASTAL AND SHELF SCIENCE, VOL. 68, P. 509-514.

[6] ARMENIO E., BEN MEFTAH M., BRUNO M.F., DE PADOVA D., DE PASCALIS F., DE SERIO F., DI BERNARDINO A., MOSSA M., LEUZZI G., MONTI P. (2016). SEMI ENCLOSED BASIN MONITORING AND ANALYSIS OF METEO, WAVE, TIDE AND CURRENT DATA: SEA MONITORING, PROC. EESMS 2016 - 2016 IEEE WORKSHOP ON ENVIRONMENTAL, ENERGY, AND STRUCTURAL MONITORING SYSTEMS, BARI, 13-14 JUNE 2016.

[7] DE SERIO F., MOSSA M. (2016). ASSESSMENT OF HYDRODYNAMICS, BIOCHEMICAL PARAMETERS AND EDDY DIFFUSIVITY IN A SEMI-ENCLOSED IONIAN BASIN, DEEP-SEA RESEARCH PART II: TOPICAL STUDIES IN OCEANOGRAPHY, VOL. 133, P. 176-185.

[8] DE SERIO F., MOSSA M. (2016). ENVIRONMENTAL MONITORING IN THE MAR GRANDE BASIN (IONIAN SEA, SOUTHERN ITALY). ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH, 23(13), PP. 12662-12674.

[9] DI BERNARDINO A., DE SERIO F., MOSSA M., PINI A., LEUZZI G., MONTI P. (2016). MICROMETEOROLOGICAL SIMULATIONS OVER A COASTAL AREA USING CALMET MODEL: ATMOSPHERE MONITORING, PROC. EESMS 2016 – 2016 IEEE WORKSHOP ON ENVIRONMENTAL, ENERGY, AND STRUCTURAL MONITORING SYSTEMS, BARI, 13-14 JUNE 2016.

[10] G. UMGIESSER, SCROCCAROI., ALABISO G. (2007). MASS EXCHANGE MECHANISMS IN THE TARANTO SEA, TRANSIT. WATERS BULL., VOL. 2, P. 59-71.

[11] DHI (2016). MIKE 3 FLOW MODEL: HYDRODYNAMIC MODULE—SCIENTIFIC DOCUMENTATION, DHI SOFTWARE 2016, HØRSHOLM, DENMARK.

[12] RODI W. (1987). EXAMPLES OF CALCULATION METHODS FOR FLOW AND MIXING IN STRATIFIED FLUIDS, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 92, P. 5305–5328.

[13] SMAGORINSKY J. (1993). SOME HISTORICAL REMARKS ON THE USE OF NONLINEAR VISCOSITIES, IN LARGE EDDY SIMULATION OF COMPLEX ENGINEERING AND GEOPHYSICAL FLOWS, B. GALPERIN AND S. ORSZAG, EDS., P. 3–36, CAMBRIDGE UNIVERSITY PRESS, NEW YORK, NY, USA.

[14] WILMOTT CJ. (1981). ON THE VALIDATION OF MODELS, PHYS. GEOGR. VOL. 2, P. 184-194.

[15] DE SERIO F., MALCANGIO D., MOSSA M. (2007). CIRCULATION IN A SOUTHERN ITALY COASTAL BASIN: MODELLING AND FIELD MEASUREMENTS, CONTINENTAL SHELF RESEARCH, VOL. 27, P. 779-797.

[16] DE SERIO F., MOSSA M. (2016). ASSESSMENT OF CLASSICAL AND APPROXIMATED MODELS ESTIMATING REGULAR WAVES KINEMATICS, OCEAN ENGINEERING, 126, PP. 176-186.

[17] MALANOTTE RIZZOLI P., BERGAMASCO A. (1983). THE DYNAMICS OF THE COASTAL REGION OF THE NORTHERN ADRIATIC SEA, JOURNAL OF PHYSICAL OCEANOGRAPHY, VOL. 13, 1983, P. 1105–1130.

[18] MALI M., DE SERIO F., DELL'ANNA M.M., MASTRORILLI P., DAMIANI L., MOSSA M. (2017) ENHANCING THE PERFORMANCE OF HAZARD INDEXES IN ASSESSING HOT SPOTS OF HARBOUR AREAS BY CONSIDERING HYDRODYNAMIC PARAMETERS, ECOLOGICAL INDICATORS, VOL. 73, P. 38-45.

[19] DE PASCALIS, F., GHEZZO, M., UMGIESSER, G., DE SERIO, F., MOSSA, M. USE OF SHYFEM OPEN SOURCE HYDRODYNAMIC MODEL FOR TIME SCALES ANALYSIS IN A SEMI-ENCLOSED BASIN PROC. EESMS 2016 - 2016 IEEE WORKSHOP ON ENVIRONMENTAL, ENERGY, AND STRUCTURAL MONITORING SYSTEMS, BARI, 13-14 JUNE 2016.

[20] DE SERIO, F., MOSSA, M. 2013) A LABORATORY STUDY OF IRREGULAR SHOALING WAVES, EXPERIMENTS IN FLUIDS, 54(6), 1536.