ANALYSIS OF CURRENT CIRCULATION IN THE PORT OF BARI

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Abstract. Real time current measurements using an AWAC Acoustic Doppler Current Profiler (ADCP) were carried out on February 2010 inside and outside the Port of Bari, located in the Southern Italy, along the Adriatic Sea. These surveys represent part of a wide field data collection program, whose aim is to study and model the hydrodynamics and water quality of the Port of Bari and its surrounding areas.The principal purpose of the present work is to analyze the current circulation in the port. Useful information referring to sedimentation processes and possible pollutants dispersion can be derived from the collected current data. Moreover, the same measurements can be used as input data for the calibration of numerical models able to simulate the current patterns in the target area. Data collected are of crucial importance for the port management and monitoring of water aquatorium.

Key words: Current measurements, Port of Bari, Hydrodynamic, Current circulation, Numerical models, Monitoring.

1. INTRODUCTION

Port areas ecosystem represents one of the most delicate and complex relationship between natural environment and human activities. The integrated monitoring of port areas is a key tool in pursuing sustainable development in these areas. In addition, it becomes one of the main subjects of governments programs for environmental monitoring and eco-sustainable environmental management.

The present work illustrates some results of field measurements and analysis of the sea current and velocity profiles assessed inside and outside the Port of Bari, located along the Adriatic Sea, in the Southern Italy (see Fig. 1). Spreading of quantity of undesirable substances, discharged into the port area, may strongly affect the local marine ecosystem. Thus, the analysis of current patterns, in the port area, is a fundamental parameter for the monitoring of water aquatorium.

This monitoring action is a topic of crucial importance for scientists, specially environmentalists and engineers. Port areas represent small and highly sensitive ecosystems that are already vulnerable and threatened. These ecosystems are significantly affected by the direct or indirect domestic or industrial pollutant discharges. In addition, port areas are also at risk from ships' emissions which contribute to the problem of excess nutrient enrichment and eutrophication that promotes increased growth of certain phytoplankton and other marine plants, which may lead to a shift in ecosystems (IMO, 2010). Moreover, cargo handling and storage, typical ship operations (e.g., fueling, cleaning, stripping, painting…) and runoff, represent significant sources of pollution of the port areas (Mestres *et al.*, 2010). The quantity of undesirable physical, chemical and biological products, discharged and developed at certain points within the port, may affect all the port areas through advection, diffusion and chemical and biological reactions. Therefore, a rational basis for monitoring of these areas requires a detailed knowledge of their hydrodynamic current patterns.

The detailed knowledge of the hydrodynamic behaviour of currents, especially in port areas, is a serious challenge for researchers, due to its complexity. Numerical models forecasting this hydrodynamics can be considered a powerful device. Anyway, in order to reproduce a reliable and accurate computed current circulation, the determination of all the main input forces and boundary conditions which drive the current patterns is required. Moreover, field measurements are necessary to calibrate and successively validate the numerical models (Mossa, 2006; De Serio and Mossa, 2006; De Serio *et al.*, 2007; Ben Meftah *et al.*, 2007a, b, c; Pollio *et al.*, 2008; Ben Meftah *et al.*, 2008; Ben Meftah *et al.*, 2009).

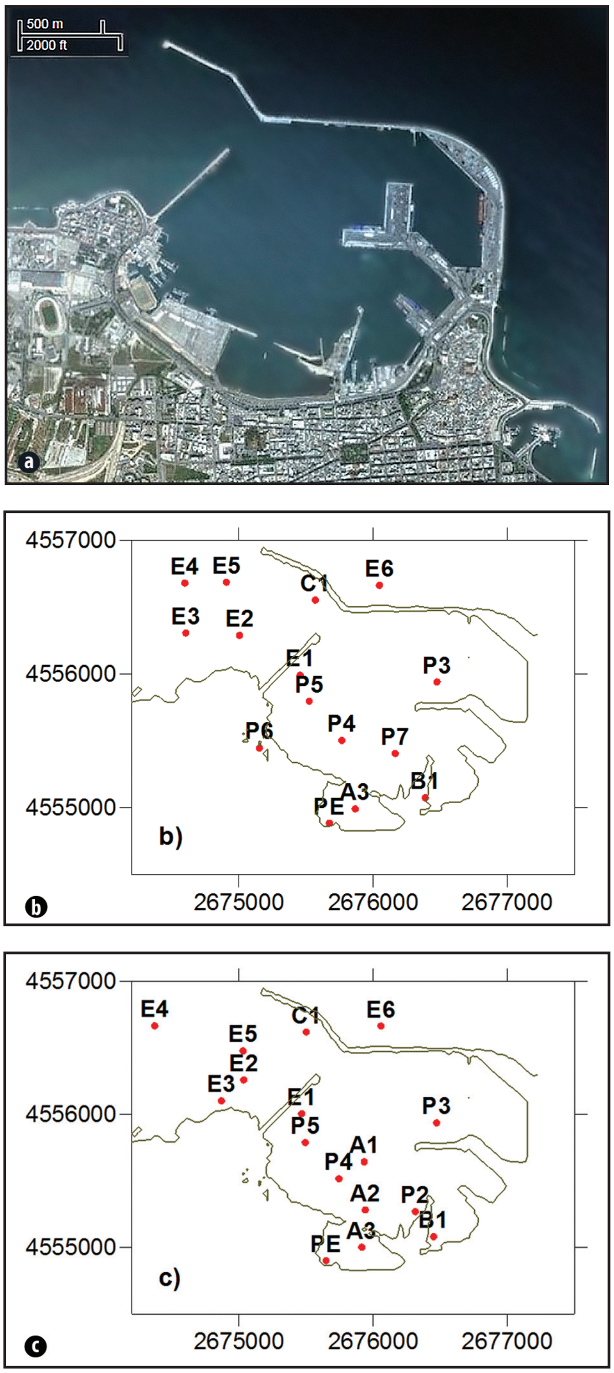

Fig. 1 a) Google Map image of the Port of Bari; b) measurement points in day 24.02.2010; c) measurement points in day 25.02.2010.

Over the last years, the environmental aspects were not of crucial importance in designing ports and the water mass exchange mechanisms, between ports and open seas, were not sufficiently studied in order to obtain efficiently flow circulations into the port areas, from an environmental point of view. Thus, the majority of the seaports are quasi confined areas. In addition, they are divided to several interconnected cells of different geometric shapes, which play an important role to reduce at the utmost the wave and current motion coming from offshore. Moreover, the ship traffic, inside the ports, strongly affects the current circulation and, as a consequence, the field flow measurements can be significantly modified during the different survey programs. This variability in the measurements, not depending from natural phenomena, otherwise provoked by human activities and interferences, negatively affects the calibration of the numerical models. In fact, this significant disturbance of current velocities inside the port, due to external factors such as ships movements, can be only partially reproduced by numerical models; therefore, it affects the quality and the accuracy of their results. For these reasons, it is better to extend the domain of modelling computation outside the port area, in order to take into account also the effect of offshore currents. Whereas, the field measurements should be carried out at several points, located inside, in the port mouth and outside the port area, where currents are characterized by greater velocity values and are less affected by the ship traffic.

The port of Bari is one of the most important ports in the Mediterranean area. It is traditionally considered as the entrance of the Europe to the Balkans and Middle Eastern countries. It has direct sea links with several of these countries such as Montenegro, Albania, Greece and Turkey. The port consists of two large eastern and western breakwaters and is divided into five principal basins. The maximum port water depth is equal to about 13m. Inside the port of Bari there are some technical assistance services and fuel supply stations for boats which can be considered as main sources of pollution.

2. MATERIALS AND METHODS

As mentioned above, the validation of the numerical models needs a large set of measured true data, coming from a monitoring action. The choice of the stationing points, where measurements should be undertaken, is based on the accuracy degree of the desired flow map, which should describe and represent the field flow motion. In this research, field data were carried out on February 2010 inside and outside the Port of Bari. Data collection was performed by the research group of the Water Engineering and Chemistry Department of the Technical University of Bari (Italy).

A Nortek AWAC vessel mounted acoustic Doppler velocity profiler was used for the measurements of the three components of the flow velocity along the water depth at series of selected stationing points. The AWAC has an acquisition frequency of 0.5 Hz, while the acoustic frequency of its beams is of 600 KHz. The AWAC was connected to a gyro and a DGPS in order to take into account the vessel velocity. The main features of the AWAC current meter are shown in Table 1. The time acquisition of the velocity profiler was longer than 3 minutes. At each station, the measurements where acquired with an interval of 1.5m, starting from 4 m below the seawater free-surface. The AWAC data were acquired with the Nortek SurveyVM software and were subsequently exported and elaborated using a task-specific spreadsheet in order to obtain the field flow velocities at the different stationing points.

Table 1 Main characteristics of the Nortek AWAC system

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 (depend on local conditions)
DGPS velocity accuracy	0.05 m/s or better
Gyro accuracy	Better than 1°

The vertical distributions of some water characteristics such as salinity, temperature, pressure, depth and density, were also measured by means of a CTD recorder. The main characteristics of the CTD recorder system are shown in Table 2.

Table 2 Main characteristics of the CTD recorder system

Quantities	Range	Accuracy	Resolution
conductivity	0÷9 S/m	0.5‰	0.07‰
pressure	0÷7000 m	1‰	0.02‰
temperature	-5÷35 °C	5‰	0.1‰

All the instrumentation was installed onboard a ship (Fig. 2), which was used to reach the pre-determined stationing points to perform the measurements. In addition, measurements were also taken along the route between two consecutive stationing points.

Numerical simulations of the current circulation, in the target area, were performed by means of the bidimensional MIKE 21 model, manufactured by the Danish Hydraulic Institute (DHI). Actually, the analysis of *in-situ* data revealed that the velocity values are quite homogeneous along the vertical, while measured temperature and salinity are quite invariant along the water column. Consequently the flow can be considered 2D and stratification can be neglected, as a first approximation.

Therefore, the basic hydrodynamic (HD) module of the MIKE 21 model was used, which is based on the numerical solution of the shallow water equations (i.e. the conservation of mass and momentum integrated over the vertical). Moreover, due to the observed field conditions, the model was run in barotropic mode, having supposed constant temperature (*T=12°C*) and salinity (*S=38.2psu*).

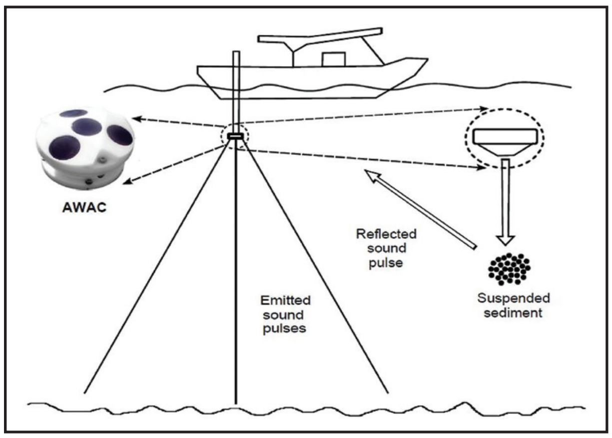

Fig. 2 Positioning of the AWAC instrument on the ship board

In order to accomplish any comparison between numerical simulations and measured data, the bathymetry and shoreline data of the port of Bari and its neighbouring area were interpolated from IIM (Hydrographic Institute of the Italian Navy) nautical charts. A computational orthogonal grid with a spatial step of 10m was then obtained.

A calibration process, by tuning the values of some crucial parameters, such as the drag coefficient at the seabed C_B and the drag coefficient of the wind stress C_W, was necessary. Actually, a preliminary calibration of the above said coefficients was already carried out in previous works by some of the same authors (e.g. Ben Meftah *et al.*, 2007a), where the following formulations were used to take into account of both C_B and C_W.

The bottom stress was expressed by a quadratic friction law:

$$\tau_B = \rho_w C_B U \left| U \right| \qquad (1)$$

where U is the numerical vertical depth-and time-averaged sea current velocity and ρ_w is the water density.

The bottom drag coefficient C_B was dependent on the Manning parameter M according to:

$$C_B = \frac{g}{\left(Mh^{\frac{1}{6}}\right)^2} \tag{2}$$

where g is the gravity acceleration and h is the total local water depth.

The wind stress was similarly calculated:

$$\tau_W = \rho_{air} C_W W_{10} \left|W_{10}\right| \tag{3}$$

with the air density ρ_{air}, the wind speed W_{10} at 10m over the sea level and the wind drag coefficient C_W.

Following literary recommendations, the wind drag coefficient may be expressed by many different bulk formulas. For example, Wu (1980, 1994) suggested:

$$C_W = \begin{cases} c_a & W_{10} < W_a \\ c_a + \dfrac{c_b - c_a}{W_b - W_a}\left(W_{10} - W_a\right) & W_{10} < W_a < W_b \\ c_b & W_a < W_b \end{cases} \tag{4}$$

where c_a is the wind drag coefficient in correspondence of the wind speed W_a=7m/s, and c_b in correspondence of W_b=25m/s. Both c_a and c_b are empirical factors, which need to be evaluated by real applications.

As written, in previous works by Ben Meftah *et al.* (2007a; 2007b), the above mentioned coefficients were calibrated, with different values for M and C_W used to reproduce a known circulation. Therefore, among all the previously tested values, those ones which provided the best match between measured velocities and numerical results were assumed in the present research, i.e. the value of M=32m$^{1/3}$/s and the value of C_W=0.0026. Previous studies also suggested that the velocity field was generally less sensitive to the bottom drag rather than to the wind drag coefficient.

The model was forced by the measured tidal elevation and the measured wind. Referring to the sea surface elevation, it was derived from the measurements undertaken at the station of Bari by the National Mareographic Network (RMN) during the period of the field measurements. The adopted time series is shown in Fig 3. Also the wind data, in the target area, were analyzed from real observations. In detail, the time series of wind intensities and directions, for the period 20.01.2010 – 25.02.2010, were provided from satellite measurements by NRC and they were used as input in the model (Fig. 4).

Given that the port area is small, analysis of the satellite wind field highlighted a spatial homogeneity in wind intensity and direction over the target area. For this reason, the model was forced by the time varying measured wind, while it was supposed uniform in space.

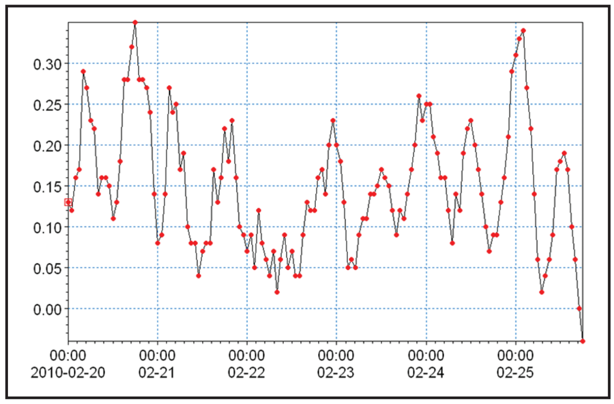

Fig. 3 Surface elevation measured at Bari RMN station (hours are on the horizontal axes, while elevation in metres, on the vertical axes).

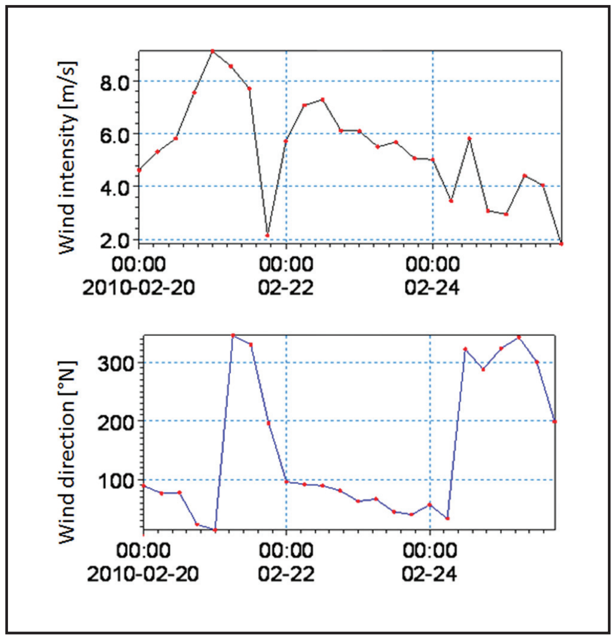

Fig. 4 Time series of satellite measured wind intensities and directions. Observation period: 20-25.02.2010

3. RESULTS AND DISCUSSION

As already written, the measurements were acquired with a frequency of 0.5Hz along the vertical axes in each stationing point (Fig.1), starting from 4m depth below the sea surface (being this the blank distance of the instrument), with a staggered interval of 2m. The current velocity was evaluated as the average over a sufficiently long time period in order to exclude the turbulent fluctuations. In fact, in recent works it was observed (Mossa, 2006; De Serio and Mossa, 2006; De Serio *et al.*, 2007; Ben Meftah *et al.*, 2007a, b, c; Pollio *et al.*, 2008; Ben Meftah *et al.*, 2008; Ben Meftah *et al.*, 2009) that an acquisition time of 3 to 5 minutes is sufficient for the AWAC profiler to give accurate time-averaged velocities.

For the present study, it was observed that these current velocities were in the range 0.001–0.30m/s. In Table 3, as an example, the principal data of the survey, referring to 24 February 2010, are shown. The table shows the different stationing points (see also Fig. 1), with their geographic positions (longitude, latitude), local depth, time at which the data were acquired, the corresponding velocity averaged along the local depth and the mean direction of the averaged velocity (relative to North). From Fig.1 it can also be deduced that only some measurement points were quite the same for the two different survey days, because of some practical limitations faced during the measurement operations.

As an example, referring to both 24 and 25 February 2010, in Fig. 5 and Fig. 6 respectively, the vertical profiles of the horizontal velocities along the mean current direction are plotted, for some selected stations, with *z* distance from the bottom. An increasing trend can be noted from the bottom up to the surface in quite all the cases. For both investigated days, a comparison among the current behaviour in internal and external points shows also that velocities have greater magnitudes outside the port (e.g. E6), while the circulation inside the aquatorium is less intense (a reduction of about the 60% is clearly evident).

Moreover, a slight variation in the profiles is observed from day 24 to day 25 February, consequently a quasi steady state can be hypothesized, referring to the averaged velocities along the mean flux direction. Particularly, this condition is more evident outside the basin (point E6), where currents are more affected by tide and wind rather than by topography changes. In Fig. 7 and Fig. 8, for both the examined days, the horizontal maps of the measured currents at the depth of respectively 4m and 6m are also shown, only referring to the examined points inside the port.

From Fig. 7 and Fig. 8 it is difficult to deduce typical settled patterns in the aquatorium, because of scattered measurement points. Anyway, for each day, a slightly variant distribution of the velocity vectors along the vertical can be observed, which endorses the approximation made by using a 2D model to reproduce the circulation. By comparing Fig. 7 and Fig. 8, an inversion in the flow is visible near the left pier at the mouth of the port comparing day 24 to day 25 February. In the central part of the basin, some local effects influence the circulation. Hence, an ascending flow directed towards the mouth can be noted at all depths, while a descending flow is evident in the southern inlet on 24 February (Fig.7). On 25 February, a cyclonic trend, which extends also to the southern inlet, can be seen in the lower part of the basin.

The acquired currents, illustrated above, were used to validate the results of the numerical hydrodynamic model MIKE 21. First, simple runs were executed, just to test the answer of the model to single forcings (e.g. constant wind or sinusoidal surface elevation on the open boundaries). In this way, a sort of hierarchy in the adopted forcing actions was derived, observing that the wind action is prevailing on the tidal forcing. Successively, the above described input and boundary data, such as the real bathymetry, measured time-varying surface elevation and wind speed, were imposed in the model in order to reproduce the ambient environment in the most reliable way. Some results of this simulation, forced by the real time-varying tide and wind, are shown as an example in Fig. 9 and Fig. 10.

Taking into account all the real factors which influence the circulation inside the port, a local and punctual comparison among experimental values and modelled ones is quite

Table 3 Principal characteristics of the survey. Day 24 February 2010

Stationing point	Position relative to the port	Longitude (°)	Latitude (°)	Depth (m)	Time (hour:min)	Velocity (m/s)	Mean direction (°)
A3	Inside	41.13285	16.85776	8.0	17:08	0.004	194.145
B1	Inside	41.13349	16.86400	6.8	17:00	0.009	107.228
C1	Outside	41.14695	16.85462	22.2	15:30	0.060	90.761
E1	At the mouth	41.14192	16.85313	13.0	14:47	0.045	141.869
E2	Outside	41.14468	16.84783	15.4	15:00	0.003	175.487
E3	Outside	41.14492	16.84306	14.3	16:11	0.013	305.811
E4	Outside	41.14828	16.84070	18.7	15:53	0.023	344.368
E5	Outside	41.14230	16.84676	11.2	16:22	0.021	285.364
E6	Outside	41.14785	16.86035	24.3	15:18	0.140	328.670
P3	Inside	41.14127	16.86525	16.3	16:39	0.025	320.494
P4	Inside	41.13747	16.85669	9.9	14:29	0.027	59.107
P5	Inside	41.14015	16.85388	10.5	14:40	0.039	125.507
P6	Inside	41.13709	16.84937	5.7	17:30	0.019	100.382
P7	Inside	41.13652	16.86142	8.0	16:51	0.092	262.082

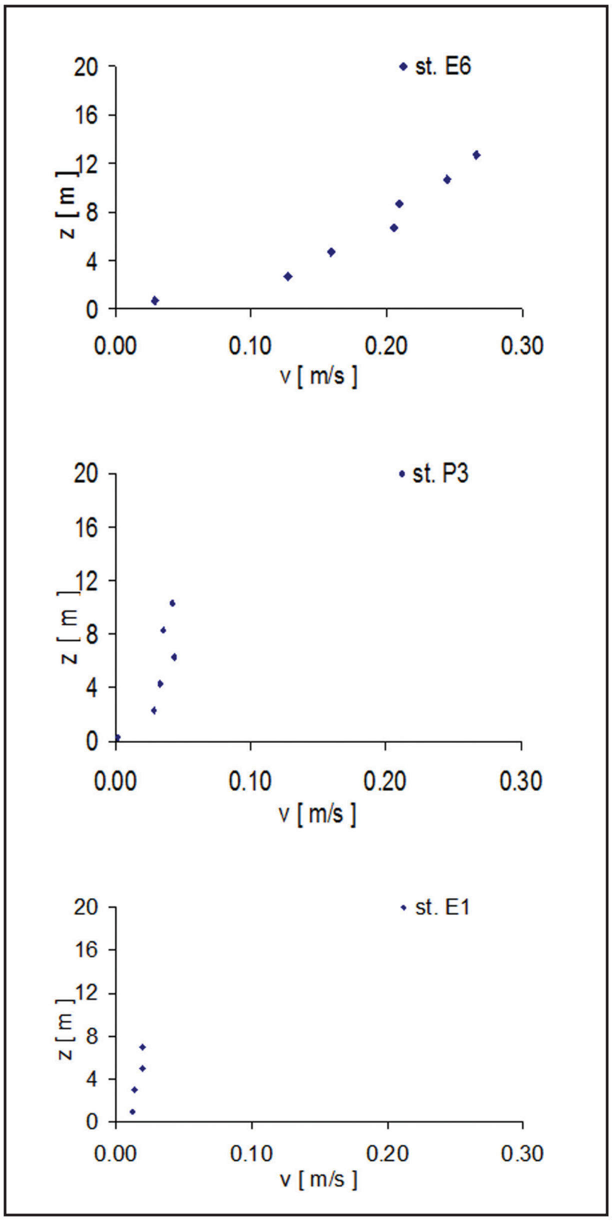

Fig. 5 Vertical profiles of the horizontal velocities along the mean current direction. Day 24 February 2010

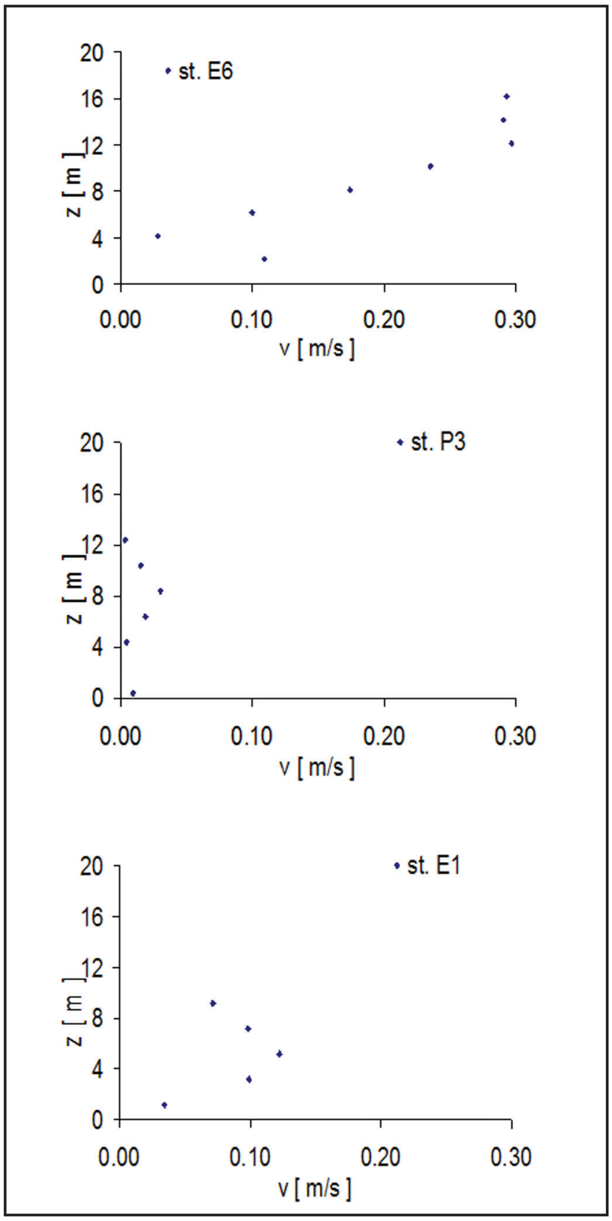

Fig. 6 Vertical profiles of the horizontal velocities along the mean current direction. Day 25 February 2010

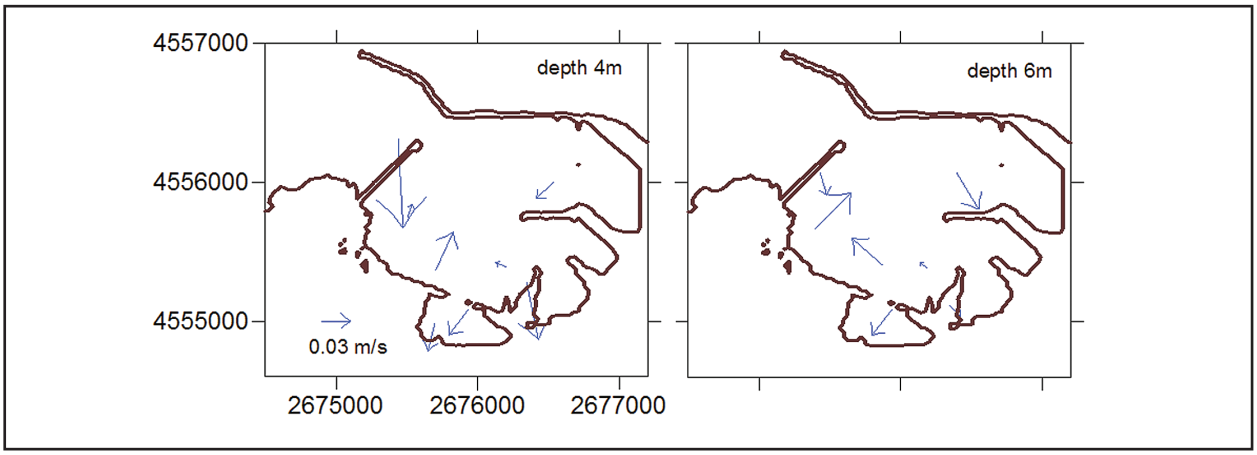

Fig. 7 Horizontal map of measured currents at 4m and 6m from the surface. Day 24 February 2010. Gauss Boaga reference system

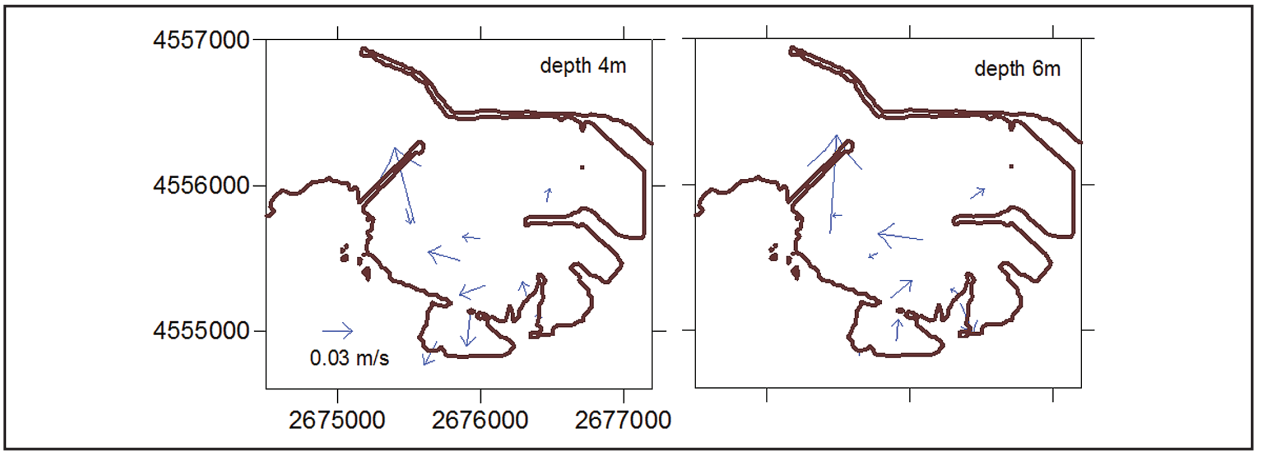

Fig. 8 Horizontal map of measured currents at 4m and 6m from the surface. Day 25 February 2010. Gauss Boaga reference system

demanding. In order to perform a comparison, in the present case, the measured velocities were averaged over the vertical, obtaining 2D measured current velocity vectors. Their matching with the velocity vectors reproduced by the model was then evaluated.

In Fig. 9, the comparison refers to the first survey day. A good agreement between field measurements and simulated velocities is evident in the central part of the area, where an anticlockwise trend is marked by both measured and modelled velocities, also in the lower area of the basin, where the descending flow is well reproduced in the inlets. In Fig.10, relative to 25 February, the increasing velocity values in the central basin are well simulated as well as the descending flow towards the inlets. The ascending flow in the upper right side of the area is also well modelled.

The horizontal flow maps of Fig. 9 and Fig. 10 are very similar referring to the currents structures, while the intensities of the velocity vectors are greater in the second survey day (Fig. 10). Consequently, a well established cyclonic trend seems to settle in the basin, revealing the tendency to a quasi-steady condition. Other horizontal maps referring to different instant times, not shown here for brevity, prove this tendency.

The flow circulation, inside the port area, seems to be little dependent from the circulation in the open sea, as can be observed from both Fig. 9 and Fig. 10, examining the velocity vectors at the mouth, which are quite tangential to the entrance in the first case (Fig.9) and characterized by a small magnitude in the second case (Fig. 10). In all the analyzed time instants, it was observed that a clearly net flow crossing the mouth is not evident. This might implies that a slight amount of water mass exchange occurs between the port and the open sea. The cyclonic structure, established in the basin, could disturb the process of diffusion and dispersion of the port-pollution charge. Such deductions need further measurements, through the port mouth, to be confirmed.

In order to get a quantitative comparison among measurements and model results a relative error was estimated, defined in the following way:

$$\varepsilon = \frac{|\text{measured value} - \text{simulated value}|}{\text{measured value}} \quad (5)$$

This error was calculated for each investigated point, relatively to both velocity magnitude and direction. Considering all the examined stationing points, an average relative error equal to 0.53 was obtained for the velocity magnitude and to 0.37 for the velocity directions.

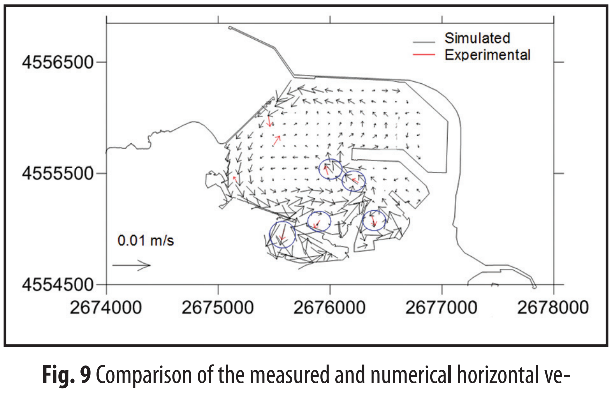

Fig. 9 Comparison of the measured and numerical horizontal velocities, averaged over the vertical. Day 24.02.2010, hour 12:00. (Best matching in the circles).

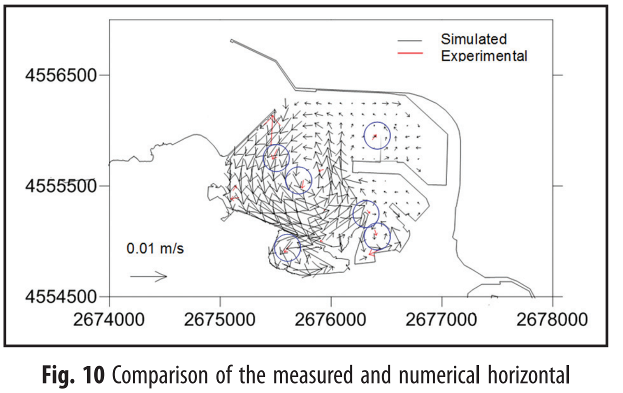

Fig. 10 Comparison of the measured and numerical horizontal velocities, averaged over the vertical. Day 25.02.2010, hour 12:00. (Best matching in the circles).

This result is appreciable, especially taking into account that: i) the measured values were not acquired in a steady channel flow, but rather in the sea, where the environment is very complex; ii) simplifications and approximations were unavoidable during the model run.

4. CONCLUSIONS

The monitoring of the hydrodynamic parameters, in port areas, is useful to study the exchanges of sea water masses between the open sea and the port area, as well as to understand the diffusion and spreading of the pollutants within the port area. A rational basis for monitoring of port areas requires detailed knowledge of the hydrodynamic patterns of current circulations in a target area. The present study examines the current circulations inside the port of Bari, referring to a typical winter time-period in February 2010. Results of both field measurements and numerical simulations of the flow motion were presented and analyzed.

A quantitative comparison highlights a substantial agreement between the observed and the simulated circulation pattern in the internal area of the port. The numerical simulation shows that the port of Bari might suffer the lack of a flexible water mass exchange with the open sea; anyhow, this observation needs more experimental and numerical investigations.

A relative error between measurements and reproduced velocities was estimated and its values were acceptable, taking into account all the simplifications faced in the modelling and all the real technical and logistical problems due to the acquisition of data in a real ambient such as the sea.

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REFERENCES

Ben Meftah M., De Serio F., Mossa M., Petrillo A. Pollio A., 2007a. "Field measurements and analysis of sea current offshore Taranto". IC-CCM'07, International Conference on Coastal Conservation and Management in the Atlantic and Mediterranean, Hammamet (Tunisia), March 22-26.

Ben Meftah M., De Serio F., Mossa M., Petrillo A., Pollio A., 2007b. "Current circulation in the gulf of Taranto: numerical simulations and experimental data analysis". Ninth International Symposium on Fluid Control, Measurement and Visualisation, FLUCOME 2007, Tallahassee, Florida (USA), September 16-19.

Ben Meftah M., De Serio F., Mossa M., Petrillo A., Pollio A., 2007c. "Curent circulation and velocity field offshore Taranto: vertical velocity profiles". Fifth International Symposium on Environmental Hydraulics, ISEH V, Arizona (USA), December 4-7.

Ben Meftah M., Mossa M., Petrillo A., Pollio A., 2008. "Misurazioni correntometriche di campo al largo della città di Taranto", XXXI Convegno di Idraulica e Costruzioni Idrauliche, Perugia (Italia), September 9-12.

Ben Meftah M., De Serio F., Mossa M., Petrillo A., Pollio A., 2009. "Numerical results of the pollutant spreading offshore Taranto", 33rd IAHR Congress, Water Engineering for a Sustainable Environment, Vancouver (Canada), August 9-14.

De Serio F., Malcangio D., Mossa M., 2007. "Circulation in a southern Italy coastal basin: modelling and field measurements." *Continental Shelf Res.*, Vol. 27, 779–797.

De Serio F., Mossa M., 2006. "Modelling of currents in a Ionian basin." MWWD 2006, Antalya, Turkey.

IMO, 2010. Marine Environment Protection Committee, 61st session Agenda item 7, "Interpretations of, and amendments to, marpol and related instruments". MEPC 61/7/3, 25 June 2010.

Mestres M., Sierra J.P., Mösso C., Sánchez-Arcilla A., 2010. "Sources of contamination and modelled pollutant trajectories in Mediterranean hargour (Tarragona, Spain)". *Marine Pollution Bulletin*, Vol. 60, 898-907.

Mossa M., 2006. "Field measurements and monitoring of wastewater discharge in sea water", *Estuarine, Coastal and Shelf Science*, Vol. 68, 509-514.

Pollio A., Ben Meftah M., Mossa M., Petrillo A., 2008. "Calibration of a sea current numerical model using field measurements offshore Taranto (Italy)", Second International Conference on the Application of Physical Modelling to Port and Coastal Protection, Bari (Italia), July 2-5, 445-454.

Wu J., 1980. "Wind stress coefficients over sea surface and neutral conditions", *Journ. Of Phys. Oceanography*, 10, 727-740.