IMEKO International Conference on
Metrology for The Sea
Naples, Italy, October 11-13, 2017

Monitoring System for the Sea: Analysis of Meteo, Wave and Current Data

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***Abstract* – The present paper aims to deduce typical physical and hydrodynamic patterns by analyzing and discussing long term and continuous recordings of marine field data. In detail, hourly measurements of wind, waves, current velocity, water temperature, salinity, chlorophyll were assessed by two monitoring stations in the period January 2016 - December 2016. They were archived in monthly time-series and successively processed to track recurrent trends and features in the target basin. Specifically, a correlation among wind, waves and current was found. Comparisons with analogous recordings of the year 2015 were also discussed.**

I. INTRODUCTION

Continues monitoring of currents in the nearshore region is of great interest because of their role in coastline erosion as well as in diffusion and dispersion of polluting tracers. In any way, technical and economic limitations make challenging to collect a large amount of data in widespread areas. Consequently, accurate numerical models are often preferred when the hydrodynamics and transport of tracers refer to extended areas. Indeed, models need to be calibrated and validated by field measurements in order to be accurate. Therefore, it is evident that field information becomes a useful tool for supporting the local authorities in coastal management and in situ decision-making [1], [2], thus it is strongly necessary,

One of the principal problems characterizing coastal datasets is the poor resolution in time of data, which are often fragmentary and intermittent. The spatial resolution is generally guaranteed with surveys along fixed transects at regular intervals. Unfortunately, these monitoring programs are ad hoc scheduled in the frame of wider projects and have duration of few days. Further, it is especially difficult to assess field data in semi enclosed areas or in very shallow coastal waters, because of technical limitations. Consequently, field measurements are still rare and sparse, so that monitoring actions should be rationally programmed [3], [4].

The present work aims to examine and discuss the long term and continuous recordings of meteo, hydrodynamic and physical data collected by some monitoring stations, with the intent to 1) delineate an annual evolution for the examined parameters in the investigated area; 2) find possible correlation between winds, currents, waves and water quality parameters.

II. STUDY SITE

The area in question is located in Southern Italy and is composed by two basins, an inner one named Mar Piccolo and an external one named Mar Grande. Mar Piccolo, whose total surface is around 21.7 km^2, is formed by two bays (*Fig.1a*), while Mar Grande with a surface of around 35 km^2, has a typical round shape. In the I Bay the maximum depth is around 15m, while in the II Bay it is around 10m. The I Bay is joined to Mar Grande by means of two channels: an artificial channel, i.e. the Navigable Channel, and a natural channel, i.e. the Porta Napoli Channel (*Fig. 1b, 1c*). The Navigable Channel is 58m wide, 375m long and 14m deep, while the Porta Napoli Channel is 150m wide and 2.5m depth. Considering these dimensions and complex topography, the hydrodynamic patterns in this coastal system can be properly studied only on a local scale. As shown in *Fig. 1c*, along its western side, the Mar Grande is connected to the open sea by means of two openings, along the Northwestern and the Southwestern boundary. This study area is also highly vulnerable, because exposed to a strong anthropic pressure, to urban and industrial discharges as well as to an intense naval traffic [5], [6]. For all these reasons, at present, it is enclosed in the so-called SIN (site of national interest) list and is under the control of the Special Commissioner appointed by the Italian Government to evaluate and dispose urgent measures of remediation and environmental requalification of Taranto city.

Hence, a monitoring of current behavior and water quality in this site is strongly necessary, allowing both to check the real-time status of the basin and promptly intervene when accidents occur. Furtherly the obtained dataset could be a useful support in numerical modelling, recently more and more used to provide forecasts. In fact, field measurements provide input information for numerical models. At the same time, they allow to validate these models when compared with the simulation outputs.

(a)

(b)

(c)

Figure 1. (a) Map of Mar Piccolo, (b) zoom view of station MP, (c) Mar Grande and location of station MG. Source Google Earth.

III. THE MONITORING SYSTEM

The monitoring system examined in the present study consists of: i) a meteo-oceanographic station installed in the central area of the Mar Grande basin (here named for brevity MG station); ii) a bottom fixed ADCP (Acoustic Doppler Current Profiler) and a wavemeter both placed in the Navigable Channel (here named for brevity MP station). All these instrumentations have been settled in the frame of the Italian Flagship Project RITMARE, with funds from PON R&C 2007-13 Project, provided by the Italian Ministry of Education, University and Research [1].

Specifically, the meteo-oceanographic station MG was installed in the Mar Grande basin during December 2013 at the geographical coordinates 40°27.6' N and 17°12.9' E (*Fig. 1a, 1c*). The local depth h in this station is on average equal to 23.5m. The station is provided with many instruments, including a bottom mounted Acoustic Doppler Current Profiler, a multidirectional wave array (both by Teledyne RD) and a weather station (by Met Pack). Other scalar parameters (such as temperature, salinity, chlorophyll) are assessed in the same station at few meters below the sea surface.

In detail, the meteorological system of he MG station uses an ultrasonic sensor placed at 1.5m above the sea surface to record wind speed and direction. It is characterized by an accuracy of ±2% of the velocity value and ±3° of the direction. The station is completed by a barometric pressure sensor and a temperature/humidity probe. They all record hourly averaged values.

Current speed and direction are measured along the whole water column by means of the ADCP. Its acoustic frequency is 600 KHz and its accuracy is 0.3% of the water velocity ±0.003m/s. It works in Janus configuration, consisting of four acoustic beams, paired in orthogonal planes, where each beam is inclined at a fixed angle of 20° to the vertical. It is bottom mounted, upward facing, with the transducer head at 0.50m above the seafloor. Considering the presence of a blanking distance of 1.60m from the sea bottom, velocities are sampled starting from a bottom distance z=2.1m up to the most superficial bin not biased by waves (on average 2m below the sea surface), with a vertical spacing of 0.50m.

Mean current velocity profiles are detected continuously at 1 hour intervals, using an average of 60 measurements acquired every 10s [4]. In this way, hourly-averaged velocity components along the water column are obtained.

During May 2014, the monitoring station MP was installed in the Navigable channel (*Fig. 1b*), at the geographical coordinates 40.473° N and 17.235° E. The local depth of this station is on average 13.7 m. The station is equipped with a bottom mounted ADCP and a wave array (both by Teledyne RD). The features and settings of the ADCP and wave array are the same already described for the MG station. The MP station started recording hourly current and wave height data in June 2014.

In both MG and MP stations, the ADCP sonar measures the component of velocity projected along the beam axis, averaged over a range cell. Since the mean current is assumed horizontally uniform over the beams, its components can be recovered as linear combinations of the measured along-beam velocities. The situation regarding waves is more complicated, since at any instant the wave velocities vary spatially across the array. As a result, except for very long waves that remain coherent during their passage from one beam to another, it is not possible to separate the horizontal and vertical wave velocity components. However, the wave field is statistically steady in time and homogeneous in space, and therefore cross-spectra between velocities measured at various range cells (either beam to beam or along each beam) contain information about wave direction [6]. In other words, each depth cell of the ADCP can be considered an independent sensor that makes a measurement of one component of the wave field velocity. The ensemble of depth cells along the four beams constitutes an array of sensors from which magnitude and directional information about the wave field can be determined.

The data acquisition and processing is managed by the research group of the Department of Civil, Environmental, Land, Building Engineering and Chemistry (DICATECh), of the Polytechnic University of Bari. All the acquired wind, wave, current and water quality data are archived in monthly time-series and successively processed.

IV. DATA ANALYSIS AND DISCUSSION

The framework outlined in this paper is made up of a sequence of analyses carried out on the data records of wind, wave heights, sea current velocity components, water quality parameter (Temperature, salinity, conductivity and chloropill), in time domain. Field measurements were examined and managed following the steps further detailed:

1. processing recorded raw data, converting them from binary file to editable files;
2. storing data in monthly tables with hourly values of detected parameters;
3. applying filters to remove bias;
4. analyzing seasonal and annual trends, by using polar plots and time series.

A. Wind and Waves

As already noted in previous works [2, 4], the fact that the study area is a semi-enclosed system does not imply that the wave field is wind-dominated.

In fact, wind incoming and wave propagation directions are very different, as derived from the annual polar plots respectively shown in Figure 2 and Figure 3, displaying the results of the MG station. Specifically, the exam of the annual polar wind distributions (Fig. 2) confirms that winds from NNW are the most frequent and even the most intense, with maxima velocity exceeding 9m/s. Frequent winds with smaller intensities are also noted spanning clockwise from NNE to ESE. Less frequent and weak winds are typically Sirocco winds. This annual record confirms what already observed for the year 2015 and 2014 relatively to NNW winds [7]. On the contrary, it shows a different behavior referring to Sirocco winds, which in previous years were the most intense ones, with velocity in the range 12-15 m/s, even if they were quite rare. Even the seasonal analysis of winds during the year 2016 confirms a prevalence of winds coming from NNW, with the highest intensity reached in winter period. Meanwhile, in autumn and spring, winds are also coming from ESE with moderate intensities (6-9 m/s).

The annual distribution of the significant wave height *Hs* is plotted in Fig.3 and endorses the results already highlighted by [7] for 2014 and 2015, that is wind waves rarely occur because of short fetches and dominant landward winds. On the contrary the basin is dominated by swell waves, entering from the Southwestern opening and propagating inside. In fact, as illustrated in *Fig.4*, the significant wave heights most frequently enter the basin from SW, consistently with the principal opening in Mar Grande borders (*Fig.2*) and with possible diffraction effects. Further, the greatest values of *Hs*, with maxima around 1m, are observed along this direction. Even the seasonal analysis of the significant wave height confirms this prevalent incoming direction, with highest values recorded in the winter period.

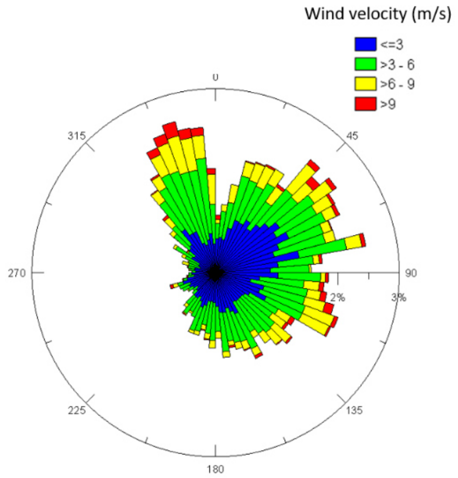


Fig. 2. Annual winds recorded in Station MG (m/s). Incoming direction shown.

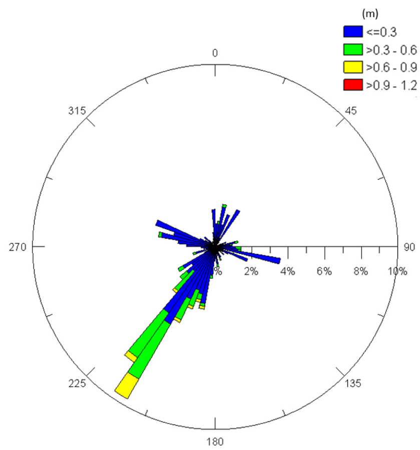


Fig. 3. Annual significant wave heights Hs (m) recorded in Station MG. Incoming direction shown.

A similar procedure has also been adopted for the MP station in the Navigable Channel. The deduced results show a good agreement with previous investigations [2, 4, 7]. In fact, the annual distribution of 2016 displays a reduction of the significant wave height in the MP station, with respect to that recorded in the MG station. Maxima observed values of *Hs* are around 0.4m, thus allowing us to deduce that the smoothed waves which reach the Navigable Channel could reasonably be swell waves generated outside the Mar Grande, entering the basin and propagating throughout. The wave propagation directions are generally confined along the longitudinal axis of the Navigable Channel itself. The seasonal analysis of the significant wave height puts in evidence that the highest values (>0.6m) are recorded in the winter period.

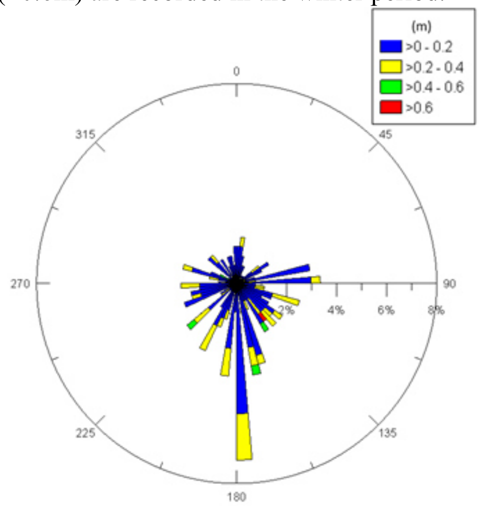


Fig. 4. Annual significant wave heights Hs (m) recorded in Station MP. Incoming direction shown.

B. Current

The hourly averaged vertical profiles of the current velocities recorded in the MG station provide the following results, which again confirm typical behaviors already assessed in years 2014 and 2015.

The annual surface currents plotted in *Fig.5a* illustrate that the most frequent and intense currents generally propagate towards SE. They especially seem to be affected by winds blowing from NNW (*Fig. 2*). A punctual correspondence between blowing winds and superficial current spreading is noted along all directions, even in terms of intensity. The annual bottom currents, as depicted in *Fig.5ba*, converge towards SW, thus flowing outside the basin through the SW opening.

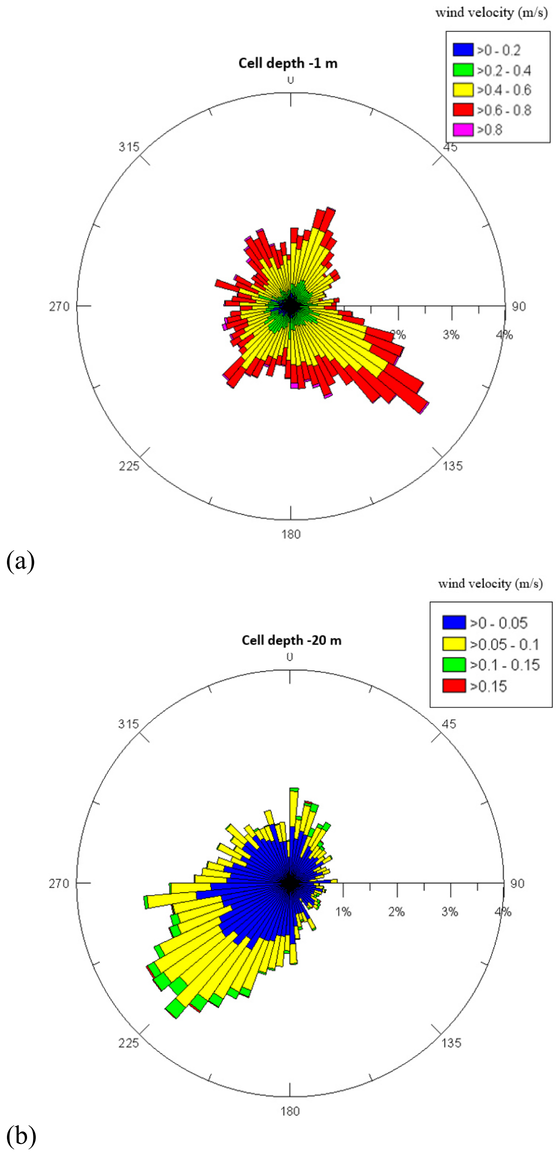
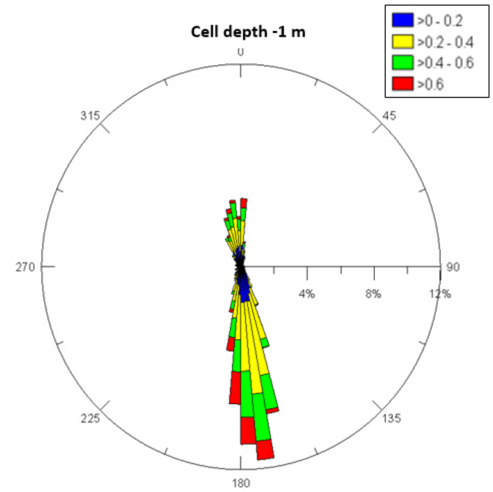
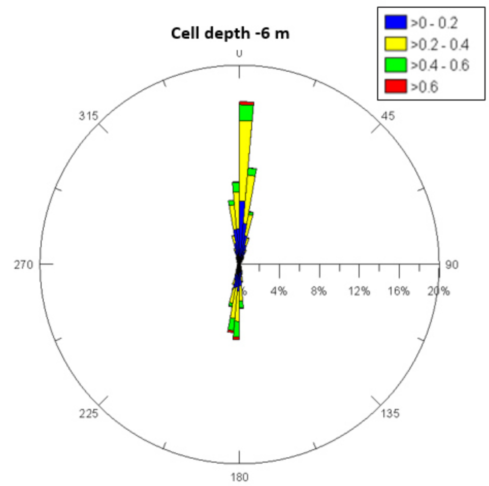


Fig.5. Annual current velocity (m/s) recorded in Station MG at surface (a) and at bottom (b). Direction of propagation shown.

The analysis carried out for the measured hourly-averaged currents in station MP (year 2016) has produced the results shown in *Fig. 6*, where the annual trends at the surface, at an intermediate depth and at the bottom are plotted.



(a)



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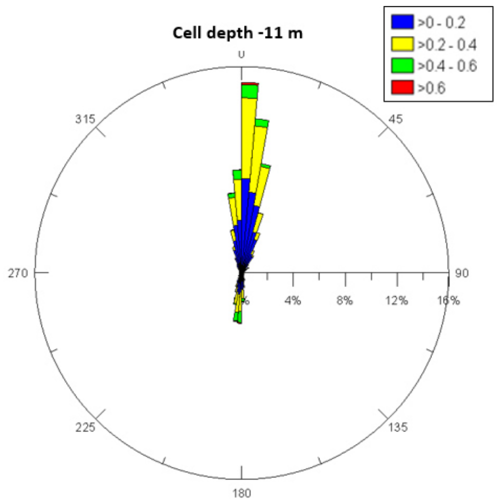


(c)

Fig. 6. Annual current velocity (m/s) recorded in Station MP at (a) surface, (b) at intermediate depth and (c) at bottom. Direction of propagation shown.

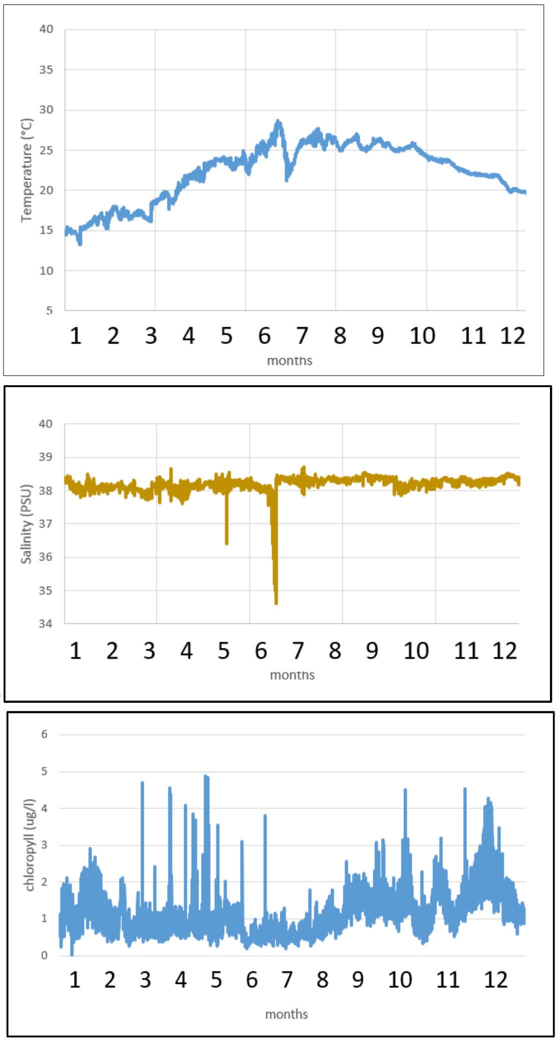
In detail, approaching the surface (*Fig. 6a*) a dominant outflowing current towards the Mar Grande is recorded, with the highest intensities (even greater than 0.4m/s). At an intermediate depth (~ 6m from the surface) the outflow is still present, but characterized by lower intensities and it is less frequent. Near the bottom (~11m from the surface) the prevailing current is inflowing towards the Mar Piccolo basin, with a dominant direction converging to the longitudinal channel axis. Its most frequent intensities are in the range 0.05-0.3m/s. This annual vertical distribution of the current velocity in the channel highlights to fundamental aspects. Firstly, in the whole examined period a double circulation is present in the channel, i.e. inflowing towards the Mar Piccolo basin in deeper layers and outflowing in the most superficial ones. This behavior confirms the data analysis carried out for the year 2015 and also proved by numerical simulations [9]. Differently from 2015's results, in 2016 the outflowing rate prevails on the inflowing one. Therefore, it is worth noting that the double flux persists in the channel, while the rate of water exchange between the two basins in the upper and lower layers has an annual variability.

C. *Water quality*

The analysis of water quality parameters may provide useful and real-time information on the state of the coastal site. In station MG the water property sensors are located at an average depth of 5.5m from the surface and specifically allow to measure water temperature *T*, salinity *S*, and chlorophyll *Chl*, assessed at hourly intervals during 2016.

From the annual records, the expected progressive increase of the superficial water temperature *T* is visible, with minima values around 18°C in the autumn and winter months and maxima values around 27.5°C in August (*Fig. 7a*). Referring to salinity *S*, its variation during the whole observation period is limited in the range 37.5–38.5psu, with the highest values being recorded in July/August, thus consistent with the typical dry period characterized by a stronger evaporation (*Fig.7b*).

The chlorophyll (*Chl*) is an indicator of both nutrient enrichment and level of eutrophication in the water bodies that leads to algal blooms. The principal source for the chlorophyll concentration in the examined area is represented by the coastal discharges and their consequent outflow of nutrients. The measured chlorophyll concentration annual trend shows highest values (around 5µg/l) during the autumn-winter months, when precipitations affect the basin with increasing discharge. In the summer period, values decrease to around 0.5µg/l (*Fig.7d*). This trend confirms previous field data of 2015 and is consistent with the reduced discharge rate in the dry season. Some local peaks are evident in the chlorophyll time series during the spring months, possibly due to occasional and limited rain events.



(a)

(b)

(c)

Fig. 7. Annual trend of hourly recorded (a) temperature, (b) salinity and (c) chlorophyll data.

V. CONCLUSION

The present study examined a large collection of meteorological, hydrodynamic and water quality parameters recorded by a continuous monitoring system located in Mar Grande and Mar Piccolo site. The main concern was to identify possible recurrent and typical behaviors and trends. The analysis refers to data recorded during the year 2016.

The annual wind distribution shows that winds from NNW are the most intense and frequent. Furtherly, the wind seems to drive the surface circulation, as shown by the annual polar plots of the superficial currents measured in the MG station. In terms of both magnitude and direction, surface currents are correlated with winds, on an annual time scale. On the contrary, it does not affect waves inside the basin.

The analysis of waves and currents data shows that the SW opening along the Mar Grande border is an important topographical element. It controls both the incoming direction of the significant wave heights and the direction of propagation of the bottom currents (as assessed by the MG station). These results confirm what deduced in previous researches [7].

The monthly vertical distributions of the current data measured in the station located in the Navigable Channel highlight that during the whole year a double circulation occurs in the channel, i.e. inflowing towards the Mar Piccolo basin in deeper layers and outflowing towards the Mar Grande in the most superficial ones. This behavior is also confirmed by previous numerical modelling outputs [6], [7].

The analysis of the water quality parameters displays expected trends for temperature and salinity, with typical increased values for both during the hottest months. With regards to the chlorophyll concentration, it could be intended as a more severe indicator of the water quality, being directly linked to the outflows of nutrients. Its presence in the basin strictly follows the alternating wet/dry seasons.

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