Marine observing systems from fixed platform in the Ligurian Sea

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ABSTRACT Two meteo-oceanographic buoys are operating in the Ligurian Sea. ODAS-ITALIA 1 is designed for open, deep-sea support for air-sea interaction studies, while the SAMA MAMBO is specifically addressed to coastal environmental monitoring. The different technical solutions adopted for each buoy, according to their specific in the employment, are described. After some years of operation, both systems have been proved able to run for long periods, thus providing reliable long-term time series of marine environmental parameters. Results so far obtained and potentialities of the joint use of the two buoys are discussed.

1. Introduction

The need for an efficient network of environmental observation and data dissemination systems has been widely recognised. Several programmes and initiatives to improve quantity, quality as well as availability of data and information and to foster collaboration among the different actors involved in these processes are being promoted. Observations of the marine environment are mainly devoted to scientific investigations, environmental quality assessment, coastal planning and management, marine circulation and sea state forecasting.

Due to its role in the climate and circulation of the Mediterranean region, the Ligurian-Provençal basin has been object of intense scientific investigation since the sixties. During winter, processes of dense water formation often occur, strong air-sea interaction processes greatly affect both the atmospheric and the marine circulation, determining a strong variability in the upper ocean thermocline; its productivity is very high and its ecosystem very rich and complex. Recently, in order to preserve the richness and variety of populations living in the Ligurian Sea, an international treaty for the delimitation of an area inside this basin (the so-called “Cetacean Sanctuary”) has been signed and new sanctuaries in coastal areas of environmental value have been created. All these aspects make the Ligurian basin an interesting research site for oceanographers, physicists, and biologists and justify efforts to maintain monitoring systems.

To this end two fixed meteo-oceanographic buoys are operative in the Ligurian Sea: ODAS Italia-1 located in the centre of the Ligurian Sea and SAMA MAMBO located near the eastern coast, facing Riomaggiore (Fig. 1). Even though they were originally designed for different scopes and to operate in different environmental conditions, their joint use, in addition to the periodic oceanographic campaigns and to fixed moorings deployed in the area, provides a marine

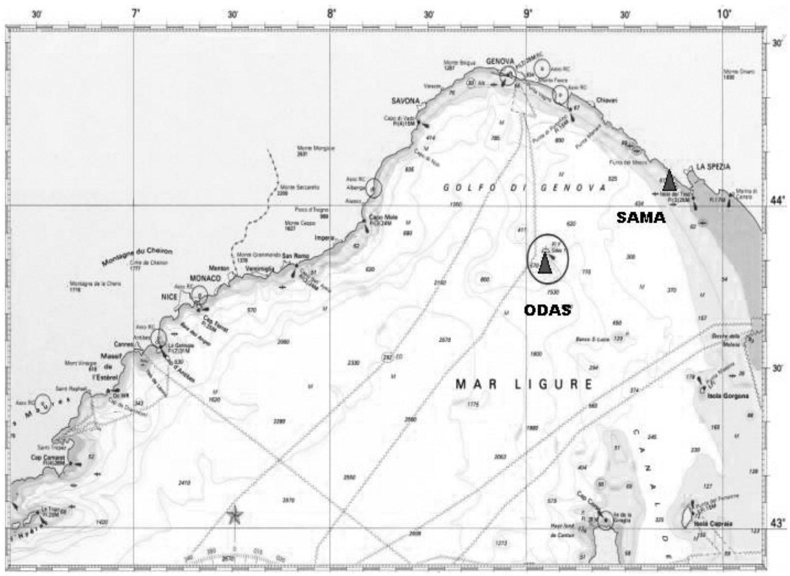

Fig. 1 - Ligurian Sea with the location of the buoys.

observing system, unique to the Mediterranean.

2. Buoy Odas Italia-1

2.1. System description

The open Sea Laboratory ODAS ITALIA-1 (Oceanographic Data Acquisition System) represents the only European example and one of the few in the world of a spar meteo-oceanographic buoy.

It is moored in the open Ligurian Sea between Genoa and Cape Corse (43°47.28'N; 9°09.78'E) on a deep sea bed (1377 m), 40 nautical miles from the coast.

In 1969, CNR-ISDGM, now CNR-ISMAR, designed the buoy for meteorological data acquisition and deployed it in the Gulf of La Spezia, initially near the coast and then in the open sea.

Between 1969 and 1991, the buoy was moored in different positions in the open Ligurian Sea while objectives and managers changed. In 1978, the buoy coordination was assigned to the CNR Ship Equipment Research Group and the implementation of the project to the CNR-IAN (now CNR-ISSIA). Since 1991, the buoy has been equipped to collect meteo-marine as well as biological parameters.

The buoy was specifically designed for air-sea interaction studies and to operate even in rough seas: for these reasons its main structural characteristic with respect to the sea heave is stability, which makes it peculiar-shaped when compared to the other more classical buoys which are based on a discus-shaped design (Cavaleri and Mollo-Christensen, 1981).

The buoy consists of a main 40 m long steel pole body (Ø 24", i.e. a standard oil pipe) divided into four sections, firmly joined by flanges and bolts. The three upper sections are water-tight and

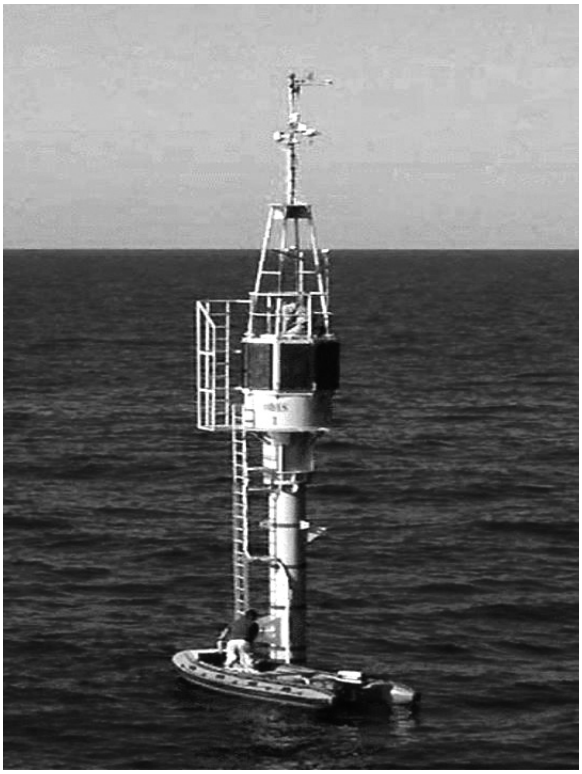
Fig. 2 - Buoy ODAS Italia1.

filled with a closed-cell foam, the one in the middle, has a thicker portion (Ø 1200 mm) to improve buoy stability and buoyancy. The fourth section is filled with water and has a stabilizing disk (Ø 2000 mm) which, for the significant mass of water it moves, dampens the buoy's vertical motion. A 1300 kg ballast hangs from below this segment: it is constituted by two big shackles (500 kg) and by 800 kg of lead pellets, all inside a container suspended under the damping disk by means of three short pieces of chain. At 6 m above the sea level, there is a small laboratory containing the control and acquisition system which can host up to two persons. On the top, a tower reaching a height of about 15 m supports all the meteorological instruments, the lights and the antennas (Fig. 2).

The mooring line is an S-shaped slack mooring, usually employed to moor surface buoys in the deep ocean. The basic configuration of this type of moorings consists in a heavy upper part whereas the lower part is buoyant or supported by glass balls to avoid possible piling on the ocean floor. The slack configuration ensures that the surface buoy is able to withstand even strong transversal thrusts, without sinking.

We can group all the equipment on board into 4 different subsystems: the control system, the communications system, the power supply system and the instrumental payload.

The first subsystem is formed by all the equipment installed on board for data acquisition; an intelligent controller hosts 8 slots for acquisition/control boards. The communication system, based on the GLOBALSTAR satellite network, provides the necessary tools for exchanging commands, information and data with the remote system ashore.

The core of the control and acquisition system is an intelligent controller, a National Instruments (NI) Compact Fieldpoint (cFP-2020) for reliable distributed or stand-alone deployment with industrial ratings for what concerns temperature range, shocks and vibration. These systems allow the complete control, acquisition and pre-elaboration of all data collected onboard. The data are recorded both locally as well as saved on an onboard memory and sent to the land station by a satellite GLOBALSTAR phone link, that makes a two-way business-to-business communication from the buoy to the station ashore possible.

A 12 V - 180 Ah battery pack provides the necessary power supply to all the devices on the buoy. It is charged by eight solar panels located outside the laboratory and by a wind generator.

Table 1 - List of the sensors installed on the buoy with the manufacturer of the equipment and the height/depth of the instrument.

Parameter	**Manufacturer and Model**	**Height /Depth [m]**
Global solar radiation	Eppley PSP	+14.6
Wind speed and direction	Gill Windsonic	+14.4
Air temperature and relative humidity	Rotronic GmbH MP102	+13.7
Air temperature and relative humidity (in a ventilated shield)	Rotronic GmbH MP102	+13.5
Atmospheric pressure	Th. Friedrichs 5004	+7.8
Water temperature	Seabird SBE39	-0.5
Water temperature and conductivity	Seabird SBE37sm	-5.8
Water temperature	Seabird SBE39	-12.5
Water temperature and conductivity	Seabird SBE16plus	-20.0
Water temperature	Seabird SBE39	-28.5
Water temperature and conductivity	Seabird SBE16plus	-36.0
Dissolved oxygen	Seabird SBE43	-36.0
Turbidity and chlorophyll	WET labs ECO-FL-NTUS	-36.0
Wave statistics (i.e, $H_{1/3}$)	Tritech Int. Ltd PA500/6	-9.4
Geographical position	Furuno GP320	+10.6
Heading	R.M. Young 32500	+7.8
Roll and pitch	Planar Tech. GmbH NS-15/V2	+8.0

The last subsystem includes all the sensors installed on the buoy to collect meteorological, oceanographic and biological measurements (Bozzano *et al.,* 2003).

2.2. Meteo-oceanographic measurements and data management

The payload onboard the buoy includes the meteorological sensors, the marine sensors, a two-axis inclinometer, a compass and a GPS receiver. The meteorological set of sensors is composed by a precision spectral pyranometer, an anemometer with sensors for wind speed and direction, two barometers, two thermo-hygrometers (one in a standard shield, the other in a ventilated shield). A marine sensors set includes six temperature and two conductivity sensors positioned along the buoy body between 0.5 m and 36 m depth, a multiparametric probe installed about 36 m deep, close to the damping disk, and three echosounders at a 9.4 m depth installed on supports spaced 120° for measuring the distance from the sea-surface above. The waveform of the sea surface is reconstructed from the acoustic backscatter (collected at 2 Hz for about 3 minutes) from these sensors, corrected for buoy response to the sea and buoy motion measured by other sensors (compass, two-axis inclinometer). By using the signals acquired from this array, the standard statistical parameters for the sea waves, such as significant wave height and period, are obtained; the direction of the waves can be estimated from the cross-correlation of each pair of signals. The manufacturer and the model of the sensors and their position along the buoy body (positive values for sensors installed above the sea surface and negative for those in the sea) are shown in Table 1.

In order to extend the sea measurements to deeper layers, a mooring is deployed near the buoy. It is equipped with an upward looking RDI Sentinel ADCP measuring currents in the upper 80 m of the water column with a vertical resolution of 8 m and three CTD SBE37 located respectively

Fig. 3 - Buoy ODAS Italia1 web page.

at 70 m, 120 m and 250 m measuring temperature and conductivity. The sampling rate is 30 minutes for each parameter. The mooring is not linked to the buoy, so data are recovered periodically during maintenance operations.

There is more power supply and space available on the buoy to install additional sensors. The modular acquisition system also features the capacity of treating different types of electrical and serial signals thus allowing the chance of installing a broad range of new and more advanced sensors.

All the measurements are collected by the onboard system on the basis of the configuration defined by the system's manager. The default operational configuration is set for hourly acquisition at all the measured parameters in a single data record. The period of sampling used as a reference is at a one-hour interval, centered around the hour (e.g., from 11:57:00 up to 12:02:59). The position from the GPS is acquired after this period and then all the marine sensors are questioned through the serial line. The other sensors (essentially all the meteorological ones) are sampled during the whole period at a lower frequency (0.1 Hz). A time window is also left for transferring the data to the station ashore and/or to receive any connection from it.

Two conditions can autonomously modify the sampling scheme. One occurs when the on-board memory is getting full (less than 100 Mbyte of free space): the system stops to acquire the

Fig. 4 - Buoy SAMA MAMBO.

sequences and stores only the average and the statistical values. The second case is when the battery pack has a low voltage (less than 11.5 V): the system automatically increases the time interval (e.g., by acquiring only one data record every three hours instead of every hour). In both cases, the system comes back to the standard functioning mode as soon as the fault is removed.

Before any new deployment of the sensors, factory or “in-house” calibration of all sensors is carried out, especially for the marine sensors. The optimum maintenance frequency is every 3 months for a routine control and every 6 or 12 months for a complete maintenance. This includes recovery and replacement of the instrumentation with new calibrated sensors, in order to avoid the effects of sensors drift.

Acquired data are processed in near-real time by applying quality control procedures developed within the framework of the European project, Mediterranean Forecasting System (http://www.bo.ingv.it/mfstep/). The database is also updated in near real-time and web pages with a summary of the latest data received and plots of past time series (last 24 hours, last week, last month) are created at http://www.odas.ge.issia.cnr.it/ (Fig. 3). On a daily basis, a subset of data received are converted into the MEDATLAS format and made available through the Coriolis data centre at IFREMER (France). Part of these data are also transmitted over the Global Telecommunication System (GTS) making ODAS Italia 1 the first buoy to feed the GTS with meteo-oceanographic data from the Italian seas. Since mid 1999, and apart from the period between January 2001 and June 2002, the buoy regularly collected and transmitted data to the

Table 2 - List of the measurements acquired by the system with the manufacturer of the equipment and the height/depth of the instrument.

Parameter	Manufacturer and Model	Height /D Depth [m]
Wind speed & direction	Young RM 05106	+ 4
Air temperature	Young RM 41342	+ 4
Atmospheric pressure	Young RM 61201	+ 4
Pressure, Temperature, Conductivity, Dissolved Oxygen, Fluorescence, pH	Idronaut Ocean Seven 341	-0.5 / -25 m

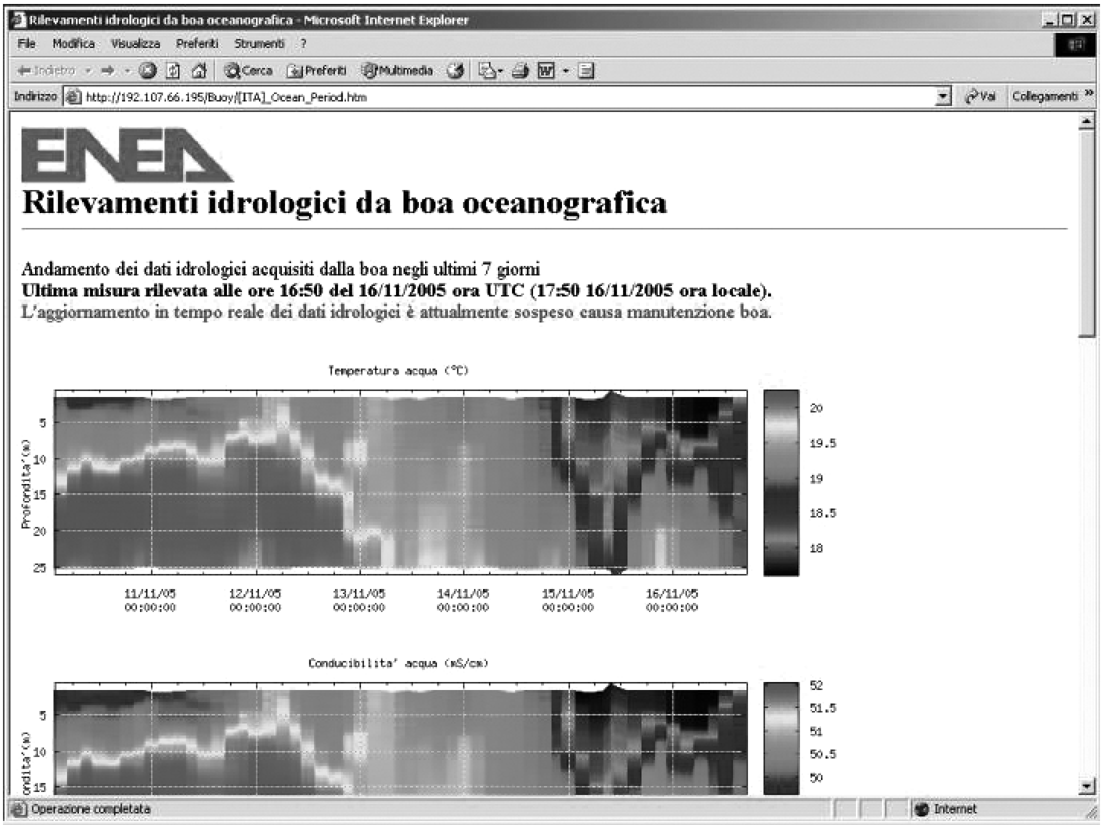

Fig. 5 - Data from buoy SAMA MAMBO displayed on the web page.

station ashore based in Genoa, thus putting at our disposal one of the longest data sets from an off-shore buoy in the Mediterranean Sea.

3. Buoy Sama-Mambo

3.1. System description

Buoy SAMA MAMBO is located in the eastern coasts of the Ligurian Sea (44° 05.24'N; 9° 43.97'E). The first prototype was developed by the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) in 1998 and was conceived to operate in coastal shelf areas. Differently from most of the existing oceanographic buoys, it is specifically designed to support a profiling monitoring system for sea water. It was moored in 2002 in front of Riomaggiore in the "Cinque Terre Protected Marine Area", at a sea depth of 30 m, with the main aim of testing the performance of such a system for long periods of operation and evaluating its capabilities for environmental monitoring applications.

It is composed of an exagonal toroidal and hollow float bearing an alluminium tripod tower with steel stands. The float is 2.30 m wide, while the tripod together with the stands reach about 5 m on the sea level. Three stands on the underside hold a 150 kg ballast to stabilize the whole

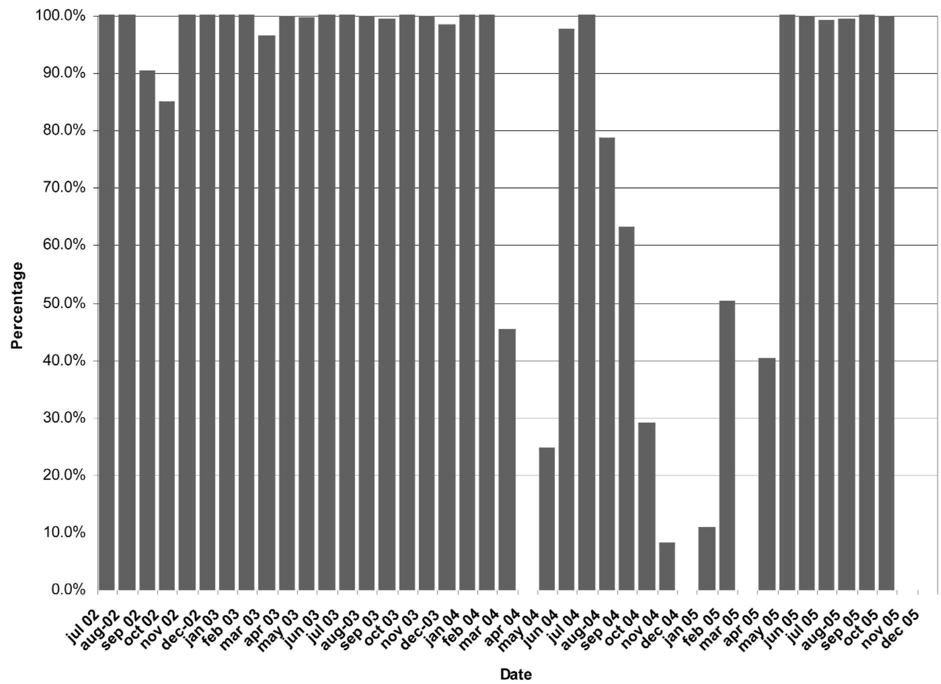

Fig. 6 - Data availability from Buoy ODAS Italia 1.

structure, which can operate up to a sea state force 7-8 and 40 knots wind. It is moored with a three line mooring, each line constituted by a 5 m chain fixed to the base, a 75 m polyester heavy-duty braided cable, plus 15 m of chain and the anchors. The main body of the float, built entirely in stainless steel, is partitioned to obtain seven independent watertight chambers. There are four peak tanks, one in the centre which hosts the batteries and the communication system and the others around it. At one side of the float there is the block and the cable guide for the probe. The tripod tower supports the controller, the winch, the meteorological sensors, the solar panels, lights and other accessories (Fig. 4).

The on-board equipment consists of the power supply, the controller system, the acquisition and transmission system, the profiling system, the meteorological station and the signaling devices.

The electrical power is ensured by three 55 W solar photovoltaic panels charging three 12 V, 70 Ah batteries; three microprocessors-controlled 10 A current regulators, a master switch and safety system are also connected to the mains box.

The buoy instrumentation, the profiling system and the communications are managed by a controller that also incorporates a GSM modem and the GPS receiver.

Sampled data are stored in a back-up memory and transmitted via modem in real time by means of a cellular telephone to the receiving station ashore. Data transmission is automatically triggered by the telephone call from the land station located at the ENEA Marine Environment Research Center. If problems occur during communications, the system tries again until all data are sent even with a time delay. The system configuration, as well as the sampling and the transmission scheme, can be modified by remote access from the land station or in situ via the on- board

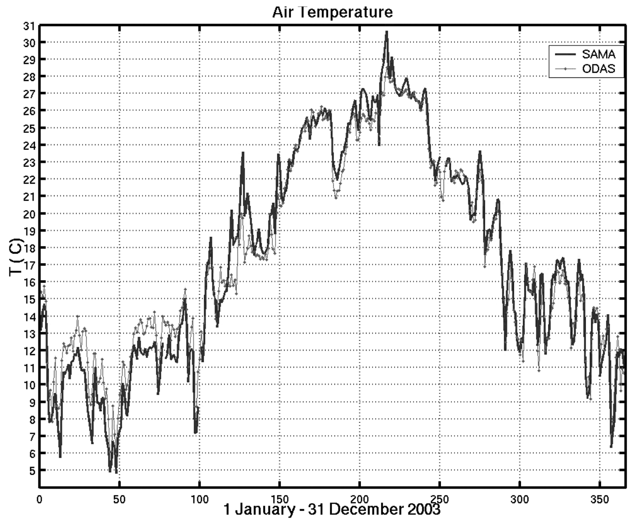

Fig. 7 - Air temperature from ODAS and SAMA MAMBO during 2003.

controller.

The profiling system is composed by the winch and by the multiparametric hydrological probe. The winch, with an internal slip-ring, has a motorized drum wound with the coaxial cable connected to the probe. It can support a load of about 20 kg, and has a maximum velocity of 15 cm/s that can be regulated with a resolution of 0.5 cm/s according to the monitoring needs. The probe has a communication RS232 port and also ASK or FSK telemetry. For long-term monitoring, it can be supplied with an antifouling system. When at rest, the probe remains in the sea at a depth of about 18 m to avoid sea wave damage and to limit the effects of biofouling.

Routine maintenance mainly depends on the measured parameters and on the season: it would require, at least, a bi-monthly substitution of the multiparametric probe during the summer period, when the fouling strongly corrupts the marine sensors. The multiparametric probe is calibrated at SACLANTCEN in La Spezia every two months. The structure and the mooring line need to be inspected at least once a year.

3.2. Meteo-oceanographic measurements and data management

The meteorological parameters presently measured by the buoy are: air temperature, atmospheric pressure, wind speed and direction. However, new sensors can be added. To compensate for the small rotation of the buoy, an electronic compass is included in the anemometer to measure the true direction of the wind. The meteorological station has an internal memory and communicates via RS232 interface with the buoys controller.

The multiparametric probe provides measurements of sea temperature, pressure, conductivity, dissolved oxygen, fluorescence and pH in the water column between 1.5 m and 25 m with a resolution of 25 cm.

The meteorological parameters are sampled according to WMO (World Meteorological Organization) standards that specify a time window of 10 minutes for each hour. The sampling rate is 1 Hz for all the parameters: average values of air temperature, atmospheric pressure, wind

Table 3 - Data availability from buoy SAMA MAMBO.

Hydrological time series												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002									••••	••••	••••	••••
2003		••	••••	••••	••••	••••	••••	••••	••••	••••	••	• ••
2004				••••	••••	••••	••		••			••••
2005			•	•••				•••	••	••••	•••	

Meteorological time series												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002									••••	••••	••••	••••
2003	••••	••••	••••	••••	••••	••••	••••	••••	••••	••••	••••	••••
2004	••••	•••		••••	••••	••••	•••		••	••••	••••	••••
2005	•••		•	••								

scalar and vector speed are computed from the 600 samples, wind gust is the maximum value.

Hydrological profiles are performed every three hours and data are transmitted by real-time to the land station.

The acquired data are automatically processed in near real time before being archived and displayed on the web-page. All data are checked for gross errors; wind and atmospheric pressure are reduced to the standard level of 10 m, data from the multiparametric probe are checked to eliminate spikes due to the different time constant of the sensors (Boniforti *et al.,* 2006) and corrected for the signal drift produced by the fouling. This last procedure is performed taking into account the comparison between the last values before the change of the probe and the first one acquired with the new calibrated probe, and considering a linear trend.

The latest multiparametric profiles and meteorological measurements as well as the data of the past seven days are made available through the web page (http://www.santateresa.enea.it/wwwste/dationline/dationline.html) (Fig. 5). The complete time series are then stored in the ENEA CRAM environmental data-bank. SAMA MAMBO started working on September 1, 2002 but several interruptions due to failure and accidental damages to the system occurred. From December 16, 2005 it has been hauled up at ENEA CRAM for a more accurate maintenance.

4. Results

After some years of operation, an assessment of the performances and a comparison between the two systems can be attempted. Despite the fact that the two structures are designed to be located at different depths, and the transmission systems are chosen according to the distance from the receiving stations, the differences regard the way of performing the measurements at sea. The main advantage of the profiling system installed on SAMA MAMBO is the high vertical resolution of the measurements and the possibility of easily substituting the probe without the need for divers. This is particularly important in the case of sensors such as Oxygen and pH that

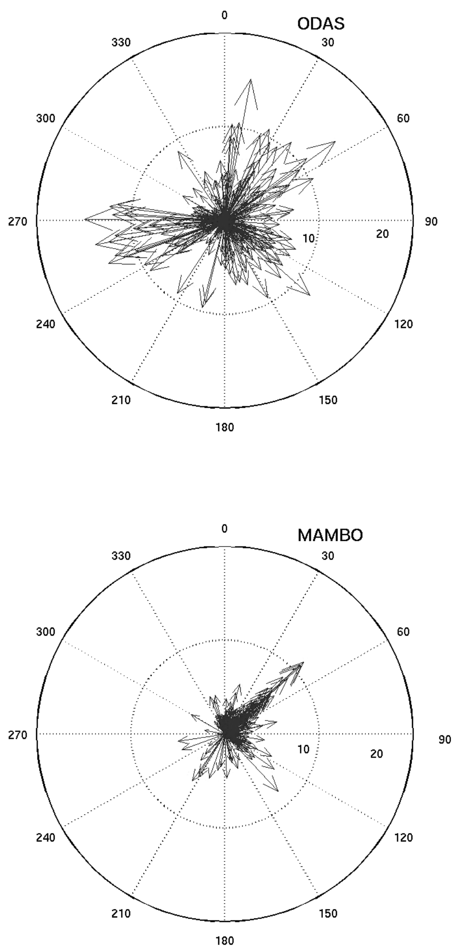

Fig. 8 - Wind scatter from ODAS and SAMA MAMBO during 2003.

must be frequently changed. On the contrary, autonomous mechanical devices at sea always pose some problems in terms of energy consumption and malfunctioning; in addition, the winch cannot operate with high waves. Failure in the transmission systems occurred for both buoys, but in most cases data were saved by the back-up memory. Both the structures and the mooring lines showed good stability even with bad weather conditions. Accidental and deliberate damage turned out to be one of the main causes of interruption, as the buoys cannot be kept under surveillance. Maintenance of the buoys requires a huge systematic effort of qualified work both at sea and in the laboratories, and such damage should be taken into account when evaluating the costs of the systems. On the whole, provided a regular maintenance is done, the two buoys have been able to operate for long periods, thus providing reliable long time series of observations. The available data sets from July 2002 to December 2005 are summarized in Fig. 6 and Table 3.

Some examples of the time series of observations collected during 2003 are described. In spite of the lack of intercalibration of the sensors and the different temporal resolutions of the measurements, a comparison between daily mean data from the two buoys can actually give an idea of the variability from the coast to the open sea and can help to estimate how reliable the use of coastal data to describe the open sea is.

Air temperature time series have similar temporal trends with mean differences generally below one degree and the annual mean respectively of 17.4°C and 17.3°C. Significant differences, of up to 4°C, occur from the end of April and the first week of May. Near-coast temperatures have a higher variability: winter minima and summer maxima are more pronounced. Winter minima occurred from February 13 and 18 with daily mean values below 5°C near the coast and about 6°C in the open sea, summer maxima were reached on August 5 with respectively 30.6°C and 28.8 °C (Fig. 7).

Atmospheric pressure does not present relevant differences from the two points of observation

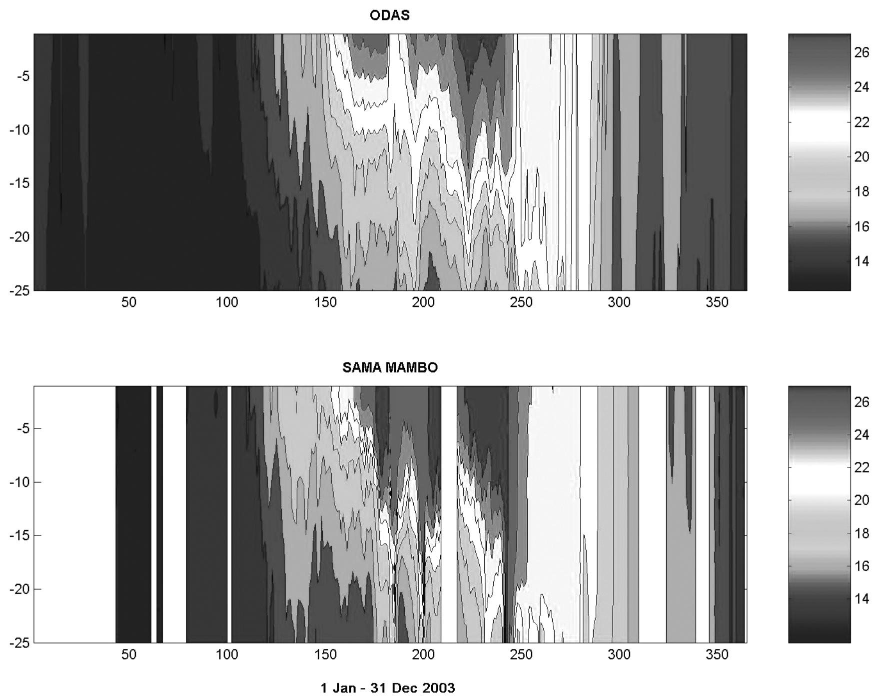

Fig. 9 - Sea temperature evolution in the upper 25 m during 2003.

which are about 37 nautical miles apart.

The wind observed from the SAMA MAMBO is strongly affected by the orography: the buoy is surrounded from NW to SE by high coasts, though the NE wind is funneled through a channel between the hills. Wind intensity is reduced: annual mean is 2.4 m/s in respect to 4.9 m/s of the ODAS (Fig. 8). The highest peaks are reached in the open sea: daily mean values up to more than 10 m/s and mainly associated to western wind occurred frequently, while near the coast only two events were observed, in correspondence to the NE wind. The annual evolution of the sea temperature in the upper 25 m of the water column allows us to investigate the upper layer stratification (Fig. 9). Surface temperatures have similar trends, apart from the episode of early July, when surface temperature observed from ODAS strongly decreased, mainly as a consequence of the strong mixing with the colder layers below. On average, the mean temperature in the upper 25 m of coastal waters is lower in winter and higher during the summer. The different dynamics characterizing the coast and the open sea are the main factors responsible for the observed differences in the vertical distribution of temperature: wind mixing is more efficient in the open sea, but the advection of waters from the lower layers tends to withstand this effect: resulting summer stratification is then more pronounced in the open sea.

The long time series of observations so far collected have been used for studies in several fields. ODAS Italia 1 was successfully used for air-sea interaction studies (Picco *et al.,* 2006), for the validation of satellite measurements as well as for forecasting model results (Bozzano *et al.,* 2004) and it is part of a Mediterranean monitoring network for Operational Oceanography

(Legrand *et al.,* 2003). SAMA MAMBO has demonstrated to be an appropriate tool for monitoring the dynamic and environmental conditions of the coastal area.

The joint use of coastal and open sea data allows us to approach a more comprehensive study of the whole area with particular attention to the interactions between coastal and open sea dynamics. The benefit was evident in the investigation of the effects at sea of the anomalously hot summer of 2003. The data collected by the two buoys permitted us to investigate what happened below the sea surface, how this affected the coastal and the open sea area to different degree sand to follow the evolution and the response of the ocean-atmosphere system for that particular event (Sparnocchia *et al.,* 2006).

The knowledge of the evolution of meteorological and oceanographic conditions in the whole basin facilitates a better understanding of the sensitivity of marine organisms to the rapid changes of the environmental conditions. In particular, it can support the study of a mass mortality phenomena that, from the important episode of 1999 (Cerrano *et al.*, 2000), frequently affected this area.

In addition, a similar network of observing systems, providing a real-time continuous environmental and meteo-marine monitoring and surveillance, can be a support to local administrators in the management of navigation, or of environmental emergencies such as oil spills.

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