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Observing Systems and Forecasting

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A Site for the Observation of a Highly-Energetic Coastal Marine System: the Straits of Messina

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Abstract

The use of a "platform of opportunity" has been experimented both as a scientific observatory in a peculiar coastal system and to support the development of new technologies for energy production from marine currents. During 2008, CNR-IAMC Messina, in cooperation with the Horcynus Orca Foundation, has installed onboard the ENERMAR-Kobold platform, deployed in the Straits of Messina, an environmental and engineering monitoring kit that includes an automatic system for the measurement of marine currents, water temperature and meteorological parameters and an underwater camera. Engineering parameters are simultaneously measured to characterize the functioning of the turbine and the pitch/roll of the platform. All the data are collected by the acquisition system and stored in a relational database. A wireless link through a web server allows the real-time access and data visualization. The marine current intensity distribution proved to be fitted through the Weibull distribution so allowing the comparison of the energy production potential of different sites. CNR-IAMC is promoting the inclusion of the ENERMAR-Kobold structure in the research national network of installations currently in operation. The perspective of an increasing energy demand from renewable sources makes it possible the forthcoming presence of a global network of platforms hosting state-of-the-art instruments to observe the marine environment.

1 Introduction

Coastal environments are very complex marine ecosystems. The Straits of Messina is a peculiar case, characterized by high biological productivity and diversity and a relevant spatial and temporal variability of the natural physical and biogeochemical processes. The long-term systematic observation of such environments and their internal equilibria through innovative technologies such as automatic measurement systems is today the first step towards a balanced development of the management policies of the area. In early 2000s, the research activity of the Istituto Sperimentale Talassografico of the National Research Council (today CNR-IAMC Messina) was supported by the National project "Realizzazione ed attivazione di una rete integrata di piattaforme costiere e mezzo mobile attrezzati per sistemi avanzati di monitoraggio delle acque (Cluster 10-SAM)", funded by the Italian Research Ministry. In this context a platform was deployed in the Straits of Messina to measure meteorological parameters (air temperature, atmospheric pressure, solar radiation, wind speed and direction) and physico-chemical and trophic characteristics of the water column at different depths up to 25m (temperature, salinity, oxygen, fluorescence, turbidity, ammonium, nitrites, nitrates, orthophosphates). The data were collected automatically and forwarded in quasi real-time through SMS messages via GSM network to the institute where they were merged with the data coming from periodic coastal surveys and stored in SAMBA the common database of the project SAM accessible via internet. At the end of the decade, the process of transferring the developed technology and the expertise acquired during the research activities was initiated by considering the use onboard "platforms of opportunity", in order to combine the continuation of the development and an immediate application. The presence of a platform deployed in the Straits of Messina by a private company to study the potential of energy production from marine currents triggered this evolution. The Straits of Messina separates Sicily from the Italian peninsula and has the characteristic inverted-funnel shape, with a total length of about 40 km in the north-south direction and a variable west-to-east width ranging from 2.8 km near the Tyrrhenian edge to 25 km at the Ionian open boundary. The narrowest cross-section (0.3 Km2) has a depth of 80 m and coincides with the presence of a sill which divides the area into a northern NE-to-SW oriented sector and a southern N-to-S one, reaching about 200 m and 1200 m of depth respectively. From an oceanographic point of view the Straits of Messina exhibits very strong tidal currents (max. 5 knots). It is occupied by different water masses, the Atlantic Water (AW) at the surface and the deeper Levantine Intermediate Water (LIW), whose mixing by upwelling currents produces a new body of typical water [1]. This enrichment condition results in a stimulating effect on the living component enhancing the biological richness. The Straits of Messina constitutes a direct route of communication between the eastern and western Mediterranean basins, as indicated by the crossing of swordfishes, tuna fishes, cetaceans and turtles. The climate in the region is temperate-humid with an average temperature above 22° C and rainfall concentrated in the cold period (fall-winter). The average annual temperature is around 18.5 °C (1916 to 1999, CV= 0.03, [2]), and the annual rain precipitation is about 1000 mm. Objectives of the present paper is to describe the laboratory for the observation of the Straits of Messina that has been implemented onboard the ENERMAR-Kobold platform. The main aspects of the research work performed in the last years are illustrated and an overview of the most relevant findings is presented.

2 The hosting platform and the measurement system

The ENERMAR-Kobold platform is a prototype built to extract energy from the marine current flow by utilizing a vertical-axis turbine [3]. It mounts a 3-bladed rotor below a round-shaped hull of 10 m diameter (see Figure 1). The platform is moored in the Straits of Messina, 200 m offshore in front of the village of Ganzirri (15 km north of the city) where the water depth is about 25 m. The plant has been permanently connected to the Italian power grid

Figure 1: The ENERMAR-Kobold platform in the Straits of Messina: a prototype built to extract energy from the marine current flow (patented in 1998 and owned by Ponte di Archimede International).

in 2008. The energy is produced by the system at any angular velocity, depending only on the current speed. The prototype has been deployed to study the performances of the turbine in relation to the environmental conditions and evaluate the potential of the production site. To these scopes, during 2008, CNR-IAMC Messina, in cooperation with the Horcynus Orca Foundation, has installed onboard the ENERMAR-Kobold platform, an environmental and engineering monitoring system to provide the input data to the turbine controller (e.g. the actual values of current velocity, pitch and roll of the hull, etc.) and assess the environmental performances of the platform. A wireless link ensures the remote control of the turbine operations and the real-time access and visualization of the environmental data through a web server. The system's architecture includes the following main six blocks:

Turbine controller. This control system measures the most important electromechanical parameters during the turbine functioning: turbine speed, generator torque and generator power. The controller is an industrial PC-type acting on the frequency converter and the brake system, while the control software was developed in Matlab. A VNC (Virtual Network Computer) connection allows a complete remote control of the turbine.

Environmental data acquisition system. The installed system is currently employing a development of SAM-BA, a hardware/software architecture and a relational data structure specifically designed for the management and elaboration of meteo-oceanographic and environmental data col-

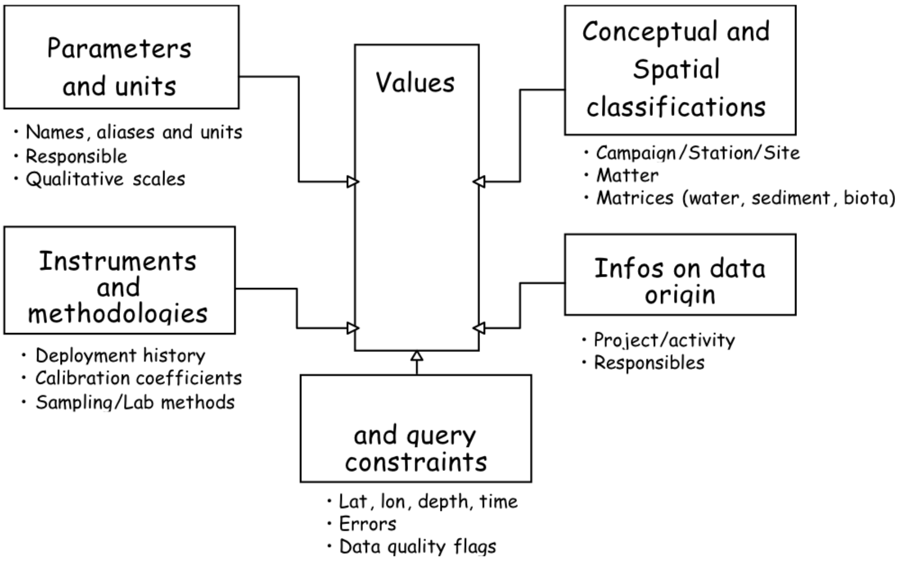

Figure 2: SAM-BA: The scheme of the relational structure developed to manage the environmental data collected onboard the ENERMAR-Kobold platform in the Straits of Messina.

lected by automatic platforms and field campaigns [4]. The hardware includes a PC and a serial multiport connected to the measurement devices, that can be directly sensors (e.g. a temperature probe) or complex instruments (e.g. a current meter). Hardware expandability is straightforward and transparent to the end user through the sharing of the tasks among several dedicated PCs that can be geographically distributed, each with a specific task (collection from sensors - onboard; database storage/query, presentation via web). The software has been developed by CNR-IAMC Messina on a open-source LINUX platform. The management of sensors/devices is ensured by a fully expandable plug-in structure. The software communicates with a PostgreSQL database for data storage. The frequency of acquisition and storage onboard is programmable according to the different characteristics of the sensors and a backup of local data is performed on a remote database using a secured ssh connection.

The measurement system includes a Linux PC and a serial multiport to connect:

1. a DAVIS Vantage Pro 2 meteo station: wind speed and direction, air temperature, atmospheric pressure, humidity, precipitation;
2. a NORTEK Aquadopp Profiler (ADCP) deployed at the seabed (20 layers, each 1 m thick) for 3D profiling. The current meter mounts a high sensitivity pressure sensor able to provide wave measurements (under development);
3. sea temperature at the seabed (built-in in the ADCP) and at 1 m of depth (by a SBE39);
4. a fluorometer and a turbidimeter, placed at -1.5 m;

5. a CROSSBOW CXTILT 2D inclinometer for evaluating the pitch and roll of the platform during strong currents periods and/or wave solicitations.

The oceanographic data (3 measurements every 15 min for currents and sea temperature at seabed, 1 measure per second for SBE39) are stored onboard in the PostgreSQL database, while meteo data are available in quasi real-time and then stored.

Camera control. Below the platform (at about 2 m depth), inside of a waterproof container, a "dome" type video color camera with PTZ (Pan-Tilt-Zoom) capability has been installed that is able to rotate on both horizontal and vertical axis in addition to variable zoom. The main purpose of this camera is to monitor the fish activities near the turbine blades and the interaction with them. The analog video signal from the camera is acquired by a MPEG4 codec/video server and converted in a digital format suitable to be transported over the LAN. The access of the video streaming and the camera PTZ controls from the local network or Internet is ensured by a web server by using a web browser.

Wireless link. The system includes two wireless bridges with directional antennas, operating in IEEE 802.11g standard at 2.4 GHz. In the actual point-to-point configuration, and given the distance of about 8 km (required to connect the Kobold platform to the Internet Service Provider), the wireless link ensures a bit-rate of 36 Mbps.

The SAM-BA database. The management of the data collected by the ENERMAR-Kobold platform is performed by the SAM-BA database, which has been tailored and further developed from its first version dating on 2004. In the frame of "Cluster 10" Programme, the SAM project [5] set the problem of regional coastal monitoring for Sicily. Among the other issues, the management of the collected data, coming from very different sources was approached through the development of SAM-BA a relational structure tailored to store:

i) meteorological data and water quality data collected and transmitted via SMS technology by a network of automatic coastal platforms
ii) data from lab analyses on water, sediment and biota samples collected during interdisciplinary campaigns at sea
iii) the data collected by an underway continuous system
iv) CTD profiles, etc...

Furthermore on line queries and graphic visualization of selected data were provided through standard web browser approach. The core of SAM-BA was developed on the ANSISQL standard, so that the database can be transported to a different ANSISQL-compliant RDBMS. This ensures to the developers the possibility of easily migrating SAM-BA on higher-performing hardware/software architectures without changing the interface codes to the database. The SAM-BA structure is modular (see Figure 2). There is a fundamental information (the measured value), around which a set of ancillary infos specify further important aspects necessary to track the life cycle of the measured value and to link it with other values in the database. Though maintaining a common area where the values are stored and correlated (the "Values" Table), in this way it is possible to associate to each record ancillary infos that can vary in relation to the "nature" of the record itself (e.g. a record coming from an automatic platform or a measure produced in the lab). The querying was developed as a web interface on the HTTPS protocol; the used language was PHP, coupled with the APACHE web server. Beyond the known reliability of both these softwares, a further note is on their availability for a wide number of hardware/software platforms. The use of the HTTPS protocol, with a bilateral exchange of certificates, makes it possible the encoding of the exchanged infos and the tracking of the accesses.

Web portal. A website for the real-time publication of the collected data has been developed and is currently available at http://kobold.horcynusorca.it/. The pages are conceived to publish all the currently acquired data (actually meteo and current velocity) onboard the platform with automatic periodic updates (typically few minutes) which can be programmed according to the research and monitoring needs. The site makes available both raw data tables and their graphical presentation. The website shows also the archive of previous data (24 hours for marine currents, full dataset for meteo data).

3 The different aspects of the research

3.1 Meteo-oceanographic aspects: the observed processes

Hydrography. From the hydrographical point of view the Straits exhibits very relevant tidal currents driven by both barotropic and baroclinic processes which depend on strong bathymetric constraints exerted by the sill and coastal morphology [6]. Important features are also the presence of an amphidromic M2 point close to the sill and the recurrent presence of two water masses, the Atlantic Water (AW) at the surface and the Levantine Intermediate Water (LIW) underneath [7]. In both Tyrrhenian and Ionian basins the interface between these two water layers is generally at a depth of 150 m whereas near the sill it uplifts to a 30 m of depth. The water fluxes through the Straits average 233x103 $m^3 \cdot s^{-1}$ and depend on tidal rhythms [8]. Tidal currents velocities often exceed the threshold of 2.0 $m{\cdot}s^{-1}$ near the sill at the NE entrance and are induced by the opposite phase in tidal amplitudes which exists between the Tyrrhenian (12 cm) and the Ionian (6 cm) seas. Due to the strong mixing phenomena that involve the whole water column the Straits generates a peculiar water mass (called Messina Mixing Waters) that flows southward and can be identified up to 150 km along the ionian coast of Sicily [9]. This phenomenology has been accurately described since the works of Vercelli and Picotti of early decades of the previous century [10], and continued until now based on oceanographic cruises with classical sampling methods. Therefore a systematic observational approach producing a long-term eulerian time series is lacking. The continuous observation of the environmental system made possible by the floating laboratory provides the opportunity to describe in a greater detail physical and oceanographic processes, already observed through classical methods. Some of the findings are reviewed below.

Currents. The current measurements were collected by the 3D ADCP (Nortek Aquadopp) every 15 min and stored onboard after a preliminary averaging process. The considered period covered 98 days for a total of 9395 valid measures. Current intensity showed a maximum of 2.24 $m{\cdot}s^{-1}$ (in S-to-N or “montante” conditions) and a mean value of 0.47 $\pm$ 0.34 $m{\cdot}s^{-1}$ (Figure 3). In terms of frequency distribution (Figure 4), after the subdivi-

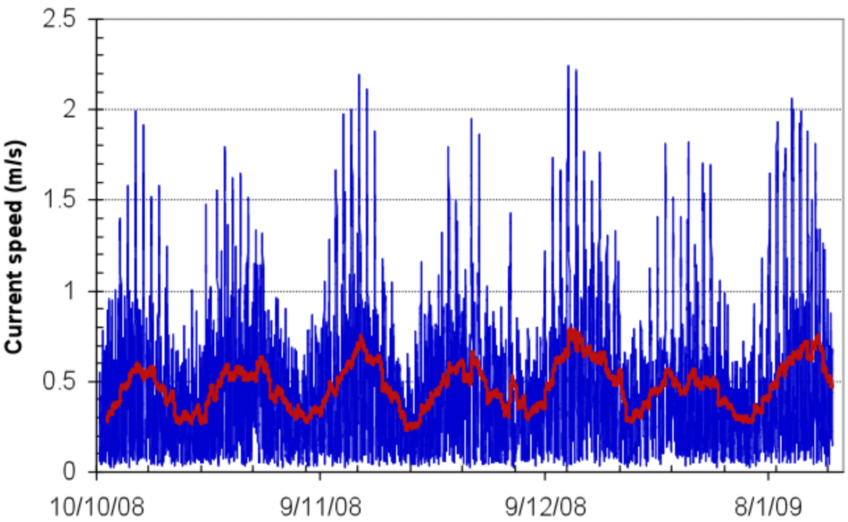

Figure 3: Straits of Messina (Ganzirri): Current intensity (measured every 15-min and averaged in the 5-to-10m layer) observed at the ENERMAR-Kobold platform from October 10th, 2008 to January 9th, 2009.

sion into 45 equal-amplitude classes of speed, the percentage of time characterized by a current speed greater than 1 m·s^{-1} was found to be 7%, which becomes 2% if we consider currents greater than 1.5 m·s^{-1}, and only 0.1% for currents greater than 2 m·s^{-1}. The cumulative frequency has the median of 0.4 m·s^{-1}, i.e. for 50% of the time, currents did not exceed such value. Following the approach used in literature [11, 12] for the ocean surface currents, the distribution that best fits the experimental data is the Weibull distribution, that is characterized by only two parameters a (the scale parameter) and b (the shape parameter). In our case, the fitting procedures calculates the following values (with 95% confidence interval): a=0.52 and b=1.44 (Chi-square Goodness-of-Fit test, P<0.001). It is interesting to note that a only affects the average current speed. It is called "characteristic speed" meaning that for 62.3% of time the current velocity did not exceed a (0.52 m·s^{-1} in our case). The shape parameter b identifies the general form of the probability density function. In particular, when it is 2, the Weibull distribution reduces to that of the Rayleigh distribution. The Weibull parameters a and b may be obtained from the mean and standard deviation of v, the current velocity measurements, using the Gamma function [13]:

$$b \cong \left[\frac{mean(\nu)}{std(\nu)}\right]^{1.086}, \tag{1}$$

$$a = \frac{mean(\nu)}{\Gamma(1 + 1/b)}, \tag{2}$$

thus suggesting the possible characteriza-

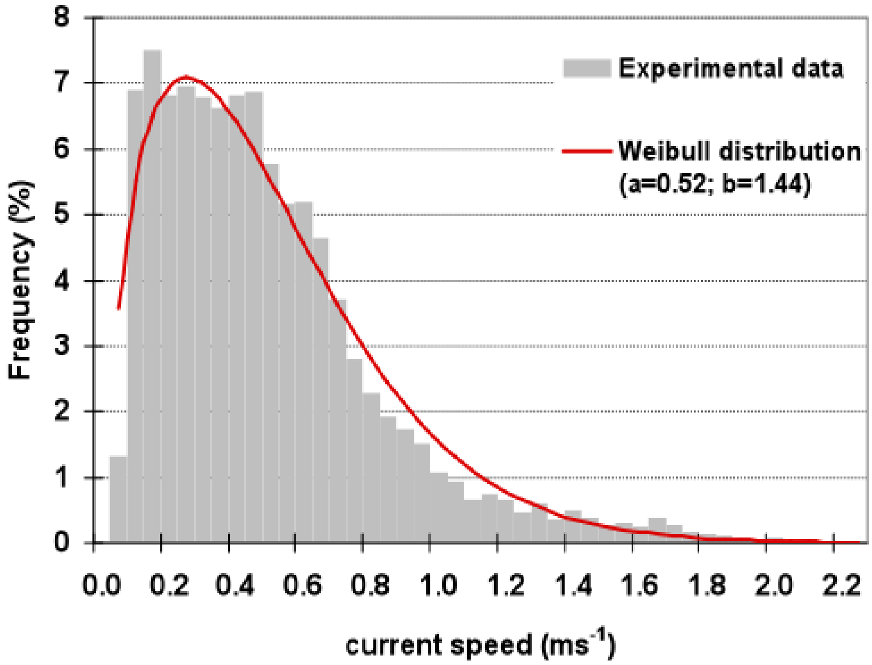

Figure 4: Frequency distribution of the current intensity data collected on the Straits of Messina (Ganzirri) and their fit with Weibull distribution.

tion of a generic tidal site through only two parameters, the scale and shape of the Weibull distribution, explicitly linked to the average and the standard deviation of the current intensities respectively. Finally, it is possible to describe some important features of the currents in the measurement site. Figure 5 shows the tidal ellipse of the current speed (averaged in the layer 5-10 m of depth). An evident dissymmetry in the order of 3 to 1 between the tidal phases ("montante" and "scendente") can be noted: due to bathy-morphological constraints the site is far more exposed to tidal currents from S to N.

Water temperature. The thermal features of the waters in the study site give insight on the heating/cooling processes and the periodic alternance of the different water masses. Figure 6 shows the temporal trend of the water temperature at the seabed (during a period of about 3 months). In October values close to 23 °C indicate a still developed late summer condition while the slow seasonal process of cooling begins at the end of November and ends in January. The high dynamics of the area is highlighted by the wide thermal range (about 7 °C) due to the presence of water masses of different origin in relation to the tide (Tyrrhenian Surface Waters, 23 °C; Intermadiate Ionian Waters, 14.5 °C). A further process

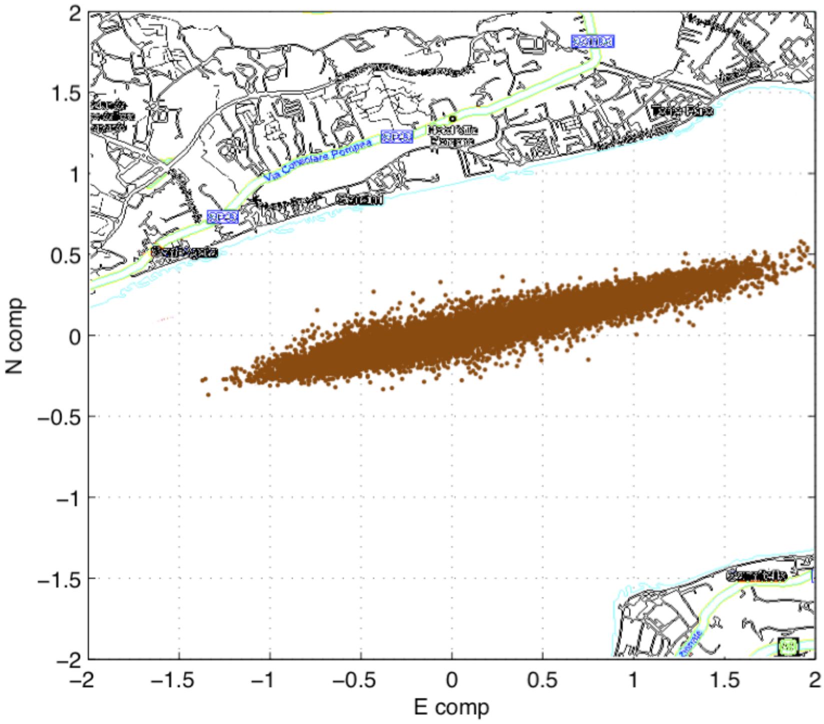

Figure 5: Tidal ellipse of the current speed (averaged in the layer 5-10 m of depth) collected near the ENERMAR-Kobold platform in the Straits of Messina.

is the periodic alternance of periods characterized by a low or high thermal daily variation depending on the moon phases: neap tides associated with low currents reduce the presence of Ionian colder water. This process disappears towards the winter months when the Tyrrhenian surface waters cool down.

Meteorology. The possibility to describe in detail particular meteorological events is a further value of an automatic observation system. The records of a 1-day winter storm are shown in Figure 7. In the first 36 hours, in normal weather conditions with a stable atmospheric pressure and a moderate wind, small periodic asymmetric oscillations of the platform induced by tides can be noted. The abrupt decrease of the pressure (from 1013 to 1002 mbar) and the strong increase of the wind speed (from 20 to 75 km$\cdot$h^{-1}) that follow induce an evident increase of the platform pitch amplitudes ($\pm$ 8 deg). After the storm, the residual oscillation due to the persistence of a rough sea can be observed for at least 12 h.

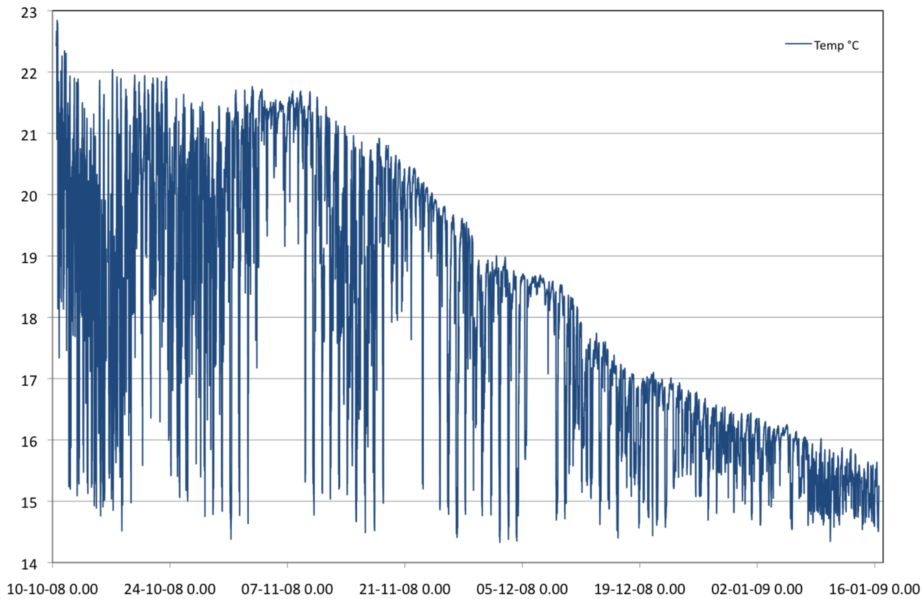

Figure 6: Temporal trend of the water temperature at the seabed (during a period of about 3 months) collected near the ENERMAR-Kobold platform in the Straits of Messina.

3.2 Technological and environmental aspects: the Energy production

An important engineering parameter in the operation of a floating vertical-axis turbine is the actual angle between the axis itself and the water flow. Due to the dynamic response of the platform system (hull+moorings) to the surface movements (tidal variations, waves, etc.), the angle can decrease with respect to its optimal value (90 deg): this reduces the performances of the turbine and provokes frictions and stresses to the mechanical parts. To address the study of this aspect we have used the data collected by the inclinometer in spring tide and calm sea conditions (duration of the observation 3 days; sampling frequency 1 Hz) to obtain the harmonic response of the platform system (Figure 8). The continuous value (at 0 Hz) indicated the need of a fine levelling of the platform by adjusting the ballast. In the tidal band (up to $2\text{x}10^{-4}$ Hz) the moon semidiurnal M2 component induces inclinations of about 1 deg mainly along the roll (S-to-N) axis. In the wave band (greater than 10-2 Hz) a small signal with a period of about 3.7 sec is the platform swing. The evaluation of the prototype efficiency and the assessment of its environmental and social impact have been achieved during the pre-operational phase in 2009. The local analysis on the marine environment showed that the ENERMAR-Kobold prototype has a very low overall

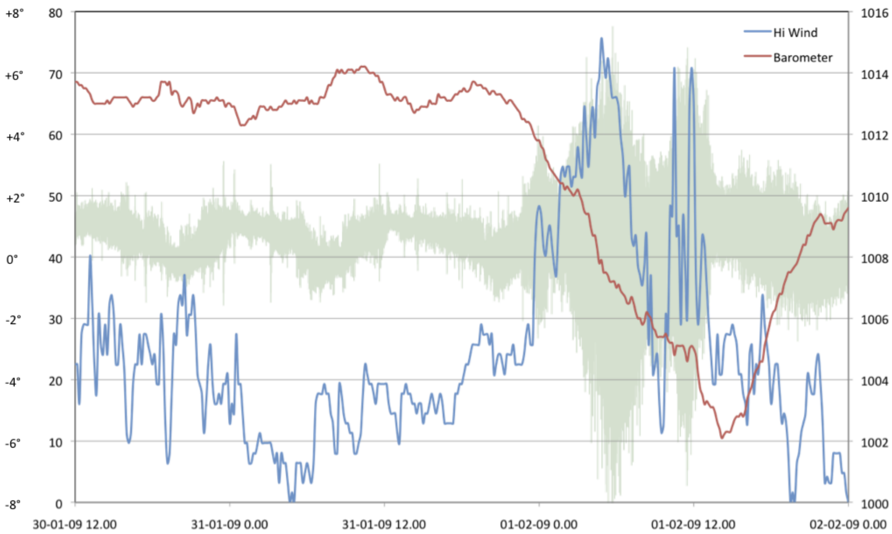

Figure 7: Weather conditions (wind speed and atmospheric pressure), and its effects on platform oscillation (pitch component) measured during the storm.

impact. The joint measurement of currents and produced mechanical power made possible to evaluate in the order of 10% the efficiency of the prototype in extracting energy from the current flow. The prototype produces energy (about 10 kW) as soon as the currents exceed 0.8 m·s^{-1} especially during "montante"phase, which is stronger than "scendente" phase in the site. Losses in the electrical system due to a non-optimal control of the turbine are still relevant at low currents (Figure 9). If we assume that the Weibull distribution for currents holds, the total theoretical power available in a generic site is not a direct function of speed, but only depends on the parameters a e b of the Weibull distribution, and can be calculated as:

$$P_{T0} = \int_0^{+\infty} P_0(\nu) f(\nu) d\nu$$

$$= \frac{1}{2}\rho S a^3 \Gamma(1 + \frac{3}{b}). \quad (3)$$

On the other hand, the total theoretical power available (per unit area) derived from direct measurements of current intensity can be expressed (using the ergodicity of the process) as follows:

$$\frac{P_{Sp}}{S} = \frac{1}{2}\rho \int_{T_i}^{+T_f} w^3(t) dt$$

$$\cong \frac{1}{2}\rho \sum_{i=1}^{k} w_i^3 \cdot p_i \Delta T, \quad (4)$$

where k is the number of classes of subdivision of the distribution (in our case 45), wi is the velocity of the ith class, pi is the absolute frequency (number of times per unit time) for which there was the ith speed, and ΔT is the unit of time (15 minutes = 900 sec). If we compare the two values (re-

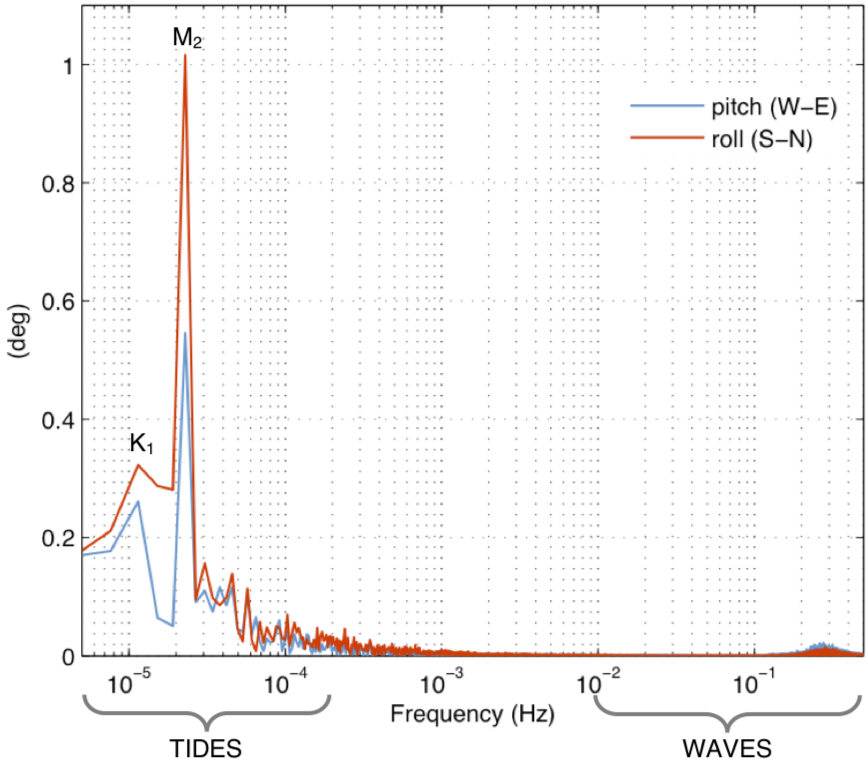

Figure 8: Harmonic response of the ENERMAR-Kobold platform in calm sea conditions. The inclinations induced by the K1 (diurnal, 23.2 h) and M2 (semidiurnal, 12.6 h) tidal components are indicated.

spectively 158 W$\cdot$m^{-2} and 169 W$\cdot$m^{-2}) obtained through the two approaches we can note that they differ by only 6.5%. Hence, considering a specific energy availability (theoretical PT0) of 160 W$\cdot$m^{-2} and a measured efficiency (η) of about 10% it is possible to estimate the total energy Ep produced by the ENERMAR-Kobold prototype in a 25-years life cycle (ΔLC) of continuous operation in the actual deployment site in the Straits of Messina. Since the efficient area S is about 30 m^2 we obtain:

$$E_p = P_{T0} \cdot S \cdot |Delta_{LC} \cdot \eta \cong 3 \cdot 10^5 MJ. \quad (5)$$

From the total inventory calculated by using the real metric computation (materials, metalworks, manufacturing, etc.) and the Life Cycle Assessment approach, the energy consumed by the prototype during its entire life cycle can be estimated in less than 2.5x105 MJ. Although the ENERMAR-Kobold is the first release of this new technology for energy production

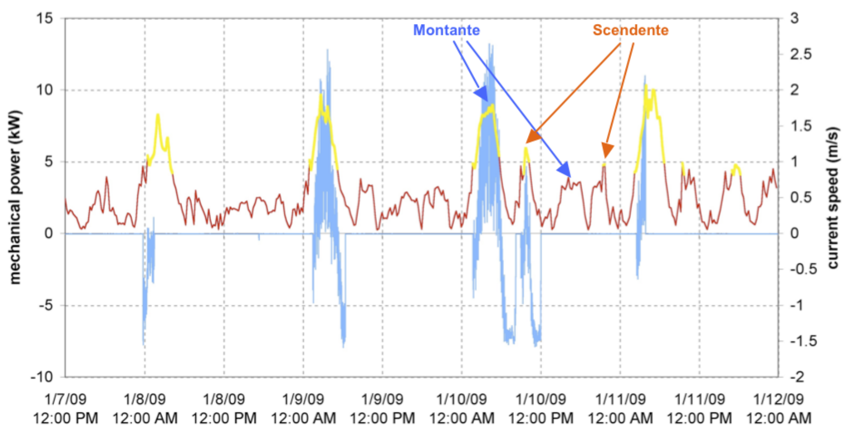

Figure 9: ENERMAR-Kobold energy production in the Straits of Messina between January, 7th and January 12th , 2009. Time series of the observed current intensity and the measured mechanical power.

from renewable sources, the energy balance is therefore positive.

4 Future developments

All sources of renewable energy are becoming an important option for a growing number of communities especially in developing countries. The rapid growth of population, the increasing energy demand, the need for a better quality of life in remote and isolated places, attract more attention and interest on renewable energy also from marine sources. Driven by the developments and assessments on the ENERMAR-Kobold prototype in the Straits of Messina, UNIDO (the United Nation Industrial Development Office) has recently launched an international partnership with South-Eastern Asian countries (Indonesia, Philippines, China) aiming at exploring the potential of exportability of this kind of technology in specific operational scenarios (small islands). The possibility of modelling the tidal currents intensities through the Weibull distribution allows to characterize a generic site by using only two parameters (the Weibull parameters a and b) directly related to the mean and standard deviation of the current intensities, that can be then estimated from a time series of current measurements with a duration of at least half lunar cycle. Furthermore, the theoretical density of power of the current flow available in each site can be calculated from the same two parameters, so that the comparison of the energy production potential of different sites is straightforward. As an example, Figure 10 shows the available density of power versus the mean velocity of the tidal current flow for several values of standard deviation. Some selected geographical sites are mapped on these curves according to their measured signature (in terms of mean and standard deviation of their tidal currents)

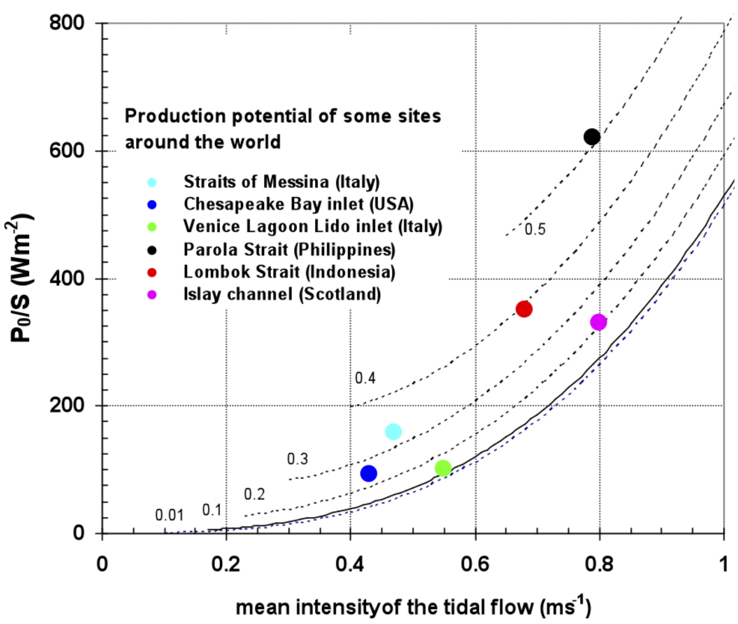

Figure 10: Power density available depending on the average speed of current flow for various values of standard deviation (dotted curves). Straits of Messina: data of this study; Chesapeake bay: data of the buoy BrownShoals-Delaware USA, January-February 2009; Venice Lagoon: source Magistrato alle Acque di Venezia (extrapolated data taken at the inlets). Lombok Strait and Parola Strait: data from field surveys in 2007 funded by UNIDO. Islay Channel: available on the web.

so that their energy production potential can be then easily compared. The laboratory for the observation of the Straits of Messina system currently hosted onboard the ENERMAR-Kobold platform can provide the following output to the research and management communities:

- continuous collection of Meteo-oceanographical parameters available in real-time via internet;
- information needed to the optimization of the ENERMAR-Kobold prototype and similar technologies;
- possibility to host instrumentation and/or sensors from different research teams to perform joint programmes (e.g. on biodiversity and climate changes).

The CNR-IAMC is promoting the inclusion of the ENERMAR-Kobold platform in the research national network of installations currently in operation. The perspective of an increasing request of energy from renewable sources makes it possible the forthcoming presence of a global network of platforms hosting state-of-the-art instrumentation to observe the marine environment.

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The CNR operational Sea Surface Temperature Products in the Framework of MyOcean Project

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Abstract

Different remotely-sensed Sea Surface Temperature (SST) products have been developed by the Gruppo di Oceanografia da Satellite (GOS) of the Istituto di Scienze dell'Atmosfera e del Clima (ISAC) and are operationally produced and distributed in near-real time in the framework of GMES (Global Monitoring for Environment and Security) MyOcean project. The products are based on the infrared images collected by the sensors mounted on several satellite platforms, and they cover the Mediterranean Sea, including the western Atlantic Ocean, and the Black Sea. The SST processing chain includes several steps, from the data extraction and preliminary quality control, to the images compositing and merging. A two-step algorithm finally allows to interpolate SST data at high (1/16°) and ultra-high (1/100°) spatial resolution, applying optimal techniques. The basic design of the MyOcean processing chain and the main algorithms are briefly described hereafter.

1 Introduction

The ISAC-GOS (Istituto di Scienze dell'Atmosfera e del Clima-Gruppo di Oceanografia da Satellite) is involved in both operational and R&D (Research and Development) activities related to the retrieval of the Sea Surface Temperature (SST) from satellite data. These activities, started within Medspiration, MF-STEP and MERSEA projects, are now primarily carried out in the framework of two international initiatives: the European MyOcean project, and the GODAE-GHRSST (Global Ocean Data Assimilation Experiment-Group for High Resolution SST, [1]). The first one is the European project devoted to the implementation of the GMES (Global Monitoring for Environment and Security) Marine Core Service for the 2009-2012 period. MyOcean project is co-funded by the European Union through the 7th Framework Programme for Research and Development, and aims to develop the first concerted and integrated pan-European capacity for ocean monitoring and forecasting. On the other hand, the GHRSST is an international scientific and technical framework specifically set up to address the need for accurate high resolution SST products, as required by several different kinds of scientific and institutional users, as well as by private companies and enterprises. In fact, the SST is a fundamental parameter for the scientific investigation of the ocean and atmosphere dynamics and climate, and it is clearly needed also by the meteorological and marine operational forecasting systems to constrain their numerical prediction models (mainly through direct assimilation). Moreover, an increasing num-

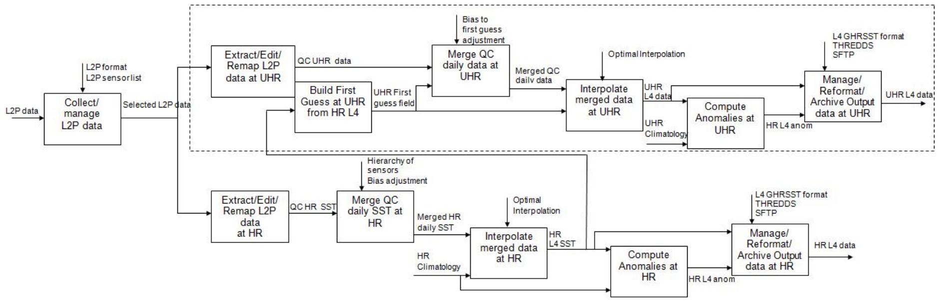

Figure 1: Scheme of the Mediterranean and Black Sea MyOcean SST processing chain.

ber of private companies (working, for example, on fisheries, tourism, marine transportation, marine environment and security managing, offshore exploration and extraction, etc.) is now requesting operational access to SST data. Actually, the main results and recommendations of GHRSST have been reflected in the design of the MyOcean SST-TAC (Thematic Assembly Centre). Within the SST-TAC, ISAC-GOS has the responsibility of the development and implementation of the operational chains for the production, validation and dissemination of the SST Level 4 (L4) data covering the Mediterranean and Black Sea. These L4 data correspond to daily gridded optimally interpolated satellite estimates of the SST at high (1/16°) and ultra-high (1/100°) spatial resolution, built from all available infrared measurements. In this paper, the present (V0) GOS-ISAC MyOcean SST processing chain is described together with the evolution to the V1 production chain, that will be fully operational only at the end of 2010. The data used and the main modules of the chain are introduced, together with a description of the algorithm for the merging/collating of the satellite passes and of the optimal interpolation techniques adopted.

2 Input data

The SST L4 processing chain is based on the merging and interpolation of the night-time images acquired by the infrared sensors installed on both geostationary and polar orbit satellites. The sensors (and platforms) presently ingested in ISAC-GOS system include: the AATSR (flying on ENVISAT), MODIS (on both Aqua and Terra satellites), AVHRR (on METOP and NOAA satellites), SEVIRI (installed on MSG). The raw data are collected and processed up to the Level 2 (L2, i.e. as SST values retrieved on the native sensor swath) by several different institutions, and are successively made available in a single common format through the GHRSST Global and Regional Data Assembly Centres (GDAC, RDAC; see www.ghrsst.org for more details). The GHRSST L2 data are written as netCDF files and contain SST observations, geo-location data, error estimates (bias error and standard deviation), land and ice flags, as well as additional auxiliary fields for each pixel, referred to as dynamic flags (therefore, these files are called L2P data).In particular, L2P dynamic flags include estimates of the surface wind field (that could be used to identify areas subjected to intense diurnal variations), surface solar irradiance (SSI), aerosol optical depth (useful to flag areas contaminated by atmospheric dust) and sea ice concentration. Through the MAster MEtadata Repository (MMR) system, GHRSST provides also metadata records for each satellite. These metadata image are based on international standards (FGDC, ISO19115, INSPIRE) and contain information on the single L2P file content (coverage, acquisition time, etc.), which are used in our system for a pre-selection of the files that are needed by the processing chain.

3 Processin chain

The ISAC-GOS SST processing chain is designed as a two-step process: the high resolution (HR) processing and interpolation is performed first, while the ultra-high resolution (UHR) is run in sequence (see the scheme in Figure 2). This architecture reflects the specific algorithm used for the UHR interpolation (see section 3.4). The whole chain is organized in five main modules/packages (M1-5), which are managed through a specific System Controller. The System Controller governs the sequence of operations and includes all error handling and communication procedures, as well as the internal and external interfaces monitoring. The five modules are described here as 'logical' steps, that apply to both the HR and the UHR L4 processing, while the specific software packages have necessarily been adapted or configured to run differently when activated by one processing or by the other. All modules have been designed in order to allow an easy configuration of the main parameters required by each operation (through configuration files). A brief description of their main functionalities is presented in the following:

3.1 External data collection (M1)

This module manages the external interface to the input data providers and the internal input data archive. It includes configurable connection protocols and editable lists of the sensors to be considered. It collects metadata from GHRSST GDAC and RDAC and downloads only the L2P data covering at least a fraction of the interpolation areas. This module is unique for both HR and UHR, and it is activated at regular time intervals (every three hours).

3.2 L2P data extraction, preliminary data quality control and remap to L3 (M2)

The second module deals with the data pre-processing. SST data are first extracted basing on the geographical coverage and local time of the observations, on pixel basis. To avoid diurnal warming contamination (see [2]), the ISAC-GOS system only selects the observations collected between 11 p.m. and 6 a.m. (local pixel time). L2P data quality control is then performed, starting from the quality flags and confidence values associated to each pixels. All the parameters used at this stage are configurable. Presently, only highest quality flag data are retained. Selected valid data are finally remapped over the final interpolation grids (Level 3, L3). The MyOcean Mediterranean HR grid corresponds to the first level of the MyOcean Mediterranean Modelling and Forcasting Centre (MFC) 1/16° grid. A similar grid has been de-

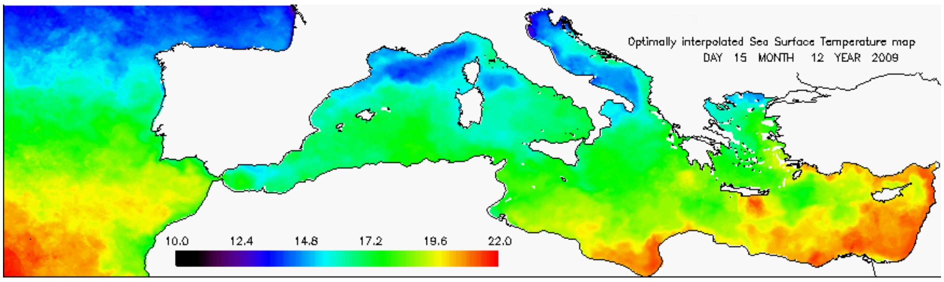

Figure 2: Example of MyOcean Mediterranean HR SST L4

veloped for the Black sea (at 1/16°). All UHR grids have been generated from the global land/sea tag file NAVOCEANO (http://www.ghrsst-pp.org/GHRSST-PP-NAVO-Land-and-sea-Mask.html).

3.3 Sensor bias adjustment, L3 super-collating and additional cloud screening (M3)

Due to computational limitations (see section 3.4), the space-time interpolation algorithm implemented at ISAC-GOS is able to ingest a single value of SST per pixel and per day. Consequently, the different images acquired by all sensors within the pre-defined time interval need to be preliminarly merged into a single super-collated image (L3 super-collated). However, the SST estimated from one sensor might significantly differ from that retrieved by another, mainly as a consequence of the differences among the sensors (number of bands, spectral resolution, scanning/viewing geometry, etc.) and/or of the different algorithms applied, which, in particular, might correct very differently the atmospheric contribution to the measured brightness temperature. Rapid changes in the atmospheric conditions might additionally lead to spurious biases at large spatial scales also between images acquired by the same sensor at different times of the day. Consequently, in order to avoid artefacts in the super-collated data, a bias adjustment procedure needs to be applied to L3 data before merging. This module thus represents one of the most difficult and crucial steps in SST data processing, which has a very strong impact on the quality of the final product. Two different algorithms are used in the HR and UHR processing. The HR scheme (originally developed within MERSEA Integrated Project, but significantly optimized for MyOcean) builds a single merged image per day by selecting the 'best' measure available for each pixel and correcting the biases among the images by adjusting them to some reference sensor measurement. Here, 'best' is defined through a pre-determined sensor validation statistics, and a simple hierarchy of sensors is identified coherently. In practice, a reference sensor list is chosen (sensors whose SST values do not need to be corrected, e.g. AATSR). Similarly, a list of sensors to be adjusted is defined and ordered for quality. For each pixel, only the observation from the best sensor available is retained. However, before adding the new data to the merged map, the large scale bias between each new image and the pixels that have already been merged is estimated and removed. In this phase, an additional check on cloud contamination is performed by flagging the pixels that result to be colder (by a fixed threshold) than the previous day value, as measured in the corresponding super-collated L3. In this way, the reference map is updated every time a new valid observation comes in. To apply a smooth bias correction (i.e. a correction that doesn't create artefacts or spurious gradients at image edges), a specific new algorithm has been developed for MyOcean. An initial bias correction map is estimated as the SST difference, i.e. by subtracting the reference values to the uncorrected observations. This map will display valid data only where the images overlap, while it will be filled by NaN (Not a Number) values elsewhere. The bias is then set to zero in the pixels where an estimate of the SST difference is not present, provided they are at a distance of at least 1500 km from the overlap zones. The final step is the iteration (100 cycles) of a 10-grid point moving window average (which ignores NaN values), which thus extrapolates the bias correction from the available SST difference towards the areas set to zero. At each iteration, the bias correction is set back to the first iteration values if these originally contained valid numbers (namely, if they were zero or valid SST difference values). A validation of this algorithm has been performed by analyzing the super-collated L3 SST and ΔSST (where Δ indicates time difference) gradients. Actually, the merging applied at 1/16° degree resolution might anyway lead to spurious SST gradients at UHR resolution, in case of uneven distribution of data and/or scattered clouds that are present in the highest accuracy sensor images. As a consequence, the UHR scheme is based on a different definition of 'best' measure, which keeps into account the continuity of the data present in the single image. In practice, the bias is not estimated with respect to the higher accuracy sensor data but between each image and the first guess field, which is build directly from the HR L4 SST (see section 3.4). This bias is estimated and removed locally (50 km). The 'best' data are then selected basing on a measure of each image data 'sparseness' (spotty/scattered data are qualified as 'worse'). Data sparseness is quantified by computing an SST gradient map after assigning an unrealistic negative value to non-valid data (e.g. -99). In this way, the gradients are much higher near cloud borders, and the images that display the lower gradients easily identify the less sparse data source for each pixel.

3.4 Interpolate L3 data using space-time optimal interpolation (M4)

The classical optimal interpolation (OI) method [3, 4] has been adapted to the Mediterranean and Black Sea MyOcean SST HR and UHR processing, starting from the previous experiences of ISAC-GOS. OI gives an estimate of an anomaly field with respect to a first guess, assuming the statistical characteristics of the variability are known (background error covariance and observation error covariance). The SST L4 analysis is then obtained as a linear combination of the observations (namely, of the SST anomalies with respect to the first guess), weighted directly with their correlation to the interpolation point and inversely with their cross-correlation. The MyOcean HR OI module has been originally developed in the framework of the MERSEA Integrated Project, while the UHR one has been specifically designed for MyOcean. The MERSEA HR statistical interpolation scheme uses a daily pentad climatology as first guess (built from 21 years of AVHRR Pathfinder data), and all its characteristics (first guess computation, covariance model, data sub-sampling strategy, inversion technique, etc.) are fully documented in Marullo et al. [5]. Marullo et al. focused on the re-analysis of the Pathfinder data [6] that was performed during MFSTEP project (see also [7]), but they used exactly the same OI scheme chosen for the MERSEA HR processing. Consequently, the common HR and UHR features will be only briefly introduced in the following, while more details will be given on the strategy chosen for UHR. More specifically, the approach proposed to solve the problem of interpolating the SST at an effective resolution of 1 km (UHR) is based on a simple concept concerning scales separation/decomposition. In practice, if we recognize that in the lower resolution maps the small scale variability has already been filtered out, both through binning on a smaller resolution grid and through statistical filtering by OI, it may be assumed that the lower resolution map, properly re-binned on the UHR grid (through a simple bilinear algorithm), may be used as first guess for a second interpolation step, where the SST anomalies, estimated now at 1 km, only contain the small scale signals. A similar approach has been adopted by the Japan Meteorological Agency (JMA) to develop their Merged Global Development SST product (http://goos.kishou.go.jp/rrtdb-cgi/jma-analysis/jmaanalysis.cgi). Actually, a sub-optimal statistical interpolation scheme is used both at HR and UHR. The scheme is sub-optimal in the sense that for each interpolation point the input data are selected only within a limited sub-domain (within a space-time influential radius), while an optimal scheme would, in theory, require that all available observations are used. Given the near-real-time requirements of our system, this step is needed to reduce the number of operations required by the statistical interpolation (mainly by the inversion of the covariance matrix). In practice, the super-collated L3 data at HR are collected within a temporal window of ten days, while at UHR only the measurements relative to the same day are used. The spatial influential radius ranges between 300 and 900 km at HR and is limited to 20 km at UHR. Moreover, in order to avoid data propagation across land from one sub-basin to the other and to speed up the input data search, both the HR and the UHR schemes are built to drive multiple analyses. In practice, the interpolation is run several times, applying different data search and interpolation grid masks, which are built cropping the original grid. Six sub-basin grids have been defined for the HR processing (eastern Atlantic, Western Mediterranean basin, Tyrrenian sea, Adriatic sea, Levantine basin, Aegean sea), and 175 masks have been constructed for the UHR. In order to avoid artifacts at the border of the different masks, two different grids are used for each sub-basin/mask, one identifying the interpolation points and one for the selection of the observations. This last includes buffer zones at the borders, whose dimension are defined by the spatial input data search radius. Before entering the influential data selection within each analysis, super-collated L3 images are checked for residual cloudy pixels at both resolutions. In practice, cloud margins are first eroded, flagging all values within a distance of m pixels to a pixel already flagged as cloudy. A second check is then performed through the comparison to the closer (in time) L4 analysis available, that is used as a reference only if the analysis error is lower than a fixed value. Data that differ from the reference field for more than a defined threshold (usually 2σ, where σ represents the average standard deviation between consecutive night images =.7 °C) are not included in the analysis. Even within the limit imposed by the influential data selection, only n observations can be effectively used because of computational time limitations. As a consequence, a strategy to remove the most cross-correlated/least correlated (to the interpolation point) data is needed. The method chosen here sorts the data as a function of their correlation to the interpolation point. The most correlated observation is selected first, while all successive data are selected only if they are found along a new direction in the space-time (until n observations are found). This allows a more balanced coverage within the influential bubble, even selecting a small number of observations. As already pointed out, the background covariance functions used at HR are based on the correlations used within MERSEA, originally estimated during the European Space Agency Medspiration project. On the opposite, different background covariance scales have been tested at UHR. The UHR covariance model has thus been defined as a result of empirical tests, even though looking at some of the quantitative metrics suggested by the GHRSST, as the gradient of the SST and the gradient of the ΔSST. The spatial decorrelation lengths have thus been varied between 5 and 15 km, but very little differences have been found on the interpolated maps in the whole range considered. The smaller value is currently used in the operational chain. On the opposite, the time scale (and corresponding input search radius) had to be reduced to 1 day, in order to avoid the sudden growth of fake spatial SST gradients in areas differently covered by satellite observations during successive days. However, more detailed validations, including comparisons to in situ data, are still in progress.

3.5 Compute SST anomalies, re-format output, manage SFTP server and THREDDS catalogue (M5)

The last module deals with the preparation of L4 data for the dissemination to the users. It manages the external interfaces to the users and the internal output data archive. Both L4 SST and L4 SST anomalies (with respect to the climatology used as first guess, see section 3.4) are delivered as MyOcean core products. All data are written in NetCDF format, following the specifications from GHRSST. Two external interfaces are used for the MyOcean V0 SST products at ISAC-GOS: an FTP site and a THREDDS server. This module thus updates the FTP site and the THREDDS catalogue at the end of each processing cycle (i.e. daily before 12 UTC).

4 Conclusions

The basic design and the most innovative modules of the SST operational processing chain, as implemented at ISAC-GOS in the framework of the European MyOcean project, have been described in this paper. In fact, ISAC-GOS is responsible of the production of SST L4 analyses covering the Mediterranean and Black Seas at high and ultra-high resolution. These L4 data are included in the MyOcean core product catalogue and are delivered daily to scientific, institutional and private users all around Europe.

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The Ocean Colour Satellite Observing System

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Abstract

The synoptic view and regular data coverage provided by satellite data make them essential to monitor marine ecosystems. Ocean colour (OC) Satellite Observing System is an essential component of operational ocean observing and forecasting systems currently developed for the global ocean and the European Seas. In the framework of this European effort, the Satellite Oceanography Group (GOS) of ISAC Rome has developed a system that produces satellite OC images and data for the Mediterranean and the Black Seas meeting the growing demand for near real-time OC products for applications in operational oceanography. The GRID based system has been developed to produce: 1) fast delivery images for environmental monitoring applications and operational support to oceanographic cruises; 2) accurate OC products for data assimilation in ecosystem models; 3) temporally consistent reanalysis products for climate change studies. The OC data processing using a specific regional algorithm developed by GOS for the Mediterranean represents an improvement with respect to the global algorithms that significantly overestimate chlorophyll concentration. Since 1999 Near Real Time and Delayed Time data are provided daily through an ad hoc automatic procedure that processes satellite data and makes higher level products available to the users within an hour of raw data acquisition from space agencies ground segments. GOS is now extending this regional algorithm to optically complex case 2 waters such as the Adriatic Sea's.

1 Introduction

A significant proportion of the world economic and social activities depend on the sea. These activities are subject to uncertainty, loss of efficiency and direct costs and damages caused by the varying impact and hostility of the marine environment. To ensure a sustainable use of the marine resources, an accurate description and a reliable prediction of the ocean state and variability is crucial. In the last twenty years observations of the ocean by sensors on Earth orbiting satellites have become an essential element of 21st century oceanography. In fact, it is now widely recognized that to monitor the ocean with the necessary sampling frequency in both space and time, it is essential to supplement conventional in situ analysis methods with data derived using remote sensing technology, primarily from Earth observing satellites. It is also recognized that it is essential to integrate the satellite and in situ measurements through the use of numerical ocean models, in order to provide timely information about the state of global ocean and Europe's seas.
Since the 90s the Unesco/IOC action on the Global Ocean Observing System (GOOS)

and its Coastal Ocean Observing Panel established as main objective the development of a world-wide network for the real time exchange and use of ocean data in predictive models of the marine environment, from physical fields to marine ecosystem variables. The European component of GOOS strongly sustained the development of a European operational oceanography (OO) system based on the integration of existing regional systems. Since the early 80s, oceanographic remote sensing technology has shown a cost-effective means to address this issue. In this context, during the last 15 years several research projects were directly targeted the development of OO capabilities, and have been funded by the EC Framework Programmes 4, 5 and 6. Similarly, the European Space Agency (ESA) funded several projects to develop satellite missions dedicated to OO. This effort led to the establishment of a number of research centres in Europe with advanced knowledge for the exploitation of satellite operational products. However, it is only recently that an ocean forecasting system, analogous to the meteorological community's, has become the marine component of the Global Monitoring for Environment and Security (GMES) program: namely the Marine Core Service (MCS). In this context, physical properties of the ocean such as surface temperature and slope, wave height and surface winds are currently measured globally at high resolution providing reliable inputs to ocean circulation models. Similarly, OC measurements of phytoplankton pigment concentration (i.e., chlorophyll, CHL) are now used to validate marine ecosystem models and as input to bio-geochemical models. This is the basis the new operational ocean observing and forecasting systems that are currently being developed for global ocean and European seas in the framework of GMES. In the last 15 years, Satellite Oceanography Group (GOS) of ISAC Rome has developed a system that provides satellite ocean colour images and data covering the Mediterranean (MED) and the Black (BLS) seas. This system constitutes the Mediterranean component of the European Ocean Colour Observing System (OCOS) and was built to meet the growing demand for near real-time OC products for applications in OO and climate studies. The system was designed to produce: 1) fast delivery images for environmental monitoring and operational support to oceanographic cruises; 2) accurate OC products for data assimilation in ecosystem models; 3) consistent reanalysis product for climate change studies.

This paper describes the GOS OC observing system and reviews the major scientific and technological steps made to develop and maintain this system. Section 2 presents the OCOS architecture, whereas the quality improvements of CHL estimates in both open and coastal waters is described in Section 3. Finally, we discuss the future development of this system in the framework of Ocean Colour Thematic Assembling Centre (OCTAC) of MCS.

2 The Ocean Colour Observing System Architecture

The architecture of the GOS OC system is based on four main modules: the Data Capture and acquisition Facility, the processing system, the data output reformatting and data archive and dissemination. These modules have correspondence with the four main functions described in the following sections and summarized in Fig-

ure 1. The system is based on GRID environment and it has a modular design composed by three separate processing chains (SeaWiFS, MODIS and MERIS), to facilitated the maintenance taking into account new sensor/satellite and software upgrades. The processing module (Figure 1, middle panel) is the interface between input data from space agencies ground segments (NASA and ESA, Figure 1, left panel) and the GOS data archive and dissemination system (Figure 1, right panel). This processing module consists of a set of shell scripts, IDL and SeaDAS procedures developed by GOS. The system operates in two modes:
1) operational mode used to produce Near Real Time (NRT) and Delayed Time (DT) products, and
2) on demand mode used to produce reanalysis or end-user defined products. NRT data are produced once a day, in less than an hour from input data availability using climatological ancillary data. In general data are available to the end-users within one day from the satellite overpass. DT products are generated when ancillary data are obtained from NASA (in general 2-3 day delay). DT products are higher quality than NRT and thus are used for data assimilation and validation of ecosystem models and to produce value-added products (e.g., phytoplankton primary production).

2.1 The input data and acquisition facility

The satellite data input to the GOS OS are the full resolution (1.1 km) LAC (Local Area Coverage) SeaWiFS, MODIS-Aqua and MERIS passes covering the MED and BLS domain. Historically, SeaWiFS Level-0 (L0) data were acquired locally by GOS receiving station (HROM). The acquisition function is performed by the Quorum HRPT Data Capture Engine installed at GOS. This station is operational since the SeaWiFS launch in 1997, and was the only SeaWiFS real-time receiving station with the complete coverage of the MED area, among the 9 other NASA authorized stations worldwide. More than 6000 satellite passes have been acquired and provided to the NASA DAAC from 1997 to 2004. GOS is still acquiring SeaWiFS for scientific use. The input for the acquisition function is the encrypted HRPT data continuously broadcasted by the satellite when it is within the acquisition circle of the GOS antenna. LAC acquisition is performed two-three times daily according to the Orbview-2 direct broadcast schedule, and is processed to L0 after decryption. MODIS L0 data are acquired automatically from the Goddard Space Flight Center, NASA, where data covering the whole globe are distributed in 5-minute granules. The system automatically selects and downloads the granules covering the MED and BLS area of interest. Similarly MERIS L2 data covering the MED are acquired from ESA rolling archive. Ancillary data, e.g., satellite telemetry and atmospheric fields are also acquired from NASA. Ancillary data include wind, atmospheric pressure, precipitable water, and ozone data from National Center for Environmental Prediction (NCEP). The source of the ozone data is EP/TOMS.

2.2 OC processing system

The SeaWiFS and MODIS processing chains are designed to process data from L0 (raw radiance counts) to L3 (geophysical products) and L4 (multi-day, multi-sensor products) and consist of five main

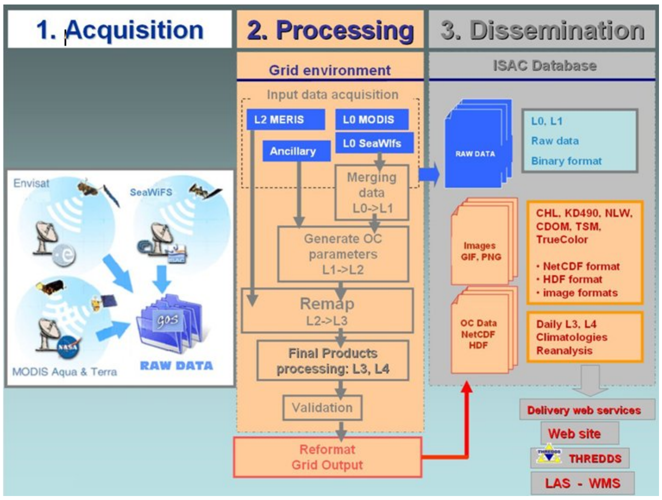

Figure 1: The GOS OC system: 1) Acquisition (Data Capture and acquisition Facility module): Data from several sensor are collected by CNR-GOS Data Capture and acquisition Facility module and sent to the processing system module. 2) Processing (processing system and data output reformatting modules): Raw input data get into the processing chain running into the Grid environment. Output data are then reformatted and stored into the ISAC database. 3) Dissemination (data archive and dissemination modules): input (raw) and output data are stored into the GOS archive. Output data are published on the GOS website and THREDDS catalogue.

processors, whereas MERIS processing chain only deals with L2 to L4 data (Figure 1). Below is a detailed description of each step.

L0 to L1 processor. In this step L0 data are transformed into standard L1A data (HDF files containing raw data, telemetry and navigation information). During this step, MODIS contiguous granules are first merged into a single L0 and then processed to L1A.

L1 to L2 processor. Here, L1A raw data are processed to obtain geophysical parameters. The main issue related to this step is the application of the atmospheric correction procedure and of the bio-optical algorithm to retrieve ocean parameters. The processing is currently carried out using SeaDAS v5.1.5 software package available from NASA website (seadas.gsfc.nasa.gov), which now allows for other than standard algorithms (i.e., MED-specific algorithms) to be implemented. L1A data are processed up to L2 applying the dark pixel atmospheric correction scheme [1]. The result of this step is the Rrs at all wavelenghts which are then used as input for the bio-optical algorithm for oceanic products retrival. L2 (HDF) files contain: Remote Sensing Reflectance (Rrs) at all wavelengths, which can be used to produce additional marine OC parameters (e.g., Coloured Dissolved Organic Matter, CDOM, Total Suspended

Matter, TSM) diffuse attenuation coefficient (Kd), aerosol optical thickness at all wavelengths (for atmospheric application), CHL concentrations using both MED and standard algorithms, photosynthetically active radiation (PAR), quality flags [2], and information about the viewing geometry such as the satellite zenith angle. Within this step Quasi True Colour (QTC) images of each satellite pass are also created. QTC is generated by combining the three OC bands that most closely represent red, green and blue (RGB) in the visible spectrum, creating an image that is fairly close to what the human eye and brain would perceive. These data can be useful for environmental monitoring. For example, SeaWiFS QTC were recently used in the framework of the EU-funded project ADIOS to monitor the occurrence of Saharan dust events in the Mediterranean Sea [3].

L2 to L3 processor. This step is common to MODIS, SeaWiFS and MERIS processing. Here, relevant parameters for each application/scientific project are extracted and remapped into single-band products over a common equirectangular geographical projection covering the entire MED and BLS domain (27.6-48.4°N, 9.5°W, -43.5°E). This processor contains customized and standard procedures. The standard procedure remaps the L2 products at high resolution (1.1 km at nadir).

Specific maps, in terms of domain, format and resolution, are produced for specific national and international scientific projects. In the framework of the Marine EnviRonment and Security for the European Area (MERSEA) and MyOcean (MyO) EU-funded projects, daily products are realized applying standard masking criteria for detecting clouds or other contamination factors, i.e., land, sun glint, atmospheric correction failure, high total radiance, large solar zenith angle (70°), large spacecraft zenith angle (56°), coccolithophores, negative water leaving radiance, and normalized water leaving radiance at 555 nm below $0.15\, Wm^{-2} sr^{-1}$ [2]. In the context of the Mediterranean Forcasting System Project, a specific chlorophyll product is realized by binning daily data over the 1/16 of degree (ca. 7 km) ecological model resolution grid with reduced spatial gaps. In the framework of the ADRICOSM Project, daily CHL data are generated for assimilation into numerical ecosystem models. This product has a nominal spatial resolution of 2 km matching the model grid and covers the entire Adriatic Sea. ADRICOSM CHL is produced within the DT processing mode. Other OC parameters not available in the L2 files, such as CDOM and TSM, are required by this project and are produced using ad hoc bio-optical algorithms from Rrs data. In the context of both ADRICOSM and ECOOP projects, a Case1-Case2 waters merged CHL is produced and more fully discussed in Section 3.2. Since MERIS L2 data are produced by ESA using standard chlorophyll algorithm a specific code was developed and implemented in the processing system to derive a MED-suitable CHL product from Rrs using the MedOC4ME algorithm (see Section 3.1). Static data (e.g., jpeg, png and gif) images are produced daily and posted on the GOS website.

2.3 Data format, archive and delivery system

Daily and reanalysis data files have been produced in HDF and lately in NetCDF format. The OC data format was updated from HDF to NetCDF 3.5, following the Climate and Forecast convention, INSPIRE, EN-ISO 19115, 19119 and 19139. NetCDF is a machine-independent format for representing scientific data. It is self-describing, portable, appendable (e.g., data may be appended to a properly structured NetCDF file without copying the dataset or redefining its structure), sharable (one writer and multiple readers may simultaneously access the same NetCDF file), archivable (access to all earlier forms of NetCDF data is supported by current and future version of the software). Moreover it allows direct access: a small subset of a large dataset may be accessed efficiently, without first reading through all the preceding data. The Data Archive (DA) is based on a "file system" and stored on a workstation cluster within the CNR IT infrastructure. DA is based on both an internal and an external archive. The internal database, accessible only by GOS, maintains all the input and output data of the processing system. The aim of the external archive is to provide end-users with access to the final product through the dissemination system. This system was developed in order to be a delivery, discovering and viewing system as requested by the INSPIRE directive, and consists of different services: 1) data access either via ftp from GOS website for static images, or through specific e-mail request for HDF or NetCDF data. 2) A Thematic Real-time Environmental Distributed Data Services (THREDDS) catalogue has been set up on GOS website for NetCDF data access. THREDDS provides metadata and data access and is built on existing technologies and protocols. THREDDS catalogues are logical directories of online data resources, encoded as XML documents, which provide a place for annotations and other metadata about the data resources to reside. THREDDS enables end-users to find out what data are available from data providers. 3) A Live Access Server (LAS) has been set up on GOS website for NetCDF data download and dynamic images creation. LAS is a highly configurable web server designed to provide flexible access to geo-referenced scientific data. LAS manages NetCDF, ASCII or binary data formats. Variables and specific data subsets (both in space and time) can be visualized on-the-fly and eventially saved into a user-selected file format. LAS allows access to background reference material about the data (metadata) and to compare (difference) variables from distributed locations. Moreover it can present distributed datasets as a unified virtual database through the use of Opendap networking.

2.4 Reanalysis and reprocessing systems

The entire SeaWiFS archive, combining HRPT acquired at GOS with the Merged Local Area Coverage (MLAC) available on NASA website (totalling more than 8000 passes) was reprocessed by GOS taking into account new algorithm developments and software updates. In general, reanalysis products are generated at least once a year or everytime a new algorithm or software update become available, by reprocessing everytime the entire archive (for consistency). The reprocessing exploits the GRID environment in order to reduce the running time. For example, the reprocessing of the entire SeaWiFS archive takes 6 days using the CNR-ARTOV GRID infrastructures. Apart from the unique software or algorithm version, the archive reprocessing does not differ from the DT processing. In the reprocessing required by the MERSEA Project, each L2 (1 km spatial resolution) was spatially binned on a sinusoidal grid projection (2 km spatial resolution) and quality controlled by applying the standard NASA processing L2 flags. These L2 spatially binned data were then merged to obtain daily images data. The obtained L3 timely binned daily images were transferred (via ftp) to the data archive connected to Live Access Server to be available to the scientific community. The reprocessing of the entire archive allows the construction of a scientifically homogeneous dataset, which can then be used for long-term analysis. For example, weekly, monthly, seasonally to yearly averages are routinely computed from daily images for such a purpose. Moreover, average fields at different space and time resolution are used to validate ecosystem models.

2.5 Operational system monitoring

The operational processing chain takes care to monitor itself: for each step, each procedure automatically alerts the operator by sending e-mails reporting on its status. When the system fails in any of its steps, it automatically tries to manage the error. For example, in case of missing L0 files from source sites, the procedure iteratively tries to download data until successful. When the error is unrecoverable (or fatal), the system reports on the steps affected by failure. There are three kinds of alerts: 1) info, which informs about the processing chain status (start/stop, produced files and so on); 2) warning, which informs that something (explained in the alert itself) went wrong. In this case, the system is still able to produce some results (typical error: one of the L0 file is missing from external source sites, but others are present); 3) error, which informs about errors preventing the completion of the chain (i.e., no L0 data available from the external source sites).

3 Mediterranean regional chlorophyll algorithms

3.1 Basin scale

Historically, an extensive calibration and validation activity was performed over SeaWiFS OC data by the SeaWiFS and SIMBIOS Projects. The result of this CAL/VAL activity was the development of empirical bio-optical algorithms (OC2v4 and OC4v4 [4]) for the CHL operational retrieval in the open ocean. This effort laid the basis for the analogous bio-optical algorithms development for MODIS (OC3,[4]) and MERIS OC sensors (Algal1, [5]). Although these algorithms were demonstrated to perform adequately at the global scale [4, 6], they were shown to perform generally worse at the regional scale. In the Mediterranean Sea, the standard NASA algorithms (OC2v4 and OC4v4) lead to a significant overestimation of the SeaWiFS-derived CHL (above 70% for chlorophyll below 0.2 mg m-3) when compared to in situ data [7, 8, 9, 6]. Using the most spatially and temporally representative in situ bio-optical dataset for the MED, GOS quantified the uncertainties of existing regional and global OC algorithms using SeaWiFS, MODIS and MERIS sensors. This analysis led GOS to identify and develop optimal algorithms for the production of high quality OC datasets for this basin: namely the MedOC4 for SeaWiFS [10], the MedOC3 for MODIS and the MedOC4ME for MERIS [11]. This work was part of

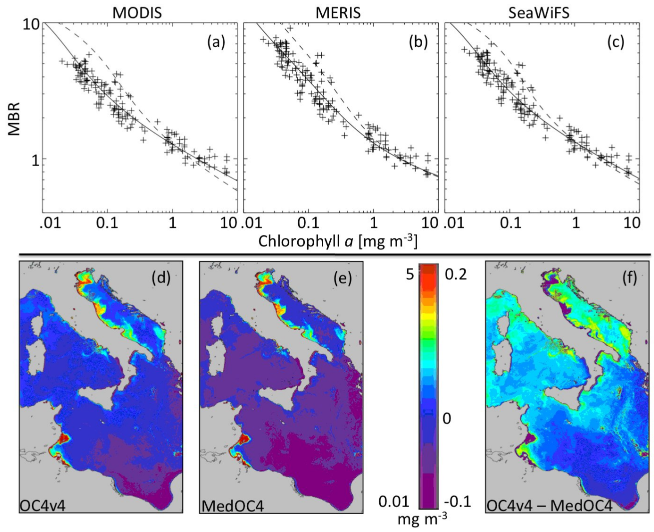

Figure 2: Mediterranean bio-optical dataset (crosses) adapted for three OC sensors (MODIS (a), MERIS (b) and SeaWiFS (c)). Continuous lines represent the regional algorithms while dashed lines represent standard algorithms. Snapshots of SeaWiFS pass over central Mediterranean Sea on 2 July 2004 re-processed with both the NASA standard processing algorithm (d, OC4v4) and the Mediterranean adapted one (e, MedOC4) their difference is also shown (f).

the MERSEA Project, which aimed, besides other objectives, to provide high quality satellite products for data assimilation and validation of global and regional models. The identification of the best-suited MED CHL algorithm and its associated uncertainty was thus an essential step to proceed to the reprocessing of the entire SeaWiFS mission (Section 2.4). More specifically, this work led to the production of a new chlorophyll dataset suitable for the assessment of and assimilation into the coupled biochemical and ecosystem models, as required by the modelling community of the MERSEA Project. Figure 2 shows the three Mediterranean-adapted algorithms (continuous lines) along with their respective standard versions (dashed lines) for SeaWiFS, MODIS and MERIS. Under the reasonable assumption that the in situ dataset (crosses in Figure 2(a-c)) well represents the actual field conditions, it is clear that the standard algorithms, for all of the three sensors overestimate in situ CHL for values below approximately 1 mg m-3. It is worth mentioning that this oligotrophic condition represents more than 70% of the basin space-time variability. In addition to overestimating low values, standard algorithms significantly underestimate high CHL. Therefore, in the context of a new and reliable operational ocean observing and forecasting system, such as the one foreseen in the framework of GMES, the use of regional adapted algorithms is strongly recommended. In this respect, Figure 2 (d-f) shows a snapshot of a SeaWiFS pass over the central Mediterranean processed with both the standard (OC4v4, Figure 2(d)) and the regional (MedOC4, Figure 2(e)) algorithms. It is clear from Figure 2(f) that there might be an order of magnitude difference at sub-basin scale (see for example the Tyrrhenian Sea) due to the implementation of the standard algorithm in lieu of the more reliable regional one. Apart from the qualitative picture offered by Figure 2(d-f), GOS focused on quantitatively assessing the uncertainties associated with standard and other than GOS-developed regional algorithms [10]. This validation exercise shows that, when these algorithms are applied to satellite-derived Rrs, GOS-developed algorithms perform better than any other algorithm built for application in the MED (with a relative percentage difference of 35% for SeaWiFS, [10]) uncertainties exceed 100% when the standard NASA algorithm, OC4v4, is used instead.

3.2 Coastal System and products: the Adriatic case

Coastal waters represent the areas of the world ocean where the human impact, intuitively due to their close and constant influence, is most intensive. Given the well-known difficulties of retrieving OC data in coastal waters along with both the ecological and the socio-economical importance of these areas, the quality-controlled data production for this area remains a very challenging issue. Under the umbrella of several national and international projects the Adriatic Sea has been investigated with both in situ and remotely-sensed data. This basin thus represents an excellent test bed for the evaluation of existing algorithms, for the development of new and more reliable algorithms, and for their quality assessment. In this context, GOS main objectives were first to assess and develop a reliable OC product over optically complex waters (i.e., Case2 or coastal waters), and second to develop a method for merging Case1 and Case2 products into a single validated product. These are not trivial issues, as it is not uncommon to observe artifacts due to the implementation of the wrong algorithm for example when using a specific Case1 waters algorithm over Case2 waters. Another source of misleading results can come from the erroneous combination or merging of different algorithms within the same image, which in turn can give rise to fronts which actually do not exist. One way to overcome this problem is to process the image twice, once with a Case1 water algorithm (for example the MedOC4) and once with a Case2 water algorithm (for example the AD4,[12]). At this point, one of the most challenging tasks when merging products retrieved from different algorithms pertaining to different water types is the exact identification of such water types. Currently the SeaWiFS and MODIS turbid water flag is set when the Rrs(670) exceeds by 25% the value expected for pure water in this band [13]. The principle underlining this approach is that it is known that in Case1 water the contribution of the water leaving radiance at this band is fairly negligible, whereas in Case2 waters it is not, due to different constituents that do not exhibit covariance with CHL. Here, a method is described that takes into account the whole light spectrum from blue to NIR bands for both water types. The rationale for this is that computing an average water type spectral signature from in situ measurements for both Case1 and Case2 waters should, in theory, give more confidence when screening the two water types. Moreover, and even more important, this last approach gives the opportunity of smoothing out spurious gradients that might result from the application of different algorithms. For the computation of these two average spectra two distinct in situ datasets were used for Case1 and Case2 waters the MedOC4 [10] and CoASTS [14, 15] datasets, respectively. Both datasets were used either to compute the spectral signature of the respective water type and to build the bio-optical algorithm (AD4 for the CoASTS,[12]). In practice, the method works as follows: a pixel-by-pixel spectral comparison is performed between satellite and reference spectra. The distance from each of the two average spectra is then computed and used as weight for merging (i.e., averaging) the two chlorophyll products into a single pixel value.

4 Conclusions and Future Prospective

The GOS OCOS architecture has been presented focusing on its evolution from a system for acquisition, storage and delivery to specific tasks to an OCTAC information system that is an integrating part of the GMES MCS. The main elements of this evolution include the setup of a data acquisition methodology, a fast processing and delivery system, quality assurance of the products, and finally the specialization of regional OC to coastal regions that are important to the MED. An important aspect of the whole system is concerned with its errors traceability and performance monitoring. Scientifically, GOS has focused on algorithm development to improve MED regional products with respect to the Global algorithm data quality. GOS, in its MyOcean OCTAC leading role, is now a European centre that delivers locally-produced value-added regional datasets for the MED, global and European seas, as well as regional products generated at the OCTAC partner facilities. It serves as central repository and contact centre for the MyOcean Information Service (MIS) that routes the end and intermediate-user requests to GOS. With the objectives of ensuring a reliable supply of data to both internal MyO users (e.g, Modelling and Forecasting Centre) and external intermediate users (environmental agencies), OCTAC will ensure operational delivery with guaranteed success percentages above agreed-upon thresholds. The product portfolio envisaged for OCTAC systems stems from the MERSEA legacy and includes baseline L3 products of CHL and Inherent Optical Properties (IOPs) from different data producers. Early, in the MyO service evolution, formats will be homogenized to ensure uniform approach to the data products regardless of the provider. Subsequently, L3 products will be intercalibrated and collated among satellite/sensors suites to ensure both optimal geographic coverage and reliable error bars for all products in view of improved assimilation into models. A considerable R&D effort (for which GOS will seek support external to MyO) will be spent to improve existing algorithms performance and multi-sensor data merging techniques. This will in turn benefit the OCTAC processing chain and thus the overall MyO service.

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Observation Networks and NRT Data Transmission: Case Studies and Integration

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Abstract

Near Real Time (NRT) monitoring systems at sea and in coastal areas are becoming more and more important in many fields. Especially when they are coordinated within networks of inter-operated data sources, they can play a key role for models validation and early warning and decision support systems. Furthermore, these actions are able to provide informations for long-term time series of metorological and oceanographical data.
The building blocks of these networks can be summarized into three main levels: instrumental (deployment and maintenance), data transmission and control, and validation and data delivery. All of them require efforts for medium and long term management, and for data format standardization.
CNR Institutes have established several meteorological and oceanographical observation points at sea for: fixed platforms, moored buoys and ocean-going research ships.
We present some implementations of NRT data transmission (tipically few minutes from the acquisition) from this network, aiming toward a better integration into National and worldwide Observation Systems.

1 Introduction

Earth is a complex system where different components (atmosphere, hydrosphere, cryosphere, lithosphere and biosphere) interact through the transfer of energy and matter on variable time and space scales. The human impact superimposes this complexity and affects several components of the system.
The ocean plays a central role in the evolution of the climatic system. Coastal areas, in particular, are fundamental for the life's equilibrium of the planet since large amount of organic substances, which are therein generated, sustain the correct structure of the food chain. The marine organisms, instead, play a crucial role in several basic biogeochemical processes for the biosphere. However, the knowledge about marine biodiversity is, at global scale, extremely scarcer than those of the terres-

trial ecosystems. This is especially due to the higher difficulty of marine environment study, which requires observation methods undoubtedly more complicated and expensive than those of terrestrial ecosystems.

The most recent studies are demonstrating that only almost continuous observations can record complex phenomena, which result by the combined action of physical, chemical and biological factors. Time series, instead, permit to reveal mechanisms and processes otherwise not detectable. They also allow to evaluate the role played by short-term events in the whole basin dynamic and evolution.

The general objective is the systematic collection of multidisciplinary data on multidecadal time scale in order to identify, comprehend and forecast the effects of the climate change regarding the marine environment, the impact on biodiversity, coastal management and marine safety.

2 Methodologies

Direct measurements are carried out in the water column, and at the interfaces between atmosphere-ocean and sediment-water. Observing system components include:

1. *In situ* data acquisition systems: shipborne systems, oceanic buoys, floats and drifters, coastal radar (HF), instrumented moorings and tripods, ROV, benthic chambers and landers, particles and aerosol samplers;
2. Satellite remote sensing: satellites using active and passive microwave, optical and infrared instruments;
3. Modeling: data assimilation, nowcasting, short term forecasting, seasonal forecasting, climate modeling, model comparison and validation.
4. Connection with data banks and Decision Supporting Systems.

2.1 Programs of Coastal Monitoring

The Italian Sea Defence Service of the Ministry of Environment, Territory and Sea (Servizio Difesa Mare del Ministero dell'Ambiente e della Tutela del Territorio e del Mare) carries out from 10 years a monitoring activity of the marine-coastal waters and environment, aimed at the knowledge and protection of environment and marine ecosystem, the identification of environmental damage causes, the prevention and battle against pollution. The monitoring plan is performing in agreement with 15 coastal Regions and concerns around 8000 km of coastline. ISPRA (formerly APAT), controls the National Wave Observation Network (RON), the National Water Level Observation Network (RMN) and the Water Level Observation Network of Venice Lagoon (RTLV) and of North Adriatic Sea. The data collected during monitoring activities are periodically transmitted from Regional Authorities to the Data base of Sea Defence Service and are available for users.

The Italian scientific community has set up an observation structure of marine environmental data (real-time monitoring and short-term forecasting) that represents a national heritage, with regard to developed expertises, employed instrumentation and quantity of collected data (Figures 1 and 2). The remarkable results obtained so far justify the implementation of other study sites, moreover in the open sea and in the coastal areas, where the lack of long-term environmental records makes difficult an exhaustive analysis of the marine domain

Figure 1: Overview of existing instrumentation relevant for oceanic observations. Upper left, R/V Urania, lower center S1 Buoy and 'Acqua Alta' Platform off Venice.

response to the climate forcing variability.
International, national and regional projects have developed observation systems in the Mediterranean and in the Italian seas, with particular relevance in the Adriatic Sea where the feedbacks to several forcings (terrigenous-anthropic, meteo-climatic, advective, etc.) produce intense and measurable signals. For this reason, the Adriatic Sea is considered as the most interesting climate sensor of the whole Mediterranean Sea. In Otranto Strait, Sicily and Corsica Channels, ongoing time-series testify the importance of these sites at basin scale; the Ligurian Sea, connected to the Ligurian-Provenćal system, is one of the convective engines of the Mediterranean Sea and also the site of dense water formation, which are fundamental for the biology of the area (Sanctuary of Cetaceous). National groups are operative in observational networks management: LTER (Long Term Ecological Research) pertaining to biodiversity and climatic change, and GNOO (National Group for Operational Oceanography) which is proposing several projects about themes connected to the marine forecast.

Heareafter we will show some examples of design, instrumentation, data collection and dissemination in the field of Real Time data acquisition.

2.2 Meteoceanographic Buoys And Platforms

ISMAR Bologna have deployed two meteoceanographic buoys (S1, Po Delta, E1, Rimini), with a Near Real Time connection and immediate publication on the WWW. The design of the system is such that it can easily accommodate different platform and data types, provided that they satisfy some common rules, among them the unique coding of the platform, and transmission protocols over the INTERNET (e-mail, ftp uploading, downloading, Figure 3). The system is better described in [1].
The data from the buoys, other than being published on the www (http://e1.bo.ismar.cnr.it and http://s1.bo.ismar.cnr.it) and stored in relational databases, are sent to other organizations, among them INGV (see the page of the Adriatic Sea Forecasting System, with comparison between model and S1 Buoy data

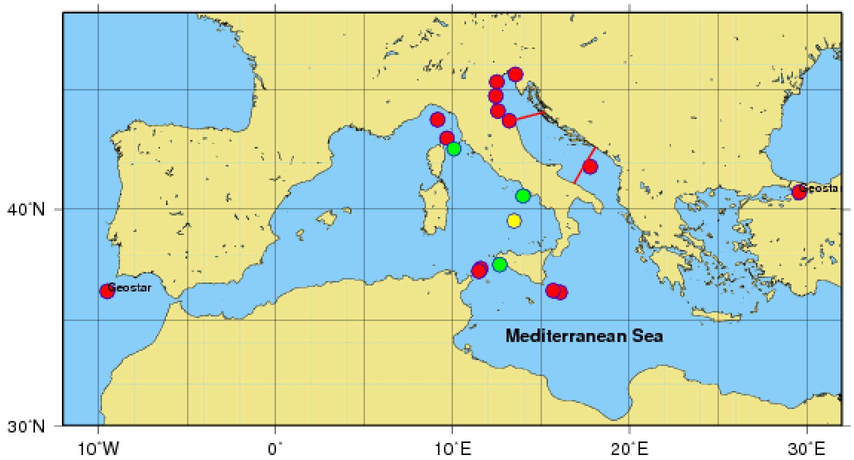


Figure 2: Observation stations operated by the Italian scientific community in the Mediterranean Sea. Red circles and transects, CNR sites; yellow, joint-venture sites; green, new planned sites. Also shown to the west and to the east are the location of two important experiment with the INGV's GEOSTAR Seafloor Observatories, on the sites of the NEAREST (http://nearest.bo.ismar.cnr.it) and ESONET EU projects, to study and forecast sesimic activity on two of most critical seismogenic structures in the world.

http://gnoo.bo.ingv.it/afs/buoy.htm). Figure 4 shows the comparison with the E1 buoy and ROMS Model temperature data (University of Ancona, A.Russo, personal communication). Time series are available since first deployments (see Figure 5).

2.3 Acqua Alta tower

The oceanographic tower "Aqua Alta" of ISMAR-CNR is located 15 km offshore the coast of the Venice lagoon, in the Northern Adriatic Sea, on 16 meter of depth. It is the only scientific structure in Italy, and one of the very few in Europe, that allows people on board for prolonged periods for intensive campaigns in the middle of the sea. The capability of having a structure in the open sea, large enough to withstand the worst storms, but small enough not to interfere, as with the large oil or gas platforms, with the surrounding environment allows highly accurate and hard to get measurements also in heavy difficult conditions.

The tower has three floors plus the terrace at 12 meters height above the mean sea level. The structure is composed of four 60 cm diameter vertical poles, a few meters apart, connected at four different levels by multiple smaller poles. The tower is fully self-sufficient for what energy is concerned, powered by two diesel power generators complemented by a very large set of batteries plus solar and wind generators. "Aqua Alta" is fully equipped with a very large set of instruments, devoted to meteorological, oceanographic and chemical parameters. Measurements go back to the early '70s, so that some time series provide sufficient information to consider climate changes. The biological communities surrounding the tower has provided ample

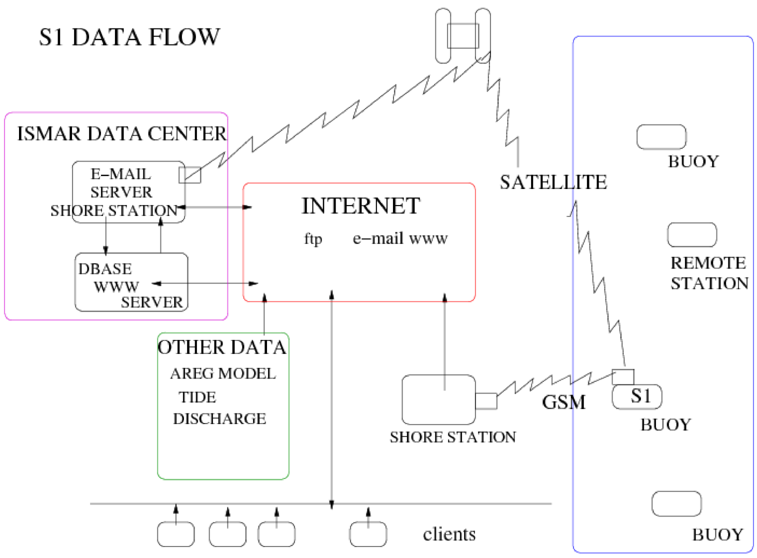


Figure 3: Meteoceanographic buoys data flow.

material for biological researches. Most of the instruments are devoted to long term measurements. However, a substantial part of the use of the tower concerns specific campaigns carried out for prolonged periods with people on board. Cavaleri [2] provide an extensive review of the researches on board till that year. The wind and wave data available from board have provided essential information for the design of the barrages, presently under construction, that will save the Venice lagoon from the worst floods. An extremely intense one, the strongest one in memory after the catastrophic 1966 one, happened in December 1979. Heavy damage was caused on board, with the second floor completely destroyed. Notwithstanding the lack of power, two mechanical instruments, an anemometer and a mareograph, provided essential data. In particular the latter provided the first evidence in the world of coastal set-up, the accumulation of water, with the consequent local sea level raising, that takes place as a consequence of wave breaking toward the coast. This finding, properly modeled [3], is now integral part of the local tidal forecast system. Recently a substantial upgrading has been done on the tower, with the introduction of extensive remote control and data handling in real time. The real time communication system is based on double Wireless "nstream" with 5GHz links in the ETSI band broken in two segments to maintain linear transmissions 1) Institute-Seafront 8,7 Km length, 2) Seafront- Tower: 14,8 Km length in open sea, link with double polarization (horizontal and vertical) These links allow a good throughput (nominal 54Mbps, real around 20Mbps) with low power consumption (around 6W).

All the devices installed onboard use TCP over IP communication protocol by TCP-serial converters and are powered by a PoE switch. All the devices including commu-

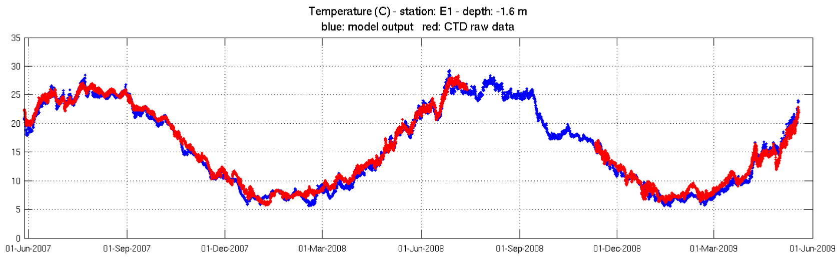


Figure 4: Temperature data comparison from E1 Buoy (red) and ROMS Model (blue).

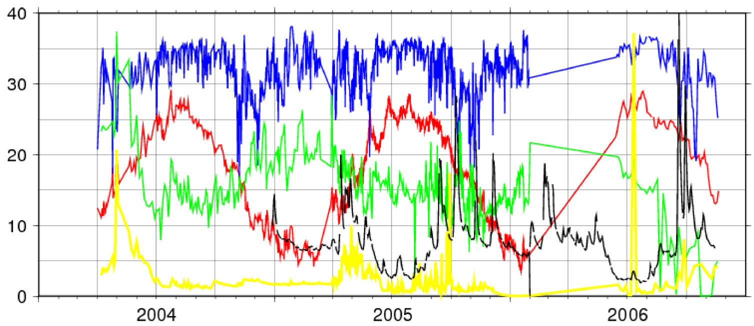


Figure 5: Yearly data from S1 Buoy (red is water temperature).

nication systems belong to Class C private networks with 16 bit subnet mask. This system is connected to the LAN of the Institute trough a Linux server acting as a bridge.

A new ADCP current-tide-wave recording system is in operation at 50 m distance from the tower, with direct connection, together with meteorological data, to servers at ISMAR with real time web publishing www.ve.ismar.cnr.it/piattaforma/sharing trough a dedicated FTP server. Some webcams have been installed for direct visualization of the meteo-oceanographic situation and control of the area, one of these has been installed at -5 depth documenting submarine biological communities and providing real time observations for early warning of the occurrence of mucilage or jelly fish presence. A streaming flow of these images is available at the web site. Furthermore, an advanced experiment has just started with an automatic system, controlled from land, capable to obtain at high rate continuous 3-dimensional measurements of the sea surface under storm conditions.

Data of the day and time series are available at http://www.ve.ismar.cnr.it/piattaforma/ and example of the data are shown in Figure 6.

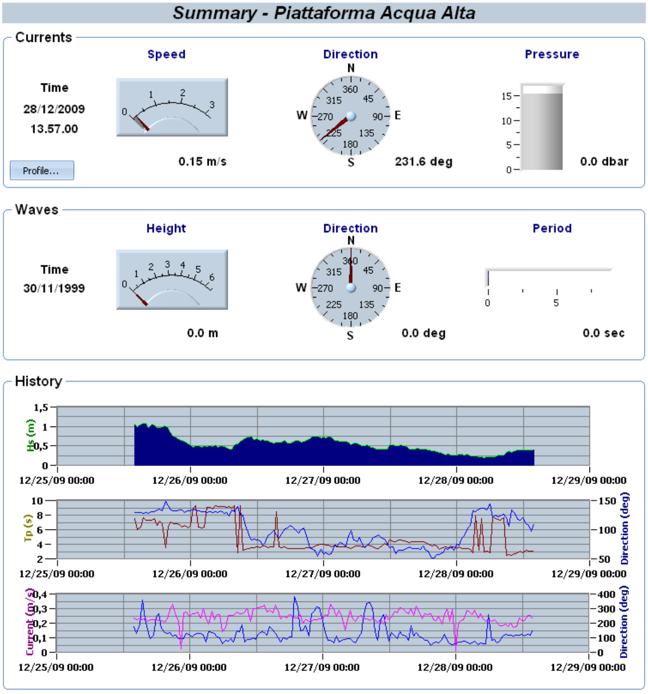


Figure 6: Real Time Data from *ACQUA ALTA* platform (http://www.ve.ismar.cnr.it/piattaforma/).

2.4 Meteomarine network in the Gulf of Trieste

The meteomarine network in the Gulf of Trieste is composed of 2 meteomarine (M), 2 climatological (C) and 1 tide gauge stations (S): Trieste Sede ISMAR (C), Trieste Molo Fratelli Bandiera (M), Trieste Molo Sartorio (S), Borgo Grotta Gigante (C) and P.A.L.O.M.A. (M).

The peculiarity of the climatological sites is that for every observed parameter there are at least 2 sensors, a digital one and an analogical one. In this way there is very little chance of losing data and information caused by hardware malfunction, instrumental breakdown or electrical problems.

Two of these sites (P.A.L.O.M.A. and Borgo Grotta Gigante) are managed in cooperation with the Local Meteorological Observatory of the Regional Agency of Environmental Protection of Friuli Venezia Giulia (OS.ME.R.).

The data collection centre is located in the offices of I.S.MAR. Trieste. Data transmission via G.P.R.S. is ensured every 5 minutes (Trieste Molo Sartorio) and every 30 minutes (Trieste Sede I.S.MAR. and Trieste Molo Fratelli Bandiera) thanks to a TCP-IP communication protocol. Sea levels are collected minute by minute while extreme values of all other parameters every 10 minutes.

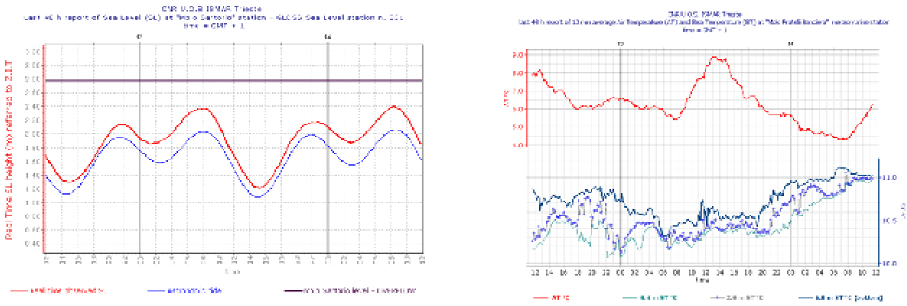


Figure 7: Some plots of near real time data published on ISMAR Trieste website. Sea level, astronomic tide and overflowing level on left; air temperature and three depths sea temperature on right.

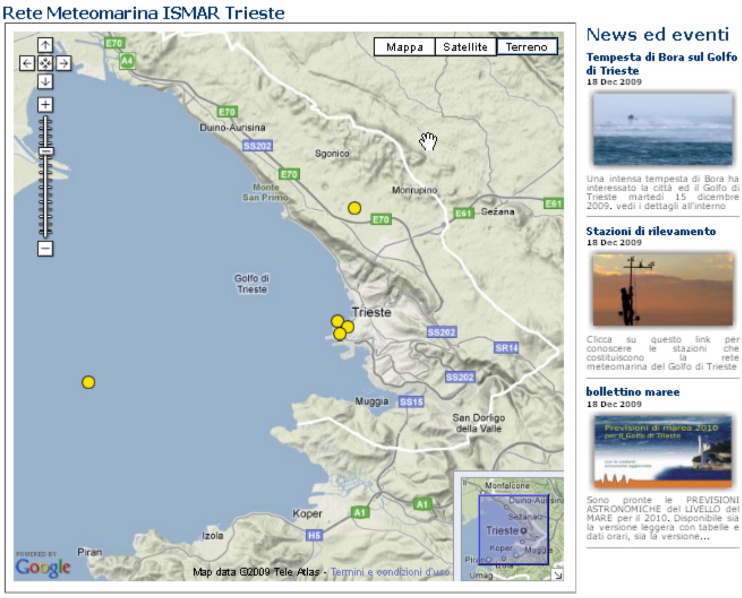
A database MySQL and the "Micros-Supervis" software control data acquisition and web publication.

The climatological site of Trieste Sede I.S.MAR. is located in the garden of the Institute and has not been moved since 1920, while before this, the station was collocated in Piazza Lipsia (1841-1902), near the city centre of Trieste, and in Villa Basevi (1902-1920) on a little hill.

The sensors are located on the tower and in the traditional meteorological huts; in the offices there are barometers, data acquisition systems and data loggers. The meteomarine site of Trieste Molo Fratelli Bandiera is situated on the external side of Fratelli Bandiera pier. The acquisition system and dataloggers have been inside a little building since the early 80s. Data of air temperature, wind velocity and wind direction, and three sea depth temperatures (0.4, 2.0 and 6.0 m) are collected.

The climatological site of Borgo Grotta Gigante, the Climatic Observatory of the Karst area since 2008, is located on the premises of the historical headquarters of the Borgo Grotta Gigante Meteorological Office, which was set up in 1966 and has been officially operating since January 1, 1967. The main characteristic of the Observatory is to maintain the traditional mechanical-analogical part of data collection, carried out by observers, alongside the electronic sensors. This factor is essential for the continuity and the homogeneity of the historical series collected to date and distinguishes the observatory from a normal weather station.

P.A.L.O.M.A. pylon is situated 8 nautical miles from the coast, in the centre of the Gulf of Trieste, between the small coastal town of Pirano (Slovenia) and Grado (Italy). The meteomarine site was installed in 2002 and meteorological parameters and sea temperature data at different depths (0.4, 2, 15 and 24 m) are collected. The tidal site of Trieste Molo Sartorio is the most ancient seatide monitoring station of the Adriatic. Founded in 1859 thanks to the "Imperial Regia Accademia di Commercio e Nautica" the station has never changed its site and is equipped with 4 sea level gauges: 2 digital OTT Thalimedes, 1 analogic OTT and 1 analogic PAGAN. One of the digital instruments is connected with the Regional Civil Pro-



Ultimi dati rilevati

station	date	time	AT (°C)	VV (m/s)	DV (°N)	RH (%)	HP (hPa)	RR (mm)	SL (m)	ST (°C)
TS Sede ISMAR	14/01/2010	11:30	6.3	2.1	92	60	1010	0.0	-	-
TS Molo F. Bandiera	14/01/2010	11:30	6.3	5.3	102	-	-	-	-	11.0 (2 m)
TS Molo Sartorio	14/01/2010	11:50	-	-	-	-	-	-	1.849	-
Golfo di TS P.A.L.O.M.A.	14/01/2010	10:25	6.1	7.5	112	50	1017	0.0	-	9.8 (15 m)
Borgo Grotta Gigante, OCC	14/01/2010	11:05	3.4	3.4	93	69	979	0.0	-	-

Figure 8: Map with the location of the meteomarine network together with the summarize table of near real time data (http://www.ts.ismar.cnr.it/).

tection network. Molo Sartorio station is part of the Global Sea Level Observing System (GLOSS) which is an international programme conducted under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organisation (WMO) and the Intergovernmental Oceanographic Commission (IOC). GLOSS aims at the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research. The main component of GLOSS is the 'Global Core Network' (GCN) of 290 sea level stations around the world for long term climate change and oceanographic sea level monitoring.
See Figure 7 and Figure 8 respectively for plot examples and accessing data via web.

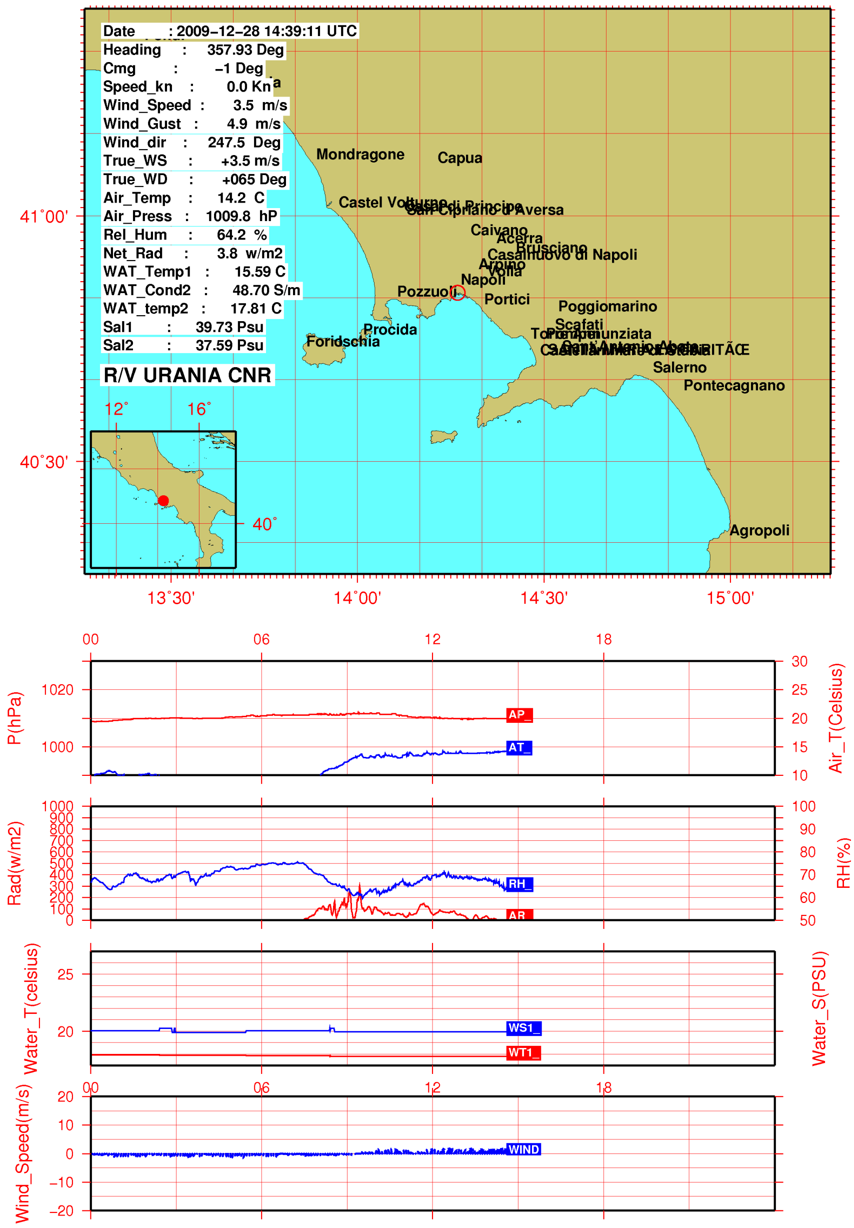


Figure 9: Snapshot of meteoceanographic Near Real Time data from R/V Urania. http://ricerca.ismar.cnr.it/OSSERVATORI/ METEO-OCEANOGRAFIA/.

2.5 Meteoceanographic Data From Ships

Research vessels, and also ships-of-opportunity, collect routinely meteorological and oceanographic data. Recently ISMAR Bologna, within recommendations of the GNOO, have installed on R/V Urania of CNR a system for the data transmission in Real Time, taking advantage of the H24 ship's flat internet connection. The system was built using the Daphne software [4], an ISMAR client/server, multithreaded Java program, that implements a data logger able to operate with different interconnected sensors, among them meteorologic stations, gps, dgps, load cells, and in general to any sensor that can communicate with a host via a RS232/422 interface or network sockets.

The program is configured trough a graphical user interface, with which it is possible to add/remove and configure sensors (device, periodic query strings, filename to log, remote upload connection etc.).

The system developed for ongoing ships, and actually operating on Urania ship, is composed of a custom developed application to acquire data from sensors, several sensors, a flat internet connection on the ship side, and a system of processing incoming data and for web publication on internet servers. The application, named Daphne, was developed in java language, is deployable into any operating system supporting java and the serial communication protocol (comm api) and is able to connect to backup servers for data replication. The following list summarizes the main features of Daphne:

- Acquisition from any number of sensors connected through serial lines: the sensors connected can be configured by accessing the configuration pane inside the graphical user interface or by mean of a configuration textual file.
- Sensor data replication: the data acquired can be replicated to a virtually unlimited number of ftp or http servers, at specified time intervals, or can be replicated to a number of connected clients (see below) in full real time.
- Can run in "server mode" or "client mode": typically one instance is ran in "server mode" inside the computer that is physically connected to the sensors. The server instance is configured to listen on a TCP/IP port for incoming connections, while other instances are ran in "client mode" and retrieves data by push messages received from the server.
- Interconnecting sensors: sensors can be connected to each others, making possible to have geographical positions and timestamps logged synchronously into the data records coming from other sensors, e.g. meteo stations, fathometers, magnetometers etc
- Fault-tolerant: Daphne can detect error conditions on sensors or network and can deal with them, closing and reopening problematic sensors or closing and reopening itself as last resort.
- Independent network data replication subsystem: the network data replication subsystem is ran into a dedicated and independent thread that can survive to network and application downs thanks to its persistent queuing design.
- Expandable: The layout of the application code was designed with expandability in mind, making easy the add of new sensor models or to add features to existent sensor code.

The system being operated on R/V Urania was configured to send data ensembles to ISMAR's ftp server from the installed systems: Aanderaa meteo station,

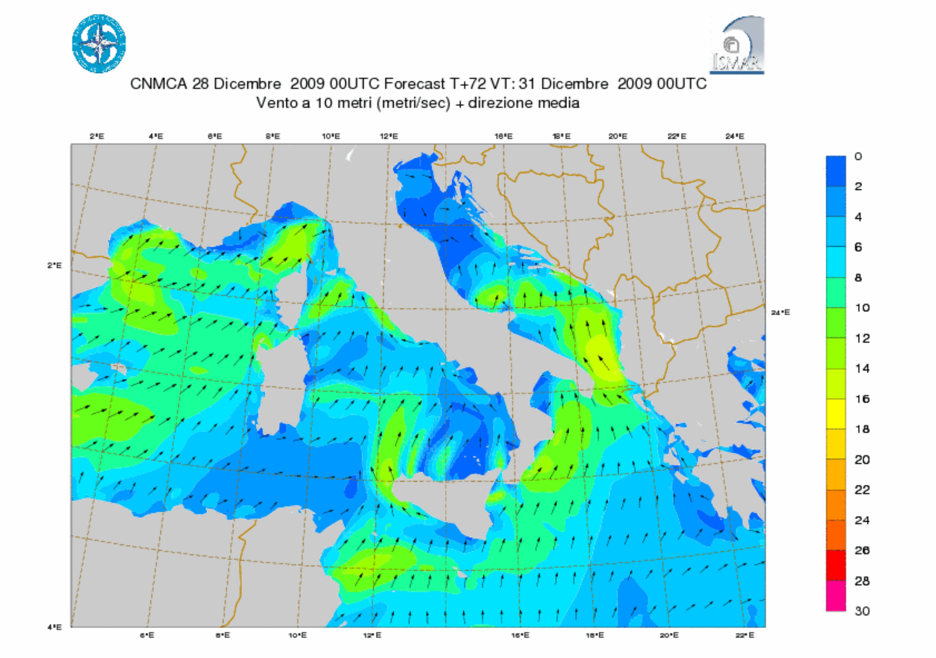


Figure 10: Snapshot of CNMC-ISMAR Venice wave forecast (http://www.ismar.cnr.it).

surface CTD data (0.02Hz) and DGPS (1Hz), the data are sent at time intervals of 5 to 10 minutes. Automated procedures are able to process and publish on the web the data within minutes from acquisition. Should the INTERNET connection have bandwidth and availability, a series of properly time and position tagged on-going data can be easily transmitted in real time, e.g., magnetometry, gravimetry, bathymetry, CTD etc. Further improvements may include transmission of attitude data, such as roll, pitch, heave information, interesting for wave analysis and ship's performance in heavy seas.

Figure 9 shows a snapshot of the information available in the website. After received from the ship, the data are stored inside a local database and uploaded to other organizations, e.g. the Italian CNMC Meteorological Service of the Aeronautics, which has also established recently a collaboration with ISMAR at Venice for the Mediterranean and Italian regions wave forecasting (see [5], [6], [7] and references therein). This forecast (see an example at Figure 10) is updated daily and published by CNMC as operational activity, and mirrored on ISMAR's website. The page of Urania's data includes automatically the closest forecasting, for data comparison and analysis.

3 Perspectives and conclusions

The main challenges of the observation system of the Italian coastal zones can be summarized:

- Enhancing the coordination efforts and interaction between government and scientific institution observation systems;
- Develop and maintain *in situ* observations with autonomous, remote and attended platforms;
- Enhancing remote sensing and ground truth validation for airbone and satellite sensors;
- Reduce time accessing data;
- Improve data assimilation and numerical modeling techniques;
- Install adequate infrastructure and logistical services to operate *in situ* observing systems.

National groups are operative in observational networks management: LTER (Long Term Ecological Research) pertaining to biodiversity and climatic change, and GNOO, which is proposing several projects in marine forecasting, giving high priority in (a) establishing research interconnected networks on common themes of biodiversity and marine ecosystem functioning, (b) forecasting their variations and (b) exploit them into socio-economic terms. We have presented some of the data that are currently being collected in Real Time or Near Real Time from moored stations (buoys, platforms) or moving platforms. The data, other than contribute to the generation of time-series, are used for model validation and decision support.

4 Acknowledgments

The work had contributions and inputs from LTER and GNOO Group Italy, and we are indebted to M. Marini, G. Catalano, G.P. Gasparini (CNR-ISMAR), R.Bozzano (ISSIA-CNR) and N. Pinardi (INGV, GNOO). The authors thank UPO-CNR and SO.PRO.MAR. for their help with R/V Urania data transmission.

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Coastal Water Monitoring from Automatic Oceanographic Platforms

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Abstract

Management and safeguard of coastal ecosystems rely on continuous monitoring by advanced technology systems. The need for new instruments and equipments for environment monitoring led to the development of a network of coastal platforms measuring main physico-chemical variables (installed in Sicily and Apulia in 2002-2003). Design joins high versatility with ease of use and affordable cost. Platforms were controlled by an expressly designed data acquisition and transmission system, fully manageable and reprogrammable via GSM and SMS. Temperature measurements were performed in situ at five depths; from the same depths, water was pumped into a measurement chamber on the buoy where temperature, conductivity, dissolved oxygen, turbidity and fluorescence were measured. Nutrients were measured spilling some water from the same measurement chamber into a pre-sampler feeding a colorimetric analyzer. A water sampler collected and fixed up to eight 250 ml samples for subsequent microbiological laboratory analysis. Air temperature, pressure, wind direction and speed and solar radiation were obtained at one hour intervals on a ten minutes sampling time. The in situ instruments allowed to detect at one hour intervals the arrival of different water masses, as well as the onset of stratification.
Measurements on pumped water were performed at six hours intervals. Acquired data were real time transmitted to a centralized data bank in Messina. Some examples of measurements are given.

1 Introduction

Due to their position at the interface between land and the sea, coastal areas represent very important sites for the global equilibrium of marine ecosystems; in these areas, multiple interests converge, linked to the tourism, recreational or productive activities. In recent years increasing importance has been addressed to the protection and preservation of the marine environment, in particular of those coastal areas, which suffered greater impact from anthropogenic activities; this has in turn stimulated the start of research programs devoted to the monitoring and surveillance of these particular zones, coupling the needs for their use, and the sustainable development and exploitation of natural resources. Offshore buoys and platforms enable to perform surveys of water quality and meteorological parameters on medium- and long-term scales [1, 2, 3, 4, 5, 6, 7, 8].

2 Materials and methods

The "Prototype Platform" was designed and built in 1996; after several years of

Figure 1: The Messina Platform

work, moored near an urban sewer of Messina town [9, 10, 11, 12], this triangular shaped platform was completely refurbished with new instruments and with an increased buoyancy and electrical power availability and transferred to a new site in the Straits of Messina (Figure 1). Thanks to its easy reachability and to the large space available, totally out of water, the platform was also used as a test bed for new instruments and software.

Six more platforms, rectangular shaped and partly submersed, derive from a major redesign and resizing of a small prototype vessel built by a commercial firm (Figure 2). The platforms were installed starting in 2002 in Sicily and Apulia, so forming a monitoring network [13, 14, 15, 16, 17, 18]. All the platforms assembled together the following equipments:

- an expressely designed data acquisition and transmission system, fully manageable and reprogrammable via GSM and SMS [16, 19]
- Meteo Station equipped with temperature, pressure, solar radiance, wind direction and speed sensors
- Idromar system for pumping water samples from 5 depths, equipped with IM50 CTDO-Turbidimeter-Fluorometer
- Experimental Systea colorimetric Nutrient Probe Analyzer
- Water sampler for microbiological laboratory analysis [14], performed using the fluorescent antibody method, or immunofluorescence
- 5 SBE 39 T in situ probes at the same sampling depths.

The Messina platform also hosted:

- Idromar IM50 CTDO probe for in situ subsurface measurements
- Nortek Aquadopp 600 ADCP.

Fluorescent antibody method, which relies on the use of immune sera specifically recognising the surface antigens of *Escherichia coli*, was developed to join the rapidity in sampling phase with the rapidity in the analytical phase [20, 21, 22, 23]. The detailed protocol was described in detail by [24]. Solar panels and wind generators were installed to recharge batteries. The data acquisition and transmission

Figure 2: The Milazzo Platform

systems of all the buoys used SMS-coded email messages (a service of the telecom provider) to transmit acquired data to the base station in Messina where they were automatically collected in a Oracle Data Bank for further validation and integration.

3 Results

The mission protocol includes hourly measurements on "static" devices (in situ T probes, meteo station, ADCP) and every 6 hours on the energy consuming pumped system (CTDO, NPA) the water sampler was scheduled "on demand". As an example of the system capabilities, some measurements are shown. Temperature trends in the water column measured in the period 13- 20 July 2003 using in situ sensors are reported in Figure 3 (a, b).

Temperatures measured in Milazzo platform are plotted in Figure 3a, a stratification is evident: minimum values are measured by the 25 meter sensor (the deepest) and the maximum ones by the 5 meter sensor (the shallowest). Nychthemeral variations can be observed, with thermal increments during the central hours of the day.

A mixing of the water column can instead be observed in Figure 3b, showing the temperatures measured in Messina Platform: temperature variations observed are caused by the tidal alternance of "montante" and "scendente" streams, with little variations among the different depths. Nutrient measurements performed using the NPA in Milazzo Platform are reported in Figure 4. During the period examined, no significant variations were found; ammonia, nitrites and orthophosphates showed low concentrations, while substantially high nitrates values were measured. *Escherichia coli* counts, as determined by the immunofluorescence method applied to the analysis of surface samples collected in Messina harbour by the automatic multisampler, are shown in Figure 5.

A quite regular course of the bacterial densities was noticed in the 28 March - 22

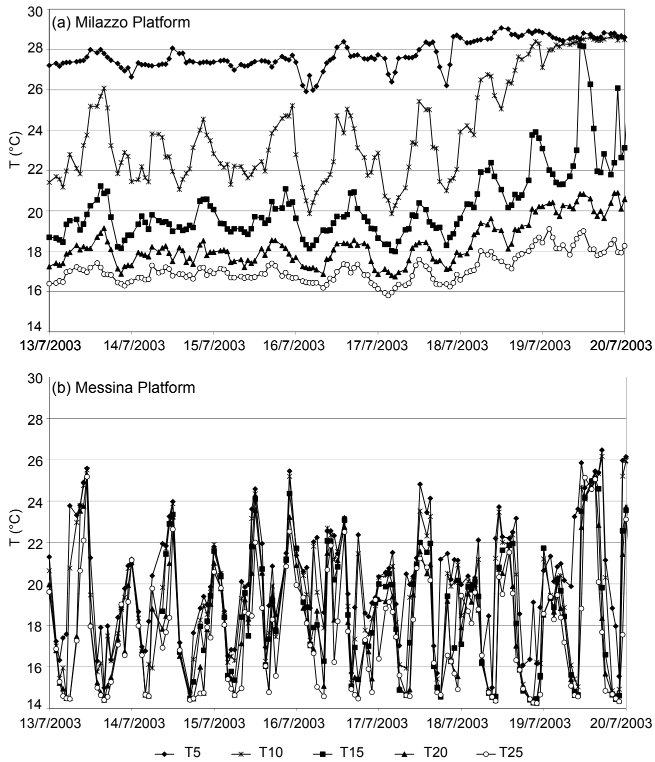

Figure 3: Temperatures at various depths measured by in situ sensors. In Milazzo platform (a) an example of vertical stratification is evidenced, while in Messina platform (b) a well mixed water column and tidal alternance can be observed.

April 2003 period, with peaks that occurred early in the morning (at 6.00) and were repeated at the same hour on the first sampling days. These peaks were further observed with a shift of 6 or more hours in the successive days. A possible explanation for this trend was that bacterial growth was more stimulated in coincidence with the arrival of high amounts of organic matter, such as those drawn from the alternating "scendente" and "montante" currents that characterise the water masses circulation within the Messina Straits. Also atmospheric measurements can be performed. A sample plot of wind speed and direction data measured from Milazzo platform in July 2003 is shown in Figure 6 (a, b), where two main wind directions can be observed. Solar radiation and barometric pressure for the same site are displayed in Figure 7.

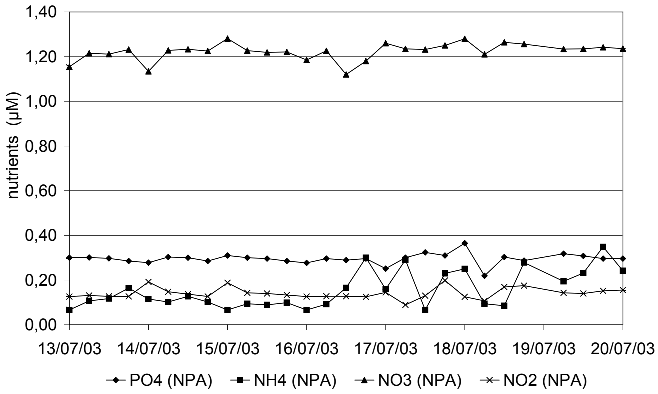

Figure 4: Nutrients in Milazzo platform.

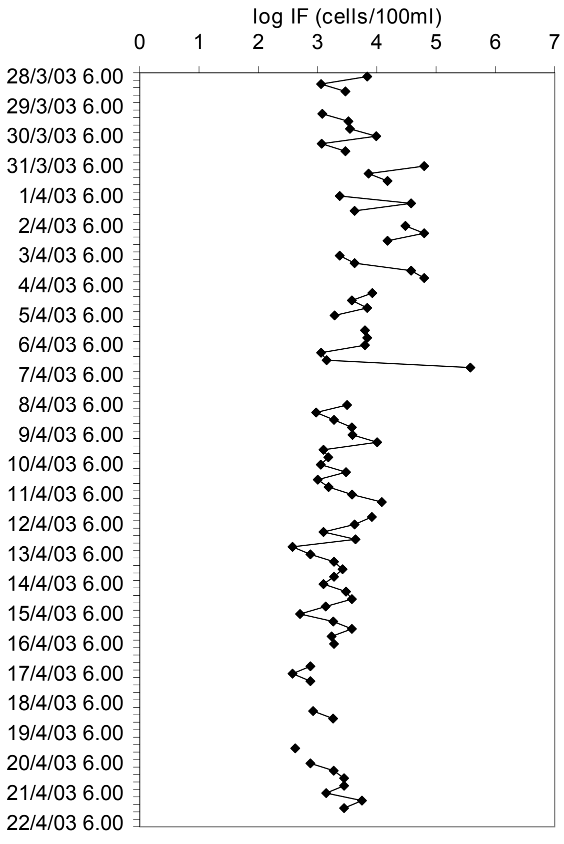

Figure 5: *E. coli* concentrations in Messina harbour.

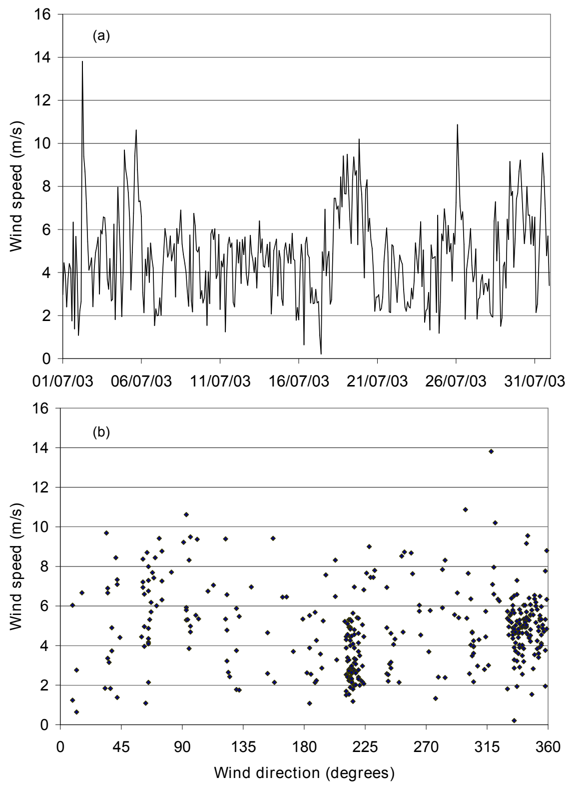

Figure 6: Wind speed (a) and direction distribution (b) measured in Milazzo platform.

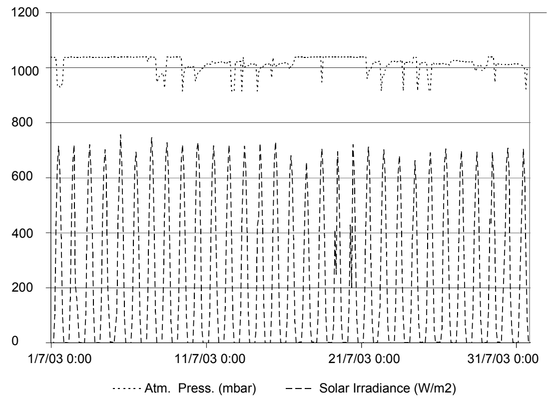

Figure 7: Atmospheric pressure and solar irradiance in Milazzo platform.

4 Conclusions

Results obtained demonstrate the reliability of the systems developed for the monitoring of coastal environments. Through the synchronous assessment of different (physical, chemical and bacteriological) parameters, a complete picture of the environmental status may be achieved. This strategy is of primary importance for the early warning of pollution episodes and the set up of appropriate restoration measures. The end of the program and of the fundings led to the dismission of the network; the platforms were brought ashore, but the data acquisition and transmission system was furtherly developed to control an automatic launcher for multiple probes [25], using a Pentium CPU and a GPRS modem. The architecture of the electronics and the control software can still be considered almost "state of the art", and can be implemented with newer computer boards offering lower power consumption, lower costs, smaller sizes, higher elaboration speed. The availability of GPRS and UMTS modems with embebbed TCP-IP stack now enables to easily and directly connect to Internet to transfer data, either as e-mail messages or via FTP, so lowering the communication costs and enhancing system performances. A further development of Fluorescent antibody method was also set up by Caruso et al. [26], which allowed to determine the viability status of bacterial cells, with high significance for health protection.
Flexibility in the assembly of the technical instrumentation makes the described systems a versatile equipment for environmental surveillance that, offering at a relatively low cost high flexibility and reliability, could constitute the core for basin-wide coastal monitoring networks. Other than the simple application in environmental management (by local authorities, fisheries, sea-farmings, touristic activities...), the monitoring network offers a wide range of potentialities also for scientific research (oceanographers, modellers).

5 Acknowledgements

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The National Wave Forecasting System in the Mediterranean and Italian Seas

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Abstract

We describe the structure and the results of the national wave forecasting system, set-up by the Italian Meteorological Service CNMCA and ISMAR, operational since July 2008. After outlining the needs for an accurate prediction of the wind and wave conditions on the sea and the characteristics of the Mediterranean basin, we briefly describe the meteorological and wave models used for the purpose, and in greater details the quality of the results and what is presently available to the users. We conclude showing maps of the very severe storm that hit the western coasts of Italy in January 2009.

1 The need

The recent winter seasons, and in particular 2009, have seen a substantial increment of the severity of the sea storms that hit the Italian peninsula (see The Medatlas Group, 2004 for long term statistics). In the western part of the Mediterranean Sea, following the action of mistral, we have repetitively seen significant wave heights larger than 7 or 8 m. During the storm of 24-25 January 2009 waves higher than 11 metres have been estimated in the basin (see later), with single wave heights larger than 20 m. Seven metre wave heights have been reached also in the Ligurian Sea, and similarly and repetitively also in the Ionian Sea. In the eastern Mediterranean violent storms have hit the area of the Nile delta.

The correct prediction of the these events, particularly if extreme, is obviously a basic need for the safety of navigation and more in general for all the marine activities. Given the geometry of the basin, such information must be distributed with a very high resolution to be able to consider its sometime cumbersome spatial variations, see [1, 2, 3]. The aim of this paper is to provide a compact, but clear, description of the highly accurate wave prediction system set-up through the collaborative action of the Italian Meteorological Service CNMCA and the Institute of Marine Sciences, ISMAR, of the Italian National Research Council. At this aim, after providing in Section 2 a compact description of the area of interest, namely the Mediterranean Sea, in 3 we briefly describe the models, meteorological and wave, we used. The results, both as statistics and examples, are given in Section 4. We summarise the situation in the final Section 5.

2 The Mediterranean Sea

The Mediterranean Sea is the largest enclosed basin in the world. It spans about 3,600 km in longitude and more than 1,600 in latitude. However, this large expanse is cut into a number of sub-basins by a complicated coastline, the dominant features being the two large protruding peninsulas of Italy and Greece, and the number of large and small islands. These divide the sea into a number of sub-basins, each one with its own name and characteristics. The Italian peninsula splits the Mediterranean into its western and eastern sections, with substantially different weather regimes. The western part, and the western coasts of Italy, are exposed to the frequent westerly storms, the main line of action of the weather systems affecting the Italian peninsula. See Lagouvardos et al., [4] for a good review of the general meteorological patterns present in the basin. The contrast between the cold incoming air and the still warm water of the basin leads frequently to an intensification of, and genesis of new, storms (cyclogenesis) that affect all the Italian seas. The meteorological prediction is further complicated by the practically continuous elevated orography that characterizes the northern border of the basin.

3 The meteorological and wave models

Worldwide numerical predictions are available, for both atmosphere and sea, from many large meteo-oceanographic centres, the classical and probably best example being the European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, U.K.). These centres, and ECMWF in particular, provide typically ten day forecasts of both meteorological and wave conditions. However, just because they work at the global level, their resolution is relatively coarse when we consider the just mentioned complicated geometry and orography of the Mediterranean Sea. This is clearly shown by the different quality of the results obtained in the oceans and in the enclosed seas, see in this respect Ardhuin et al. [5], Bidlot et al. [6], and Cavaleri et al. [7]. This creates the need for a smaller scale model, focused on the area of interest, fed with the large scale information of the global models, but able to zoom on the specific area of interest working with high resolution and enhancing the quality of the local results. At this aim two high resolution, meteorological and wave, models have been set-up, providing what is at present the most detailed information available for the Mediterranean, and in particular the Italian, seas.

The National Centre for Aeronautical Meteorology and Climatology (CNMCA) has assembled and made operational the high resolution numerical meteorological prediction model COSMO-ME covering a large area including the Mediterranean Sea. The general formulation of this model has been developed by the COSMO international consortium including the national meteorological services of Germany, Greece, Italy, Romania, Russia and Switzerland (www.cosmo-model.org). COSMO-ME is numerically integrated starting from initial and boundary conditions derived from an advanced data assimilation system set-up by CNMCA and starting from the global data provided by ECMWF. The system provided highly detailed meteorological and wind in particular, forecasts up to 72 hour advance with an horizontal resolution of 7 km and 42 vertical levels.

For the evaluation of the sea state, i.e. the wave height, throughout the Mediterranean Sea the basic information is the wind blowing over the sea, obviously varying in time and space. This information is provided by the just mentioned meteorological model of CNMCA. For the waves, any large scale wave prediction model can describe the wave conditions, at given time and location, only in statistical terms, in practice providing the so-called significant wave height and mean period and direction that characterize the local conditions. This is the essential information required by most users. However, much more detailed information is available. The fundamental idea of a spectral wave model is that the sea can be represented as the superposition of many different waves, each one with its own height and length (hence period), moving in different directions. The wave spectrum is the ensemble of the energy, in practice height squared, of all these components. The evolution in time and space takes into account all the physical processes that concur to the generation, dissipation, evolution and transport of this energy throughout the basin. In the present wave forecasting system we consider 30 frequencies and 36 directions, the latter uniformly distributed over the 360 degrees. The 36 frequencies cover the wave lengths from the order of metre to 600 metres. In the Mediterranean the information is provided with a resolution of 1/20 degree, about 5 km. The model used in WAM, an advanced wave prediction model developed by the collaborative work of all the world specialists in the subject and presently in use at many of the world meteo-oceanographic centres. ISMAR has been one of the developers of the model. Together with the accuracy of the wind speed and direction provided by the COSMO-ME model, this resolution ensures the capability to describe well the wave conditions not only in all the large basins surrounding the Italian peninsula, but also in all the little gulfs and bays that characterize the Italian coastlines.

More detailed descriptions of both the COSMO-ME and WAM models can be found respectively in Bonavita and Torrisi [8] for the former and in Komen et al. [9] and Janssen [10] for the latter. A thorough discussion of the present state of the art in wave modelling is provided by The WISE Group [11].

4 Results

Figure 1 shows a typical example of wind and wave fields over the Mediterranean Sea. Please note that the information available is extremely more detailed than shown in the figure. For the clarity only one every so many arrows has been drawn. Clearly the overall view provides a general idea of the general situation. However, much more information, at 5 km resolution as specified above, is actually available and it is possible, with the data at disposal, to zoom on a specific area and appreciate all the details of both the wind and wave fields. The general fields, at both the Mediterranean and Italian scales, are available at the two websites www.meteoam.it and www.ismar.cnr.it. The forecasts are updated every 24 hours and extend 72 hours in the future, with the maps available at 3 hour intervals.

The quality of the results has been verified by comparing the wind and wave model data versus the ones available from satellite, namely scatterometer for wind speed and altimeter for wave height. The resulting comparisons, for one recent month, are shown in Figure 2. There is a slight underestimate of the wind speed by the model (panel a), but the general structure of the comparison is very solid. The scat-

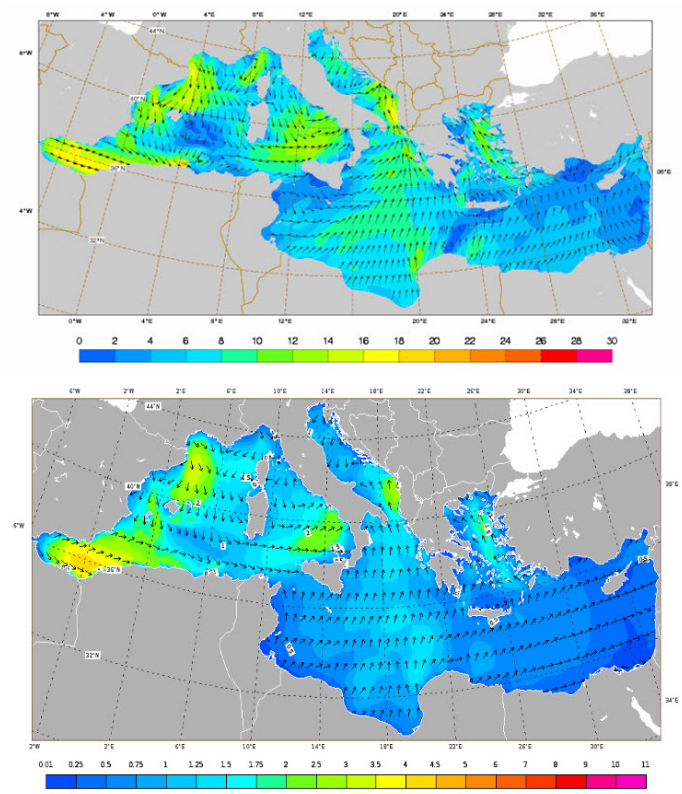

Figure 1: Example of wind (up) and wave (down) forecast in the Mediterranean Sea. Reference time is 03 UTC 27 December 2009. Note the scales below the figures, m·s^{-1} and m for wind and waves respectively.

ter around the best-fit lines is mainly due to the natural turbulence of the wind fields, where there is an unavoidable level of randomness in the model-satellite intercomparison. However, the very good quality of the general wind fields is clearly shown by the perfect fit of the model significant wave heights (panel b). Waves are the best parameter to judge the quality of the input wind fields. They are extremely sensitive to also minor changes, and are an integrated effect in space and time, of the driving winds. Therefore high quality results for wave heights are a certain indicator of very high quality wind fields. A more extensive statistics for both wind speeds and wave heights is reported in Table 1. It is clear that the data suffices all the needs for any practical application.

We conclude this short presentation describing the exceptional storm that hit the western Mediterranean Sea on 24-25 January 2009. The wave fields for the area of interest, at six-hour intervals, are shown in Figure 3. In the early hours of 24 a strong libeccio (south-west wind) was

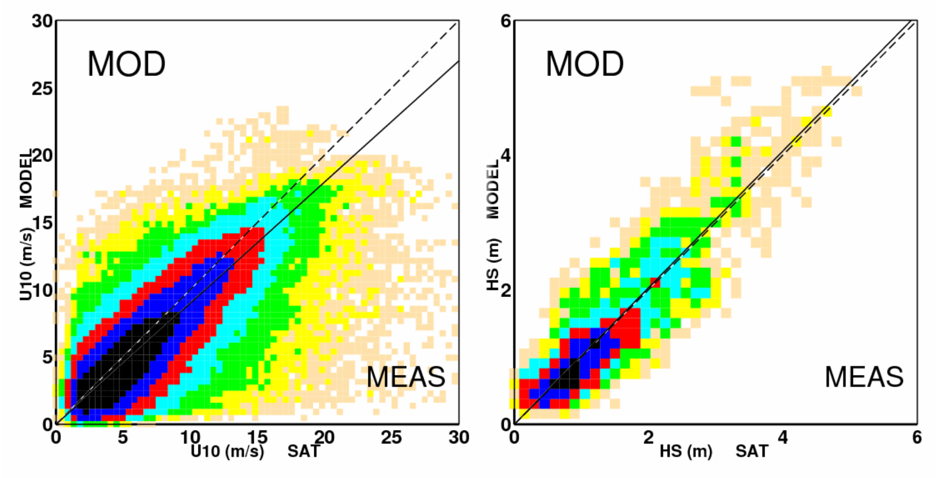

Figure 2: Scatter diagrams of one month comparison between model wind speeds (left) and wave heights (right), versus scatterometer and altimeter data respectively, in the Mediterranean Sea. See Table 1 for the numerical results.

	best-it slope	bias (m/s, m)	scatter index
wind	0.96	0.25	0.26
waves	1.01	0.02	0.22

Table 1: Statistics of the comparison between model wind speeds and significant wave heights in the Mediterranean Sea shown in Figure 2.

blowing between the Alboran sea and Sardinia, leading in the evening (3a) to already high wave conditions west of Sardinia. However, following a standard pattern of this kind of storms, the libeccio was soon followed by a very violent mistral, blowing from north-west, between the Pyrenees and the Massif Central, over the gulf of Lion and towards Sardinia. In this area (3b) the wind speed went up to 24 $m{\cdot}s^{-1}$ over a large area blowing the significant wave height up to and above 11m. Note that this implied single wave heights till, and larger than, 20 m. Note also the white spot at the location of the highest wave heights. An 11 m upper limit had been chosen for the scale of the plot as a compromise between possible, but rare, maximum values and a better resolution of the wave height scale. The storm, still with highly sustained wave heights, propagated towards south-east (3c), moving then progressively towards the Ionian Sea (3d), due to reach the coasts of Egypt and Is-

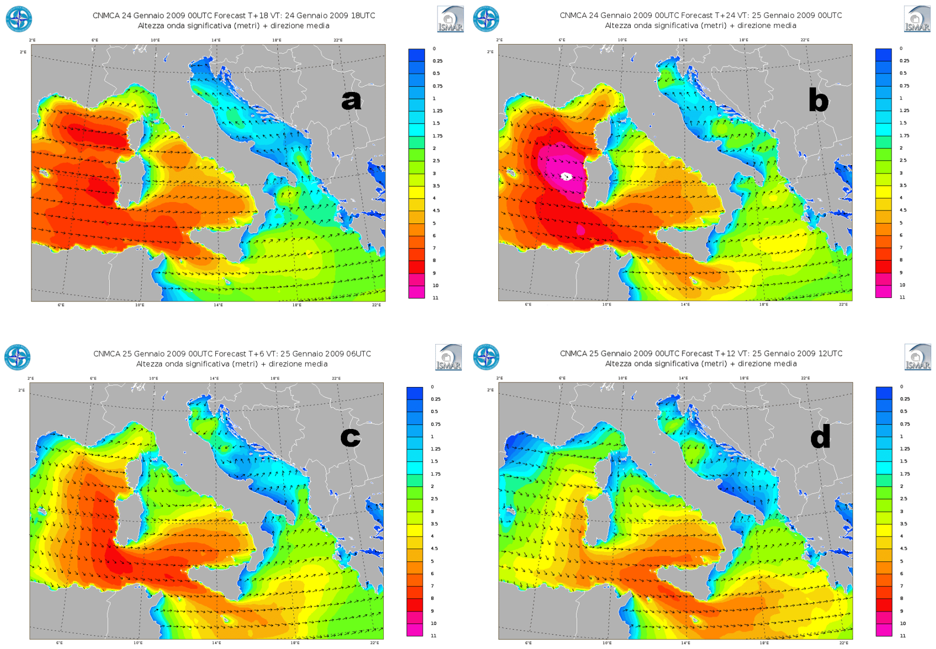

Figure 3: Sequence of wave fields in the Western Mediterranean Sea during the storm of 24-25 January 2009. The fields, from a to d, are at six-hour intervals, starting at 18 UTC January 24.

rael as long period swell two days later. A quick statistics showed the storm to be the most violent one of the last ten, perhaps twenty, years. Notwithstanding its exceptional character, the storm was well forecast, and timely warning were issued to the population, so that no practical damage was caused to persons and vessels.

5 Summary

The wind and wave forecasting system set-up by CNMCA and ISMAR for the Mediterranean Sea is the one presently available with the highest resolution. 7 km for wind and 5 km for waves ensure a detailed description of the situation also in the smallest bays and all the enclosed seas of the basin. The basic information derived from this paper can be summarised in the following points:

1. high resolution wind and wave forecasts are available for the whole basin, and in particular for the Italian seas, up to 72 hours in advance,
2. the results are openly available at the two websites www.meteoam.it and www.ismar.cnr.it, where they are displayed, at both Mediterranean and Italian scales, at three hour intervals;
3. extended direct comparisons with satellite data, for both wind and waves, shows the very high quality of the

model results;
4. the models have been verified both in standard and exceptional conditions, confirming the solid physical basis of the system, hence its capability to provide high quality forecasts in all possible conditions;
5. the archive progressively built with the system results can be used both to derive longer term statistics, suitable for any marine construction and activity, and to know the wind and wave conditions at one location or in a given area present during specific events of the relatively recent past.

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Real Time Marine Data Acquisition: the Coastal Oceanographic Observatory Network in Adriatic Sea

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Abstract

Currently, several operational marine centres issue routine seasonal forecasts produced with coupled ocean-atmosphere models. For good result they require also real-time knowledge of the state of marine area as regard as oceanographic and atmospheric parameters. Effectiveness of marine climate knowledge and predictability resides in fast, reliable, scattered and numerous information on the initial marine and atmospheric conditions. The aim of this work is to present a review of the existing real time stations in the Adriatic sea and a critic state of the art with the aim to propose a new single and standardized coastal oceanographic observatory network based on previous existing oceanographic buoys set up by different projects and institutions and with various features. The network ISMAR could be based on various oceanographic buoys located along the Adriatic Sea coastal waters transmitting real time data, accessible, after a data quality control and sensor/instrument field calibration validation, on internet by a web site. In this way it will be possible to have a single system of real time oceanographic and meteorological standardized data available for regional stakeholders, policy makers, economic operators, environmental safety and tourists. Data will also be useful to improve forecast systems active for the Adriatic Sea.

1 Introduction

In the states most advanced in the world, about two decades ago, officials agency of environmental protection and scientists realized that the nation had to integrate the assets of its many sea and coastal observing systems and focus them on providing solutions to societal needs solutions that address the missions of several agencies and organizations. Catastrophic weather events, coastal pollution, harmful algal blooms, declines in living marine resources, and climate change underscore the importance of creating a more integrated approach to providing data and information needed to manage and mitigate the impacts of human activities, natural disasters, and

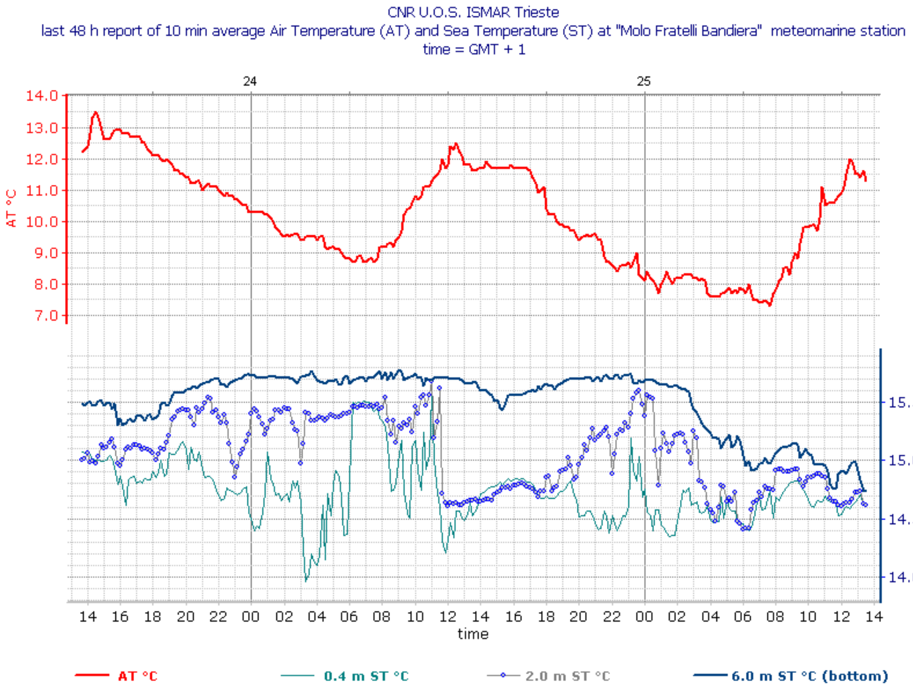

Figure 1: Plot of air (AT) and sea (ST) temperature form 23 to 25 November 2010

climate change on goods and services provided by the sea, and coasts. While the nation has developed some of the most sophisticated and comprehensive lakes, estuarine, and marine monitoring programs in the world, these individual programs are not as robust, effective, or comprehensive as they could be in protecting the societal and economic security of the nation, and therefore in providing the quality of life our citizens expect [1, 2].
The Marine Environment and Security for the European Area (MERSEA) Strand-1 Project was established in January 2003 to conduct an 18-month preparatory study of the key issues in setting up the marine elements of the joint European Commission (EC) and European Space Agency (ESA) initiative on Global Monitoring for Environment and Security (GMES).
The motivation for the marine element of GMES arises from the wide range of international bodies, treaties, conventions, and organizations at global, regional, and national levels concerned with monitoring and protecting the marine environment in Europe. The United Nations Convention on the Law of the Sea (UNCLOS 1982) provides the regulatory framework at the global level for all activities at sea. Supporting these are the International Convention for the Prevention of Pollution from Ships (MARPOL 1973/1978), the framework for preventing dumping of pollutant material (London Dumping Convention 1972), and the International Convention

Station name	Geographical position
Trieste	45°38.836' N, 13°45.658' E
Paloma	45°37.097' N, 13°33.913' E
Acqua Alta	45°18.830' N, 12°30.530' E
S1	44°44.552' N, 12°27.429' E
E1	44°08.599' N, 12°34.219' E
TeleSenigallia	43°44.210' N, 13°13.130' E
S6	41°32.755' N, 16°02.675' E

Table 1: AIOOS network components positions

on Oil Pollution Preparedness, Response, and Cooperation (OPRC 1990). These are complemented by specific conventions and agreements for particular maritime regions, such as the Oslo and Paris Commission (OSPAR) for the Northeast Atlantic and the European shelf seas, the Helsinki Convention (HELCOM) for the Baltic, the Barcelona Convention for the Mediterranean, and the Copenhagen and Bonn agreements. These legal frameworks set the foundation for policies on sustainable development and protection of the seas. Their overarching goal is to establish a sound balance between economic and social benefit on one hand and acceptable environmental impact on the other hand. International agreements place obligations on nations to monitor the marine environment. GMES (www.gmes.info) is a response at the European level to provide a common infrastructure for meeting this need, while serving as the European contribution to the Global Earth Observation System of Systems (GEOSS) (www.geoss.org/) [3].

In the Adriatic sea, the first approaches of coastal oceanographic observatory systems are beginning with ISMAR-CNR network. As an example of data acquisition, Figure 1 reports near-real time data of air temperature and sea temperature at different depths at Trieste, from 23 to 25 November 2010.

The Adriatic Sea is the most continental basin of the Mediterranean Sea. It lies between the Italian peninsula and the Balkans and is elongated longitudinally, with its major axis (about 800 km by 200 km) in NW-SE direction. The basin shows clear morphological differences along both the longitudinal and the transversal axes and has been divided into northern, middle and southern subbasins [4]. The Adriatic Sea has complicated morphology and bathymetry. The western coast is low and generally sandy, while the eastern coast is rugged, with multiple islands and coves. The northern subbasin, extending from the northernmost coastline to the 100 m isobath, is extremely shallow (mean depth

Figure 2: Geographical position of buoy, research vessel (Urania, G. Dallaporta, Tecnopesca II), platform and other fixed sites (red circles) located in Adriatic Sea managed by Institute of Marine Science (ISMAR), National Research Council (CNR)

30 m) with a very gradual topographic slope along its major axis. It is characterized by strong river runoff; indeed, the Po and the other northern Italian rivers are believed to contribute about 20% of the whole Mediterranean river runoff [5]. The middle Adriatic is a transition zone between northern and southern subbasins, with the three Jabuka depressions reaching 270 m depth. The southern subbasin is characterized by a wide depression about 1200 m in depth. Water exchange with the Mediterranean takes place through the Otranto Strait, which has an 800 m deep sill. The present study focuses on the northern and central continental Adriatic margin, where circulation is mainly controlled by wind stress and river discharge.

Two currents dominate circulation in the Adriatic: the West Adriatic Current (WAC) flows toward southeast along the western (Italian) coast, and the East Adriatic Current (EAC) flowing northwest along the eastern (Croatian) coast [4, 6]. Being a continental basin, the Adriatic Sea circulation and water masses are strongly influenced by atmospheric forcing [7, 8, 9]. The major winds blowing over the Adriatic Sea are Bora and Sirocco.

Bora winds are generally from the northeast and are associated with a high-pressure system over central Europe [3]. Bora is a cold and dry wind where air spills through gaps in the Dinaric situated along the Adriatic's eastern shore, resulting in intense wind jets at specific points along the Adri-

Air	Hydrology
Air temperature	Water level
Atmospheric pressure	Wave
Humidity	Current
Wind direction	Water temperature
Wind speed	Salinity
Wind gust	Dissolved oxygen
	Turbidity

Table 2: Some common network parameter

atic eastern coast due to catabatic effects [8]. The Bora wind system causes the free sea surface to rise near the coast and this intensifies a coastal current toward the south (WAC).

2 Buoys, platforms and other fixed site

Table 1 showes the list of the network that are operative at the moment. Other systems (e.g. "S6", 41°32.755' N, 16°02.675' E), that were active until a few years ago could join the infrastructure in the next future.
ISMAR-CNR operates several multi-parametric observing systems, most of them are placed along the Italian coasts and transmit data in real time to the receiving stations at coast (Acqua alta, S1, E1). Some of the systems such as Paloma and TeleSenigallia are operating in near real time while and S6 is not operating in real time now, but can be developed in this direction. The station locations are reported in Figure 2. Table 2 showes the list of the common network parameters.

3 Integrated ocean observing system benefit

Adriatic Integrated Ocean Observing System (AIOOS) will provide data and information products needed to significantly improve the nation's ability to achieve these four interrelated societal benefits:

- Improving predictions of climate changes and weather and their consequences on coastal communities and national economy;
- Improving the safety and efficiency of maritime operations;
- Mitigating effects of natural disasters;
- Protecting and restoring healthy coastal ecosystems.

These benefits will be accomplished by efficiently linking observations to modeling via data management and communications to provide services, products, and decision-support tools needed to achieve these goals. To maximize the societal benefits, AIOOS must focus development efforts on ready assets and the greatest opportunities for valuable, synergistic uses. AIOOS is a complex system of systems that is best implemented in stages. Phased implementation requires the prioritization of existing assets that monitor variables that are essential and common to more than one societal benefit. The highest priority assets measure these core variables, using both in situ and remote sensing platforms, to provide new or existing products that can be improved by integrating data from more than one program, institution, or agency.

4 The future goals

- Compare existing ocean observing systems data to check the quality and consistency of the products and information;
- Identify and develop high-priority sensors and associated algorithms;
- Production of well-documented, sustainable, reliable, and quality-controlled data streams produced by existing monitoring assets;
- Choice of critical ocean variables and provisioning of high-quality, well-documented data in a timely fashion;
- Integrated data products for more accurate and timely assessment of environmental conditions.

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North Thyrrhenian Sea Monitoring through a Combined Use of In Situ, Satellite Data and Regional Ocean Models

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Abstract

Ocean dynamics at regional and coastal scales need adequate description of small scale phenomena such as sub-mesoscale vorticity, coastal upwelling, river-sea interaction etc. No methodology is self-sufficient in providing proper reconstruction of the water quality parameters at such spatial scales: the integration of in situ and remote sensing data with hydrodynamic models is nowadays the basis of most operational oceanographic systems even on regional and limited coastal areas.
A prototypal tool for marine monitoring in the North Tyrrhenian area is being implemented in the framework of the EU-funded project MOMAR, leaded by Tuscan Regional Government. This paper describes the ongoing work to develop a regional operational system for marine monitoring of the North Tyrrhenian and Ligurian Sea area, based on remote sensing and ocean modelling. The satellite remote sensing component of the project mainly focuses on chlorophyll (from MODIS and MERIS) and SST (from MSG) measurements, via algorithms calibrated for the area of interest. An oceanographic model (based on the ROMS code) is being implemented at 400 m over the Tuscany area, with the aim of describing the physical and biogeochemical variability typical of such coastal regions.

1 Introduction

The monitoring of marine-coastal water quality derives the maximum benefit from the integration of oceanographic and biogeochemical models with in situ and remote observations. On this basis current systems for operational oceanography are structured, which in turn support the model systems for the analysis and prediction at sub-regional or coastal scales. No simple approach leads to a comprehensive reconstruction of the quality parameters throughout the water column, especially if small scale dynamics phenomena have to be described.
A number of more or less sound algorithms exist for processing satellite observations in order to produce maps of physical and biogeochemical features in the sea surface layer. Some of them are implemented in the generation of what we could name standard operational products. Similarly, a number of codes are available for wave, hydrodynamic or biogeochemical simulations, which are differently implemented

(i.e. configured and calibrated) in several centres, according to their core businesses. The development of shared objective methodologies for monitoring marine areas common to different regions of different countries, is the basis on which common policies for the management (i.e. control, protection and exploitation) of the marine environment can be established.
The creation of a monitoring tool shared among four maritime regions (Tuscany, Corsica, Sardinia and Liguria) is the main objective of the European Transnational Cooperation project MOMAR (integrated system for Monitoring and control of the Marine environment), whose leader is Regione Toscana.
A large part of the project is devoted to compare the different methodologies for monitoring various aspects of the marine environment, developed by the different regions through their centres of expertise, at a research or operational level. Common validation measurements campaigns are planned for this purpose, covering representative area of common interest, in addition to the sharing of legacy measurement facilities, observation and simulation methodologies, and regional databases, which are the endowments that each region brings to MOMAR and that compose the project background.
In this paper we present the contribution that LaMMA, as Consortium between Regione Toscana and CNR, and as partner of MOMAR, is bringing to the project through its research and operational activities.
In chapter 2 we describe two customised algorithms and processing chains, that operationally produce SST and chlorophyll maps from MSG-SEVIRI and MODIS sensors respectively, over the area of interest for the project. In chapter 3 the development of the hydrodynamic and biogeochemical high resolution components is described, based on the ROMS code. The issue of their integration with the observational components is also introduced, starting from previous experimental results and looking at the current development activities, focused on the MOMAR objectives.

2 Ocean Data

2.1 SST data processing

An accurate monitoring of Sea Surface Temperature (SST) on a long time period is a critical issue to improve meteo-ocean forecasting models at several scales. Satellite observations respond satisfactorily to this need, being in situ measurements (buoys or ships) very few and inhomogeneous, thus more suitable to calibrate remote observations.
The high temporal frequency (every 15 minutes) of the new generation of sensors, such as MSG, allows the resolution of the SST diurnal cycle and, in principle, a greater number of cloud-free observations. Also, the good spatial resolution (3 km at nadir) enables to follow the dynamics of the ocean-atmosphere system, even on a long time period.
In this context, the MSG-based monitoring of SST gives an opportunity complementary to that well established in literature, based on data from polar sensors (e.g. AVHRR), taking a full advantage of the high domain coverage, temporal and spatial sampling.
The fundamental basis of the nowadays multi-channel SST algorithms is the differential water vapor absorption in the various atmospheric window regions of the spectrum. The current operational real-

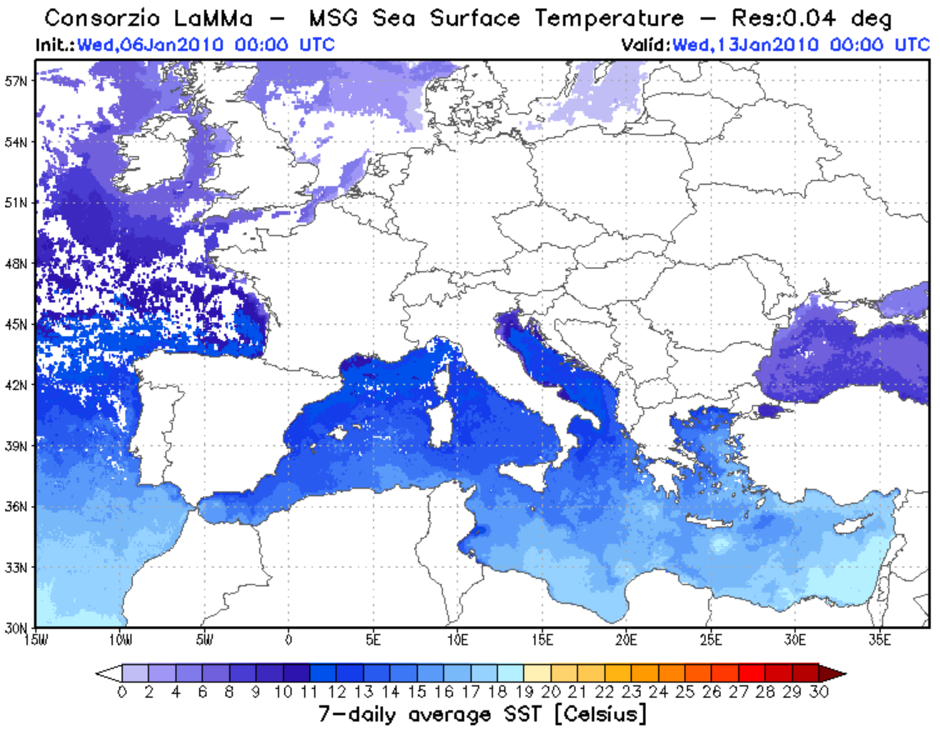

Figure 1: SST map for the Mediterranean area, averaged on 7-days, for 6th-13th of January 2010.

time SST retrieval method implemented at LaMMA Consortium, is based on two spectral windows within the 10-13 µm interval in both night and daytime conditions [1]. This procedure is based on an algorithm that uses a nonlinear split-window technique in the thermal infrared channels, centred at 11.0 and 12.0 µm, primarily designed and developed in the framework of EUMETSAT O&SI SAF project [2, 3]. The primary calculation of SST is carried out on a hourly basis for the Euro-Mediterranean area; Figure 1 shows an example of Sea Surface Temperature map for the Mediterranean area, averaged on 7-days, from 6th to 13th of January 2010 (http://www.lamma.rete.toscana.it/previ/eng/sst_msg.html). SST fields have been derived in view of their integration in an operational coupled meteo-ocean system, which may resolve scales of interest at spatial/temporal details comparable with the other monitoring modelling tools available in the MOMAR project. Thus, a more suitable calibration of SSTs on the area of interest and their higher temporal sampling (hourly) with respect to the real-time widespread products appear fundamental to achieve the project objectives.

To validate the hourly estimated satellite-based SST data, the temperature data measured in situ by the buoys of the Na-

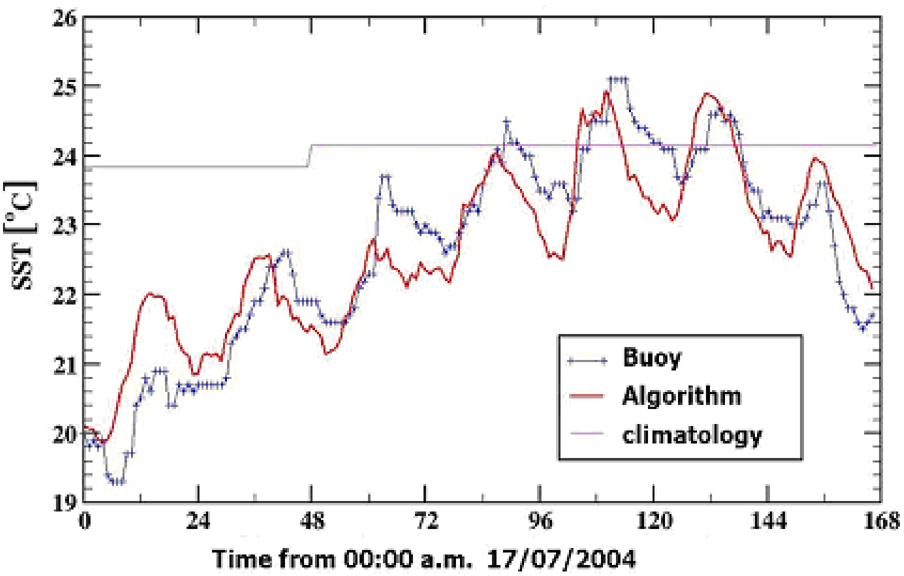

Figure 2: SST as function of the hours passing from 00:00 a.m. of the 17th July 2004, for the La Spezia buoy. The measured SST, the estimated SST and the climatological value are reported.

tional Ondametric Network (RON) have been used. The estimated and measured SST data were compared directly, but note that they refer to different water depths (i.e., for satellite Tsubskin a few mm, for buoy Tbulk under 1m). This makes them comparable during the night, but much less during the day, when the discrepancies may reach several degrees under intense diurnal solar heating, surface wind and mixing in the surface layers. The analysis of the validation results was then performed by means of a crossed comparison with meteorological charts and other meteo-marine parameters (e.g. significant wave height), thus to evaluate if the differences of the two temperatures are compatible with the different physical mechanisms which differentiate the two water sheets.

Several time intervals were analyzed for different seasons of the year in order to evaluate the behaviour of the algorithm under different diurnal heating and weather conditions. The capability to reconstruct the daily cycle has also been evaluated, as shown in Figure 2, where measured (by La Spezia buoy), estimated (by MSG–based algorithm) and climatological SST data are compared.

The results show an overall good agreement between in situ and satellite data and the ability to reconstruct the daily cycle of SST with good detail. The largest differences are in the middle of the day, in agreement with the peak of solar heating. Under strong wind conditions, when the surface

mixing is greater, the satellite data are very close to the in situ ones. These results to date suggest that the accuracy of satellite-based SST data is higher than 1K.
Finally, the extent of discrepancies between in situ and satellite SST data have been also analysed by means of statistical parameters. A good quality of SST estimate has been achieved, being MAE, RMSE, SDs values of 0.6°, 0.8° and 0.5°, respectively.

2.2 Estimation of chlorophyll concentration

Chlorophyll a is the major photosynthetic pigment in surface and in oceanic plants: all plants, algae, and cyanobacteria which photosynthesize contain chlorophyll a. Within the phytoplankton species, chlorophyll a is an ubiquitous pigment, so the amount of ocean chlorophyll a is related to the phytoplankton surface content. Phytoplankton makes up the basis of the marine food web [4], and plays a crucial role in the global carbon cycle, fixing inorganic carbon and converting solar to chemical energy. Phytoplankton growth implies the conversion of CO_2 to organic carbon: the rate of growth and of carbon fixation is called primary production [5].
Remote sensing of sea colour is based on the study of the reflective properties of the main optically active seawater constituents: phytoplankton, whose concentration is generally estimated by chlorophyll; a non-algal particulate matter which, in coastal waters, is mostly represented by suspended sediments; colored dissolved organic matter, also named yellow substance. In shallow waters the optical properties of sea bottom and of benthos may also play a major role [6]. In Case 1 waters chlorophyll a is inversely related to the ratio of the reflectance R (λ) in the blue versus green [7]. Based on this principle, several bio-optical algorithms to estimate chlorophyll concentration [CHL] have been developed and are routinely applied for global ocean studies.
The OC3M and MedOC3 algorithms, are bio-optical empirical algorithms based on computing on a pixel-by-pixel basis the maximum band ratio (MBR) between two bands in the blue wavelength range (443 and 448 nm) out of one band in the green wavelength range (547 nm). The MBR has the potential advantage of maintaining the highest possible satellite sensor signal-to-noise ratio over a 3-orders-of-magnitude range in the chlorophyll concentration [8]. The two algorithms form is a fourth degree polynomial regression between log-transformed [CHL] and log-transformed MBR. Both algorithms only work for Case 1 waters, and while OC3M was developed on a global in situ data set, MedOC3 was calibrated using a representative open-water bio-optical dataset collected in the Mediterranean area, and is declared to match the requirements of unbiased satellite chlorophyll estimation [9].
The OC5 algorithm was proposed by Ifremer [10]. This algorithm was developed in order to correct for the [CHL] overestimation brought by the standard OC3M algorithm in the Bay of Biscay and the English Channel. OC5 is a modification of the 3-band algorithm OC3M obtained by including the 412 and 547 channels. The effect of backscattering due to suspended matter on the ratios used as inputs in OC3M is revealed by the 547 channel, whereas possible atmospheric over-correction and the absorption by yellow substance and NAP are indicated by the 412 channel. The application of a lookup table, relating triplets

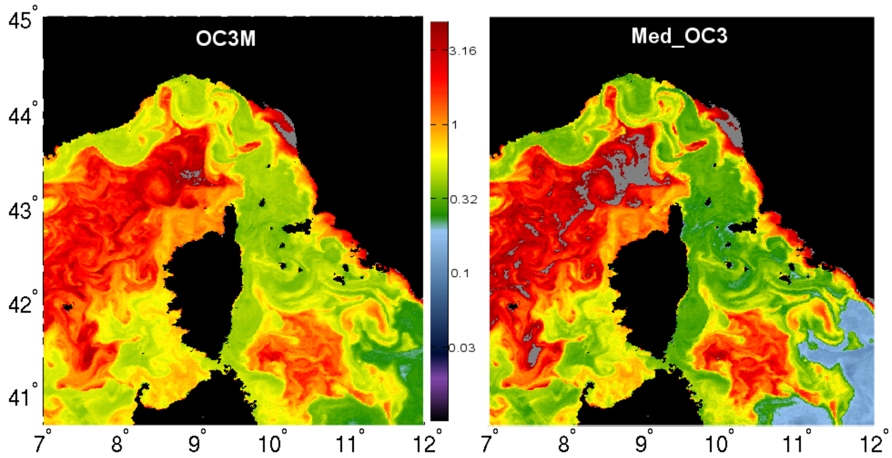

Figure 3: Estimated [CHL] maps obtained by OC3 and MedOC3 algorithms The scale is common for all maps.

	Average [CHL]	Regression slope	r	RMSE
Chl_a	0.13			
OC3M	0.23	1.35	0.607	0.12
MedOC3	0.19	2.3	0.537	0.32
OC5	0.23	2.07	0.725	0.19
SAM	0.15	1.35	0.607	0.11

Table 1: Accuracy statistics obtained for the four [CHL] algorithms described.

(OC3M band ratio, 412 and 547 bands) to chlorophyll a concentration, provides realistic concentration maps, and the algorithm performs well also for Case 2 waters.
The SAM_LT algorithm, recently proposed by Maselli et al. [11], is based on the simulation of a wide range of reflectances by varying the concentrations of the three optically active constituents. Next, a comparative analysis of measured and simulated remote sensing reflectances is performed in order to look for a minimum of a specific error function. This function is based on the cosine of the angle between the standardised vectors of measured and simulated reflectances. From a statistical viewpoint, this cosine is equivalent to the correlation coefficient between the two reflectance series. Similarly to this, it can vary from -1 (complete negative agreement) to +1 (complete positive agreement) and measures the similarity in shape between the two reflectance vectors without detecting amplitude spectral differences. In this way, the algorithm is insensitive to amplitude variations of the mea-

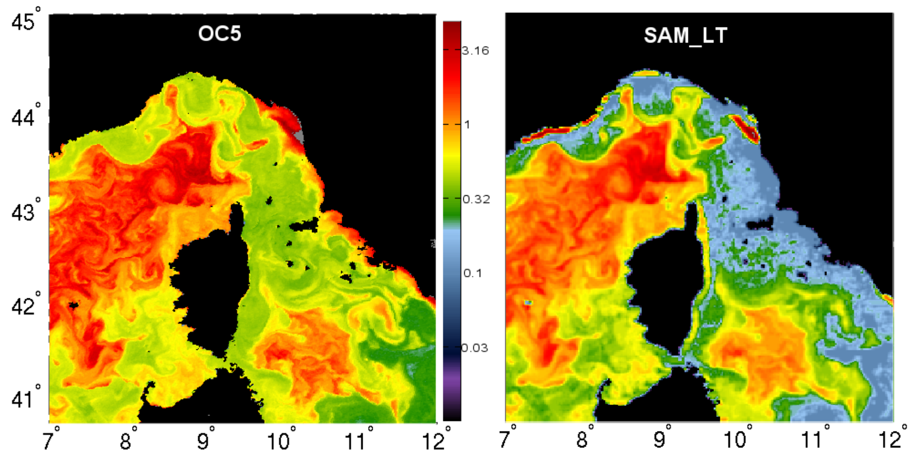

Figure 4: Estimated [CHL] maps obtained by OC5 and SAM_LT algorithms The scale is common for all maps.

sured reflectances, which may be due to the presence of seawater constituents with variable spectral properties and/or to inaccurate atmospheric correction of the satellite data [11]. Since all specific coefficients of absorption and backscattering coefficients used are obtained from a bio-optical survey of the Ligurian and North Tyrrhenian Seas, the algorithm has intrinsically a local validity.
The four algorithms described were applied to a series of Aqua MODIS images taken in 2010 in correspondence of in situ water samplings, as fully described in Lapucci et al.[12]. The comparison of measured and estimated [CHL] gave the results summarised in Table 1. In general, the standard OC3M and MedOC3 algorithms notably overestimate [CHL]. This tendency is also evident for OC5, while it is almost completely corrected by SAM_LT.
Examples of the maps obtained by the four algorithms are provided in Figures 3 and 4. Clear differences in estimated [CHL] can be noted, especially for coastal, case 2 waters, where the standard algorithms are known to be inaccurate.
An 8-day chlorophyll a average is computed by an operational chain processing MODIS AQUA data by the MedOC5 algorithm, and is available on LaMMA website http://www.lamma.rete.toscana.it/.

3 The regional scale modelling component

The hydrodynamic model is based on a regional implementation of the Regional Ocean Modeling System (ROMS), an incompressible, free surface, hydrostatic, primitive equation circulation model [13]. ROMS uses a generalized vertical, terrain-following coordinate system (s coordinate); a pre-operational configuration has been tested using a vertical mixing parameterization based on a Mellor-Yamada 2.5 scheme in the vertical, while the horizontal mixing parameters, similarly to others

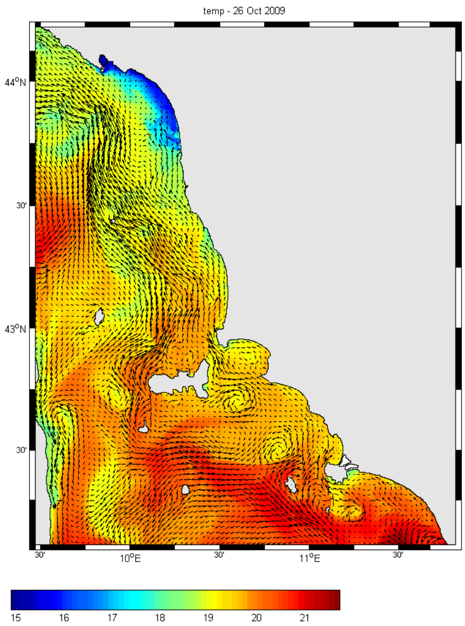

Figure 5: Numerical model results for the 26 October 2009 temperature field (colors) and the corresponding current velocities (arrows).

regional high resolution models, are intentionally taken zero since an internal numerical diffusivity of the advection scheme can hide that of the horizontal turbulence. Air-sea interactions are imposed using fluxes derived from the WRF operational model (at 3 Km resolution) available at LaMMA. Turbulent fluxes are estimated with the COARE algorithms [14]. All the main rivers are included using near real-time flow measurements furnished by the Hydrological Service of the Tuscany Region.
The model has a 400 m horizontal resolution and 30 vertical levels. Such a high resolution has been decided with the aim to model submesoscale dynamics (such as eddies, filaments, fronts), that have been shown to have a strong influence in biogeochemical cycles (such as the nutrient-bacteria-plankton cycle, Koszalka et al. [15]). Moreover, since regional hydrodynamics strongly depends on the real density distribution, and accurate mesoscale data from larger scale runs are needed, it has been decided to take external boundary conditions to the Regional model from the MENOR model, based on the MARS3D code and currently run by IFREMER (partner of MOMAR) at a 1.2 Km resolution over the North-Western Mediterranean Sea. A similar 400 m resolution model around the whole Corsica region is run by IFREMER, whose area is partially superimposed to that of the Tuscany model: a work of model intercomparison and intercalibration is under development as a com-

mon research effort of the French and Italian groups.
To handle the external information and specify open boundary conditions, an adaptive nudging technique, developed by Marchesiello et al. [16], is used. Radiation conditions are used to determine whether an open boundary condition is passive (outward propagation) or active (inward propagation): in the active-boundary case the solution is strongly nudged towards external data, while such nudging is far weaker (by a factor of 10) in the passive-boundary case (meaning that nudging on inflow is much stronger than on outflow).
In the model area, between the Northern Tyrrhenian and the Ligurian sea, the main fluxes which enter the domain through the southern boundary, are northward directed. This is due to both prevailing winds which are the south-west and less frequently the south-east, and to the Tyrrhenian large scale circulation which determines the presence of a cyclonic circulation on the Southern edge of the model. Such a flow, which mainly moves along the Eastern Corsica coast and passes through the Corsica channel, giving an important contribution to the so-called Liguro-Provençal current, is not obviously constant but comes with a great seasonal variability. On the eastern boundary an inward flux may enter the area due mainly to locally westerly winds (in typical large scale atmospheric cyclonic circulation in the western europe), which eventually separates and determines an anticyclonic gyre south of Cap-Corse. The overall circulation on the area is organized in a series of cyclonic and anticyclonic eddies, whose structures have been observed both from the analysis of hydrographic data and satellite data (such as altimetry, ocean colour, SST). Mainly in the northern Tuscany coast, an important contribution is shown to come from the three main rivers (in the order, Arno, Serchio and Magra), which induced a (northward) buoyant coastal current. Anticyclonic gyres and Ekman pumping mechanisms, mainly forced by wind, come with this circulation, confirming that in the area important vertical exchanges between water masses take place [17]. As an example of model calculations the 26 October 2009 temperature field and the corresponding current velocities are reported in Figure 5.
Ocean models require a careful calibration of parameters for turbulence, bottom friction, atmospheric forcing. This can be at least partially overcome, by the use of field surveys even guided by the modelling requirements. To accomplish this need, in the project MOMAR specific measurements campaigns have been designed, as an important project result by itself, in order to provide hydrographic, biogeochemical and current meter data measured extensively on the area. Some smaller campaigns have been carried out to verify an ADCP vessel mounted configuration and to get some current profiles in order to calibrate the model. The major campaigns are planned for 2011, with the support of the ship “l’Europe” by IFREMER (May 2011), using such ADCP towed methodology, CTD and biogeochemical profiles, and AUV (Autonomous Underwater Vehicle) measures. A later campaign has also programmed (September 2011) mainly using lagrangian measurements (drifters and floats) on the Tyrrhenian part of the Tuscany Archipelago.
The numerical results of the operational model are planned to be published by June 2011 on the LaMMA website. This will eventually be the basis for a later configuration of a biogeochemical model of the

area, which will benefit of the result of the biogeochemical measurements taken during the project and to the satellite data which have been described in the previous chapters.

4 Concluding remarks

In this paper an ongoing work describing a prototypal system for monitoring sea water in the Tuscany regional sea has been described. Such a system includes both observational and modelling components. Remote sensing observations for chlorophyll and SST have been successfully implemented and run operationally in Real Time and Near Real Time. Since more accurate chlorophyll estimation is essential to biogeochemical/ecosystem models, a new algorithm – SAM_LT – has been calibrated and tested over the examineted area, and also the OC5 algorithm, which also shows promising result in the study area. Such products will be operational by the end of the MOMAR project. A regional ocean model has been implemented over the Tuscany Sea area and will be the basis for a future biogeochemical model of the area. These models take initial/boundary conditions from external data model, provided by IFREMER. Satellite data previously described will be used for calibration purposes, together with a large set of in-situ data that will be collected in the framework of MOMAR campaigns.

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Operational Observing and Forecasting System for Dissolved Oxygen and Environmental Parameters in the Northern Adriatic Sea

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Abstract

The northern Adriatic Sea (NA) is affected by strong anthropogenic pressure, superimposed to a large river runoff. The consequent pressure exerted on the NA ecosystem either triggers or worsens negative phenomena like anoxic/hypoxic events. During the summer-autumn period, the NA is often exposed to these events, which can be categorised as either coastal (relatively frequent south of the Po River delta during the summer) and offshore (rare, affecting wider areas).

An operational system for monitoring and forecasting anoxic/hypoxic events has been set up in the framework of the EU LIFE "EMMA" project.

The system is composed of a meteo-oceanographic buoy; a numerical prediction system based on the Regional Ocean Modelling System (ROMS), including a Fasham-type module for biogeochemical fluxes; and oceanographic surveys. Every day since June 2007, the system provides 3-hourly forecasts of marine currents, thermohaline and biogeochemical fields for the incoming three days. The system demonstrated its ability to produce accurate temperature forecasts and relatively good salinity and dissolved oxygen forecasts.

The Root Mean Square Error of the dissolved oxygen forecast was largely due to the mean bias. The system is currently being improved to include a better representation of benthic layer biogeochemical processes and several adjustments of the model. While developing model improvements, dissolved oxygen forecasts were improved with the removal of the 10-day mean bias.

1 Introduction

The northern Adriatic (NA) Sea represents a very small portion of the total area of the Mediterranean Sea, and it is very shallow, with an average bottom depth of approximately 35 m. The hydrology and dynamics of the NA are primarily influenced by meteorological forcing, thermal variations and river runoff. Bora and Sirocco are the most frequent winds in the area and often generate strong windstorms, which are able to introduce relevant modifications to the NA mean circulation.
Despite its limited volume the northern Adriatic receives 20% of the total Mediterranean river runoff and this significant contribution of freshwater and nutrients comes mainly from the Po river whose annual average flow rate is approximately 1500 m^3s^{-1}. In autumn, intense cooling and evaporation processes, usually associated with Bora wind events over the NA, create conditions causing dense water formation during the winter.
The NA Sea is one of the most biologically productive regions of the whole Mediterranean, and it it has been affected at different times and ways by phenomena such as eutrophication, onset of massive mucilaginous aggregates, hypoxic and anoxic conditions. Hypoxia is usually defined as occurring in regions where dissolved oxygen concentrations are less than 2 $ml \cdot l^{-1}$ (equivalent to 2.8 mg l^{-1}). This concentration is the lower tolerance limit for many benthic species. The formation of a hypoxic bottom layer in wide areas of the watershed can cause major ecological problems such as the mass mortality of marine animals, defaunation of benthic populations and a decline in fisheries production with a strong impact on the considered regions.
In particular the Po River delta area can be regarded as a favourable environment for the development of hypoxic conditions.
To improve understanding of these phenomena and at the same time meet the needs of local authorities to get information and reliable predictions about their evolution, we have implemented an operational system for the observation, monitoring and short-term forecasting of hypoxic events in the Romagna coastal area (south of the Po River Delta, northern Adriatic Sea), thanks to the support of European LIFE project ”EMMA”.
The observational component of the EMMA operational system consists of a meteo-oceanographic buoy; the predictive system is based on 3D hydrodynamic numerical model, the Regional Ocean Modelling System (ROMS), coupled with a module for biogeochemical fluxes; periodic oceanographic surveys complement the system. The system is described in more details in Russo, [1].
Different kinds of models have been used to forecast hypoxic events in some areas of the world, Justić et al. [2] report a wide review for a relevant area such as the northern Gulf of Mexico. In particular Hetland and DiMarco [3] used ROMS model with a parameterisation of biological activity through various simple respiration models (rather than a biogeochemical flux model such as done in our implementation) for modelling the Texas-Louisiana shelf; they found that evolution of hypoxic events in the Gulf of Mexico results primarily from vertical processes, while advection of hypoxic waters in other shelf region did not appear a relevant factor. In the NA scales involved are much smaller than in the Gulf of Mexico, and studies of the Emilia-Romagna Region Environmental Agency indicate that advection of hy-

poxic waters provides relevant contribution to the development of hypoxic phenomena along the Emilia-Romagna coastal area; for such reason we used ROMS with the biogeochemical module.

2 Materials and methods

2.1 In situ measurements

With the support of the EMMA project, the meteo-oceanographic buoy E1 was deployed by ISMAR-CNR (Bologna) in August 2006 using the R/V Dallaporta, about 6 km off the coast of Rimini on a bottom depth of 10.5 m. The buoy is equipped with meteorological sensors for air temperature, air pressure, wind speed and gusts, wind direction, relative humidity, and net solar radiation.
Data are recorded every 15-30 min and transmitted real-time via cellular and Internet connection to the ISMAR-CNR Bologna at intervals between one and three hours.
During an EMMA oceanographic cruise conducted in the NA from the 21st to the 24th of May, 2007 onboard the R/V Dallaporta, 123 CTD vertical profiles were collected; temperature, salinity and dissolved oxygen values acquired during this cruise were used to initialise the ROMS model.
R/V Daphne regular coastal monitoring performed monthly (biweekly in summer season) by the ARPA Daphne (Cesenatico) integrates the E1 buoy continuous data. Further oceanographic cruises performed by R/V Urania and R/V Dallaporta in the NA provided useful data for spatial extension of the E1 buoy information, for checking its sensors, for validating the model results.
Po River runoff data are measured by the Hydro-Meteo-Clima service of the ARPA – Emilia Romagna Region (Bologna, Italy) at the Pontelagoscuro site.

2.2 Numerical Models

The predictive system of EMMA operational system is based on three-dimensional hydrodynamic model, the Regional Ocean Modelling System (ROMS, http://www.myroms.org) coupled with a module for biogeochemical fluxes, the Fennel module; the whole system is described by Haidvogel, [4].
ROMS is forced by a limited area numerical weather prediction model, COSMO-17 (formerly LAMI), a local implementation of the Lokall Model (LM [5]). COSMO-I7 atmospheric model provided to the ROMS marine model short wave radiation, wind, air temperature, humidity, cloud cover and atmospheric pressure, needed to compute heat, water and momentum fluxes at the air-sea interface. The COSMO-I7 model is managed by the ARPA-EMR-SIMC, by the USAM (Ufficio Generale Spazio Aperto e Meteorologia of the Italian Air Force) and by the ARPA Piemonte.
The operational version of ROMS described in this work has been implemented and is being managed at the Dipartimento di Scienze della Vita e dell'Ambiente at Università Politecnica delle Marche (Ancona, Italy), and it is more deeply described in Russo, [1].
The model was initialised using an averaged field output of a diagnostic run in which temperature and salinity were held constant in order to lower the spin-up time. Such temperature and salinity fields originally came from objective analysis mapping of data collected during the May 2007 synoptic cruise (described in the previous section) combined with climatologic data

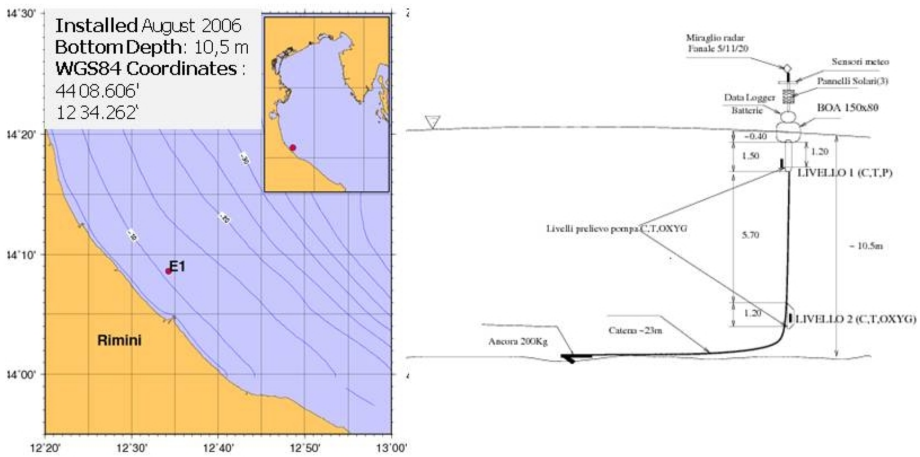

Figure 1: E1 buoy position (left) and its schematic (right).

for the southern part of the Adriatic basin. Also, the dissolved oxygen 3-D field was obtained by combining data measured during the synoptic cruise in the NA and climatological values elsewhere. The other biogeochemical variables were initialised by interpolating the output of the long-term simulation (5 years) conducted in the Adriatic Sea with a coarser resolution ROMS grid [6].

At Otrant Strait, the only open boundary, a radiation condition [7] is applied for all tracers; as hypoxic phenomena in the area of interest (NA) are mainly driven by Po river and local environment dynamics, we expected that such choice would not have had relevant effects on them along the time span of interest (few years).

Every day since June 2007, the system provides 3-hourly forecasts of marine currents, thermoaline and biogeochemical fields (including dissolved oxygen) for the incoming three days.

3 Results

The EMMA operational system has being providing real-time data (E1 buoy) and forecasts (ROMS hydrodynamic model with biogeochemical module) continuously since August 2006 and June 2007, respectively. Time series of raw data provided by the buoy and the corresponding output of model forecasts are shown (no filter or special processing has been applied) in Figures 2-5. Five minute data averages and corresponding instantaneous model outputs at three-hour intervals are showed for temperature, salinity and dissolved oxygen values.

The surface layer temperature (at a depth of 1.6 m) is presented in Figure 2. Minimum values of approximately 6 °C were recorded in January 2007 and 2008. Surface heating began at the end of February, with temperatures reaching values above 25 °C (up to 28 °C in 2008) in July and August of both years; some cooling was evident during July 2007, with tempera-

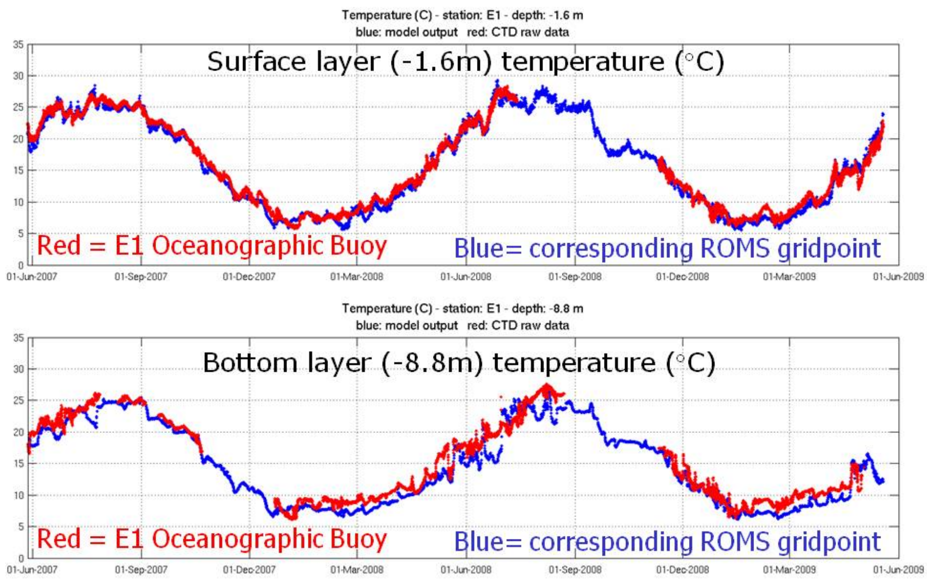

Figure 2: Time series of temperature (°C) from June 2007 to May 2009 at surface (1.6 m depth, upper panel) and bottom layer (8.8 m depth, 1.5 m above seafloor, lower panel) for the period from the 1st of June, 2007, until the 31st of August, 2008, as measured by currentmeter at E1 buoy and as forecasted by the ROMS model at the nearest model gridpoint.

tures of less than 25° C being observed for a few weeks. The period of autumn cooling began at beginning of September in 2007 (with a temperature drop of approximately 5 °C in roughly one week) and in mid-September of 2008 (with a temperature drop of almost 10 °C in a roughly two weeks). The temperature forecasted by the model (in blue) closely follows the temperature recorded by the buoy, showing good forecasting capabilities in the surface layer . The Root Mean Square Error (RMSE) of the model forecast was 0.90 °C over the whole period, with a minimum of 0.65 °C in the summer and a maximum of 1.02 °C in the winter season. The correlation between the measured and forecasted temperature was very high (0.993).

The bottom layer temperature (at 8.8 m depth) is presented in Figure 2. Temperature minima were reached at beginning of January 2008 and in January 2009, with values below 7 °C. Maxima were reached at the beginning of August 2008 and August 2007, with values of over 25 °C. The cooling period in both 2007 and 2008 began in September with a fairly abrupt drop of several degrees centigrade (approx-

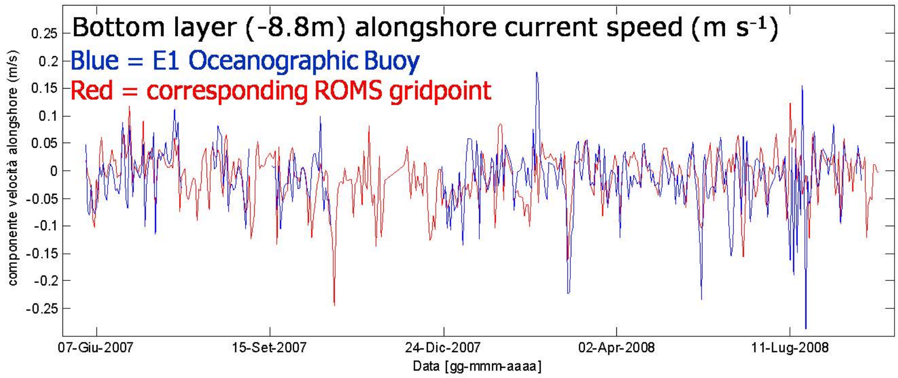

Figure 3: Time series of daily averaged alongshore current speed (m·s^{-1}, positive toward southeast) in the bottom layer (8.8 m depth, 1.5 m above seafloor) for the period from the 1st of June, 2007, until the 31st of August, 2008, as measured by currentmeter at E1 buoy and as forecasted by the ROMS model at the nearest model gridpoint.

imately 7 degrees in 2008 and 3 degrees in 2007). This cooling continued until the January minimum, at which point the temperature stabilised at approximately 7-8 °C until March when the heating period began. A sudden increase of several degrees centigrade was observed in mid-May 2008 and in the beginning of May, 2009. The model is able to forecast changes in the bottom layer temperature reasonably well nevertheless the observed temperature was often underestimated. The best model performances were obtained in the first part of the period (summer-autumn 2007) and from November, 2008 until January, 2009. The RMSE was almost double that of the surface, with an average value of 1.77 °C over the whole period, a minimum value of 0.98 °C during the autumn and a maximum value of 2.10 °C during the spring season. Instead, the correlation between the measured and forecasted temperatures remains very high (0.976).

Bottom currents are relevant to the development of hypoxia as they can enhance or reduce hypoxic events by means of the advection of waters that are either poor or rich in dissolved oxygen; hypoxic waters that may reach the Rimini area mainly flow parallel to the coast from the Po River Delta area (i.e., from the northwest). Figure 3 shows the daily averaged alongshore component of the bottom layer currents (positive values indicate southeast currents; daily averages are here presented in order to avoid readability problems caused by the tidal high frequency variability). The model correctly forecasted the current speed during several periods, while at other times the predicted direction of the current was incorrect. Generally, the forecasted bottom currents appeared to be underestimated, with a constant monthly mean bias of approximately -0.05 m·s^{-1} throughout the entire period. The RMSE remained at approximately 0.1 m·s^{-1}, except in July 2008 when it doubled. In July, 2008, the highest currents of the entire periods were recorded by the E1 buoy current meter, whilst the model did not show any anoma-

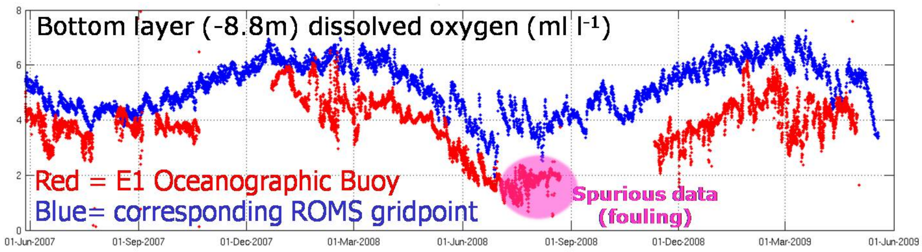

Figure 4: Time series of the bottom layer (8.8 m depth, 1.5 m above seafloor) dissolved oxygen (ml·l^{-1}) from June 2007 to May 2009 as measured by the E1 buoy and as forecasted at the nearest gridpoint of the ROMS model.

lous patterns. During this period, the E1 buoy was found to be heavily biofouled; such occurrence modified its buoyancy and very likely affected the current measurements.

Dissolved oxygen (Figure 4) was recorded at the E1 buoy in the bottom layer (8.8 m depth) only. Minimum values of less than 2 ml·l^{-1} indicated hypoxia and were reached in June-August 2008 in response to the marked increase in the June Po River runoff (though it should be noted that during July 2008, biofouling accumulated on the sensor and the data from this time period were thus not fully reliable). The model was able to forecast the general cycle of dissolved oxygen at the bottom during the entire study period, though the model performance was variable (the model performed quite well during the first months, but less well after the spring of 2008). The RMSE was 1.67 ml·l^{-1} over the two years, with a maximum value of 1.92 ml·l^{-1} in the autumn and a minimum value of 1.34 ml·l^{-1} during the spring season. The correlation between the measured and forecasted dissolved oxygen values was relatively good (0.730).

A more detailed quantitative analysis of the model performance has been conducted by means of the Mean Square Error (MSE) as follows: MSE = $< (m_i - o_i)^2 >$ where m_i = modelled values and o_i = observed values. According to [8], and [9], the MSE comprises contributions from the mean bias, MB = <m> - <o>, the standard deviation error, SDE = S_m - S_o, and the cross-correlation:

$$CC = \frac{1}{S_m \cdot S_o} \cdot \langle m_i - \langle m \rangle \rangle \cdot \langle o_i - \langle o \rangle \rangle,$$

$$RMSE^2 = MB^2 + SDE^2 + \frac{2 \cdot (1 - CC)}{S_m \cdot S_o},$$

where S_m and S_o are the respective modelled and observed standard deviations.

Results of the MSE analysis of dissolved oxygen measured by the E1 buoy and the corresponding modelled values are shown in the first panel of Figure 5. It is evident that monthly RMSE values were dominated by MB, which showed an initial increase and then appeared to stabilise during 2008 and 2009. The SDE, or amplitude error, indicates that the forecast had a feasible variability, with the exception of the late winter - early spring period when the modelled data showed less variability than measured data. The monthly correlation between the measured and forecasted dissolved oxygen was not high, and also

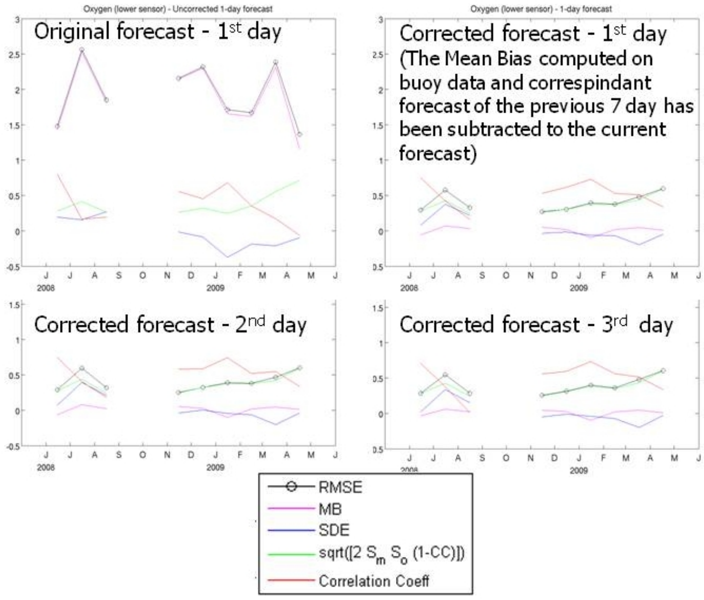

Figure 5: Monthly values of model-data error terms for dissolved oxygen at the bottom level of the E1 Buoy from June 2008 to May 2009; the first panel show the statistics of the uncorrected 24 hour forecast, the other panels show the correspondant statistics of the 24, 48 and 72 hour forecasts after correction by the mean bias computed over the previous 10 days.

showed negative values in August, September and December 2007.
As the mean square error (RMSE) was largely due to the MB, the variability of the processes was simulated correctly and the bias can be reduced by applying data assimilation techniques and by using post processing. Second, third and fourth panels in Figure 5 show same statistics as first panel after the MB computed over the previous 6 days has been removed from the 24, 48 and 72 hour dissolved oxygen forecasts. It is evident the strong RMSE reduction, and the forecast quality is preserved over the spanned 3-days. Figure 6 compared to Figure 4 shows an evident improvement of forecasted dissolved oxygen time series (obtained by removal of the MB iteratively computed over the previous 10 days).

4 Discussion

The EMMA system is a reliable tool that provides data and forecasts continuously in the Rimini area. Forecasts provided by the model showed a good performance for temperature, while performance for both the salinity and dissolved oxygen was not so strong.
Prediction of dissolved oxygen is weaker mainly because of the numerous limita-

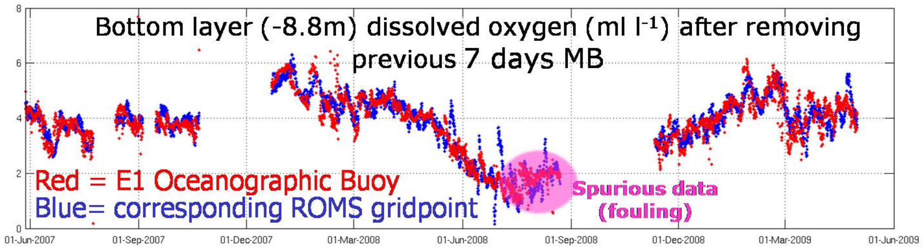

Figure 6: Time series of the bottom layer (8.8 m depth, 1.5 m above seafloor) dissolved oxygen (ml·l^{-1}) from June 2007 to May 2009 as measured by the E1 buoy and as forecasted at the nearest gridpoint of the ROMS model after being corrected for Mean Bias computed over the previous 7 days.

tions of biogeochemical module.

In addition, considering that nutrient concentration data were often not available (except for the Po river based on literature data), the riverine input of water and nutrients is rather inaccurate, as well as the nutrient input from the coast.

The current operational implementation was based on the consideration that in most situations in marine ecology, physical processes are the primary determinants of the biogeochemical dynamics, so when "simple" biological models are used in conjunction with an accurate representation of abiotic factors or rather coupled with sophisticated hydrodynamic numerical models (as ROMS model), they are capable of describing a large part of the system observed.

Comparisons with buoy data demonstrated the model ability to accurately forecast the surface temperature, while close to the bottom (at approximately 9 m) they showed a more evident deviation from observed values but still maintained a very high correlation with the observed values.

Forecasts of the bottom currents appear to underestimate the measured values at the E1 buoy in several cases in quite shallow waters (approximately 10 m depth); these currents could reflect effects, as wave-current interactions, which were not considered in the present model. For these reasons, improvements in forecasting hypoxia in addition to the biogeochemical flux module could be acquired also in other ways, e.g., by increasing the resolution and improving the turbulence parameterisation, air-sea fluxes, boundary conditions at the Otranto Straits (deducing them from AREG or MFS system), runoff from minor rivers, by coupling with a wave model, by the timely (preferably once a year in spring) re-initialisation from data measured during synoptic surveys in the NA.

The system is currently being improved to include a better representation of benthic layer biogeochemical processes, open boundary conditions and several adjustments of the model.

5 Conclusions

In the Mediterranean area the EMMA system is probably the first system that is able to produce operational 3-D short-term fore-

casts of hypoxia. Analysis of results and data comparison showed the persistent capacity both to monitor and to operationally forecast hypoxia in the short-term (3 days) in the Rimini area.
Despite the absence of data assimilation and the simple biogeochemical module, ROMS model has been able to forecast the dissolved oxygen in Rimini and in wider Emilia-Romagna coastal area with a reasonable degree of approximation for almost two years of continuous integration. On the other hand it is clear that, in order to produce more accurate forecasts of dissolved oxygen and other marine properties, the model would benefit from several improvements, which are currently being developed; while working on the latter ones, dissolved oxygen forecasts are improved by removing the Mean Bias computed on E1 buoy data collected during the 10 days before the current forecast release.

6 Acknowledgements

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An Integrated Marine Observing System in the Ligurian Sea

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Abstract

The Ligurian-Provencal basin plays a fundamental role in the climate and in the circulation of Mediterranean regions and, consequently, it has been object of intense scientific investigations since sixties. In order to better understand the peculiarities of this basin, an integrated marine observing system, composed by two fixed buoys (one offshore and one coastal) and two sub-surface moorings is working in an operational way in the Ligurian Sea. This work aims at describing the two fixed platforms setting up the Ligurian Sea integrated marine observing system and at evaluating the need to maintain the observatory in order to guarantee continuous acquisition of data suitable for scientific and technological improvements. The different technical solutions adopted for each buoy according to their specific employment are here described. Some years of operation have proved that both systems are able to satisfactory run for long periods, thus providing reliable long term time series of marine environmental parameters. Results so far obtained and the potentialities of the joint use of the two buoys are enlightened.

1 Introduction

Continuous marine environment monitoring represents one of the main topics for the oceanographic community involved in models developing and in the analysis of climate changes.
The space-time scale of the phenomena to be investigated, the need of resources in terms of researchers and equipped vessels and adverse meteo-marine conditions make difficult collecting long time series of data. However, the needs for an efficient network of environmental observations and data dissemination systems addressed to a large range of users, from scientists to local authorities, is nowadays generally well and widely recognised. To this end, several efforts are made all over the world to improve quantity, quality and availability of data and information and to foster collaboration among the different actors involved in these processes.
Part of the problem might successfully be overcome by using permanent custom-made facilities. Fixed or floating installations in general, and buoys in particular, are the only means for in situ collection of

data series over long periods of time even under heavy sea conditions. Such systems may provide valuable information for observations, modelling and analysis of marine and ocean parameters that support operational ocean activities such as fisheries, recreational boating, natural hazards warnings, search and rescue operations, marine activities, as well as scientific inquiry, thus contributing in a wide sense to the objectives of operational oceanography.

Through an ocean observing system different user groups can receive accurate descriptions of the present state of the oceans including living resources, continuous forecasts of sea conditions, and estimates of climate change indicators.

Furthermore, despite of significant construction and management costs of the platforms, data collected with buoys, or permanent installation in general, have the lowest unit cost taking into account the expected lifetime of such platforms.

2 Scientific and Technological Aspects

The Ligurian-Provencal basin, for its role in the climate and in the circulation of the Mediterranean region, has been object of intense scientific investigation since the sixties [1]. During winter, processes of dense water formation often occur; strong air-sea interaction processes greatly affect both atmospheric and marine circulation, determining a strong variability in the upper ocean thermocline [2]; its productivity is very high and its ecosystem very rich and complex. In this basin, an international treaty for the delimitation of an area (the so-called ”Cetacean Sanctuary”) has been signed and new protected coastal areas and marine parks of environmental value have been created to preserve the richness and variety of the environment. All these aspects make the Ligurian sea an interesting research site for oceanographers, physicists, and biologists.

Besides the environmental and scientific aspects mentioned, the Ligurian basin and its coastal area are important for national marine and maritime activities such as, among the others, underwater defence and surveillance technologies development, monitoring tools, shipbuilding, tourism, etc. In order to provide, both local and international community, with effective solutions, to promote innovation and pre-competitiveness of activities related to maritime industrial research and to enhance the value and visibility of excellence in areas concerning marine technology, the Ligurian District for Marine Technologies (DLTM) has been created as an answer to the local versus global needs of marine products innovation, technology and science. It is a joint-venture among local and national private and public companies working in the marine and maritime business with research institutions.

3 The Integrated Marine Observing System

Several fixed platforms operate regularly in the Ligurian basin making them possible candidates for future national investment in marine monitoring systems, for fostering innovative monitoring technologies and becoming natural outlets for direct appliance of new research and industrial products.

In particular, two integrated systems exist: one off-shore, located in the centre of the Ligurian Sea and constituted by the ODAS

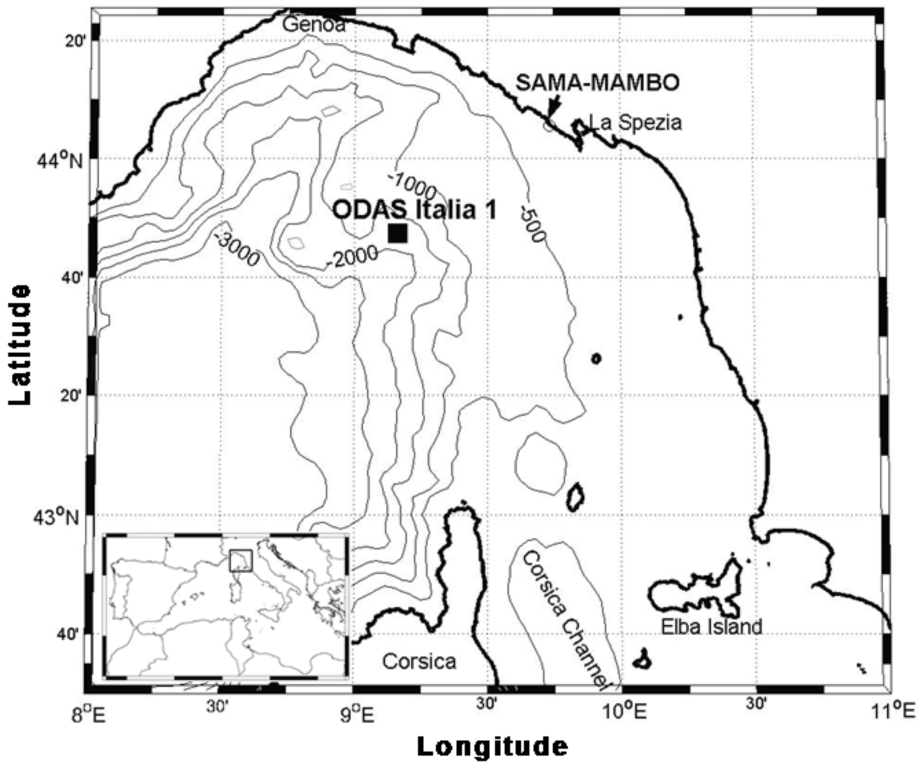

Figure 1: Position of the fixed platforms part of the Ligurian Sea integrated marine observing system.

Italia 1 buoy and a deep-ocean sub-surface mooring, and the other on the eastern coast of Liguria based on the SAMA-MAMBO buoy and on a shallow water sub-surface mooring deployed in front of Riomaggiore in the marine national park of Cinque Terre [3] (Figure 1).

Although originally designed for different scopes and to operate in different environmental conditions, the integrated use and exploitation of these two buoys, in addition to the periodic oceanographic campaigns and to the fixed moorings deployed in the area, provides an effective and quite unique marine observing system in the Italian seas.

3.1 The ODAS Italia 1 Buoy

The "ODAS Italia 1" (Oceanographic Data Acquisition System) off-shore observing system represents the only European example and one of the few in the world of spar meteo-oceanographic buoy [4].

The current research project was based on previous significant experiences made in the past 40 years by CNR in the field of equipped buoys to meet the needs of the scientific community.

Figure 2: The operation of launching at sea the ODAS Italia 1 buoy in April 2008.

This platform is one of the oldest marine observing system developed by CNR: it was designed in 1969 by CNR-ISDGM, now CNR-ISMAR, for meteorological data acquisition and deployed in the Gulf of La Spezia, initially along the coast and then in the open sea.
Between 1969 and 1991, the buoy was moored in different positions in the open Ligurian Sea. During this long period of time, several research groups took care of the maintenance and development of the platform and even aims and research objectives changed accordingly. In particular, in 1978 the technical coordination was assigned to the CNR ship Equipment Research Group and the implementation of the research project to the CNR-IAN (now CNR-ISSIA).
During its long lifetime the buoy was used for a plenty of research objectives, from the original one more related to naval engineering aspects to the general acquisition of meteorological parameters. In the 70ies, it was also used for development and construction of components to be used on buoys in order to draw the attention of industries to this type of activity: first on board electronic acquisition and radio transmission systems were tested within that framework. Later on, regular acquisition of meteorological parameters continued coupled with a new ecological interest related to the macrofouling growing along the buoy body. Most of this work has been loosed both for the lack of a specific in-

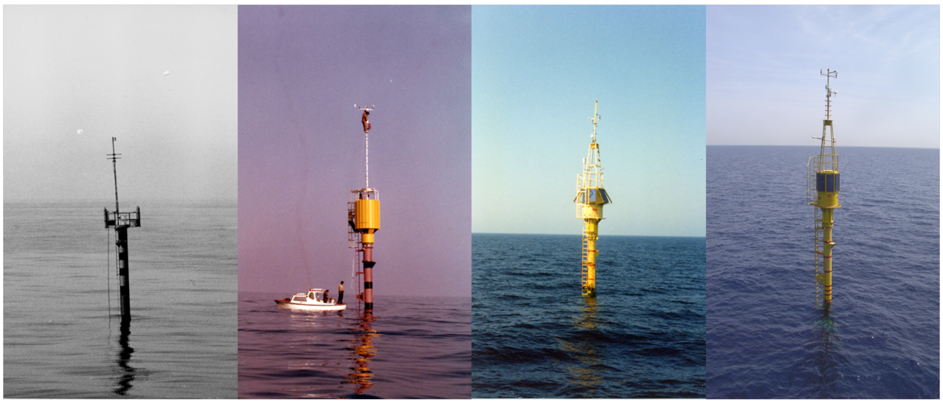

Figure 3: The upper works of the ODAS Italia 1 buoy as it varies along the times from 1970 till now.

terest in preserving the old experiences as well as for the dispersion of people that worked on the past projects. Starting from late 90ies, the use of the buoy was laid to one of the original aims becoming one reference point for the acquisition of meteorological and oceanographic parameters. [5].

It also spent some periods into dockyards both for lack of interest and for maintenance also due to accidents: being permanently moored at sea since about 40 years, the buoy experienced some accidents, the more recent ones are the break of the mooring line in 2001 and 2007, and the collisions with un-indentified ships occurred in 1991 and 2007.

Due to last mentioned accidents in 2007, the buoy was recovered into a dockyard for the repair of the damages. With the invaluable support by the CNR-UPO (Ufficio Programmazione Operativa) and the cooperation with the Italian Navy, the buoy was recovered into the Arsenal of La Spezia (Figure 2). The top trellis was completely rebuild and even the damages to the underwater part were repaired, so that after few months, the buoy was launched again at sea and repositioned at the center of the Ligurian basin.

It is currently moored at the centre of the Cetacean's Sanctuary, in the open Ligurian Sea between Genoa and Cape Corse (43°49.25'N; 9°06.77'E) on a deep sea bed (1200 m), 35 nautical miles far from the coast. The project has two aspects: a technological and methodological approach, for the development of equipment and systems for wide range environmental monitoring and an oceanographic and ecological approach aiming at getting a thorough picture of the area and related problems.

The hull of the buoy is yet the original one. The buoy consists of a main 40 m long steel pole body divided into four sections firmly joint by flanges and bolts. The three upper sections are water-tight, and one of them, the one in the middle, has a thicker portion to improve buoy stability and buoyancy. The fourth section, the deeper one, is filled with water and has a stabilizing disk which, for the significant mass of water it moves, dampens the buoy vertical motion. A ballast hangs from below this segment.

At 6 m above the mean sea level there is a small space. This upper part of the buoy was the only one that periodically was renewed (Figure 3) in order to accomplish new requirements for the research work and to follow the technological improvements. Actually, it is a closed space containing the electronic system for powering the instrumentation, controlling and acquiring the measurements. Inside, few people can work during the maintenance activities. On the top, a tower reaching a height of about 15 m above the mean sea level supports all the meteorological instruments, the light and the antennas.

The buoy is maintained in position by a slack mooring line.

The buoy was originally designed for air-sea interaction studies and for collecting meteorological data even in rough sea: for these reasons one of the main structural characteristic is its stability with respect to the other more classical approach based on discus-shaped buoys [6].

Since 1991 the buoy was equipped to collect information on meteo-marine as well as biological parameter and gain more insight into the ecosystem.

During the years, CNR-ISSIA also cooperated with several SMEs in order to fit the buoy with efficient and reliable measuring and acquiring systems, however, since 2004, the whole on board electronic equipment have been developed and customized at CNR-ISSIA.

The meteorological set of sensors is composed by a precision spectral pyranometer, a precision infrared radiometer, a sonic anemometer, a barometer, a thermo-hygrometer and a compact meteorological station measuring atmospheric pressure, wind speed and direction, dry temperature, relative humidity and also rainfall. Marine sensors set includes six temperature and two conductivity sensors positioned along the buoy body between -0.5 and -36 m, a multiparametric probe installed at about -36.0 m depth close to the damping disk [4]. A wave meter system has been developed at CNR-ISSIA composed by three echosounders installed upward looking at about 10 m depth on supports spaced 120° [7].

Other measurements, defined as service measurements (i.e., current produced by solar panel and wind generator, GPS position, case temperature, etc.), are acquired.

All the measurements are collected by a control and acquisition system whose core has been built around an embedded intelligent controller for reliable distributed or stand-alone deployment with industrial ratings for what concern temperature range, shocks and vibration. This system allows the complete control, acquisition and pre-elaboration of all data collected onboard.

The transmission system provides the necessary tools for exchanging commands, information and data with the remote system ashore and it is based on a standard GSM modem and on a satellite modem using the Globastar constellation. Acquired data are processed in near-real time by applying quality control procedures developed within the framework of the European project "Mediterranean Forecasting System: Toward Environmental Predictions" (MFSTEP) [8].

The web site http://www.odas.ge.issia.cnr.it is dedicated to the observatory and contains a summary of the last received data and several plots of past time series (last 24 hours, last week, last month) regularly updated.

On a daily basis a subset of received data 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 WMO's Global Telecommunication System (GTS) with the identifier WMO61010 making "ODAS Italia 1" the first offshore buoy to fed the GTS with meteo-oceanographic data from the Italian seas. This activity has been promoted by the National Group for Operational Oceanography (GNOO) and the service was set-up by the Meteorological Service of the Italian Air Force which is the deputy institution to operate the GTS system at a national level.

3.2 The SAMA-MAMBO Buoy

The SAMA MAMBO buoy 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 the sea water.

Since 2002 it was moored in front of Riomaggiore in the "Cinque Terre Marine Protected Area" at a sea depth around 30 m with the main aim to test the performance of such a system on long periods of operation and to evaluate its capabilities for environmental monitoring application. It is composed by an hexagonal toroidal and hollow float bearing an aluminium tripod tower with steel stands (Figure 4) and it is moored with a three lines mooring.

The main body of the float, entirely realized in stainless steel, is partitioned so as 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 three others around. 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.

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

The buoy instrumentation, the profiling system, and the communication are managed by a controller which 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 ashore receiving station. Data transmission is automatically triggered by the telephone call from the land station located in the ENEA Marine Environment Research Center. In case of communication failure, the time slot is expanded to allow for the completion of the data transfer.

The system configuration as well as sampling and transmission scheme can be modified by remote access from the land station or in situ via the on board controller. The most valuable feature is the profiling system, 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. 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 reduce biofouling.

The meteorological parameters measured on the buoy are air temperature, atmospheric pressure, wind speed and direction. To compensate for the small rotation of the buoy, an electronic compass is included in the anemometer to measure the true direc-

Figure 4: The SAMA-MAMBO buoy at sea in front of Riomaggiore.

tion of the wind. The meteorological station has an internal memory and communicates via RS232 interface with the buoys controller.
Meteorological parameters are sampled according to WMO (World Meteorological Organization) standards that specify a time window of 10 minutes each hour. The sampling rate is 1 Hz for all the parameters: average values of air temperature, atmospheric pressure, wind scalar and vector speed are computed from the 600 samples, wind gust is the maximum value in the time series.
The multiparametric probe provides 25 cm resolution profiles of sea temperature, pressure, conductivity, dissolved oxygen, fluorescence and pH in the water column between 1.5 m and 25 m. Hydrological profiles are performed every three hours and data are transmitted in real time to the land station.
The acquired data are automatically processed in near real time before being

archived and displayed in 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 [9] 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. Last received multiparametric profiles and meteorological measurements as well as the data of the past seven days are made available through web page (http://www.santateresa.enea.it/wwwste/dationline/dationline.html).
The complete time series are stored in the ENEA-CRAM environmental data-bank.

3.3 The deep-sea mooring

In order to extend the capabilities of oceanographic measurements at higher depths with respect to the ones made possible by using only sensors attached to the body of each buoy, two mooring lines are deployed close to the surface buoys.
They are in general equipped with an upward looking acoustic current profiler measuring currents in the upper 80 m of the water column and with several conductivity-temperature-pressure sensors at different depths.
Sensors on the mooring line operate in an autonomous way with a sampling rate of few tens of minutes.
The deepest sensor on the mooring close to the ODAS Italia 1 buoy is acoustically linked to the surface buoy, so that data from this sensor are available in near real time in the same way as the measurements collected by sensors on the buoy.
Data from the other sensors are collected periodically during maintenance operations, when the mooring lines are recovered and redeployed.

4 Discussion

The long time series of observations so far collected have been used in several applications.
Data from the ODAS Italia 1 buoy were successfully used for air-sea interaction studies [10], for the validation of satellite measurements [11] as well as of forecasting model results [12] and it is part of a Mediterranean monitoring network for Operational Oceanography [13].
The SAMA MAMBO buoy has been recognised as an appropriate tool for monitoring the dynamic and environmental conditions of the coastal area. The joint use of coastal and open sea data allows to approach a more comprehensive study of the whole area with particular attention to the interactions between coastal and open sea dynamics.
For example, the benefit was evident in the investigation of the effects at sea of the anomalous hot summer of 2003 (Figure 5). The data collected by the two buoys permitted to investigate what happened below the sea surface, how this phenomena affected at different degree the coastal and the open sea area and to follow the evolution and the response of the ocean-atmosphere system to that particular event [14].
Also the analysis of the episodes of mass-mortality, which in the Ligurian Sea seems to occur more frequently in the last decade, can be supported by the joint use of the two monitoring systems [15].

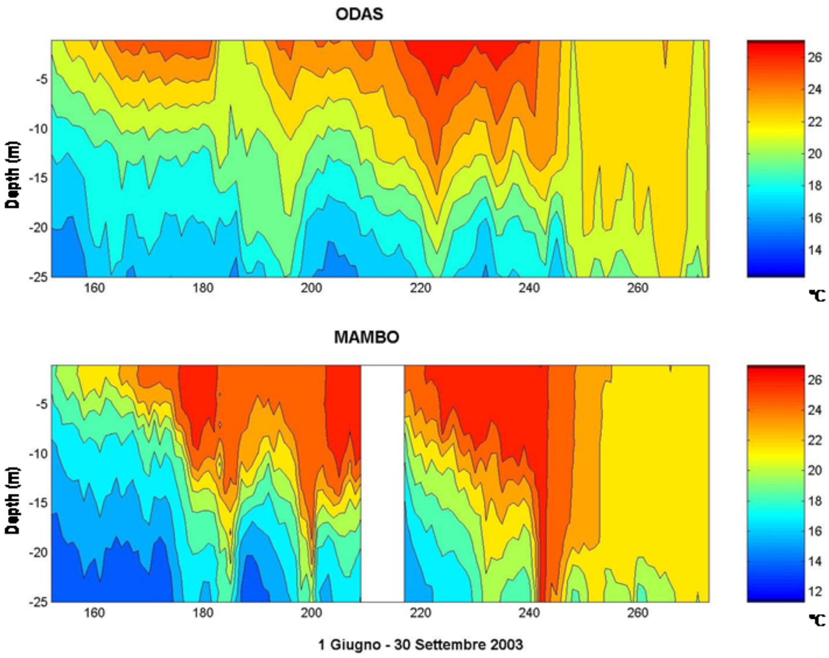

Figure 5: The water temperature profiles related to the anomalous hot summer in 2003 as measured by the two monitoring systems.

Even if the two systems share the same scientific objectives in operational oceanography, consisting in the acquisition of long term series of meteorological and marine parameters for the sea state monitoring, an assessment of the two systems can be also performed in the technological domain.

For example, the two buoys differ in the methods used to perform measurements at sea: both techniques show advantages and some drawbacks. The main advantage of the profiling system of the SAMA-MAMBO buoy consists in the high vertical resolution of the measurements and the possibility to easily substitute the probe without the need of divers, which is particularly important in the case of sensors that must be frequently changed. On the contrary, autonomous mechanical device at sea always pose some problems in terms of energy consumption and malfunctioning. The ODAS Italia 1 measuring method allows the collection of data at only few fixed depths and it requires the intervention of a diving team to replace the sensors but with a longer lifetime.

It is noteworthy the contribution that, within the framework of the National Group for Operational Oceanography, the data collected in near-real time by such observing systems may provide to the calibration and validation processes of the numerical models.

Important results have been also obtained for what concern the communication techniques that have been specifically devel-

oped and applied in the two systems. The ODAS Italia 1 buoy is equipped with a double transmission system (GSM and satellite) both using the same type of protocol for data transmission. By using this techniques, more than 93% of data have been successfully transferred to the station ashore within 6 hour from on board collection, thus making them useful for data assimilation into the forecasting models and for near-real time distribution.
Unfortunately accidental and deliberate damages should be taken into account when evaluating the costs of such systems, both due to deliberated vandalism acts as well as due to inobservance of naval prohibitions and regulations.
Operating at sea structures such as these buoys requires systematically huge effort of qualified work both at sea and in the laboratories, which should be justified by the obtained results.
Routinely maintenance mainly depends on the measured parameters and on the season: it would require a bi-monthly replacement of the multiparametric probe during summer period, when the fouling strongly corrupts the marine sensors, and a yearly inspection of the structure and of the mooring line.

5 Conclusions

The described integrated observing system is nowadays a reference site both in national and international context. Indeed, the coastal site has been involved into local projects promoted by the Protected Area of Cinque Terre whereas the off-shore one is currently part of the EuroSITES project [16]. Both the systems participated to the "Ligurian Air-Sea Interaction Experiments", a joint research program among national and international institution carried out in the Ligurian Sea in 2007 and aiming at the evaluation and the development of parameterizations of the oceanic and atmospheric boundary layers and their interactions [17].
The availability of near-real time data is extremely useful for several applications in the oceanographic field not only for the assimilation of the observations into the forecast models but also for the numerical models validation and calibration.
The described observing systems, able to continuously monitor and survey the meteo-marine environment in near real time, can be also of support to the local navigation or in case of environmental emergencies such as oil spill or extreme weather conditions.
The research groups leading the scientific aspects also took care of outreach activities. Among them, several events were organised in order to promote and disseminate to a wide public the multidisciplinary research related to the Ligurian Sea integrated marine observing system [18].

6 Acknowledgements

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The financial support of the CNR Ufficio Programmazione Operativa taking care of the naval security issues of the ODAS Italia 1 buoy is gratefully acknowledged.

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Implementation of a Meteo-Marine Forecasting Chain and Comparison between Modeled and Observed Data in the Ligurian and Tyrrhenian Seas

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Abstract

An operational meteo-marine forecasting chain for the whole Mediterranean area has been implemented for both scientific and operational purposes at Consorzio LAMMA (Laboratory of Monitoring and Environmental Modelling for the sustainable development). The atmospheric component of the chain is constituted by the Weather Research and Forecasting Model (WRF), while the marine component is constituted by the full-spectral third-generation ocean wind-wave model WaveWatch III (WW3). In this work the outputs of WW3 model are compared to data collected from two buoys, recently installed in the Ligurian and Tyrrhenian seas by the Hydrological Service of Tuscany Region, over a period of some months. Modeled wind data are compared with available data from coastal weather stations in the area, over the same period. The modeled data show good correlation with the observed dataset and demonstrate a good capability of the implemented models to give reliable wind-wave forecasts in the Ligurian and Tyrrhenian seas.

1 Introduction

Wind waves affect many human activities, therefore, their study, observation and prediction are a fundamental task of any weather forecasting center. In this context, at European level we have the European Centre for Medium-Range Weather Forecasts (ECMWF) wave forecasting system, based on WAM model [1] (www.ecmwf.int/products/forecasts/ wavecharts/index.html#forecasts), that delivers 0.25 deg resolution wave forecasts for the whole Mediterranean Sea. Wind and wave model data from the ECMWF have been also used for the preparation of an atlas of the wind and wave conditions in the Mediterranean Sea [2].

Other, higher resolution, wave forecasting systems are those implemented by the Operational Oceanography Group of CNR-IAMC Oristano (www.sos-bocchedibonifacio.eu/GOO/wave.htm), based on meteorological forcing from the University of Athen's SKIRON model (forecast.uoa.gr/forecastnew.php) and the WWMII wave model, based on the SWAN coastal model of the Delft university of Technology and integrated in the SHYFEN hydrodynamic model developed by CNR-ISMAR Venice (sites.google.com/site/shyfem/project-definition) [3], which delivers wind and wave forecasts over Sicily Strait, Bonifacio Strait and La Maddalena Arcipelago and over the western Mediterranean Sea. Another relevant implementation, based on WAM model is that developed by CNR-ISMAR, in collaboration with CNMCA (www.meteoam.it/modules/Nettuno/nettuno.pdf) (), that runs at high resolution over the whole Mediterranean Sea, with forcing from the atmospheric model COSMO-ME (www.cosmo-model.org/).

An operational meteo-marine forecasting chain for the whole Mediterranean area has been implemented at Consorzio LAMMA (Laboratory of Monitoring and Environmental Modelling for the sustainable development), which is a consortium between Regione Toscana and National Research Council (for more information see: www.lamma.rete.toscana.it). The forecasting system consists of a meteorological component, based on the WRF-ARW atmospheric model, developed at the National Center for Atmospheric Research (NCAR), and a marine component, based on the WW3 wind-wave model, developed at the National Center for Environmental Prediction (NCEP). The current configuration of the WRF-WW3 chain is the result of several years of study and operational activity at LAMMA, in the fields of numerical weather prediction and development of meteo-marine operational forecasting services e.g. [4, 5].

In this work, a comparison between wind/wave data computed by the LAMMA model chain and in-situ data measured by weather stations and ondametric buoys is performed, and the main results are reported.

A first comparison between modeled and observed data was done during the early stages of implementation and tuning of the meteo-marine operational chain. In particular, forecasted wave data were compared with those recorded by buoys of the Rete Ondametrica Nazionale (RON), deployed along the Italian coasts. However, it must be pointed out that these data are delivered in a quite discontinuous way, with several periods of missing data, due to buoy or transmission malfunctions, especially in recent years.

Buoys allow accurate in-situ measurements of marine data and have been frequently used for model validation e.g. [6, 7], but they can measure only local data. A huge amount of environmental data over the sea comes from satellites. Such data have been also used to validate wind and wave models e.g. [1, 8, 9]. Although also satellite data have some deficiencies, they can be considered complementary to buoy data. Hence an optimum validation process should involve both satellite and buoy data [10]. This approach will be adopted in future works at LAMMA.

In this paper, the modeled wave data, generated by the first 24 hours of each operational run, have been compared with in-situ observations collected every half hour by two Datawell Waverider MkIII buoys, recently deployed in the Tuscany Arcipelago by the Hydrologic Service of Tuscany Region. The first buoy (43° 34' 12" N, 9° 57' 25" E), near the NNE side of the Gorgona island, started to regularly record and transmit wave data in November 2008, while the second buoy (42° 25' 12" N, 10° 49' 18" E), near the NNW side of the Giglio island, started in May 2009. The systematic comparison of model and buoy data reported

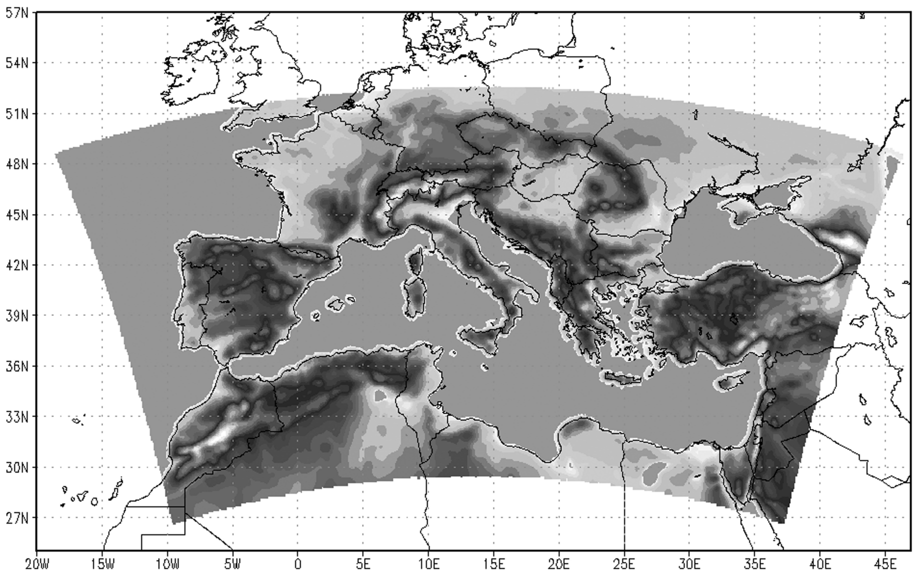

Figure 1: Domain of the WRF-ARW grid.

in the present work covers the period of availability of buoy data.

2 Forecasting models

The LAMMA meteo-marine forecasting WRF-WW3 chain is active since June 2006, except a few cases of short interruptions due to hardware failures. This chain is operating on a cluster of Linux PCs hosted in the LAMMA facilities in Livorno. The system performs two operational runs every day, the first initialized at 00:00 UTC and the second at 12:00 UTC. Both runs produce wave forecasts over the whole Mediterranean sea, at 0.1 degrees of resolution (namely about 10 km at 45° of latitude), for 72 hours, i.e. three days. Furthermore, the run initialized at 12:00 UTC also produces high resolution 72h wave forecasts, at about 2 km of resolution, over a nested domain, covering the Ligurian and high Tyrrenian seas.
In the following two sections, more detailed descriptions of the numerical models used in the LAMMA meteo-marine forecasting chain, with their respective configurations, will be given.

Meteorological model The version 2.1.2 of the WRF-ARW model is used in the LAMMA meteo-marine forecasting chain both for scientific purposes and for the regional weather service. The acronym ARW refers to the dynamical nonhydrostatic solver of the Weather Research and Forecasting system that is developed and maintened by the Mesoscale and Microscale Meteorology Division of NCAR e.g. [11, 12]. The main features of the model are:

- Fully compressible, Euler nonhydrostatic. Conservative for scalar variables.

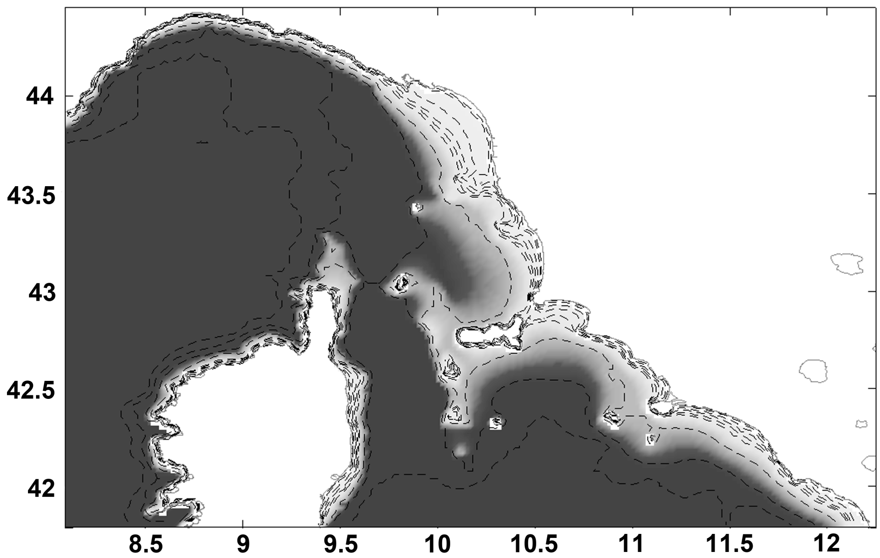

Figure 2: Domain of the WW3 high resolution grid.

- Terrain-following hydrostatic-pressure.
- Arakawa C-grid.
- Time-split integration using a 3rd order Runge-Kutta scheme, with smaller time step for acoustic and gravity-wave modes.

In the LAMMA configuration, the model has a horizontal grid with a resolution of 0.2 degrees (about 20 km) over a domain covering the whole Mediterranean area (224x136 points), as shown in Figure 1, and a vertical grid of 31 levels unequally spaced from ground to 100 hPa, with the first 10 levels concentrated in the boundary layer (about 1.0 km above the ground level). The model runs with a 100 s time-step. The most relevant physical options adopted are listed below (for technical references on specific topics see: www.mmm.ucar.edu/wrf/users/pubdoc.html).

- Micro-physics: Eta Grid-scale Cloud and Precipitation scheme also known as Eta Ferrier scheme.
- Cumulus parameterization: Kain-Fritsch scheme.
- Long wave radiation: Rapid Radiative Transfer Model.
- Short wave radiation: Dudhia scheme.
- Surface layer physics: Eta similarity scheme based on similarity theory.
- Land Surface: Noah Land Surface Model.
- Planetary Boundary Layer: Mellor-Yamada-Janjic scheme.

Finally, initial and boundary conditions are given by the NCEP - Global Forecasting System (GFS) deterministic model at the current resolution of T382L64 (about 50 km). Boundary conditions are updated with the GFS forecasts every six hours.

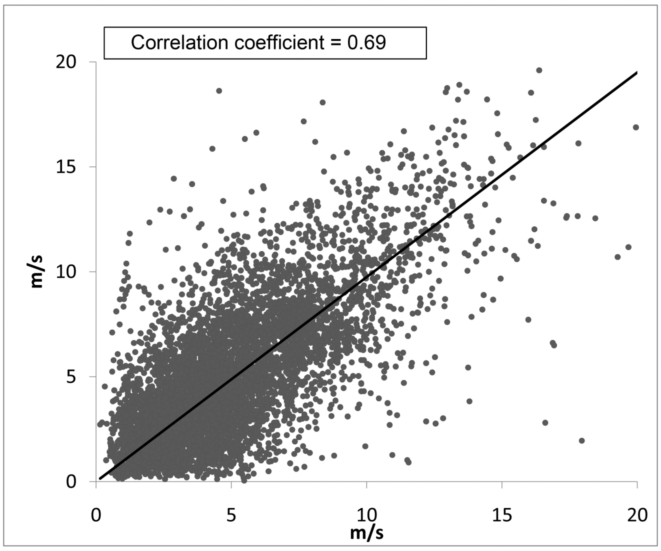

Figure 3: Scatter plot of modeled and observed (Gorgona weather station - ARSIA) wind speeds (February - November 2009). The solid line at 45° is only a guide for the eye.

3 Wave model

The WaveWatch III full-spectral third-generation ocean wind-wave model used in the meteo-marine forecasting chain has been developed at NOAA/NCEP (Tolman, 2002b) in the spirit of the WAM model (WAMDIG, 1988) (Komen, 1994). In the LAMMA operational chain it is implemented the version 2.2 of WW3 (see: polar.ncep.noaa.gov/waves/wavewatch/wavewatch.shtml), with the following configuration:

- Latitude-longitude spherical grid.
- Discrete interaction parametrization (DIA).
- JONSWAP bottom friction formulation.
- Linear wind and current interpolation.
- Seeding of high-frequency energy.
- Spectral discretization on 30 frequencies in the interval 0.04-1.1 Hz and 36 directions.

The horizontal resolution of the grid over the whole Mediterranean sea is 0.1 degrees along both the meridian and zonal directions, while the resolution of the nested run (see Figure 2) is 0.02 degrees along both directions. Wind forcing data are taken from the output of the WRF-ARW model. A scaling factor of the WRF 10 metres wind speed is used as tuning parameter in order to optimize the WRF-WW3 (one-way) coupling.
For what concerns the initial sea-state of every operational run it has been chosen the "hot-start" approach that is shortly described below. Each WW3 run generates a set of restart files with an interval of 12 hours. The restart file contains the wave spectra for the whole computational domain at a given time. The correct (i.e. at the right time) restart file is then used to initialize the wave spectra of the next operational run of WW3. This procedure permits to

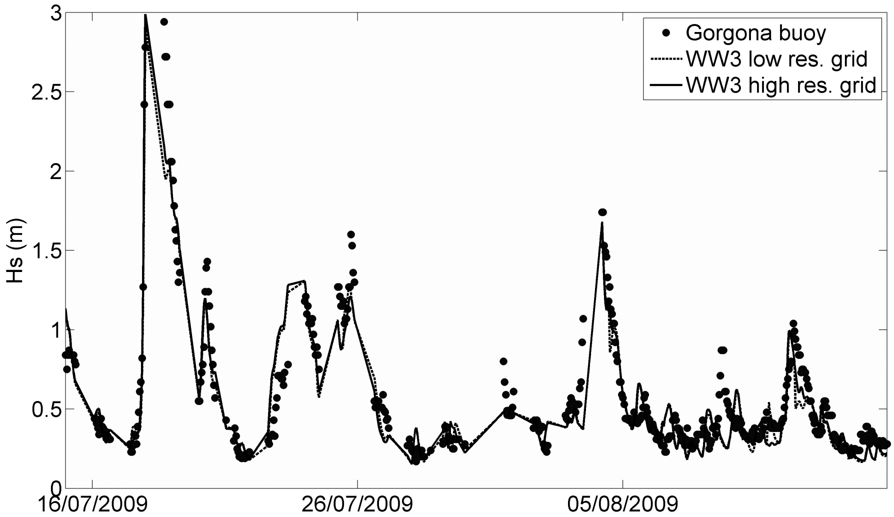

Figure 4: Time series of modeled and observed (Gorgona buoy) significant wave heights from 15 jul 2009 to 15 aug 2009.

minimize model spin-up ("hot-start"). The availability of several restart files allows to overcame the lack of one or more runs in an operational environment.

4 Data comparison

4.1 Wind data

Wind is the atmospheric forcing, and essentially the only one, that determines the development of waves at sea. Hence the quality of the wind forcing is essential for the good performance of the wave model and it determines to a large extent the evolution of the forecast errors [13]. It must be also noted that, in order to obtain reliable wave predictions in a given area, it is necessary to have good wind forecasts not only in that area, but also in a larger area surrounding it. This is due to the fact that the sea state in a given site is the result of the coexistence of different components, i.e., the wind sea, generated by the wind over that site, and the swell sea, determined by the evolution of waves generated by the wind in the surrounding area. Obviously, in order to obtain good wave forecasts, good parameterizations of the mechanisms of energy transfer from wind to waves and of the mechanisms affecting waves propagation and transformation are also needed. These are present in WW3 model and further tuning of the parameters governing such parameterizations have the potential of substantially improve model performances.

In view of the use of wind data for the wave prediction, an extensive validation of wind data from WRF was performed in the past, by comparing them with data measured by weather stations in a belt of few kilometers along the coasts of the whole

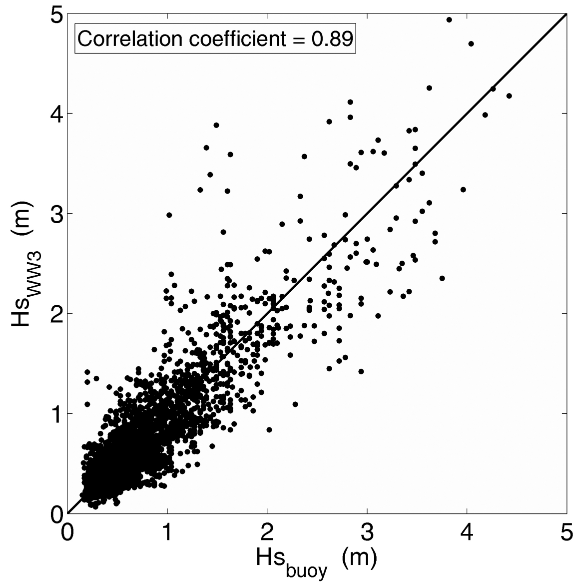

Figure 5: Scatter plot of modeled and observed (Gorgona buoy) significant wave heights (February - October 2009). The solid line at 45° is only a guide for the eye.

Mediterranean area [14]. Coastal stations have been adopted, due to the lack of systematic in-situ measurements at sea. The results obtained showed a good correlation between the calculated and observed series of data, although the Root Mean Square Errors normalized with respect to the average wind speed (nRMSE) were in the range 30-50%. Since in some cases the nRMSE values are quite high, probably the WRF model configuration can be further improved.

In order to estimate the quality of the forecasted wind used to compute the wave data of the present wave analysis, we also made a comparison of the WRF wind data with those from a weather station, property of the Agenzia Regionale per lo Sviluppo e l'Innovazione nel Settore Agricolo-forestale (ARSIA), located in the small Gorgona island near the position of the North buoy. The time series for the period February - November 2009 are plotted in the scatter diagram of Figure 3, and the correlation coefficient is reported. The results show a quite good correlation between the calculated and measured data and a nRMSE equal to 46%, in agreement with the previous validation analysis. We note that, since the weather station is a ground station, while the closest model grid point is over the sea, the difference between modeled and observed data can be partially due to orographic effects.

4.2 Wave data

An initial validation of the WW3 model was performed by using the RON data in June and July 2006, in order to test and

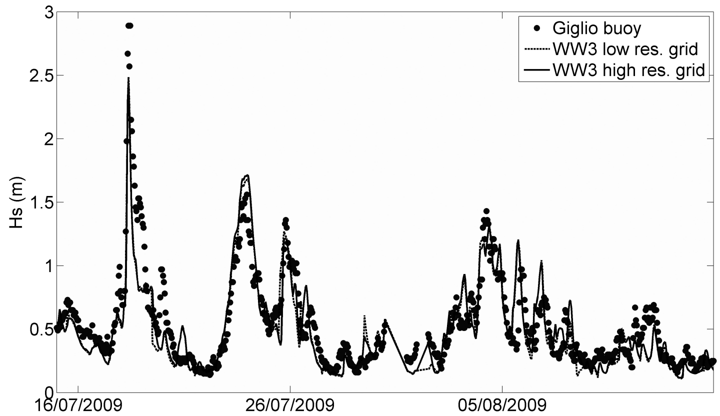

Figure 6: Time series of modeled and observed (Giglio buoy) significant wave heights from 15 jul 2009 to 15 aug 2009.

calibrate the first implementation of the LAMMA forecasting chain. The comparison between modeled and observed significant wave heights showed an overall good temporal correlation for the most of the events. A tuning process over the scaling factor of the 10 meters wind speed pemitted to optimize the agreement between simulated and measured wave height values.
After this very basic tuning procedure we have analysed the performance of the "adjusted" model chain in the Ligurian and Tyrrhenian seas over the periods of some months corresponding to the times of operational use of the buoys recently installed by the Hydrological Service of Tuscany Region. The forecast wave heights for the first 24 h of each run are compared with the buoy measurements at corresponding times. The modeled data are interpolated from the uniform spatial grid in WW3 to the buoy positions by simply taking the nearest neighbor point. Moreover, the half-hourly buoys data are interpolated to the modeled data time by using a nearest neighbor interpolation method (a linear interpolation method does not change significantly the results).
A comparison between the model results and the buoy observations at the two measurement locations is shown in Figure 4. The plot represents a part of the time series of modeled and measured significant wave heights for the Gorgona location from 15 jul 2009 to 15 aug 2009. The series for the whole period (February - October 2009) are plotted in the scatter diagram of Figure 5, and the correlation coefficient is reported. The normalized Mean Bias Error (nMBE), Mean Absolute Error (nMAE), and nRMSE between the buoy measurements and the model results for the whole period are reported in Table 1. Similar plots and statistical errors for the Giglio location are reported in Figure 6 and Figure 7 and in Table 1. The plots show that the observations are in reasonably good agreement with the model predictions. The difference between low and high resolution data is very small.

	nMBE	nMAE	nRMSE
Low res. Gorgona	-2%	24%	36%
High res. Gorgona	-2%	25%	37%
Low res. Giglio	-5%	26%	36%
High res. Giglio	-2%	27%	39%

Table 1: Statistical errors for the significant wave height series.

Besides the significant wave heights analysis, a preliminary directional validation has been also made. This validation requires a deeper study with respect to the previous one, since in this case the different spectral components must be analyzed e.g. [15]. At the moment only a mean wave direction analysis has been faced. Some first results are reported in Figure 8 and Figure 9. The first figure represents the comparison between the wave roses of the Gorgona buoy and the WW3 forecast for wave heights above 1 m, in order to discard errors in the model forecasts probably due to deficiencies in the description of small scale dynamics like those related to breeze regimes,. The second figure shows a part of the time series of modeled and measured mean wave directions for the Gorgona location from 15 jul 2009 to 15 aug 2009. This plot illustrates the good temporal correlation between the two series of data. The correlation coefficient of the whole series is about 0.7; the nRMSE, normalized with respect to 180°, is about 35%. A more exhaustive study of the wave direction results is in progress.

Although discrepancies are sometimes present, mainly in cases of low wave height values, the correlation between the calculated and observed series of data is good. The nRMSE is still too high, although in agreement with that of the wind forcing, and some adjustments for the configurations of the models are needed to reduce the statistical errors. A better configuration will be searched for in the next future by performing a fine tuning of the relevant parameters governing the computational schemes and physical parametrizations of the models. However the results above demonstrate a good capability of the implemented forecasting chain to give reliable wind-wave forecasts in the Ligurian and Tyrrhenian seas.

5 Conclusions

Wind and wave model forecasts produced by LAMMA meteo-marine forecasting chain are compared with anemometer and buoy observations respectively over the Ligurian and Tirrenian seas. The comparison provides a first insight into the performance of the operational forecasting

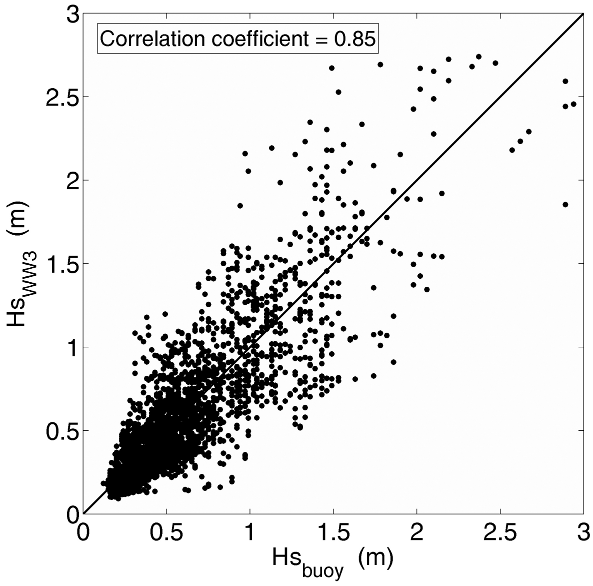

Figure 7: Scatter plot of modeled and observed (Giglio buoy) significant wave heights (May - October 2009). The solid line at 45° is only a guide for the eye.

system (wind and waves). Although the correlation between modeled and observed data is quite good, it is however evident that some adjustments of the model parameters are still needed to reduce the statistical errors. This calibration will be performed on a new operational chain based on WRF-NMM (Nonhydrostatic Mesoscale Model) (see www.dtcenter.org/wrf-nmm/users/docs/overview.php) and the last version of WW3 [16], now in a test phase at LAMMA, running on a multi-processor platform of the latest generation. The increased computational power allows a longer forecasting period (120 hours, i.e. five days) for the run over the whole Mediterranean sea, and a larger domain for the nested 72h high resolution run. When the testing period will be completed, the new more powerful chain will be substituted to the old one.

6 Acknowledgements

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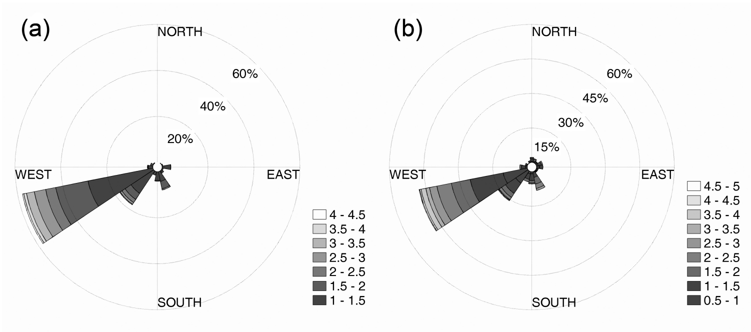

Figure 8: Wave roses of observed (a) and modeled (b) wave data (Gorgona).

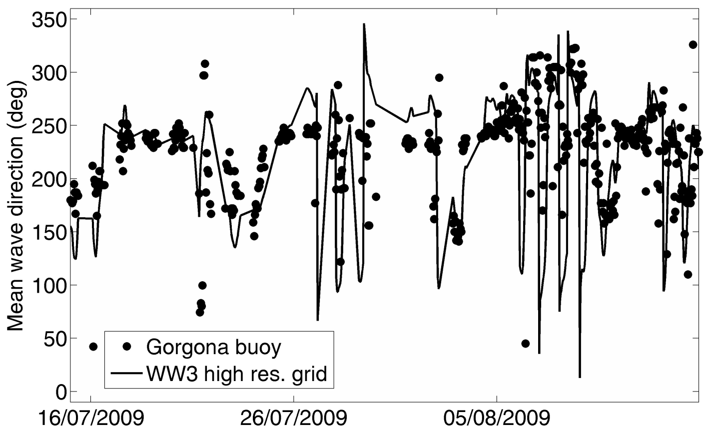

Figure 9: Time series of modeled and observed (Gorgona buoy) mean wave directions from 15 jul 2009 to 15 aug 2009.

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Satellite Derived Winds as Support to the Regional and Coastal Oceanography

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Abstract

This contribution underlines the importance of satellite derived winds for marine applications at regional scales and nearby the coast.
The wind is one of the most important forcings of the sea, and its determination by atmospheric models may be unsatisfactory in regional basins and coastal areas, where the orography plays an important role in modifying the air flow, as for example in the Mediterranean Sea.
Furthermore, the experimental in-situ determinations of the wind, taken mainly along coast, are often unrepresentative of the wind offshore, and wind reports from open sea platforms and buoys are too few to provide an exhaustive picture of the wind fields.
Satellite winds are therefore of paramount importance, offering unique wind data set with spatial resolution fine enough to resolve the large scale and mesoscale features of the wind, included those due to the air-land and the air-sea interactions.
The present spatial resolution of scatterometer data is good for regional scale marine applications, but insufficient for coastal meteorology and oceanography. The Synthetic Aperture Radar (SAR) wind fields, routinely evaluated by a methodology developed at ISAC, are well suited for coastal applications.
In this contribution we show how the scatterometer winds can be used as support to the storm surge forecasts in the Adriatic Sea and to understand and monitor the permanent gyres in the Mediterranean Sea, and how satellite-borne SARs may offer unprecedented description of coastal winds.

1 Introduction

The wind is the forcing of many phenomena occurring on the sea. This forcing acts inside the Marine Atmospheric Boundary Layer (MABL), the air layer over the sea surface where exchanges of sensible and latent heat and momentum take place over a large spectrum of time and spatial scales. It drives the sea waves, the drift ocean currents, the storm surge waves and the storage of CO_2 in the sea due to the breaking waves.

The spatial scales of the atmosphere-ocean interaction range from the micro-scale ($O(1)$ m, $O(1)$ s) to the synoptic scale ($O(10)$ day, $O(1000)$ km). While the interaction processes at synoptic scale are fairly well known, those at the meso-scale γ and β ranges, where atmospheric processes from 2 km to 20 km and from 20 km to 200 km respectively occur [1], are still to be fully understood, due both to the lack of data suitable to resolve these scales and to the poor parametrization of the sub-

grid processes in the atmospheric models. Local modulations of the low-level wind field, especially in regions where steep orography surrounds the sea, occur in these ranges where, indeed, global atmospheric models have a resolution inappropriate to reproduce them accurately.
A typical region where atmospheric phenomena at mesoscale β and γ should be taken into account is the Mediterranean Basin. The complexity of its coastal orography and the presence of mountainous islands and coastlines, deeply influence the local scale atmospheric circulation in the MABL, producing local effects at spatial scales down to a few kilometers. In the Mediterranean Basin, many regional wind systems, local cyclogeneses and wind flow disturbances induced by orography have a spatial variability at the mesoscale β. The air-sea exchanges depend primarily on the wind vector $\mathbf{w}$, on the air T_a and dew T_d temperatures, and on the sea surface T_s temperature. The knowledge of these quantities is required to evaluate, for instance, the wind stress (momentum flux) $\boldsymbol{\tau} = C_d(T_a, T_s, T_d) \cdot |\mathbf{w}| \cdot \mathbf{w}$, where C_d is the drag coefficient,as ell as the gas transfer velocity $k = 2.8310^{-2} \cdot |\mathbf{w}|^3$ [2]. It is thus evident that the accuracy of the wind speed determination is of paramount importance.
Sensing the sea surface, the satellite-borne sensors discussed in the next section measure the wind field blowing at the MABL bottom level. Satellite active microwave sensors are the only instruments able to provide accurate information about the wind field in the MABL over large areas, day and night, regardless of the cloud coverage.
In this paper we present some of their applications in the Mediterranean Sea.
It is structured as follows: section 2 introduces the satellite sensors and the wind data used in this work; section 3 illustrates a possible use of the scatterometer winds in the storm surge forecasting activity and section 4 shows some application of these data to oceanographic studies. In section 5 the wind fields derived from SAR images are discussed in view of possible applications in coastal oceanography. Final section 6 introduces new wind products, derived by a blend of model and satellite data, which could become important for oceanographic applications.

2 Satellite sensors and data

This section introduces the satellite active microwave sensors which provide the wind field over the ocean surface: the scatterometer and the SAR.
The scatterometers, such as those on board of ERS [3], QuikSCAT [4] and Metop [5] satellites, measure the wind field (speed and direction) over the oceans with a grid spacing of 12.5 km $\times$ 12.5 km, and a nominal accuracy of 2 ms^{-1} in speed and 20° in direction in the wind speed range 3-20 ms^{-1} (but the accuracies derived from comparisons with in-situ data are generally better).
Scatterometer data are widely used by the scientific community: they are assimilated into the global atmospheric models [6] and in limited area models for coastal wind forecasting [7, 8], used in global scale and mesoscale meteorology studies [9, 10, 11], in climatology [12, 13], in the assessment of the performances of the global [14] and regional atmospheric models [15].
SARs are imaging instruments, providing radar images of the earth surface at high spatial resolution (few metres), from which

it is possible to derive the wind field over the sea at spatial resolution of the $O(1)$ km with different techniques: using the backscatter signatures produced by the atmospheric wind rolls or those occurring at the lee side of islands as effect of wind shielding [16], computing the local gradient of the image backscatter [17, 18] or processing the images by the two dimensional Continuous Wavelet Transform (2DCWT) [19, 20].

Applications of the SAR derived wind fields to coastal meteorology and oceanography are at the beginning [21].

In this paper we'll use SAR images provided by the Envisat satellite of the European Space Agency (ESA).

3 Satellite winds as support to storm surge applications

The wind forecasts provided by the global models, such as the Integrated Forecast System of the European Centre for Medium-Range Weather Forecasting (ECMWF), may not describe with sufficient accuracy the strength and the spatial pattern of the wind fields in regional basins. This is commonly thought to be a results of a poor representation of the orography surrounding the basin (if any), of the poor real grid resolution of the model (often indicated as 10 times the model nominal space grid [22]) and of the unrepresentativeness of the parametrization of the sub-scale processes. The scatterometer winds do not suffer from these limitations [9].

With the aim to understand if and where the forecasted winds differ significantly from the measured ones, statistical comparisons between the ECMWF-forecasted and the satellite-measured winds have been carried out for the Adriatic Sea, in the framework of a joint project with the Istituzione Centro Previsioni e Segnalazioni Maree (ICPSM) of the Venice Municipality, responsible for the storm surge forecasting in the city of Venice.

The Adriatic Sea is bounded along its major extension by the Balkan Mountains at east and by the Apennines at west: under south-easterly winds, these mountain chains favor wind channelling alongside, while under north-easterly winds the gaps in the Balkan Mountains determine wind funnelling crosswise. These effects, due to the interaction between the land and the air flow, may change the wind spatial pattern at the basin and local scales.

Figure 1 reports the mean wind difference between ECMWF and QuikSCAT winds over a period of 30 days in summer (left panel) and autumn (right panel). In general, the model underestimates the wind speed, particularly close to coasts and in the northern Adriatic Sea. A visual comparison of the two maps in the figure informs that the bias of the forecast winds changes throughout the year: this is not surprising because it is likely that the forecast quality depends on the dominant wind direction as well as on the mean air-sea stability conditions over the period considered. The evaluation of these dependencies is still ongoing.

The knowledge of the biases is particularly important when the forecasted wind is used as a forcing in the storm surge models: since the real forcing exerted by the wind on the sea surface is expressed by the wind stress, which is proportional to the wind speed square (see Section 1), even small biases become relevant because the storm surge model further propagates the wind errors into the surge forecasts [23].

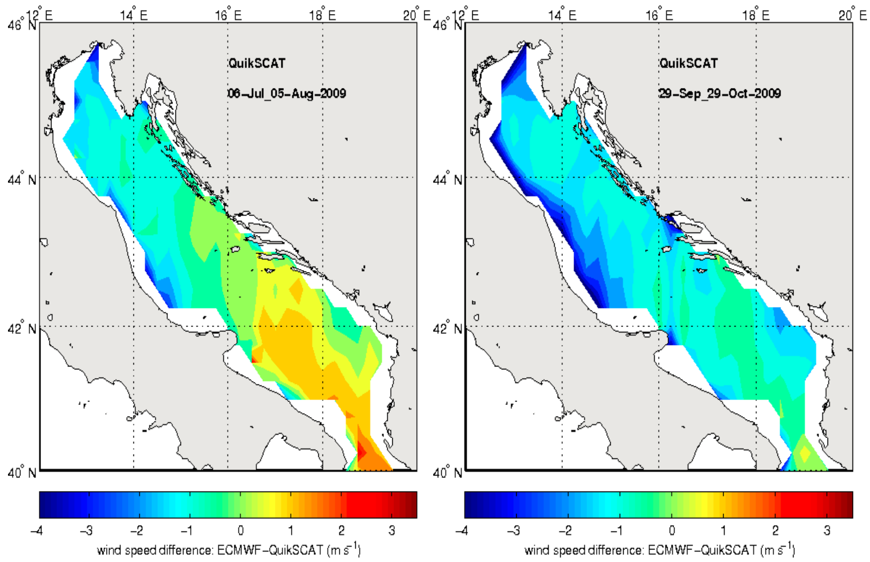

Figure 1: Maps of the ECMWF-QuikSCAT wind speed difference over 30 days. Left panel: from 6 July to 5 August 2009. Right panel: from 29 September to 29 October 2009.

4 Satellite winds as support to oceanography

In this section we discuss about the use of satellite winds for oceanographic applications. There are two important meteorological quantities to consider in oceanographic applications: the wind stress $\boldsymbol{\tau}$ and the wind vorticity $\omega = (\nabla \times \mathbf{w})_z$, which is proportional to the Ekman pumping $w_{ek} = (\nabla \times \boldsymbol{\tau})_z/\rho f$, where f is the Coriolis parameter and ρ the air density. The Ekman pumping w_{ek} is a vector quantity describing the vertical velocity at the top of the atmospheric boundary layer.

As stated in the introduction, the wind stress is the main forcing at the ocean surface, and its evaluation is very difficult.

The wind vorticity is a vector quantity which describes the rotation properties of an air flow. Positive vorticities imply counter-clockwise rotation of air masses (cyclonic in the northern hemisphere) and an upward motion of the air; negative vorticity a clockwise rotation (anti-cyclonic in the northern hemisphere) and a downward motion.

In the context of the present study, the wind vorticity (or the Ekman pumping) is important because it can be correlated with the ocean vorticity associated to the sea gyres [24]: its knowledge is important to understand if and in what extent the permanent or semi-permanent features of the observed ocean currents are wind dependent. Here, we present the mean wind stress field as derived from QuikSCAT and MetOp scatterometer data as well as the Ekman pump-

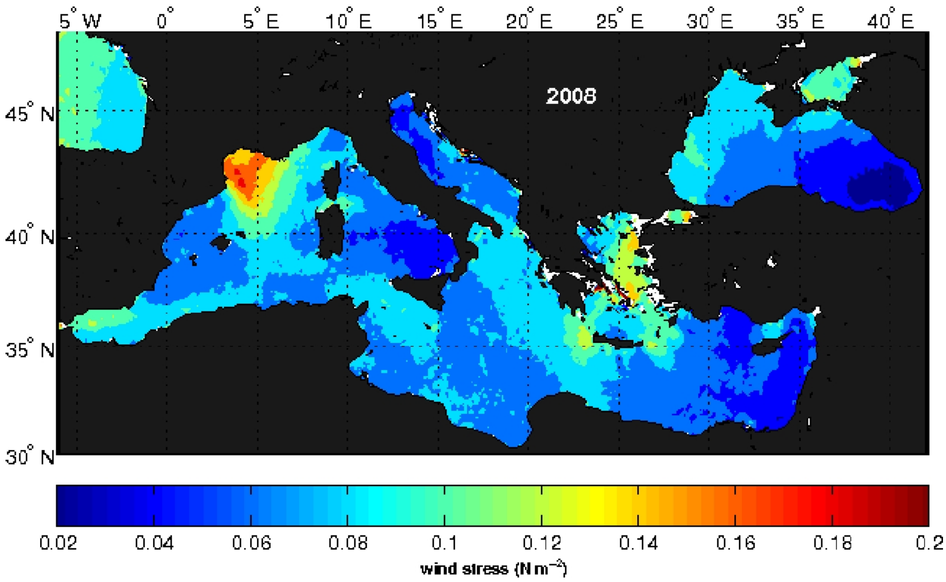

Figure 2: The mean field of the wind stress obtained from QuikSCAT and MetOp wind data for 2008.

ing, a quantity already used in [25] and [10].

Figure 2 reports the mean wind stress over the Mediterranean Sea for 2008: it shows, besides the large areas of highest intensity (Gulf of Lion, Alboran Sea, north-eastern Black Sea, Aegean Sea and northern Ionian Sea), several small coastal areas where the wind stress is higher than in the surroundings (east of the Bonifacio Strait in Tyrrhenian Sea, Marmara Sea, east and west of Crete Island, eastern central Adriatic Sea), due to the air flow modifications brought by the orography-air flow interaction. The identification and the monitoring of the wind stress anomalies may be relevant, along with other information like the sea surface temperature, to explain the intermediate and dense water formation occurring both in the western and in the eastern Mediterranean and, more in general, to evaluate the importance of the wind on the Mediterranean circulation, a problem not yet fully understood [26].

Figure 3 reports the summer and autumn 2008 mean fields of the atmospheric Ekman pumping, which map the presence of seasonal cyclonic (positive values) and anticyclonic (negative values) structures on the wind field. The relevant information brought by Figure 3 is:

- on the basin scale, the different patterns in autumn (characterized by large areas of negative w_{ek}, mainly located in the northern part of the basin) and summer (when large areas of positive w_{ek} lie in the western Mediterranean and in the western Black Sea);
- on the regional scale, the predominant cyclonic circulation in the Alboran and Aegean seas and in the Gulf of Lion;
- the existence of small scale, dipole-like

structures of Ekman pumping, a clear indication of the role of the land on the spatial structure of the wind, for instance east of the Bonifacio Strait and south of Crete Island, here more developed in summer than in autumn;

- the patchy texture of the Ekman pumping, indicating how scatterometer can resolve the small spatial scales, which reveals both the inner structure of the large areas of positive or negative w_{ek} and that of the small basins like the Adriatic Sea, where cyclonic areas alternate with smaller anticyclonic areas, particularly in autumn and winter (not shown) or coastal areas like the Mediterranean coast of Turkey, characterized by permanent and strong cyclonic activity.

5 Satellite SAR winds for coastal marine applications

Coastal marine applications need data as much close to coast as possible. In the previous section we have seen how important the scatterometer wind fields can be in evaluating the possible atmospheric influences on the sea circulation in regional scale basins as the Mediterranean Sea. However, with the grid sampling of 12,5 km by 12,5 km currently offered by scatterometers, it is impossible to have wind data closer than about 20 km to the coast, and thus scatterometer winds cannot be used for coastal marine applications. At present only SAR images, thanks to their fine spatial resolution, can provide information about the coastal winds.

As an example to illustrate the capabilities of SAR, we report in Figure 4, an ESA Envisat ASAR Wide Swath image covering a portion of about 400 km by 400 km of the Tyrrhenian Sea (see the inside panel) with a pixel of 75 m by 75 m. The physical quantity represented by the value of each pixel is the normalized radar cross section, which is non linearly related to the surface wind speed: brighter pixels indicate higher winds. With this in mind, and in virtue of the high spatial resolution of SAR images, we can extract information about the wind blowing over the sea virtually up to the coast.

The wind field derived from the ASAR image of Figure 4 with the 2DCWT method, shown in the left panel of Figure 5, provides very detailed information about the spatial structure of the wind much closer to coast than scatterometer, as seen in the right panel, which reports the QuikSCAT wind field at 12.5 km by 12.5 Km grid spacing.

Thus, SAR derived winds are an unique experimental tool able to provide wind fields for marine coastal studies and applications.

6 Integrating atmospheric model with satellite winds

A recent trend in geophysical marine applications is the blending of wind measurements from multiple satellite sensors and wind fields coming from numerical atmospheric model analyses.

NASA provides a dataset of ocean surface winds, at 25 km by 25 km of grid spacing, for climatological studies for the period July 1987 through December 2009, derived combining numerical model analyses and remote observations from several satellites and sensors. The method requires the ECMWF Operational Analysis wind components as a starting estimate of the wind field. It is described in [27] and [28]. On the European side, the Centre ERS d'Archivage et de Traitement (Cersat) of the French Research Institute for Exploitation of the Sea (IFREMER) daily provides gridded ocean surface winds from QuikSCAT scatterometer and radiometers observations every six hours [14]. Because the observations are not uniformly distributed in space and time, the data are analyzed using an optimal interpolation technique based on the kriging approach [29], in order to obtain regularly gridded fields. The quality of the resulting blended field is very high, similar to that of satellite wind retrievals, even if the agreement with moored buoy observations is better offshore than near-shore, and higher than that of the model analysis fields; it is well suitable for marine applications, despite their time delay release hinders operational use.

7 Acknowledgments

Scatterometer QuikSCAT data have been downloaded from the Physical Oceanography Distributed Active Archive Center (PODAAC) of the Jet Propulsion Laboratory, Pasadena, USA.
MetOp Scatterometer data have been obtained from the Koninklijk Nederlands Meteorologisch Instituut (Dutch Meteorological Service KNMI, www.knmi.nl) operating in the framework of the Ocean & Sea Ice Satellite Application Facility (www.osi-saf.org) of EUMETSAT.
The Envisat ASAR Wide Swath image has been downloaded from the ESA web server http://oa-ip.eo.esa.int/ra/asa on the framework of the Project Start Up C1P.5404 of the European Space Agency.
We thank the Istituzione Centro Previsioni e Segnalazioni Maree (ICPSM) of the Venice Municipality for providing the ECMWF forecast wind fields.

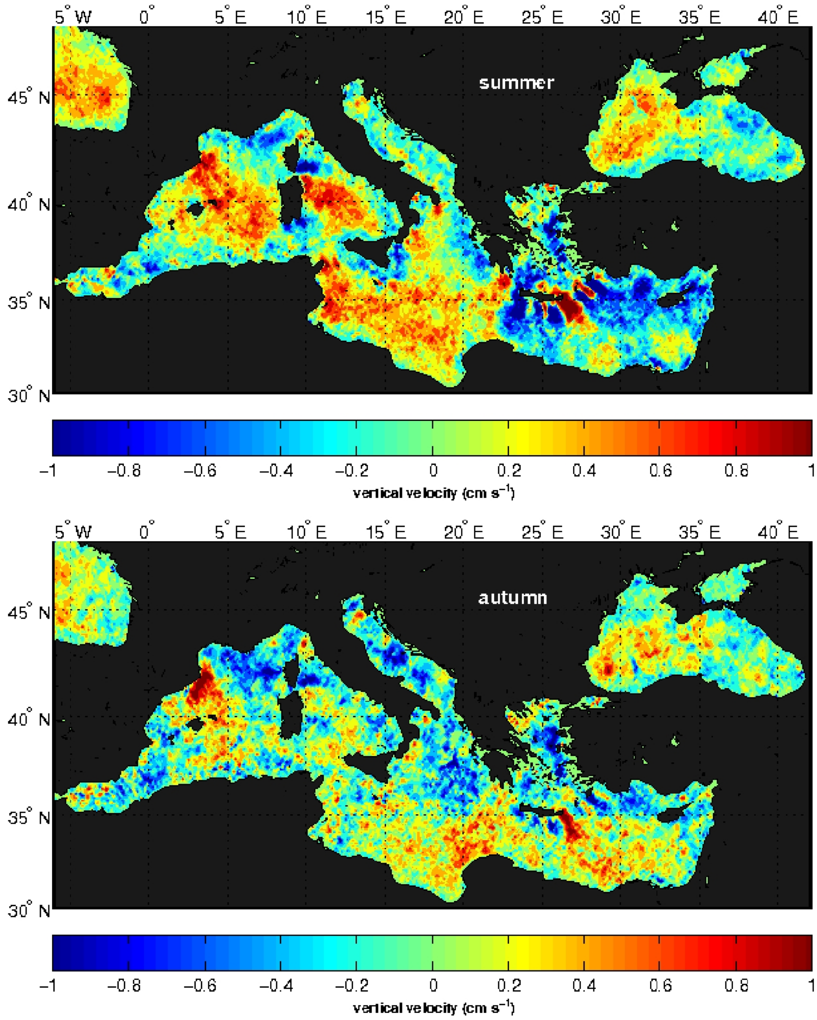

Figure 3: The seasonal mean fields of the atmospheric Ekman pumping w_{ek} obtained from QuikSCAT and MetOp wind data for 2008. Top panel: summer. Bottom panel: autumn.

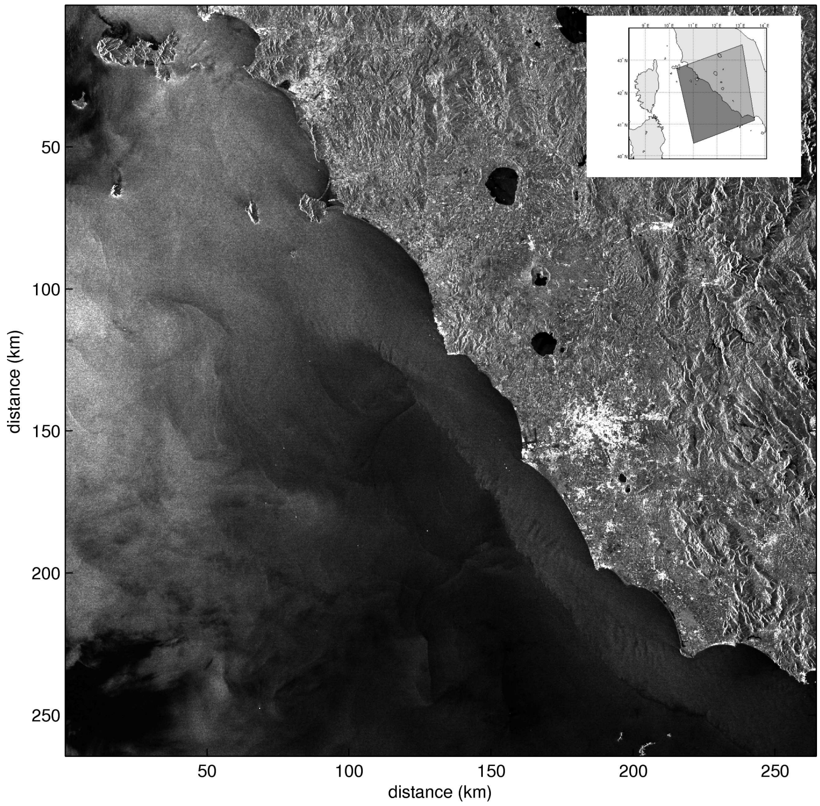

Figure 4: The Envisat ASAR Wide Swath image (1-Mar-2009 at 20:59:43 GMT) selected to illustrate the coastal marine application of SAR. Inside panel: the image location in the Tyrrhenian Sea. Orbit: 00487. Frame: 36613.

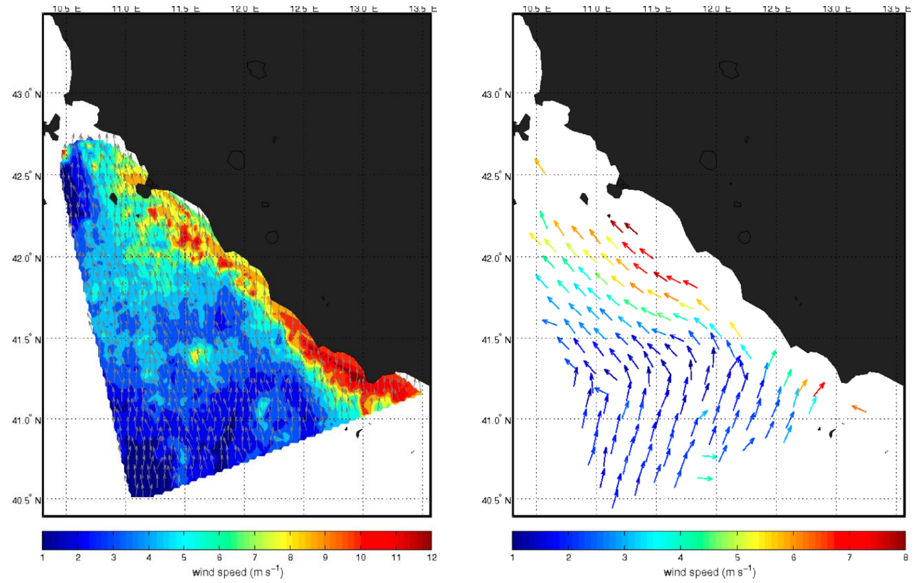

Figure 5: Left panel: the wind field derived from the processing with CWT2 method of the ASAR image of Figure 4. Vectors are plotted at reduced space resolution for readability. Right panel: the wind field from QuikSCAT scatterometer, at 0.125° by 0.125° grid, measured about three hours before the SAR pass time.

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Operational Ocean Forecasts in the Sicily Strait

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Abstract

The Operational Oceanography activity in the Mediterranean sea starts in 1998 in the context of the Mediterranean Forecasting System (MFS) program. The aim was exploring the predictability of the marine ecosystem properties from basin to coastal scales. Within this framework, the Sicily Channel Regional Model Forecasting System (SCRMFS) have been producing operational ocean forecasts of the Sicily Strait since 2004. SCRMFS, based on the Princeton Ocean Model, was recently upgraded to use the hourly SKIRON atmospheric forcing, while its horizontal resolution was increased from 5 km to 3.5 km. The SCRMFS is nested to the OGCM-MFS1671, the coarse resolution model of the Mediterranean basin. A five-day forecast is produced every day by the SCRMFS, providing detailed and accurate prognostic 3D fields of the currents and hydrology of the area. The performances of the system have been assessed using remotely sensed satellite surface temperature measurements of one cloud free day (October 7^{th}, 2009). For each day we computed a set of daily averaged skill scores to evaluate the modelled surface temperature fields, which allowed us to draw some general consideration on the quality of the forecasts.

1 Introduction

The operational forecast of physical processes can contribute to understand the function of marine sub-systems, as well as the effect of marine conditions on human operations at sea. Several applications such as shipping, support to marine environmental management [1], fisheries management [2], tourism [3], search and rescue, oil spill fate modeling and dispersion of pollutants [4] and naval operations require a scientific basis of understanding and, frequently, high resolution modeling applications for limited regions [5]. This gives the need to link a hierarchy of successively embedded model domains (Limited Area Model) for the downscaling of the large hydrodynamic basin scale, from the coarse resolution to finer grids in coastal areas, through the nesting techniques [6, 7]. The MFS modeling system is then composed by a hierarchy of embedded operational forecast models ranging from the basin scale to the coarse scale. In the operational chain a large-scale coarse-resolution general circulation model covering the entire Mediterranean basin produces analyses and forecast fields for the whole basin but also initial and lateral boundary conditions for the regional models. The Sicily Channel Regional Model Forecast System (SCRMFS) is one of the coastal/regional models of the Mediterranean Forecasting System [6, 8] covering the Sicily Strait area with a full three-dimensional implementation of the Princeton Ocean Model [9, 10]. The advantage in using high resolution models like SCRMFS is a more detailed description of the circulation in these regions as the Malta, Tunisian and Libyan shelves, which include some mesoscale components that cannot be resolved by the coarse resolution model. In order to evaluate the accuracy of forecasted SST produced by SCRMFS, some skill scores have been computed: as the root mean square of the difference between the forecast fields of SST and the truth (as represented by the known satellite observations) and the standard mean error (bias). The analyses of the forecast fields have been performed on relativity to October 7^{th} 2009.

2 Numerical models, observations and methodology

2.1 The Mediterranean ocean Forecasting System

The Mediterranean Forecasting System (MFS) of sea circulation [11] currently produces ten-days ocean forecasts for the whole Mediterranean Sea once a day. The start of the forecast is at 12:00 UTC of each day. Once a week, on Tuesday, the ocean forecast is produced from the last seven days of analyses, while in the other days from a simulation. MFS covers the whole Mediterranean basin with a horizontal resolution of 1/16 of degree (approximately 6.5 km) and 72 unevenly spaced z-coordinate levels on the vertical. This model could be defined as an eddy resolving model for the Mediterranean Sea as the first internal Rossby radius of deformation is around 10-15 km in summer. The ocean analyses-forecast consists of daily mean oceanographic fields computed from 12:00 to 12:00 of the following day. These fields are used to prescribe the initial and lateral conditions of SCRMFS.

2.2 The surface forcing

The surface forcing for the SCRMFS is provided by the Limited Area Model SKIRON, a numerical weather prediction model developed at the University of Athens. It provides 5-days forecast of atmospheric parameters at high frequency (hourly fields) with a horizontal resolution of 10 km [12]. The core of the system is based on the ETA/NCEP model that has been developed at the National Centre for Environmental Prediction (NCEP/NOAA). Initial and boundary conditions are taken from the coarse model NCEP/GFS (0.5°x0.5°, 26 pressure levels). The atmospheric parameters include hourly fields of: mean sea level pressure, air temperature at 2m, wind speed and direction at 10 m, convective and accumulated precipitation, cloud cover, sensible and latent heat fluxes, incoming and outgoing shortwave and long-wave radiation fields and evaporation.

2.3 The Regional Ocean Forecasting System for the Sicily Strait

The SCRMFS provides a daily near real time operational 5-days forecast of the three-dimensional structure of temperature, salinity, current velocity and other physical parameters. The model uses a uniform horizontal orthogonal grid with a resolution of 1/32° ($\sim$3.5 km) in longitude and latitude (257 x 273 mesh points), while in the vertical it uses 30 sigma levels. The sigma levels are bottom following with a logarithmic distribution near the surface. This permits more details at the surface layer while the other below layers to the bottom are equally spaced. The model bathymetry (Figure 1) is based on the U.S. Navy 1/60° Digital Bathymetric Data Base (DBDB1) by bilinear interpolation onto the SCRMFS grid. Additional light smoothing was applied to reduce the sigma coordinate pressure gradient error [9]). The minimum depth was set at 5 m. The model domain covers the geographical area from 9°E to 17.1°E in longitude and from 30.5°N to 39.5°N in latitude. Time integration is done using a split explicit scheme where barotropic and baroclinic modes are integrated separately with time steps of 4 s and 120 s, respectively. The basic numerical formulation of the ocean model is based on the Princeton Ocean Model (POM and solves the equations of continuity, motion, conservation of temperature, salinity and assumes that the fluid is hydrostatic and the Boussinesq approximation is valid [10]. At the surface SCRMFS is forced by the weather prediction model SKIRON through an interactive air-sea module. The net short-wave radiation flux and the downward long-wave radiation flux at the sea surface are provided directly by the weather prediction model at 1-hour interval, while latent and sensible heat fluxes are given by the bulk aerodynamic formulas using the Kondo scheme for the turbulent exchange coefficients. For the surface salinity flux, the evaporation rate is calculated from [13] and combined with the precipitation provided by SKIRON. Surface momentum fluxes are calculated using the computed drag coefficient of Hellerman and Rosenstein. These parameters are interpolated in space and time into the regional ocean model in order to drive the air-sea processes. At the three open boundaries (western, northern and eastern) SCRMFS is nested with the MFS1671 through an off-line one way nesting technique of the forecasted daily mean fields of temperature, salinity and total velocity [7]. The initialization is obtained in slave mode (re-initializing every day with a "cold start") through the downscaling and optimization of coarse resolution forecast fields (temperature, salinity and current velocity) using the Variational Initialization method, named VIFOP [14]. This method reduces the high frequency oscillations during the initial condition (spin-up time) and ensures the physical consistency of the coarse fields, the initial and lateral conditions then imposing the conservation of global divergence and, finally, the strong constraint on the sea surface elevation tendency. For a more detailed description of VIFOP implementation on SCRMFS, including sensitivity studies see [15]. Daily SCRMFS generate short-term (five days) forecasts of temperature, salinity, currents and sea level elevation as daily averaged fields. The surface forcing is provided by the SKIRON 120-hours forecast, which are available daily with start at 00:00 UTC. The lateral forcing is provided by MFS1671 10-days forecast, which are also available daily as daily mean averaged fields centred at midnight UTC. The both operative chains, MFS and SCRMFS, are illustrated in Figures 2 and 3, respectively.

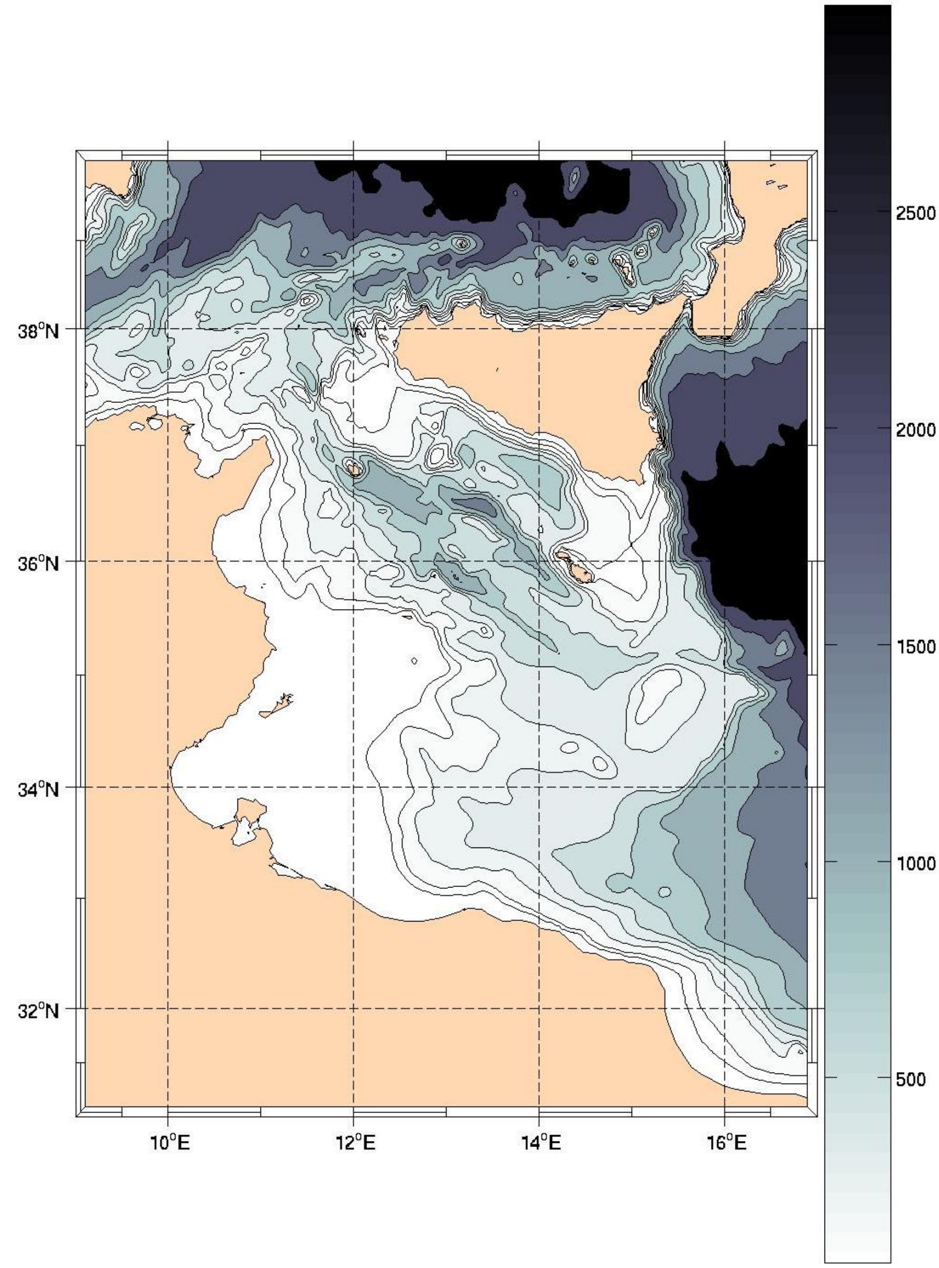

Figure 1: Model Bathymetry (in m) obtained by bilinear interpolation of U.S. Navy 1/60° Digital Bathymetric Data Base (DBDB1) into the SCRMFS grid. Minimum depth set at 5m.

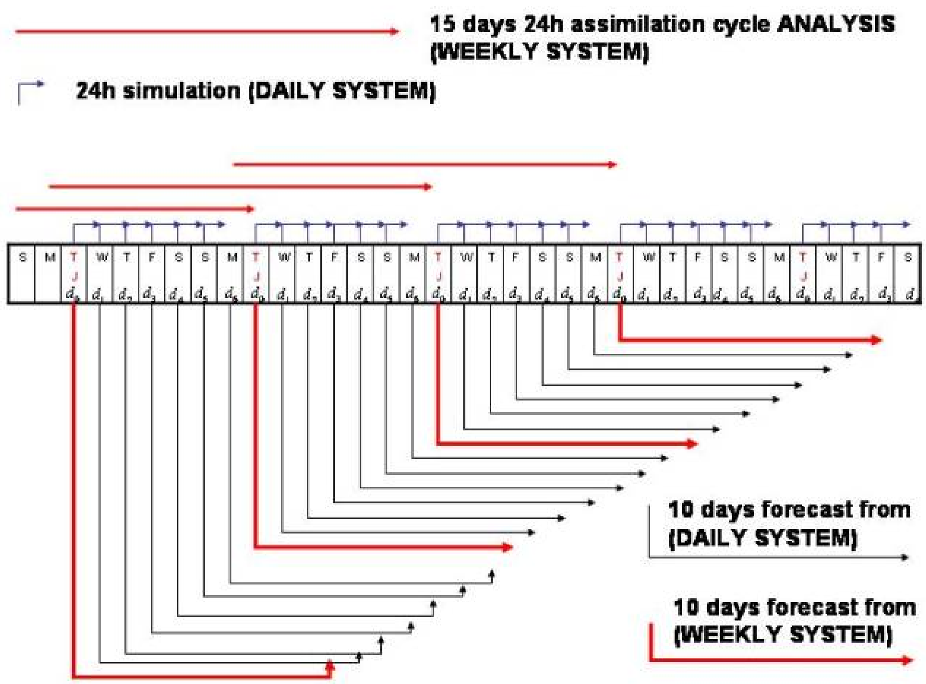

Figure 2: Schematic representation of +10 day ocean forecast from the daily (black line) to the weekly (red line) system, the weekly analyses system and the 24h daily simulation system (blue line) for the coarse resolution MFS.

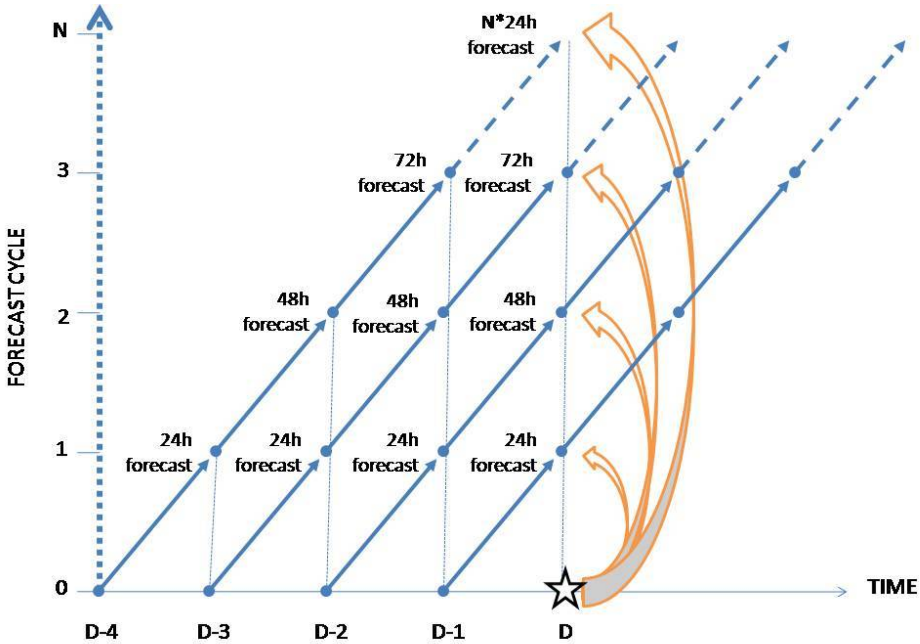

Figure 3: Schematic representation of the slave mode forecast cycles in SCRMFS. The term N is the number of forecasted days or cycles provided every day. The star is the available SST observation at present day D, while the curving arrows represent the cycles of comparison between the observed SST from satellite and the corresponding SST forecasted field at +24h released at time D-1 (last cycle), +48h released at time D-2 (one cycle before or cycle one), +72h released at time D-3 (two cycles before or cycle two), +96h released at time D-4 (three cycles before or cycle three) and +N*24h released at time D-N (N-1 cycles before, cycle N-1). The number in the abscissa denotes the forecasting day in each cycle.

2.4 Satellite observations

In order to evaluate the operative Sea Surface Temperature (SST) forecasted from SCRMFS, a daily Near Real Time Optimally Interpolated Sea Surface Temperature (OISST) dataset has been used. This dataset covers the Mediterranean Sea and the Eastern Atlantic areas at 1/16° resolution. It has been developed for direct assimilation in MFS1671 [16]. The version used is Near Real Time multi-sensor on daily basis (NRTv1) obtained from the Advanced Very High Resolution Radiometer (AVHRR on board NOAA-17 and NOAA-18) night-time data [17]. These satellite observations have been assumed as the sea-truth, although the data are obviously affected by errors of several types (negligible for our purposes). OISST have been interpolated into the regional model grid before performing the comparison with the forecasted SST.

3 Skill evaluation

In a slave mode forecast, the performance especially depends by quality of initial condition derived from the downscaling of the first day of forecast of the coarse resolution model. The data used in this study are the daily averaged forecasts (5 cycles for a single day) relative to a cloud-free day individuated in the forecasted period, namely October 7^{th} 2009. The forecast skill of the SCRMFS on daily basis is monitored by calculating different types of statistics between the forecast fields and the observations. The statistics are calculated for the all domain and some sub-domain, as defined in Table 1. The mean BIAS is calculated as the averaged difference between the Tf(x,y,t) and OISST(x,y,t) at each forecast cycle, while for the SST Skill Score we used two non-dimensional biases: the bias due to mean and the bias due to standard deviation (STD) between Tf(x,y,t) and OISST(x,y,t) at each forecast cycle. Then, the metric BIAS, RMSE and Sea Surface Temperature Skill Score (hereafter SSTSS) are defined by:

BIAS = [Tf(x,y,t) - OISST(x,y,t)],

RMSE = $\sqrt{[BIAS(x,y,t)^2/N]}$,

SSTSS = (1 - RMSE^2/STD^2) 100.

These statistical metrics (scores), defined in [18], gives a measure of discrepancy between known satellite observations, OISST(x,y,t), and the corresponding values forecasted by the model, Tf(x,y,t) at each forecast cycles (Figure 3). The model scores have been computed imposing two constrain: the depth of Tf(x,y,t) at the first sigma layer less than 10 cm and a threshold of the 50% (analysed error of OISST) to the OISST (x,y,t) data have been applied. A skill score value of 1.0 indicates that the forecasted SST and the observation are identical, while lower values indicate poor agreement. A negative score means that the forecast error is larger than the standard deviation.

4 Forecast results

The forecast statistics for SST have been calculated relatively to October 7^{th} 2009 over the entire domain and over four subdomains (Table 1). The daily RMSE calculated during each forecast cycle over the whole domain is shown in Figure 4. The values of the standard deviation are always larger than the RMSE (forecasts versus satellite) and they increase quasi-linearly with forecast cycles. From the fifth cy-

Sub-Regions	Latitude	Longitude
Sardinia Channel	37°N – 39.5°N	9°E – 12°E
Sicily Channel	35°N – 38°N	12°E – 15°E
Tunisian Shelf	33°N – 37°N	10°E – 12°E
Libyan Shelf	31°N – 35°N	12°E – 17°E

Table 1: Sub-domains.

cle (the forecast produced five days before the satellite observation) to the first cycle (one day before) the RMSE decreases of about 0.1°C (from 0.7°C to 0.6°C), and the standard deviation is between 0.95°C to 0.90°C (Figure 4A). As previously defined in section 3, the skill score is equivalent at a SSTSS increase and maintains values ranging from 0.37 to 0.44 during the forecast cycles (Figure 4B). Then, the last forecast cycle improves of about 19% than the fifth. In order to better understand how the quality of the forecast varies in space RMSE, STD and BIAS have been computed for the four sub-domains, as defined in Table 1. This subdivision has been done taking into account only geographic limits. In the Sardinia Channel, the RMSE during the five forecast cycles is between 0.63°C to 0.42° (Figure 5A), and the STD is rather low. This is equivalent at a negative SSTSS (-0.16 at the last forecast cycles), meaning that the forecast errors are larger than standard deviation. In the Sicily Channel the RMSE has a approximately constant value of about 0.6°C (Figure 5B), with a SSTSS of 0.62 at the last forecast cycle. Then, in both sub-domains, the performances of the SCRMFS are rather different, lower in the Sardinia Channel and higher in the Sicily Channel. The reason is mainly due to the spatial variability of the surface dynamics (Figure 6), characterized by a strong mesoscale activity and large horizontal temperature gradients, especially induced by the Atlantic Ionian Stream along the southern coast of Sicily [1], cyclonic and anticyclonic eddies. This is also confirmed by the BIAS field of SST (Figure 7) which shows strong negative values (about 2.5°C) mainly along the southern coast of Sicily. Higher values are found on the shallow and narrow shelf along the eastern coast of Sicily and locally at some mesoscale features. These high errors can be attributed to the computation of the diffusion terms that may constrain the heat flux to stay close to the surface. Better results have been obtained over the Tunisian sub-domain (Figure 5C). Here the RMSE doesn't exceeds 0.4°C, while at the last forecast cycle is about 0.32°C, with a SSTSS of 0.74. This increased performances of SCRM in this area are due to a lower spatial variability, represented by STD. On the contrary, over the Libyan shelf the model shows relative low performances (0.21 at the last forecast cycle). This is mainly due to a sensible decrease of the standard deviation and consequently to a superficial dynamic even if the RMSE keeps the same values as over the Tunisian shelf.

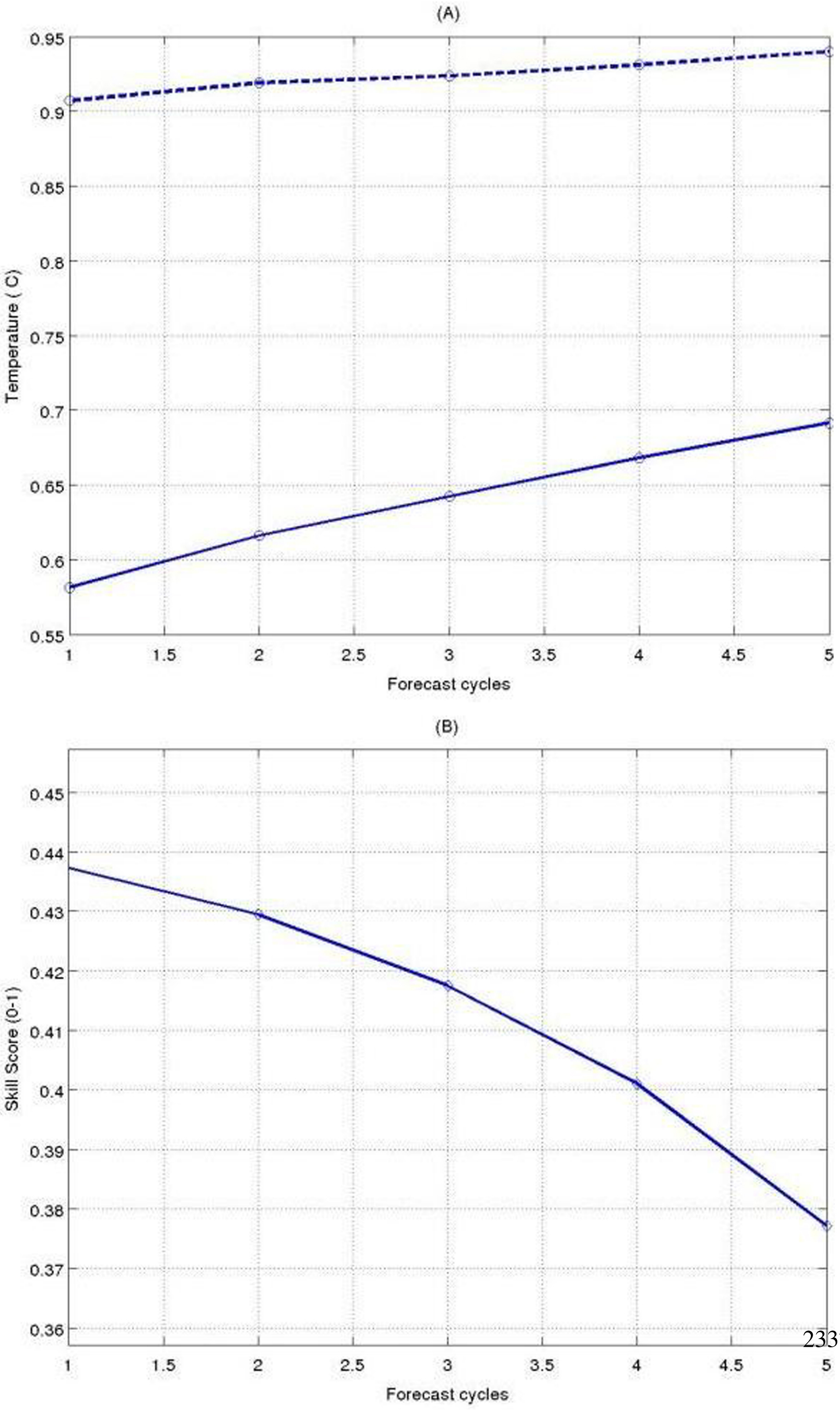

Figure 4: A) The RMS difference between the available satellite SST observations and the predicted SST (solid line) and the standard deviation (dot line) during the last 5 forecast cycles. For each cycle, the RMSE and SD are calculated only over the points where the ”estimated” analysis error of SST is less 50%. The number in the abscissa denotes the released forecasted day respect the observation. B) SSTSS over the whole model domain during the last 5 forecast cycles. For each cycle, the RMSE and SD are calculated only over the points where the ”estimated” analysis error of SST is less 50%. The number in the abscissa denotes the released forecasted day respect the observation.

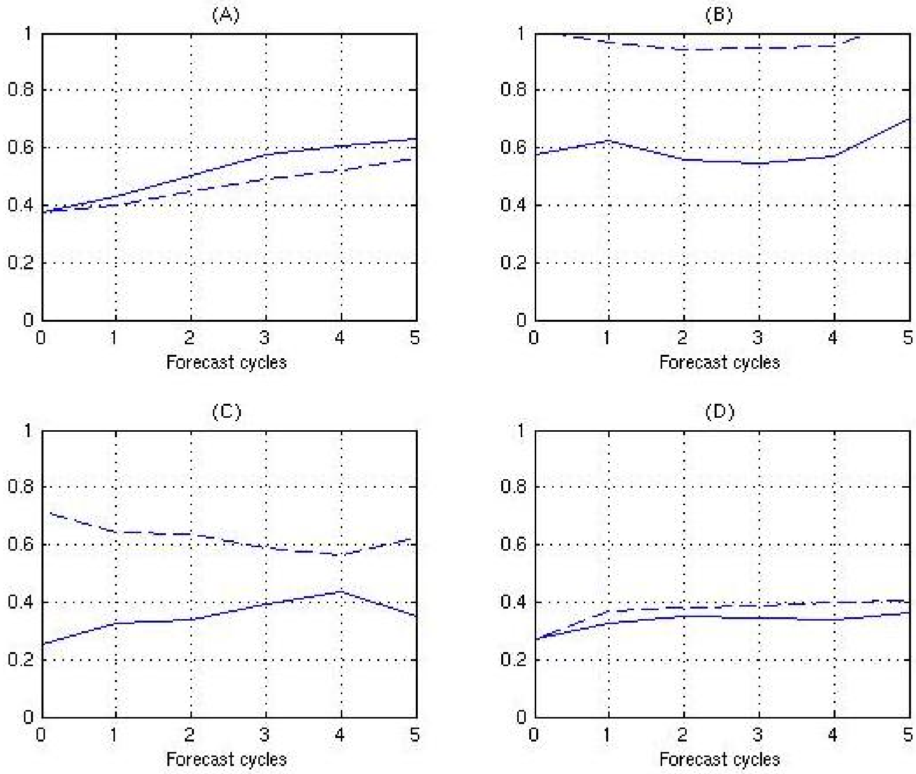

Figure 5: RMSE of the surface temperature computed on each sub-domain, as defined in Table 1 during the last 5 forecast cycles on October 7th 2009 in the: A) Sardinia Channel, B) Sicily Strait C) Tunisian Shelf and D) Libyan shelf. The RMSE value in 0 position of the abscissa denotes the error in the initial condition for the October 7^{th} 2009. The solid line represents the RMSE, while the dashed line is standard deviation.

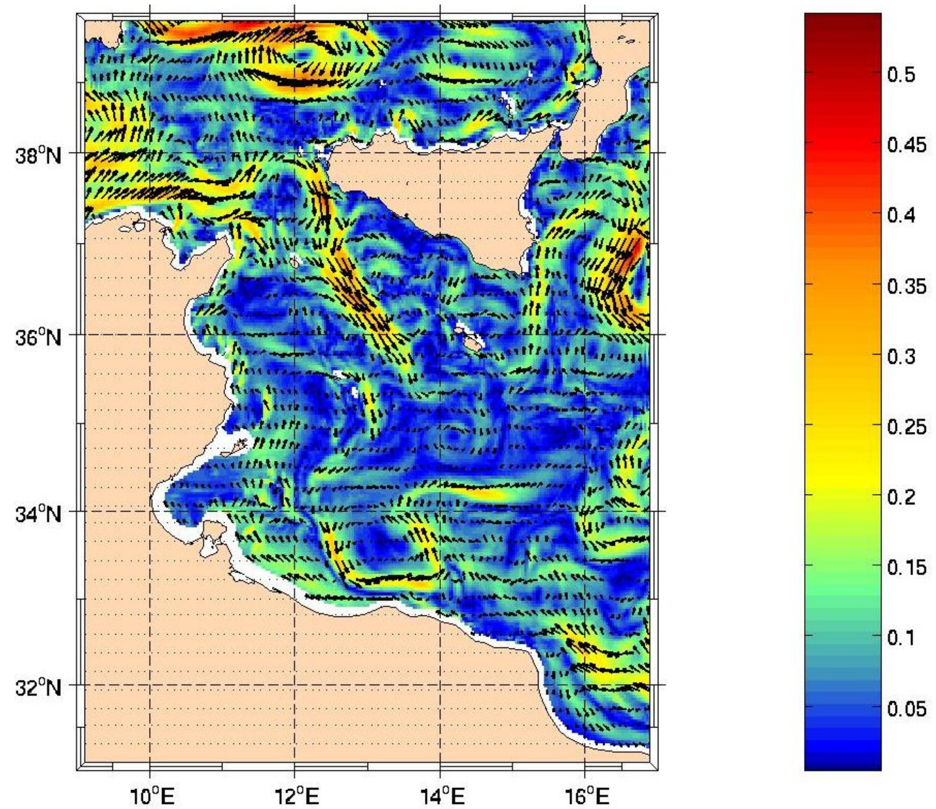

Figure 6: This figure shows the sea surface current velocity (in m/s) at -5 m for fifth forecast cycle on October 7^{th} 2009. The synoptic circulation show several well known features as the Algerian Current, an energetic Atlantic Ionian Stream which mainly flows inside the Sicily Channel meandering south of the Sicily coast and a well developed North Atlantic Ionian Steam. The Algerian Tunisian Current is weaker, while the circulation over the Tunisian and Libyan shelves is driven by south-east winds. In the open Libyan sea, between Malta and the Libyan coast, the circulation is dominate by several mesoscale features.

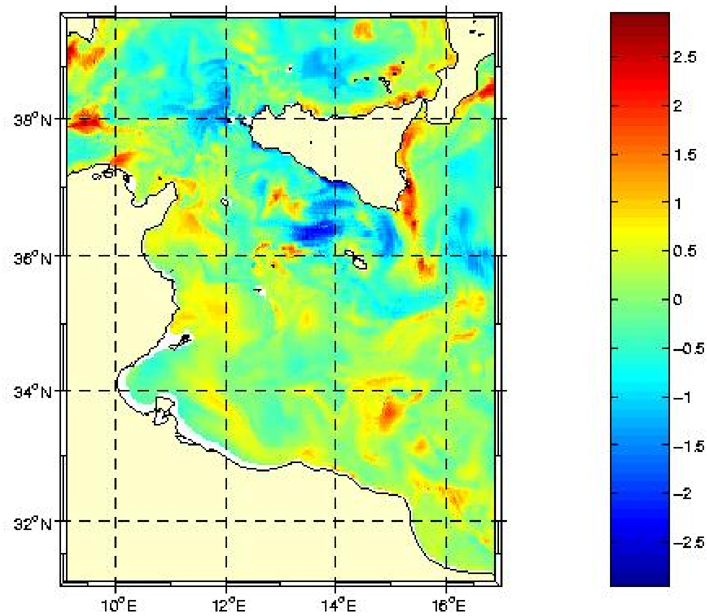

Figure 7: BIAS of SST on October 7^{th} 2009 computed at the fifth forecast cycle and then produced four days before.

5 Summary and conclusions

The SCRMFS shows an averaged SSTSS of 0.44 at the last forecast cycle. Higher performances are obtained over the Tunisian shelf and Sicily Channel where the SSTSS is 0.74 and 0.5 respectively. Lower performances are obtained in the Sardinia Channel (-0.16) and Libyan shelf (0.21). The analyses of the standard deviation, BIAS and Root Mean Square error suggest that the errors are due to different reasons. The atmospheric forcing and the superficial dynamics, which induce strong horizontal gradients of temperature for upwelling and mesoscale features. An example is represented by the upwelling located along the western and southern coast of Sicily induced by westerly winds and by inertia of the isopycnal domes of the AIS meanders. This is the main reason of the performances of SCRMFS in the Sicily Channel. Other reasons, which limit the performances of SCRMFS, could be related to computation of the diffusion terms. The relatively higher RMS error in the shallower areas of the domain, such as over the Tunisian, Libyan and narrow shelves, can be attributed to the computation of the diffusion terms that may constrain the heat flux to stay close to the surface. Then, the model overestimates the SST. Other reasons are the inaccuracy in the physics of the bulk formulae that are used for the derivation of heat fluxes, the coarse horizontal resolution of the atmospheric forcing, and the reduced numerical resolution in the vertical, due to the thickening of the first sigma layer over the deeper regions (western Ionian sea and Tyrrhenian Sea). In conclusion, the assessment of the SST predicted by the SCRMFS during the five forecast cycles show its reliability in reproducing SST synoptic remotely sensed data and the root mean square error decrease during the cycles forecast (from fifth to last). Within the limits of period of study, which is not sufficiently long, these preliminary results permit to identify the main deficiencies of SCRMFS. So, once assessed the skill of the model to reproduce hydrology and hydrodynamics, it can be used to investigate areas with a substantial deficiency of data and to provide an improved knowledge of the sea circulation.

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