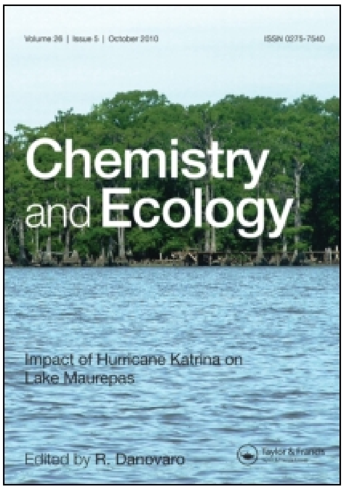

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

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To cite this Article Zappalà, Giuseppe and Azzaro, Filippo(2004) 'A new generation of coastal monitoring platforms', Chemistry and Ecology, 20: 5, 387 — 398
To link to this Article: DOI: 10.1080/02757540410001727990
URL: http://dx.doi.org/10.1080/02757540410001727990

Chemistry and Ecology
October 2004, Vol. 20(5), pp. 387–398

Taylor & Francis
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A NEW GENERATION OF COASTAL MONITORING PLATFORMS

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(Received 15 September 2003; In final form 27 February 2004)

The need for new instruments and systems for environment monitoring encouraged the development of a network of coastal platforms combining a high versatility with ease of use and affordability. Almost every instrument can be fitted on the platforms, thanks to the large amount of available power provided by both solar panels and wind generators. All the platforms host a pumping system that pumps water from five depths into a measurement chamber where a multiparametric probe is fitted and from where other devices (e.g. samplers or analysers) can draw samples. *In situ* temperature measurements are provided at the same pumping depths. A colorimetric nutrient analyser and a meteorological station complete the basic equipment. On one of the platforms, a remotely controlled water sampler and an ADCP are also fitted. The data-acquisition and transmission system enables the platform to be controlled remotely using a special macro-commands set. Several examples of use are presented.

Keywords: Coastal monitoring; Buoys; Nutrients

1 INTRODUCTION

At the end of the 1990s, the Italian Ministry for University and Research (MIUR) funded the Cluster 10, a set of marine research programmes. Among these, the "PI-CNR" (Potenziamento Infrastrutture—Infrastructure increase) and the "SAM" (Sistemi Avanzati di Monitoraggio—Advanced Monitoring Systems) projects jointly designed new devices (coastal monitoring platforms and advanced instruments) to best fit the research needs.

In recent years, surveys of water quality and meteorological parameters, on medium- and long-term scales, have been made possible by the availability of different kinds of coastal and offshore buoys and platforms, like those described, among others, by Carof *et al.* (1994), Grisard (1994), Eriksen (1997), Griffiths *et al.* (1999), Paul (2001), Seim *et al.* (2002), Nittis *et al.* (2003) and Pinardi *et al.* (2003).

Buoys can have various shapes: discus (e.g. NOAA, OCEANOR), stylus (e.g. ODAS ITALIA, SEMB, PALOMA) or floating platforms, like NOAA's NOMAD and those described in the present paper. Their functions may also be different; they can be "specialized" for wind-wave measurements (Skey and Miles, 1999) or suitable for general purpose and/or physical, chemical and biological measurements, like those of Woods Hole Group's

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ISSN 0275-7540 print; ISSN 1029-0370 online
DOI: 10.1080/02757540410001727990

SEMB, those applied within the GLOBEC program (Irish *et al.*, 1999) or the "advanced technology platform", described by Zappalà *et al.* (1998).

The monitoring systems can perform meteorological observations and measurements of physical, chemical and physico-chemical parameters characterizing sea water state and quality, current speed and direction; the measuring devices range from "static" sensors (e.g. Pt100 for temperature) to colorimetric analysers for nutrients; a water sampler, taking samples for further laboratory determinations, may also be included in the systems to complete the series of measurable parameters.

Water measurements can be carried out *in situ* at fixed depths, on samples pumped from various depths into a measurement chamber on the buoy, or using profiling instruments; the main advantages and disadvantages of the different choices are summarized in Table I.

Power supply and data-communication equipment often represent the main design constraints, limiting the frequency and kind of measurements and being limited by the size of the buoy. The first is usually provided by solar cells that recharge batteries, while the choice of the data-transmission system depends on the distance from the shore and on the quantity of data to be transferred. Offshore buoys generally use dedicated HF–VHF–UHF radio links, satellite (INMARSAT, ARGOS, etc.) communication or (rarely) cellular telephony (ETACS, GSM or satellite-based); for coastal buoys, GSM and GPRS offer a low-cost solution, also enabling the use of SMS and e-mail to transfer data and/or commands.

A special effort has been made recently to further improve the know-how acquired in previous programmes, described in Crisafi *et al.* (1994), Zappalà *et al.* (1999), Zappalà (2002) and Zappalà *et al.* (2002b), thus making the PI-CNR project an opportunity not only to buy

TABLE I Summary of measurement strategies advantages and disadvantages.

Measurement strategy	*Advantages*	*Disadvantages*
In situ at fixed depths (the most commonly used)	• Failure of one instrument will not stop data acquisition • Good quality of measurements if instruments are properly maintained • Measurements at the different depths are almost simultaneous • Low power consumption	• Every depth needs an instrument, so limiting the number of measurement points • Instruments are exposed to possible damages and fouling and need a scuba for maintenance
Pumped samples (IFREMER's MAREL buoy; see Legrand *et al.*, 1994 or the CNR platforms presented in this paper)	• Only one instrument is needed • Measuring instrument can be more easily maintained and also kept in freshwater between measurements • Availability of the water samples also for other instruments (*e.g.* colorimetric analysers, water samplers, etc.)	• Failure of the measuring instrument or of the pumping system will stop data acquisition • Limited number of measurement points • Degradation of sample quality: possible variations in temperature, dissolved oxygen and turbidity • Measurements at the different depths are delayed of the time necessary to bring water to surface • Power consumption
Profiling instruments (OGS-MAMBO buoy; see Deponte *et al.*, 2002; Viezzoli *et al.*, 2002; or McLane Moored Profiler (Morrison *et al.*, 2000)	• Only one instrument is needed • Measurements can be performed with the desired depth resolution	• Failure of the measuring instrument or of the profiling mechanism will stop data acquisition • Profiling mechanism maintenance • Power consumption

expensive instruments but also to develop advanced technology devices to be used in monitoring activities.

The first result is a network of seven coastal monitoring platforms, managed by SAM (five platforms in Sicily) and PIT-AGEM (Two platforms in Apulia) research programmes, first described in Zappalà *et al.* (2002a, c).

The main design goals have been:

- efficiency,
- modularity,
- expandibility,
- reliability,
- low cost.

This paper describes the platforms with the advanced equipment, showing some examples of measurements obtained through the application of these new technologies.

2 TECHNICAL DESCRIPTION OF THE SYSTEMS

2.1 Platforms

The "Prototype Platform" was designed and built in 1996; this triangular platform was working for several years and was moored near an urban sewer of Messina town, as reported by Zappalà *et al.* (1998). For the PI-CNR project, it 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.

Thanks to its easy accessibility and the large space available, being completely out of the water, the platform (Fig. 1) is also used as a test bed for new instruments and software.

FIGURE 1 Messina platform.

Six new platforms were built; rectangular and partly submersed, they were produced by redesigning and resizing a prototype vessel built by CEOM (an ENI group company); during spring–summer 2003, the platforms were modified, increasing the buoyancy and electrical power availability (Fig. 2).

All the platforms have the following equipment:

- an expressely designed data-acquisition and transmission system, fully manageable and reprogrammable via GSM and SMS;
- a meteo station equipped with temperature, pressure, solar radiance, wind direction and speed sensors;
- a system for pumping water samples from five depths (Idromar), equipped with an IM50 CTDO turbidimeter-fluorometer;
- an experimental colorimetric Nutrient Probe Analyser (Systea);
- prearrangement for a water sampler for microbiological laboratory analysis;
- five SBE 39 T *in situ* probes at the same sampling depths.

The Messina platform also hosts:

- an Idromar IM50 CTDO probe for *in situ* subsurface measurements;
- a water sampler for microbiological laboratory analysis;
- a Nortek Aquadopp 600 ADCP.

2.2 Power-Supply System

The electrical generation system combines both solar and wind energy. The system implemented in Messina buoy uses three 12 V, 85 W solar panels with an integrated shunt

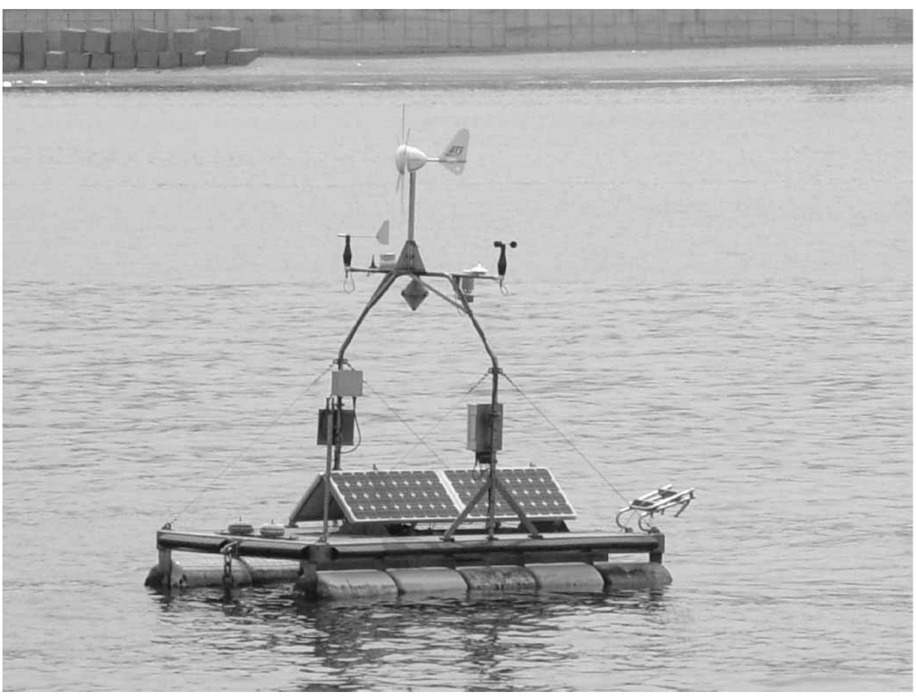

FIGURE 2 Milazzo platform.

voltage regulator, three 12 V, 45 Ah sealed lead batteries, and a 12 V, 200 W wind generator. The other buoys have four 12 V–85 W solar panels with an integrated shunt voltage regulator, eight 12 V, 50 Ah Monolite batteries, and a 12 V, 200 W wind generator.

The architecture is simple and reliable: each solar panel charges a lead battery or a couple of Monolite batteries; the charge coming from the wind generator is distributed, via a set of diodes, to all the batteries; and another set of diodes allows the systems to be supplied from the "best working" battery.

2.3 Data-Acquisition and Transmission System

The data-acquisition and transmission system, shown in Figure 3, is based on the IEEE P996.1 standard; it features a 40 MHz, 386 CPU, 10 RS-232 ports, an eight-inputs 12 bit ADC, 48 power outputs with connected circuit status feedback, 24 simple power outputs and a dual-band GSM modem. It meets (with some variations) and sometimes exceeds the capabilities of the ARES architecture described by Lessing and Henderson (1999).

The software was written in Microsoft Professional Compiled BASIC v7.1. It enables full control of the platform instruments in both local and remote mode using a special set of macro commands that also include conditional execution of branches; this feature can be very useful in case of partial operativity of the platform, for example as a result of low battery level or failure of some instrument.

Each hour, an embedded "sequence manager" starts a programmed sequence of macro commands that can be different for each time; this is remotely reprogrammable. New releases of the software can be uploaded to the instrument without suspending the normal operation of the system.

The macro commands can be combined into sequences using a simple text editor. The syntax of the commands is very easy: every macro command begins with the letter Z, followed by a letter identifying the command and by the variable parameters (if any). The commands available include:

- system-management commands;
- instrument-management commands;
- conditional branch commands;
- data-transmission commands.

A sample sequence of macro commands is presented in Table II.

During inactivity periods, the system enters a low-power "sleep" mode, from which it is awakened synchronously each hour by the sequence manager or asynchronously by the

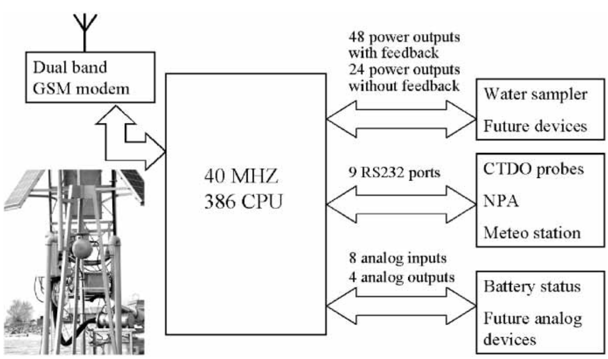

FIGURE 3 Data-acquisition and transmission system.

TABLE II Sample measurement sequence.

```
ZZ seqtemp.dat
ZZ this is a sample measurement sequence, sequentially reading input from the
ZZ five SBE 39 Temperature probes and then transmitting the acquired data
ZZ the lines starting with "ZZ" are comments
ZZ switch on T-probes
ZI 49 1
ZZ the command "ZI xx y" switches on (if y = 1) or off (if y = 0) output n. xx
ZZ T-probes power supply comes from output n. 49
ZZ wait 60 seconds
ZU 60
ZZ the command "ZU xx" causes a pause of xx seconds in the elaboration
ZZ read probes, starting with the deepest
ZZ the command "ZT xx" causes acquisition from the T-probe on serial input n. xx
ZT 10
ZT 9
ZT 8
ZT 7
ZT 6
ZZ transmit measured data
ZE
ZZ the "ZE" command sends the data measured by the five T-probes
ZZ switch off T-probes
ZI 49 0
ZZ end sequence
```


reception of a modem connection. A watchdog timer automatically resets the system in case of hanging.

Measured data are transmitted via GSM SMS and e-mail to the main data centre. The use of e-mail enables the data centre to be allocated in the most convenient place, without any need for proximity to the platforms: in fact, the data of all the SAM and PIT-AGEM buoys are collected and managed in Messina. The command-data flow is shown in Figure 4.

2.4 Pumping System

The pumping system was designed by Idromar for use on platforms. The instrument pumps sea water from five depths into a measurement chamber, where an IM50 CTDO probe with fluorometer and turbidimeter sensors is fitted. The water can be extracted to feed the NPA probe and the automatic water sampler. At the end of the measurement cycles, the chamber is washed with freshwater.

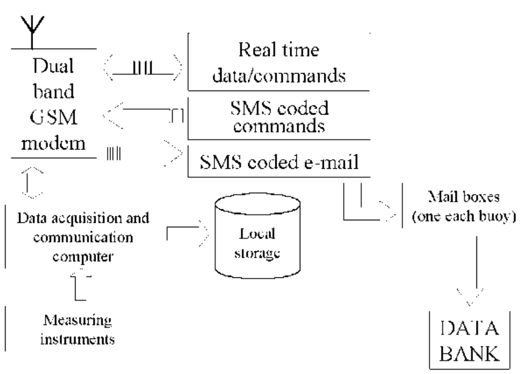

FIGURE 4 Command-data flow.

2.5 Automatic Water Sampler

An autonomous water sampler, shown in Figure 5, was designed and built for use on platforms (see Zappalà *et al.*, 2003). This instrument can fill eight 250 ml bottles and add a fixative to prevent degeneration of the sample for further laboratory analysis. After the sampling, the fluid circuit is washed with freshwater. It is possible to program and control all sampling events remotely.

2.6 Nutrient Probe Analyser

The Nutrient Probe Analyser (NPA) is a new experimental device, designed by Systea (Rome) for automatic nutrient monitoring. Using the loop flow analysis (LFA) technique, the instrument can sequentially measure ammonia, nitrate, nitrite and orthophosphate in a few minutes by one or two on-board double-beam solid-state colorimeters. The detection limits are: ammonia and nitrate + nitrite 0.3 μM; nitrite 0.15 μM; orthophosphate 0.06 μM (Azzaro *et al.*, 1994).

The results are given in concentration units; all measured values are stored with date, time and sample optical density; the same data are remotely available through a serial communication port, which allows the complete remote control of the probe. All the analyser programming functions can be addressed by a detachable external control panel, using a 16-key keyboard and a 2 × 16 row LCD display.

Analysis requires only about 100 μl of wet reagents (those recommended by international standards, according to Strickland and Parsons, 1972); the reagent bags are refrigerated by the surrounding water.

To overcome the time limits of the colorimetric measurement method and to investigate environments with fast variations in the water column, a water pre-buffer tank was designed

(a)

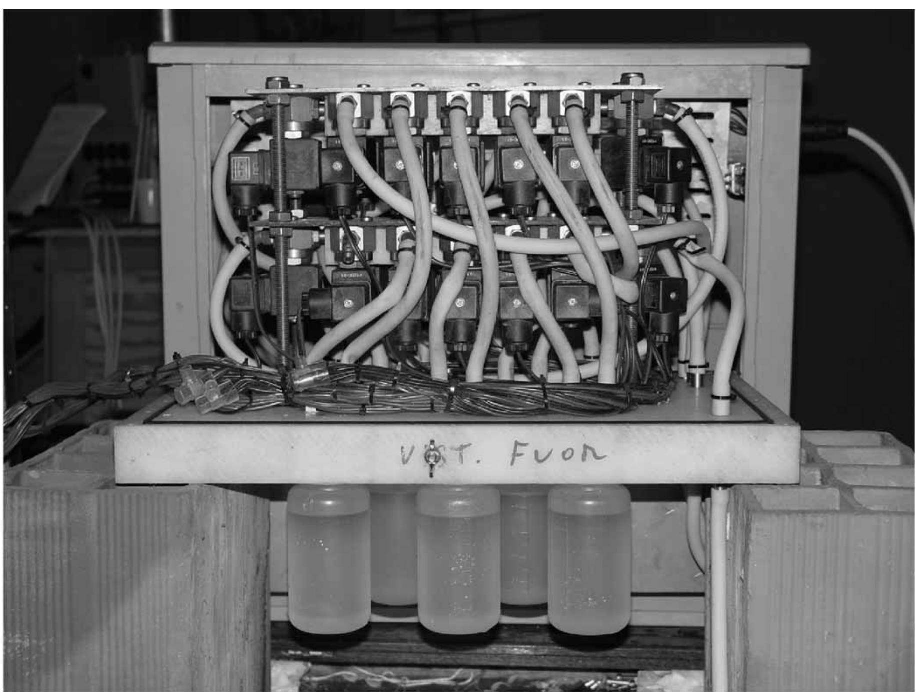

FIGURE 5 (a) Water sampler. (b) Pump box.

(b)

FIGURE 5 Continued.

as a part of the SAM activities; this has been tested on the Messina platform and in the near future will also be used on the other platforms.

2.7 Meteo Station

The meteo station is based on Theodor Friedrichs sensors measuring air temperature, wind direction and speed, pressure and solar radiation; a Precision Navigation blind compass measures the heading of the platform, thus referencing the wind direction measurement.

2.8 Aquadopp ADCP

The Nortek Aquadopp is a profiling device whose performance from a buoy is now being tested. It measures current speed and direction in 20 layers equally spaced in depth.

2.9 Data Bank

All the data, automatically or manually measured, are collected in a Data Bank integrating an Oracle DBMS with a GIS. Data transmitted from the buoys via SMS are automatically inserted into the DB, for further validation and integration. With this system, it is possible to query the DB, view the results and plot them on a graph.

3 EXAMPLE MEASUREMENTS

The platforms were installed between spring and summer 2002 in the selected areas, starting with the test period, and scheduled to last until December 2002; the results obtained suggested some improvements to the systems (buoyancy, power availability, some software macro instructions) that were implemented in spring–summer 2003.

The mission protocol included measurements every hour with "static" devices (*in situ* T probes, meteo station, ADCP) and every 6 h with the pumped systems (CTDO, NPA) that have a high power consumption; the water sampler was scheduled "on demand".

All the instruments were factory-calibrated just before installation; in accordance with maintenance operations, sample measurements were performed with boat-installed instruments, to be used for the final data validation not yet completed. The maintenance routine includes periodic sensor cleaning (at intervals depending on the mooring sites) and factory recalibration once a year. As a sample of the system's capabilities, measurements taken during 13–19 July 2003 are shown.

Temperature trends in the water column measured using *in situ* sensors are shown in Figures 6 and 7. Temperatures measured on the Milazzo platform are plotted in Figure 6. stratification is evident: minimum values are measured by the 25 m sensor (the deepest)

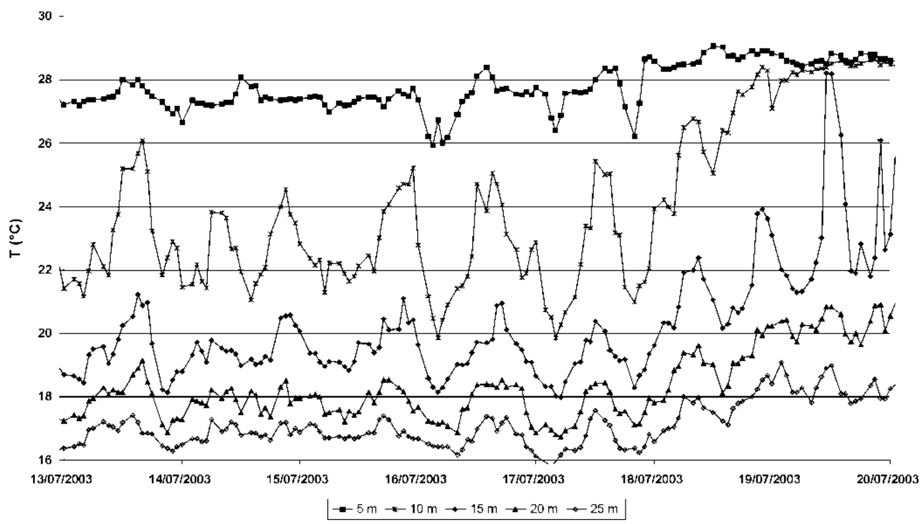

FIGURE 6 Temperatures measured on the Milazzo platform by *in situ* sensors.

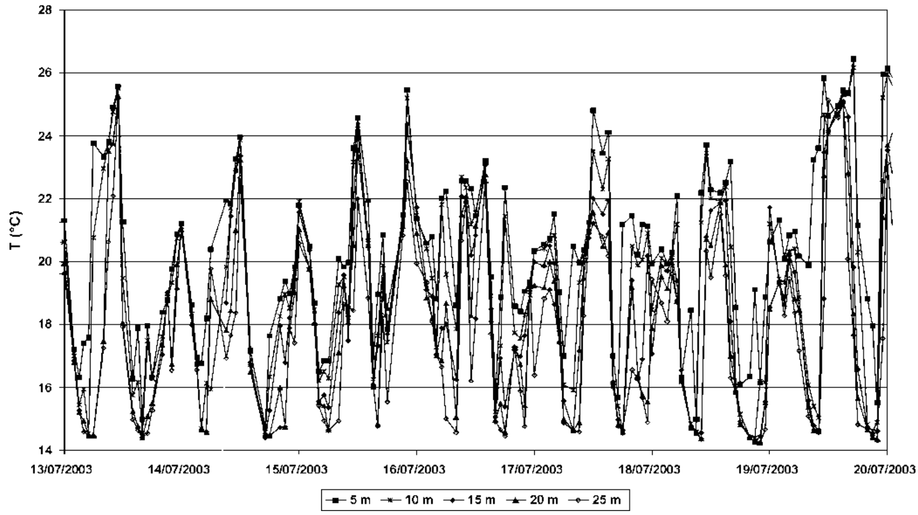

FIGURE 7 Temperatures measured on the Messina platform by *in situ* sensors.

and maximum values by the 5 m sensor (the shallowest). Nychthemeral variations can be observed, with thermal increments during the central hours of the day. Water-column mixing can be seen in Figure 7 (which also shows the temperatures measured on the Messina Platform): the temperature variations observed are caused by the tidal alternation of "montante" and "scendente" streams, with little variation between the different depths.

Initial observations show a difference in temperature measurements on pumped samples with respect to the *in situ* measurements performed by the SBE39 sensors, which are chosen as reference; certainly, the precision of the CTD is not as good as that of the SBE probes, but this cannot justify such a difference, which is mainly due to the heat exchange in the pumping pipes, in the pump itself and in the measurement chamber.

Working on a sufficient amount of data, it should be possible to characterize the devices and their thermal characteristics and so build up a correction model for temperature, but this

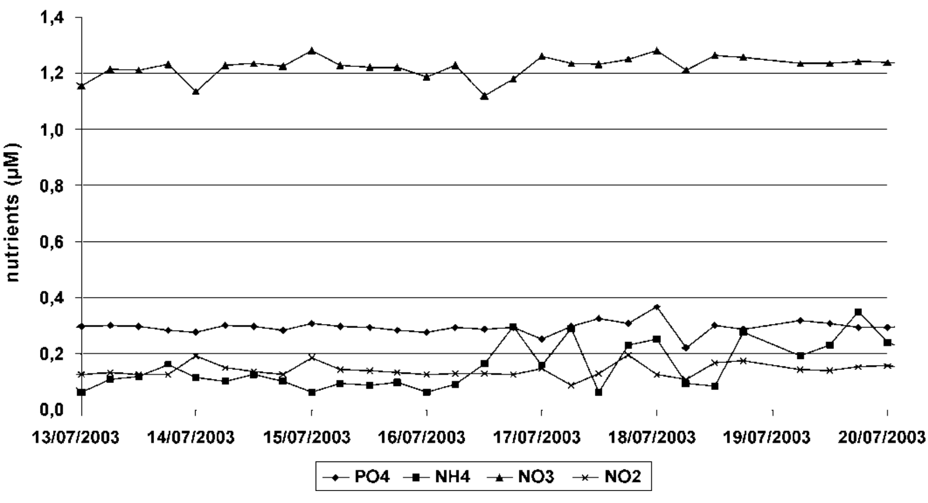

FIGURE 8 Nutrients on the Milazzo platform.

work probably is not necessary for the general purposes of environment monitoring, being superseded by the *in situ* measurements.

Thus, the pumping system temperature measurement should be used only in calculating parameters deriving from other sensors in the same probe or measurement chamber (e.g. salinity), or as a trend indicator; otherwise the *in situ* probes should be used.

Nutrient measurements performed using the NPA in Milazzo Platform are reported in Figure 8. During the period examined, large variations were not found; ammonia, nitrites and orthophosphates showed low concentrations, whereas nitrate values were substantially higher.

4 CONCLUSIONS

The flexibility of the assembly of the technical instrumentation makes the systems described here versatile for environmental surveillance; because of the relatively low cost, high versatility and reliability, it could form the basis for basin-wide coastal monitoring networks.

The use of a standard PC architecture enables software routines to be developed and tested using powerful languages and debuggers, on the desktop computer, thus simplifying the addition of new instruments.

The ability to remotely reprogram mission parameters or the whole system can help to meet the varying needs that might arise in long-term observations (e.g. failure of a measuring subsystem or low power availability because of a problem in the battery charge circuits, or simply the choice of a new monitoring strategy).

With SMS and e-mail for command and data transmission, it is possible to position the control and data centre at the most convenient site, and also to have more than one, without any need for antennas for radio links or contiguity to the buoys; an Internet connection with e-mail access is all that is needed to monitor the system; also, some commands can be issued using a normal GSM phone.

A new modem and software version are now under trial, using GPRS and direct connection to an SMTP mailer to lower the communication costs.

The overall application is multi-purpose: by simply varying the mounted instruments and the data-acquisition schedule, it is possible to tailor the system to fulfil scientific objectives (creation of data sets for oceanographers, modellers, etc.) as well as environmental management objectives (nowcasting and monitoring for local authorities, fisheries, sea-farming, touristic activities, etc.).

Acknowledgements

Funding for the activities in this study is from the Cluster 10 MIUR "PI" and "SAM" programmes. This paper was presented at the Workshop "Una rete di progetti per lo sviluppo delle Scienze del mare nel Mezzogiorno d'Italia: primi risultati del piano Ambiente Marino", Bari, 26 November 2002.

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