The Nazare Canyon observatory (W Portugal) Real-time monitoring of a large submarine canyon.

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***Abstract*- In 2002 the Portuguese hydrographic office - Instituto Hidrográfico (IHPT) - started a program of monitoring of the largest submarine canyon of the European margin: Nazare Canyon. Since it incises a rather sensible continental margin, characterized by the presence of a protected area for marine life (Berlengas marine reserve), the proximity of important routes for maritime traffic and the existence of traditional fishery centers, efforts was conducted to the maintenance of a mooring array equipped with currentmeters/ADCP, which was complemented with multidisciplinary surveys conducted on a regular basis.**

Here we describe the more recent experience in the monitoring of Nazare Canyon, through Project MONICAN (MONItoring of the Nazare CANyon area), financed by the EEA Grants mechanism.

The monitoring system integrates an array of two multi-parametric platforms, one coastal meteorological station and two coastal tide gauge stations, all providing real time data transmission. The array of multi-parametric platforms is the central component of this system.

Public dissemination of the data collected by the monitoring system is a key aspect of the MONICAN project. The real-time data can be freely accessed through a dedicated web portal.

Innovative experiences are being conduct to validate the recent installed systems and test the capability of performing regular observation of the Nazare Canyon area, using low cost sensors on non-dedicated surveys and ships of opportunity.

Further developments to take place in the very near future will reinforce the monitoring capacity installed by IHPT in this area.

I. INTRODUCTION

With a length of more than 270km and extending from abyssal depths of 5000m to about a few hundred meters from shore, were it reaches depths of 150m, the Nazare Canyon is the largest submarine canyon of Europe and one of the largest of the World.

The canyon cuts a particularly important and sensible area of the Portuguese continental margin, in what regards environmental, economical and social issues. South of the canyon, the Berlengas Islands area is a refuge for the marine wildlife and become, since 1981, a Natural Reserve of major importance. The reserve confines, offshore, with major north-south routes for maritime traffic, which renders it particularly sensible to pollution accidents. Over the centuries, several fishing communities established along this coast, profiting the richness of the shelf waters surrounding the Nazare Canyon and creating important fishery harbors such as Peniche. Over the last few decades tourism become one of the key development factors for these communities, involving a large fraction of the population and creating new areas of activity based on the sea. More recently, the Nazare area also emerged as a key region for activity areas such as oil prospection, wave energy extraction or the implementation of new strategies for fish growth such as the use of artificial reefs.

All the above mentioned activities and human pressure that are presently focused in the Nazare Canyon area require a good understanding if the oceanographic processes taking place in this area and the monitoring of these processes Here we describe the development conducted in recent years by the Portuguese Hydrographic Office (Instituto Hidrográfico-IH) towards the implementation of an observatory of the oceanographic conditions affecting the Nazare Canyon area.

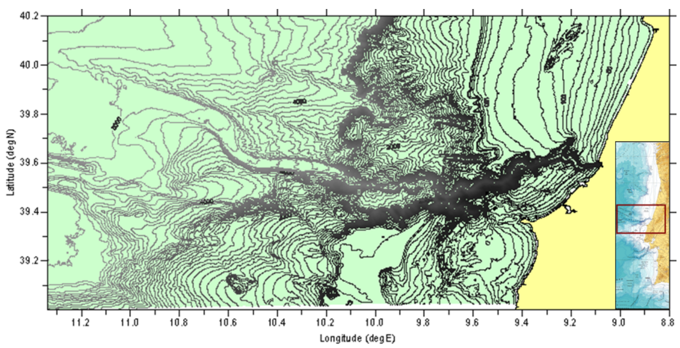

Figure 1. Bathymetric map of Nazare Canyon area.

II. IH LONG-TERM MOORING ARRAY

Large submarine canyons can promote considerable impacts on the continental margins they incise, either by creating preferential pathways for the interaction between coastal areas and the deep ocean, by modifying the shelf circulation and being the source of highly energetic dynamical processes or by focusing surface wave energy. In the recent years, a large international and multidisciplinary effort was focused on the Nazare Canyon area, aiming to highlight the main processes that take place at this canyon and to understand their impacts on the sediment transport and deep ecosystems. This effort is was initiated in 2002, and is being supported by major European projects such as projects EUROSTRATAFORM

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(2002-2005), HERMES (2005-2009) and HERMIONE (2009-2012).

As part of its contribution to these projects, IH started, in late 2002, a program of long-term mooring observations of the upper and middle sections of Nazare Canyon. From 2002 to 2005 two currentmeter moorings were maintained at two positions along the canyon axis, one by a bottom depth of 1700m, in the inshore portion of the upper canyon section and the second by 3300m depth, in the middle canyon section. Since 2005, the mooring array was extended with an additional mooring, deployed by 700m, in the inshore part of the upper canyon section. All the three moorings cover the complete water column, with instruments placed from near surface (about 30-50m depth) to near bottom levels (20 meter above bottom), preferentially at depths that correspond to the main water masses that characterize the area. The moorings are equipped with Aanderaa RCM-7, RCM-9 and RCM-11. In one of the moorings of the upper canyon section an upward looking 300 kHz RDI ADCP is being used to provide current data in the upper hundred meters of the water column.

The moorings are maintained in a permanent basis, with periods of deployment of 4-5 months, followed by short periods of maintenance of 2 weeks during which the data is downloaded and the equipments and mooring elements are prepared for the following deployment.

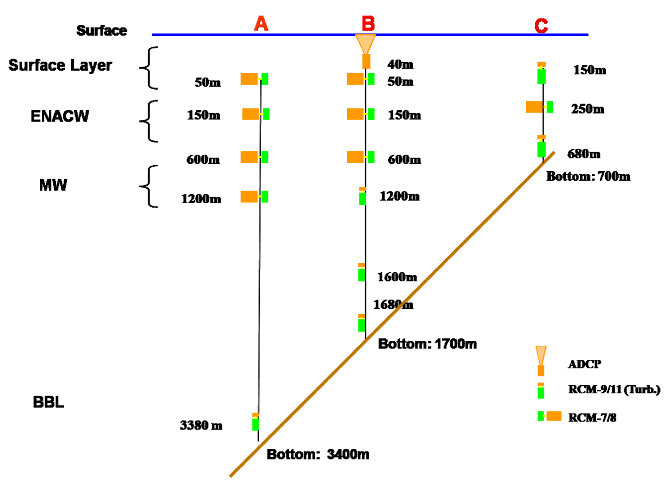

Figure 2. Scheme of the three long-term currentmeter moorings maintained by Instituto Hidrográfico at the Nazare Canyon.

III. REAL-TIME MONITORING – MONICAN SYSTEM

The interest that was raised among the local authorities and general public by the observations collected using the IH long-term mooring array, as well as the recognition of the importance of monitoring the conditions in the canyon and the impacts this topographic feature promotes on the shelf and coastal areas, motivated the step forward towards the implementation of real-time monitoring capacities in the area

The building of such capacities started in 2008, in the framework of project MONICAN (MONitoring of Nazar CANyon), financed through the European EEA Grants program. The project extends from 2008 to 2011 and its central goal is the implementation of a real-time monitoring system which integrates an array of two multi-parametric platforms, one coastal meteorological station and two coastal tide gauge stations. Additional measuring platforms and observational actions are also being conducted in association with the development of the MONICAN system.

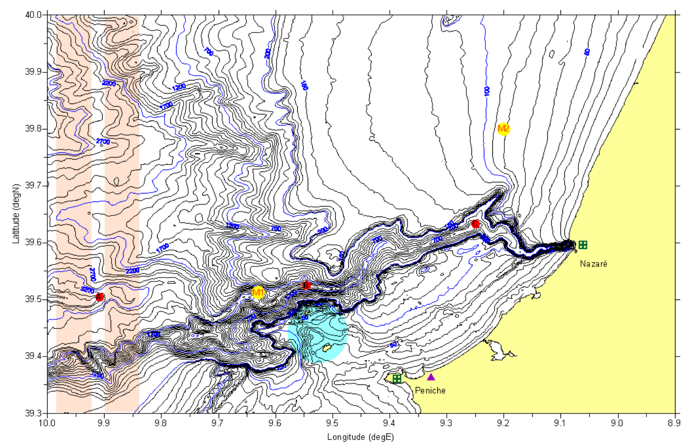

Figure 3. Zoom of the bathymetric map of Monican area. Yellow dots (●) mark the location of the MONICAN mooring array, the purple triangle (▲) indicates the coastal meteorological station and coastal tide gauge stations are marked with a green cross (⊞). Red dots (●) indicates the currentmeter mooring with insertion of .the location of Berlengas Natural Reserve area in blue (●). Routes of maritime traffic (■)

The MONICAN project also includes the development of operational forecasting capacities for the Nazare Canyon area, with the implementation of several numerical models that could simulate and forecast the dominant processes. The monitoring system is, then, intended to provide real-time data to feed the assimilation schemes implemented in those models.

A. *Multi-parametric buoys*

Two meteo-oceanographic Oceanor WAVESCAN buoys were deployed offshore Nazare as part of the MONICAN system. These platforms collect directional wave data as well as meteorological, oceanographic and water quality parameters. They are powered by solar panels and re-chargeable batteries.

One of buoys (deep buoy, 39º 30’ 43.6’’N, 009º 37’ 47.1’’W) was deployed in April 2009, at a position located over the middle section of the canyon, by a water depth of 2000m. The second buoy (shallow buoy, 39º 45' N 009º 12' W) was deployed in March 2010 at the mid shelf north of the canyon, by 80m depth.

The WAVESCAN buoys pre-process the raw data collected by the different sensors that are available for real time transmission. Selected parameters are transmitted hourly to the onshore receiving station that comprises a PC connected to the Internet. The communication is provided by a two-way INMARSAT-C satellite link, which allows the reception of the data from the buoy, as well as the change of configurations if needed. The complete raw and pre-processed data sets are stored on the buoy hard disk, and can be downloaded during the period of maintenance of the system.

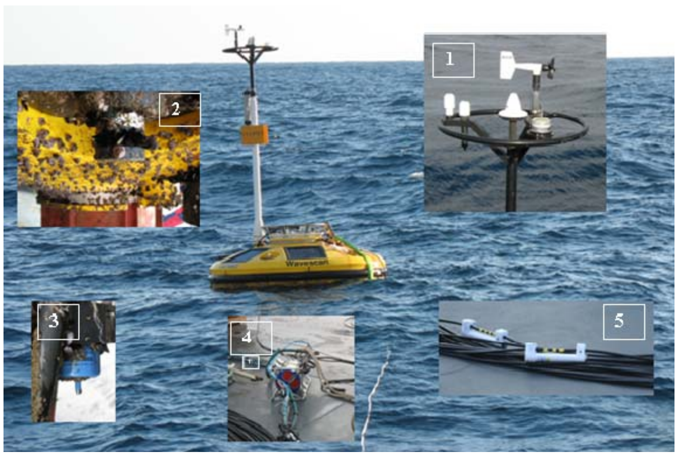

Figure 4. Deep MONICAN WaveScan buoy. The inserts show details of the sensors installed on the buoy. (1) meteorological sensors and INMARSAT antenna, (2) chlorophyll sensors after a 8 month deployment, (3) surface thermistor, (4) 300 kHz ADCP, (5) inductive thermistor chain.

Both buoys are equipped with GPS *(Global Positioning System*). The buoy's position is output as part of the data string and a watch circle can be established around the buoy's deployment position and monitored.

The buoys have several options regarding sensors and equipment. The core sensor is a solid state inertial motion sensor – *WaveSense* (*Oceanor*) – which integrates accelerometers, angular rate sensors, magnetoresistive sensors and one temperature sensor for compensation of temperature effects.

They are also equipped with a mast that supports meteorological sensors and communication antennae. Both buoys are equipped with similar meteorological sensors, which include a digital barometer (*Vaisala*, PTB330A) for atmospheric pressure measurement, a relative humidity and air temperature sensor (*Vaisala*, HMP45A) based on a capacitive thin film polymer sensor. An analog wind speed/direction sensor (*Young* 04106 JRMA) is installed in the deep buoy while in the shallow buoy the option was an ultrasonic wind speed and direction sensor (*Young* 85106).

Concerning to the oceanographic parameters, both buoys are equipped with a downward looking 300 kHz acoustic Doppler profiler (*Workhorse Sentinel RDI*), installed at 7m depth, which provides current data in the first 100m of the water column. Both ADCPs are configured for self recording. In addition, current speed and direction and velocity error are sent in real time for a total of 7 ADCP bins. The data collected from the first period of deployment of the deep MONICAN buoy are illustrate on figure 5 and is consistent in a 100m of water column. The percent good confirms that the mooring is stable and the movements of the buoy on the surface don't influence significantly the optimal angle for the ADCP optimal measurements.

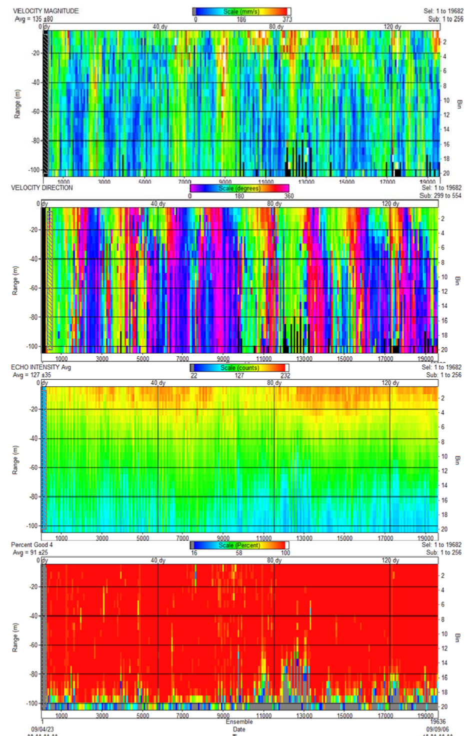

Figure 5. ADCP data collected from the first period of deployment of the deep MONICAN buoy. From top to bottom: current speed, current direction, echo intensity and percentage of good data with a 4 beam solution.

Sea surface temperature (1m depth) is measured in each buoy using an *Aanderaa* 4050 temperature sensor. In the deep buoy, in addition, an inductive thermistor chain (*Sea-Bird*, SBE 39IM) is used to measure water temperatures at 4 different depths. The measuring levels were selected to be 10m, 50m, 100m and 200m, but these can be easily changed during the period of buoy maintenance.

Water quality sensors installed in the buoys include dissolved O_2 sensors (*Royce*, 96A) and Chlorophyll-*a* optical sensors (*MiniTracka* II HB176, *Chelsea Instruments*). The shallow buoy also includes a turbidity sensor (*Unilux, Chelsea Instruments*), which allows to monitor the evolution of the surface nepheloid layer. In the deep buoy this sensor was replaced by a hydrocarbon sensor (*Nereides OILSPY* 1606) that detects the presence of floating hydrocarbons using a polymer membrane. Equipped with this sensor, the deep MONICAN buoy can act as an alert system to oil spill accidents. This is of vital importance in an area located in the border of major maritime routes and characterized by the presence of a Marine Reserve.

The system is in operation since April 2009, with the deployment of the deep buoy. This buoy provided a first period of monitoring that extended until January 2010. Regular maintenance periods are conducted after about 6 months of deployment for both buoys.

The two MONICAN buoys installed offshore Nazare provide a flexible platform, particularly suited for the installation of different additional sensors. New sensors or replacement of the sensors already installed can be easily done during the periods of buoy maintenance.

B. Coastal Meteorological Station

The MONICAN system also includes one coastal meteorological station (AWS 2700, *Aanderaa*), installed at Ferrel (39º 23' 16.5''N, 009º 17' 29.52''W). This station is operated by IH since July 1984 in a continuous basis. The station provides wind speed and direction, atmospheric pressure, air temperature, relative humidity and solar radiation. The meteorological data collected at this station is sent in real-time to IH using a GSM communication.

C. Tide Gauge Station

Two tide gauges are also included in the MONICAN real-time system. One of the stations is already installed at Peniche (39º 21' 12.7'' N, 009º 22' 02.7'' W). The second will be soon installed at Nazare. Both stations are based on radar tide gauges and data transmission by GSM.

D. Other monitoring actions

Complementary to the implementation of the MONICAN array of monitoring platforms, other less conventional platform and strategies are being developed and tested with the aim to extend the information of the oceanographic conditions in the Nazare Canyon area. One of such systems is the CORSED platform, which was developed at IH for the monitoring of currents and suspended particle water in the water column. The platform is 5m height and integrates two ADCP (one 300 kHz RDI upward looking and one 1200 kHz RDI downward looking) and two *Aandreaa* RCM9/*Seaguard* currentmeters equipped with turbidity sensors. The platform can also integrate additional sensors, such as a LISST sediment sampling sensor. The platform is equipped with an acoustical link that can send the sensor information to a surface buoy. The CORSED platform was already used in the Nazare area, as a stand-alone platform with data transmission to a research vessel. Future plans include the deployment of the buoy as part of the MONICAN array, with real-time data transmission assured via acoustical-radio link using a surface buoy (MOBBY buoy) as the retransmission antenna.

Figure 6. The CORSED platform being deployed during a test, showing the two ADCPs, the two RCM-9 and the LISST.

A second area of development presently being explored at IH is the use of low cost sensors in monitoring actions conducted in regular basis and using ships of opportunity or non-dedicated surveys. This comprises the use of trawled chains of sensors or the deployment of low cost moorings for monitoring the water column or near bottom conditions in ocean and nearshore environment. The low cost sensors being used are DST Star-Oddi thermistors and CTDs. They are small sensors with an internal logger memory and battery that allows the easy and fast deployment without special support platforms.

E. Data Management and Public Dissemination

The data collected from the multi-parametric buoys is sent to IHPT via *Inmarsat-C* satellite. At the receiving station the message sent by the buoy is decoded, converted to an *ascii* file and loaded on an Oracle database. The real-time data set sent by each MONICAN buoy comprises the relative humidity; air temperature; atmospheric pressure; wind speed; gust and direction; surface sea temperature, significant wave height; mean and peak wave direction, wave peak period, oxygen and chlorophyll-a concentrations at near surface (1m), and current speed, direction and error at 7 depths measured by the near surface ADCP.

In addition to these parameters, the deep MONICAN buoy also sends in real-time sub-surface temperature data collected at 10m, 50m, 100m and 200m water depth (*SeaBird* thermistors connected via inductive cable) and an index for the presence of hydrocarbons at the surface. The shallow MONICAN buoy, by its turn, also sends turbidity data from the sensor installed at 1m depth.

From the experience of the first eleven months of deployment of the deep MONICAN buoy, we can say that the reception of data is quite good, with losses in real time on the order of 2% of data. These gaps can be restored after the maintenance periods, every six months, when all the data is recovered from the buoys data loggers. After processing, this data is loaded in the local databases.

The complete data set collected by the buoys is made available to the general public, being disseminated through a web portal (http://monican.hidrografico.pt). Here data can be retrieved or visualized for the distribution of a specific parameter for the last hour, day, week or month.

An evaluation of the performance of the sensors installed on the buoys is presently being conducted by comparing the buoy measurements with observations available at other stations or conducted during oceanographic surveys. For the meteorological data, this comparison is done on a monthly basis, by comparing the data received from the Wavescan buoy with data collected at the Ferrel coastal meteorological station (Figure 7). In the very near future, all data included in the MONICAN web portal for public access will be quality controlled. The data validation will be done taking into consideration the characteristics of each parameter and checking for acceptable values for this geographic area and for the differences between consecutive values.

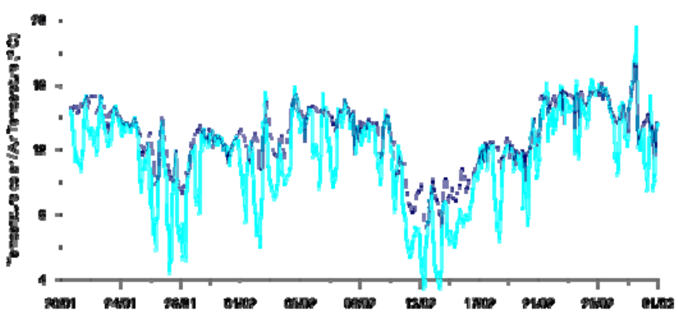

Figure 7. Comparison of the air temperature measurements at the Ferrel meteorological station (cyan) and at the MONICAN deep buoy (dark blue), for the period from 20th January to 1st March 2010.

IV. TAKING THE PULSE OF THE CANYON.

Besides contributing to bring decisors and general public to a close contact with the ocean environment just offshore their doors, the monitoring capacities presently installed by IH at the Nazare Canyon are also allowing an increased insight on the canyon processes and on the impacts of such processes in the adjacent shelf and deep ocean waters.

The real-time observations collected by the MONICAN platforms are providing a continuous monitoring of the changing oceanographic conditions and associated forcing mechanisms in this area marked by seasonal variability and well exposed to the North Atlantic influence. Real-time data collected during the first period of deployment of the deep MONICAN buoy is presented in figure 8. From the beginig of May until the end of June, it shows the decay of wave conditions towards the low energy summer regime and the corresponding building of the seasonal surface stratification. in response to solar heat input and weak vertical mixing. From end of October the real time observations revealed the transition to the highly energetic winter regime, characterized by successive storm events, (maximum wave heights frequently exceeding 10m) which, in combination with surface heat loss, promote the erosion of the stratification and the development of a ten meters thick winter mixed layer.

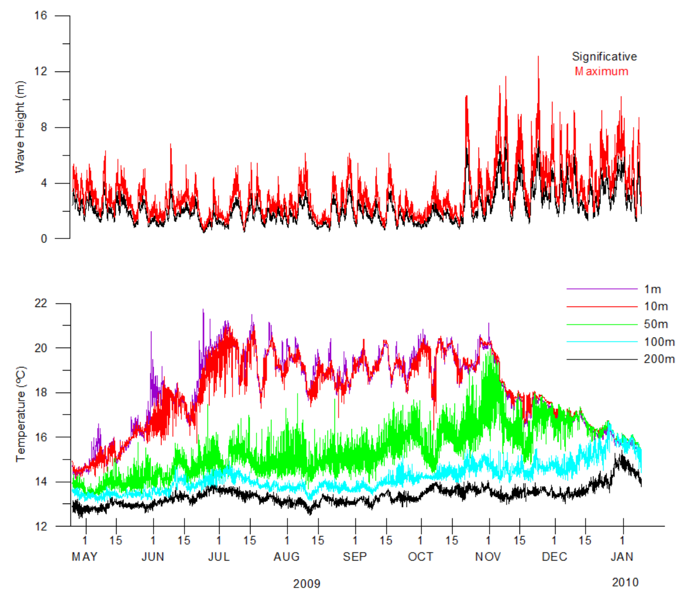

Figure 8. Time series of wave height (upper panel) and temperature in the upper 200m depth (lower panel) measured at the deep MONICAN buoy, from April 2009 to March 2010.

The real-time observations can guide the planning of observational programs that aim to characterize the high frequency processes that take place in this submarine canyon. Processes such as the high turbidity flushing events that were put in evidence, previously, by the IH long-term mooring array (figure 8). Several of these events can occur each year, triggered by major storms, and lead to a large exportation of sediments and water properties from the nearshore environment of the canyon head to the abyssal plain environment on the middle and lower canyon sections.

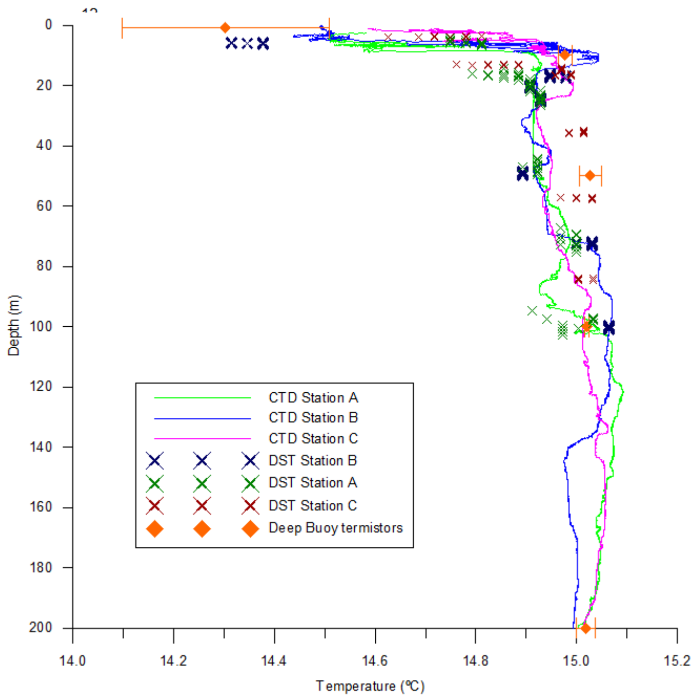

Figure 9. :. Time series of wave height (upper panel) measured at Leixoes, about 200km north of Nazare Canyon and near bottom turbidity at 20m above the bottom (lower panel) measured at the long-term mooring maintained by IH in a bottom of 1700m depth along the Nazare Canyon axis.

Figure 10. Temperature profiles from CTD, temperature dispersion from DST sensors in each CTD station and average temperature from buoy thermistors.

In articulation with the real-time monitoring effort, strategies for monitoring the canyon area of influence using ships of opportunity are also presently being developed and tested in the Nazare Canyon area. The tests already conducted aimed not only to evaluate the capacities of the systems in the rapid survey of such a complex area but also to provide data sets that can be used to evaluate the performance of the sensors installed in the real-time platforms. In a recent experiment, conducted on the 11th March 2010, a 100m long chain was equipped with 7 DST sensors (nominal depths 5, 10, 20, 30, 50, 75 and 100m) with a 20 s sampling period and trawled along a triangular transect that enclosed the deep MONICAN buoy. The data from the thermistors was complemented with CTD casts taken at the vertices of the triangle and both sets were compared with the real-time data collected by the thermistors installed on the buoy and along the inductive cable.

The experiment proved the very good consistency between the different data sets (figure 10). It also provided confidence in a sampling strategy based on the use of low cost sensors trawled through the area by ships of opportunity or profiting non-dedicated surveys, to map the oceanographic conditions in the canyon's area of influence. The test conducted in March 2010 was focused on a small area around the deep MONICAN buoy. Despite its small dimension, the area exhibited strong spatial variability since it was located in the transition between oceanic waters and shelf waters with a marked low salinity, low temperature signal over the first 10-20m depth. , presenting (figure 10). Future actions will be directed to evaluate the operational difficulties involved in the use of such system for the coverage of larger areas of the canyon.

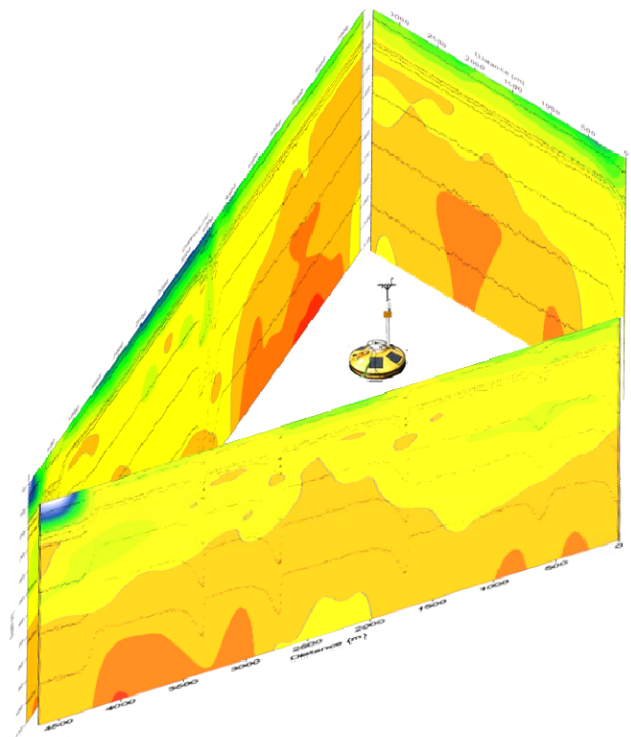

Figure 11. Temperature section from DST temperature sensors along a triangular transect enclosing the deep MONICAN buoy.

V. NEAR FUTURE DEVELOPMENTS.

In this contribution we provided a brief overview of the monitoring system presently installed and maintained by Instituto Hidrografico in the Nazare Canyon's area, which is looked as the first step of implementation of a Nazare Canyon laboratory. The developments planned to be conducted by IH in the near future will consolidate this conception infra-structure. They include the extended articulation of the IH long-term moorings and the real-time MONICAN system, in particular in the use of the real-time transmission capacities of the MONICAN platforms to integrate data collected at near bottom depths inside the canyon by the IH moorings.

The future actions also comprise the test of sensors and strategies for the observation both of the global area were the canyon is inserted as well as the nearshore environment. The experiments with the trawled thermistor/CTD chains will be continued during 2010-2011. If the results proven to be consistent, these observations will be conducted on a regular basis, profiting periods of mooring maintenance or opportunity ships.

A program of observations of the littoral area north of the Nazare Canyon head is planned to be conducted in September 2010. Low cost sensors, among other equipment, will be used to monitor the inner-shelf and surf zone environments and the data collected will be used to improve the modeling effort of the nearshore processes. This first experiment will also be used to evaluate the observation techniques and to prepare a following survey to be conducted during the winter, under highly energetic conditions.

An HF radar coastal station will be installed in the Nazare area, between 2010 and 2012, in the framework of a national funded project SIMOC (Coastal Currents Operational Monitoring System), recently approved. In the first stage, this station will be operated for a period of one year, during which the data collected will be used to feed the data assimilation models implemented under the MONICAN project. After the evaluation of results, this station could be maintained for a longer period and integrate the Nazare Canyon laboratory network.

ACKNOWLEDGMENT

The MONICAN (PT0042-GAE-00037-E-V1 – EEA FM) project is financed by EEA Financial Mechanism. HERMIONE (Contract 226354) project is funded by FP7-ENV-2008, the EUROSTRATAFORM project (EVK3-CT-2002-00079) was funded by the 5th Framework Program and HERMES (GOCE-CT-2005-511234) was financed through the 6th Framework Program.