MEDITERRANEAN EUROCENTRE
FOR UNDERWATER SCIENCES
AND TECHNOLOGIES

Evaluation and Selection of the MEUST Submarine Site

February 2013

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Abstract

This report summarizes the results of the investigations performed to select the MEUST submarine site. Measurement campaigns have been conducted during 2012 on several locations off shore of Toulon. During this period the most distant site has shown a higher sensitivity to bioluminescence seasonal variations, whereas the more coastal sites had similar conditions as Antares. This observation combined with logistic constraints leads to select a site located at similar latitude as Antares but more western on the other side of the CC5 telecommunication cable to Corsica. The route of the MEUST Main Electro-Optical Cable has been defined accordingly, with some flexibility to allow fine tuning of its end point as function of the outcome of the final site characterizations scheduled in 2013.

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1) MEUST siting

The submarine site of the pioneering Antares neutrino telescope had been selected more than ten years ago with the goal to minimize the potential hazards on the quality of the sea water environment while maintaining affordable operational conditions from the logistics point of view. This resulted in a site (42°48’N, 6°10’E) located south of the Porquerolles island at the bottom of the break shelf, in between the operational CC5 telecommunication cable to Corsica (westwards) and the military trajectography hydrophone array Tremail (eastwards). After many years of operation the Antares site conditions have proved to be stable, apart for the known seasonal variation of bioluminescence activity, whose intensity boost in Spring varies from one year to another.

Whereas it would a priori sound natural to choose the same site as Antares for MEUST, the longer term context of the project and the larger size of the KM3NeT neutrino detector have called for revisiting this issue. As already mentioned, the available space on the sea floor in the vicinity of Antares is limited by the CC5 cable and the Tremail array, which could restrict the expendability of the MEUST detector towards a full KM3NeT Building Block. In addition, within grouped deployment campaigns of a large detector, sea operation further away from the coast could be affordable, should a more distant site offer significantly better conditions than Antares. It is also worth investigating whether the sea operation costs could be reduced by probing the quality of a site closer to Toulon.

These considerations have led to organize regular measurement campaigns on 3 potential sites indicated on figure 1.1:

- a distant site, named “FAR” (42°40’N, 5°55’E), located South of Toulon 20km from the break shelf**.**
- a closer site, named “NEAR” (42°48’N, 5°58’E), located South of Toulon at similar latitude as Antares**.**
- a site adjacent to Antares, named “NE” (42°48.2’N, 6°10.8’E), located 1 km North-East of Antares.

In addition, measurements have been performed on the “OPERA” site (42°47’N, 6°05’E) close to Antares on the other side of the CC5 cable, where an autonomous mooring line has been operated for several years for sea sciences. Reference measurements are also provided by the Antares detector on the Antares site.

2) Evaluation Instruments

a) Autonomous Optical Modules

In order to monitor one of the main quality factors of the water environment, the optical background, three (+ one spare) dedicated autonomous Optical Modules (OM) were developed and built at CPPM. As shown in figure 2.1, each OM is made of a glass sphere equipped with two 3” photo-multipliers controlled by a standalone programmable data acquisition board storing the data in a data logger. The device is powered by an independent battery located outside the sphere.

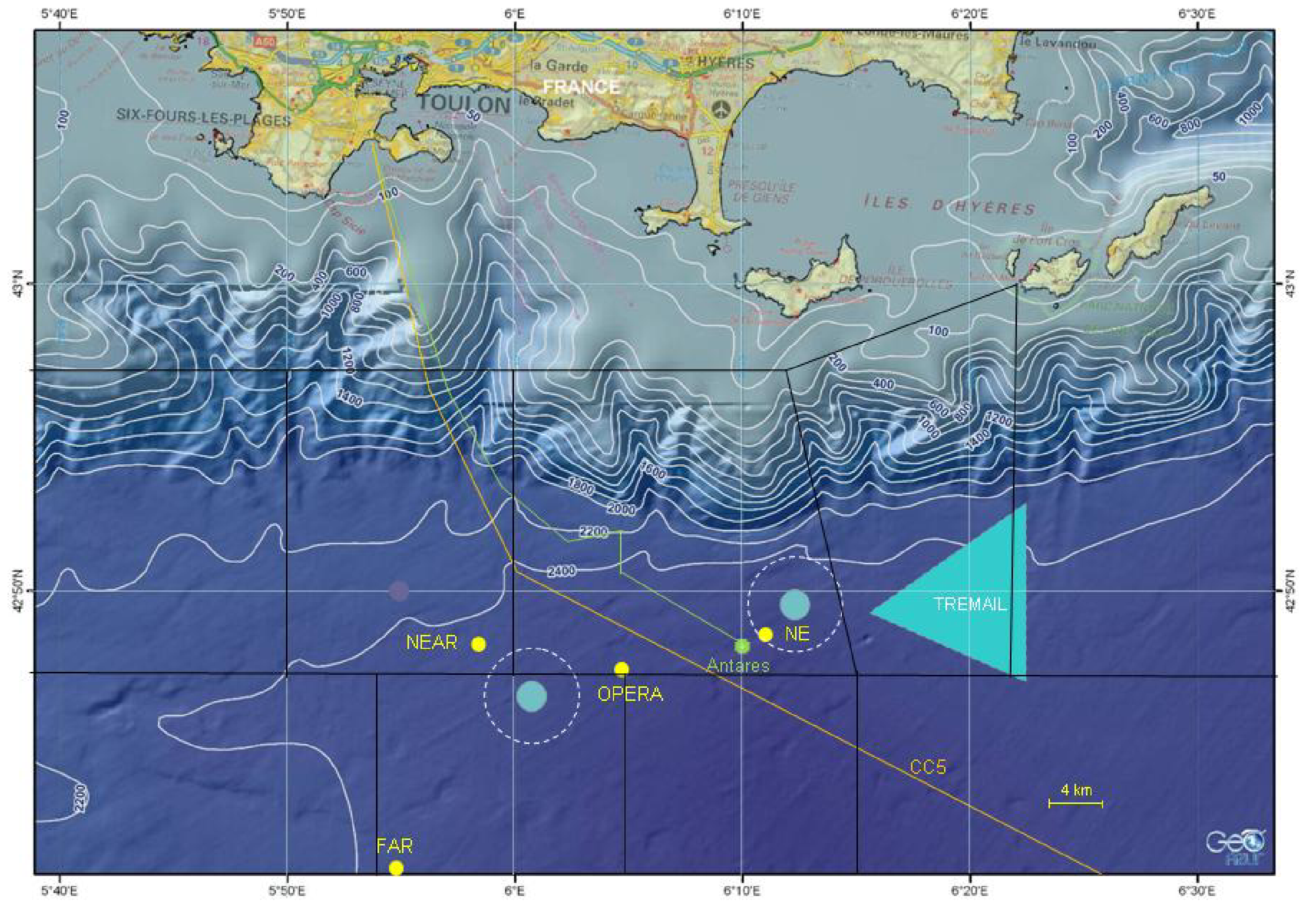


Figure 1.1: Location of the 3 potential sites (FAR, NEAR, NE) investigated for MEUST. Measurements were also performed on the OPERA and Antares sites. The map also shows the CC5 telecommunication cable to Corsica, and the western boundary of the military trajectography hydrophone array Tremail. The 2 light blue circles indicate the spatial extension of a full KM3NeT Building Block corresponding to the DU array (full circle) and the limits of the internode cables of the Marigold network (dashed circle).

The photomultipliers are 3” Hamamatsu R6233 equipped with a low consumption C11779 active base. The quantum efficiency of the photo cathode is ~20%. Typical gains of 3.10^6 are obtained with HVs of 1350V. Operating thresholds for rate counting are 0.6 photo-electron (pe). Within one OM, PMT #1 and PMT #2 are positioned on one meridian of the glass sphere, with respective pointing directions of $+33^o$ (“vertical PMT1”) and -74^o (“horizontal PMT2”) with respect to its south pole downwards direction.

The PMT signals are read out by a QUARKNET board which increments a counter per PMT each time its signal is above the threshold. The QUARKNET counters are read every second by a NORTEK data logger and stored in a local memory. Coincidences between the 2 PMTs are also monitored. The stored data therefore directly provide the individual and coincidence rates of the 2 PMTs in Hz.

The OM is powered by low voltage batteries located in a separate equipressure container filled with silicone oil. 20 batteries of 7.4V and 2 batteries of 3.7V are used, providing a total charge of 100 A.h and 26 A.h, respectively. In order to minimize power consumption, OM measurements are activated 50 mn every 4 hours. Under these conditions the typical autonomy of an Optical Module is 45 days. Due to the time needed for stabilization of the PMTs, only the last 1000s of each cycle are used in the analyses.

At two occasions (in February and September), the Optical Modules were calibrated in a dark room at deep sea water temperature (13^{o}C), and deployed together close to each other in the deep sea to check that their counting rates were equal after subtraction of the baseline rates. The dark room calibration consisted in tuning the PMT discrimination thresholds to 0.6 photo-electron (pe), using the measured single pe peak as a reference, and to measure the resulting PMT baseline counting rates in the dark. These baseline rates range from 2 to 5 KHz and were found to be stable within o(1 KHz) from February to September. The September values are used in the raw data corrections (section 3b).

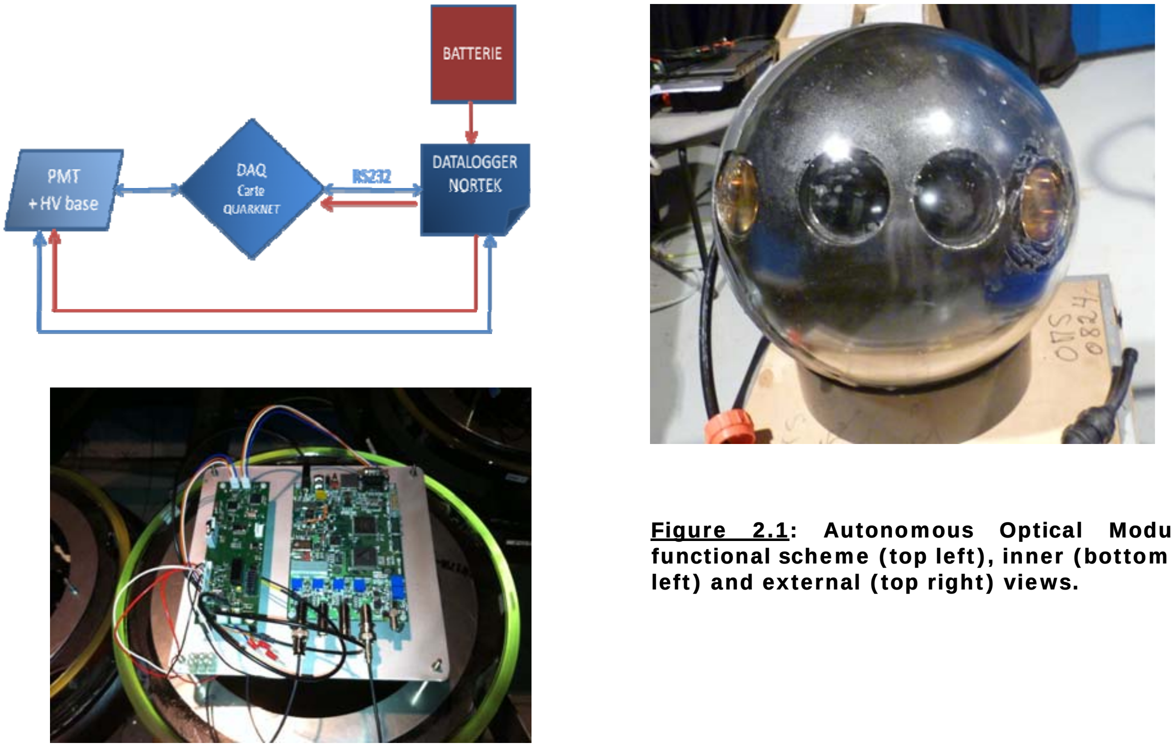


Figure 2.1: Autonomous Optical Module: functional scheme (top left), inner (bottom left) and external (top right) views.

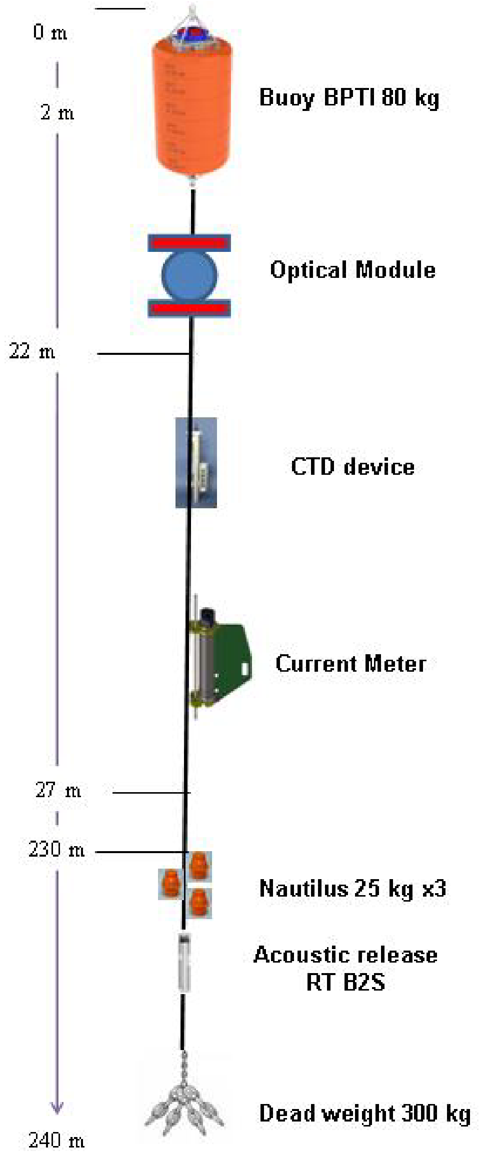
b) Mooring lines

The autonomous OMs together with conventional sea science instruments are fixed on autonomous mooring lines deployed on the seabed.

The general structure of the mooring lines is shown in figure 2.2. The lines have a height of 240m and are kept on the seabed with a dead weight, from which they can be disconnected by an acoustic release for recovery. One autonomous OM and its battery are fixed with a dedicated support frame close to the top of the line at a nominal height of 220m. A few meters below the Optical Module, two conventional sea science instruments complement the measurements:

- A current meter, NORTEK Aquadopp, for sea current monitoring by sound Doppler effect. This device measures the sea current intensity and direction every 10mn with precisions of 0.5 cm/s and 0.1^{o}, respectively. Its autonomy is about 6 months.

- A “CTD” device (microcat Sea Bird SBE 37) which measures the sea water conductivity, temperature and density for monitoring of the flow of the different sea water layers.



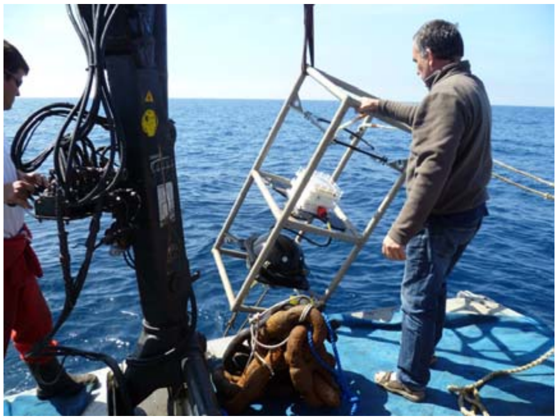


Figure 2.2: General structure of the autonomous mooring line (left) and view of the frame with the autonomous Optical Module (top).

Two such mooring lines were built for deployments at the FAR, NEAR and NE sites.

The OPERA site was also studied by implementing an autonomous OM on the existing mooring line. On the OPERA line the nominal heights from the seabed of the OM and the current meter are 260 m and 509 m, respectively.

c) Antares reference measurements

During the site investigations the Antares detector was also used to provide reference measurements of the sea currents. No current meter was operational on Antares during this period, but the sea currents could still be reconstructed from the monitoring of the Antares detection lines deformations by the positioning system. Unfolding the mechanical model of the lines provides a precision on the sea current of 1 cm/s in intensity and few degrees in direction. It was proven to be in very good agreement with the direct measurements of a current meter, except at very low current (< 2-3 cm/s) as well as at very high current (> ~15 cm/s), where a saturation effect appears in the unfolding of the lines deformations, leading to some underestimation of the highest current periods on the Antares site.

The Antares reference data have been available since the start of the Antares deployment in 2006. This data set provides an invaluable overview on the long term fluctuations of the water properties on the Antares site. It allows to better assess the significance of the fluctuations observed on the other sites in the shorter 2012 evaluation period.

3) Measurement campaigns

The instrumented autonomous lines, including the OPERA line, have been regularly deployed and recovered since February 2012. A typical deployment/data taking/recovery+readout cycle covers a period of 1.5 month. Due to logistics constraints data taking could not be totally synchronous between the various sites. Figure 3.1 summarizes the data taking periods on all sites with the corresponding instruments in operation. Five evaluation periods, labeled P1 to P5, are defined with, for each of them, several sites having both the OM and the current meter operational for comparison.

Figure 3.1: **Summary of the periods investigated on the various sites until November 22nd, and corresponding instruments in operation. The 5 periods labelled P1 to P5, defined to compare the sites under various activity conditions, are also indicated.**

a) Sea currents

The evolution as function of time of the sea current intensities and directions are given in figure 3.2 for the 5 sites under consideration.

The beginning of the investigations corresponds to a period of high sea currents, which then slowly decrease to reach the usual baseline speeds in summer. This corresponds to the usual transfer, at the end of winter, of dense cold surface waters to the deep. This phenomenon was particularly active in 2012 with both convection and cascading effects observed in the Gulf of Lion, a region known to influence the Toulon area

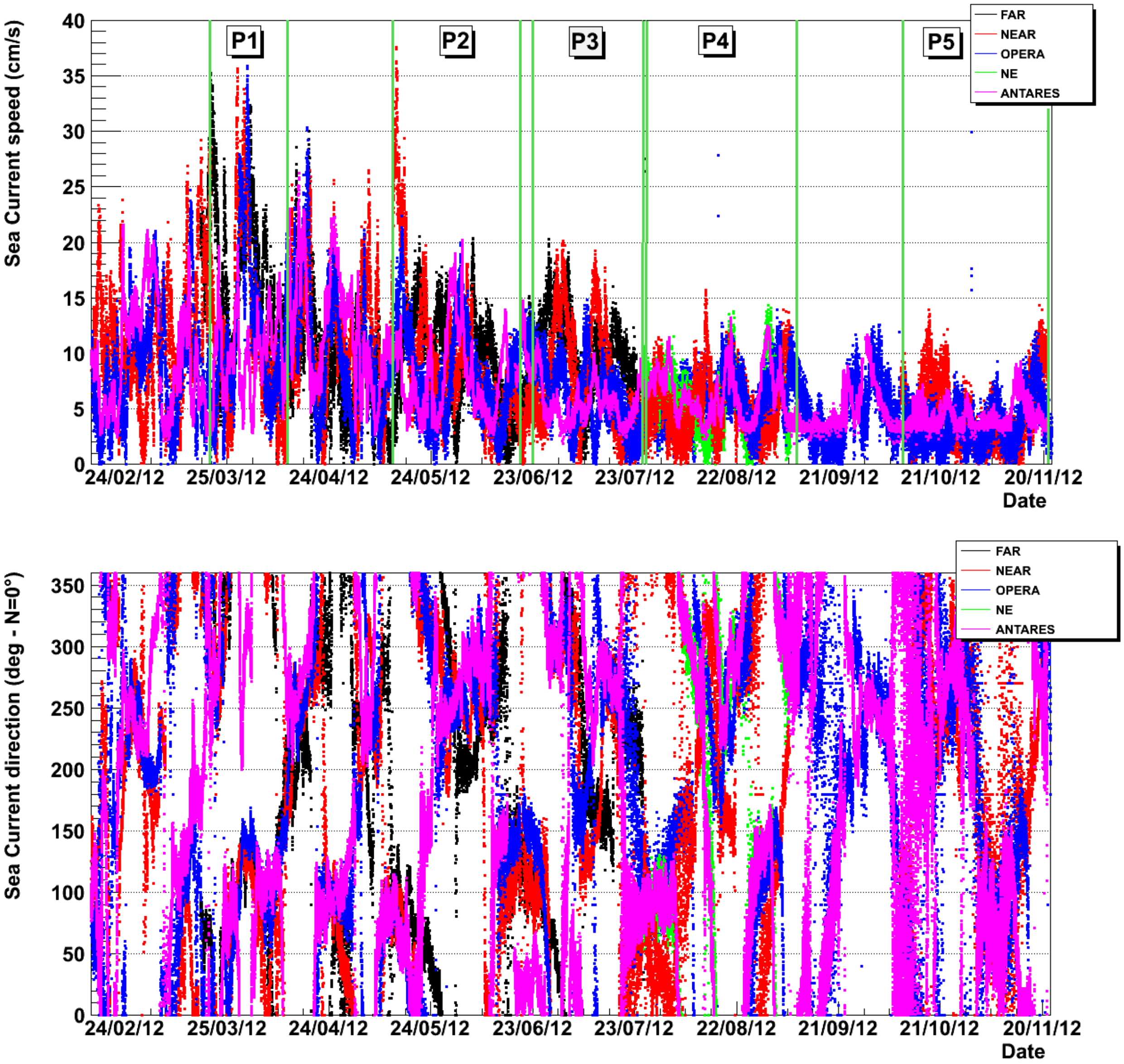


Figure 3.2: **Variation of the sea current intensities (top) and directions (bottom) for the 5 sites considered. The five periods defined in figure 3.1 are also indicated.**

It can be seen that both intensities and directions of the sea currents are comparable and well correlated between the 5 sites, with some time shifts of a few days between the sites due to their different locations.

b) *Optical counting rates*

The optical activity in the deep sea water is directly monitored from the Optical Modules counting rates. As already mentioned in section 2a), due to the time needed for stabilization of the PM responses, only the last 1000 s of each 50 mn cycle of data taking is used for the measurements. The raw rates are first corrected for the dark noise levels determined in the calibration process for each PM (section 2a). After this calibration correction, for a given time slot of 1000 s, 3 estimators of the optical activity can be built from the distribution of the rates measured every second (figure 3.3): the baseline rate (mean of a gaussian fit to the peak of the distribution), the median rate (quantile at 50% of the distribution) and the mean rate (average of the distribution). As shown in figure 3.3 right, there are systematic shifts between the 3 estimators but their evolution is strongly correlated in time. In the following the median rate will be used since it is sensitive to the full distribution (unlike the baseline) but depends less on tail fluctuations than the mean rate.

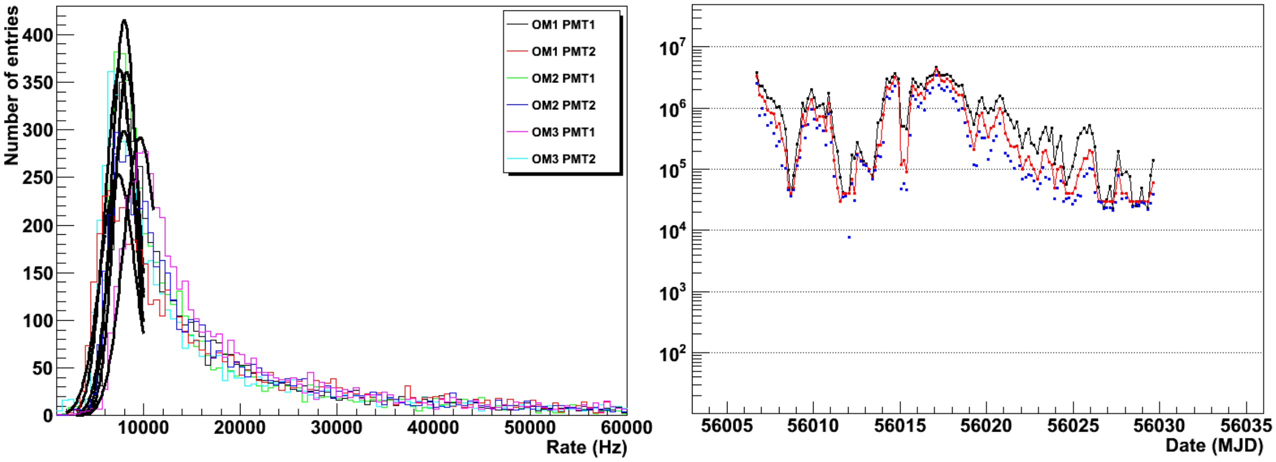


Figure 3.3

Left: distribution of the PM counting rates measured in an in-situ common calibration of the 3 autonomous optical modules (36 hour quiet period); the curves represent the Gaussian fits of the baseline rates. Right: evolution as function of time of the 3 activity indicators (black: mean, red: median, blue: baseline) of one PM for a one month period with strong optical activity.

The evolution of the median rates measured for 4 sites are shown in figure 3.4. They show the same trend as the currents intensity measurements (figure 3.2 top) with a high activity period starting end of winter and then slowly decreasing towards summer to a baseline of ~3 KHz, corresponding to the expected ^{40}K decay counting rates for these types of PMT. As already mentioned in 3a), deep winter convection as well as cascading phenomena occurred in the Gulf of Lion in 2012. These phenomena increase bioluminescence due to both increased current speeds and renewing of deep waters of the Western Mediterranean Sea. While the increase of bioluminescence with current speed is a well known mechanism due to direct mechanical stimulation of present organisms, the formation of new deep waters enhances bioluminescence due to the input of organic matter and organisms. Figure 3.5 shows that the correlation between sea current intensity and bioluminescence is directly visible for both PMT orientations in our autonomous measurements. Both sea current intensities and optical counting rates can therefore be used as indicators of the relative quality of the sites at a given moment.

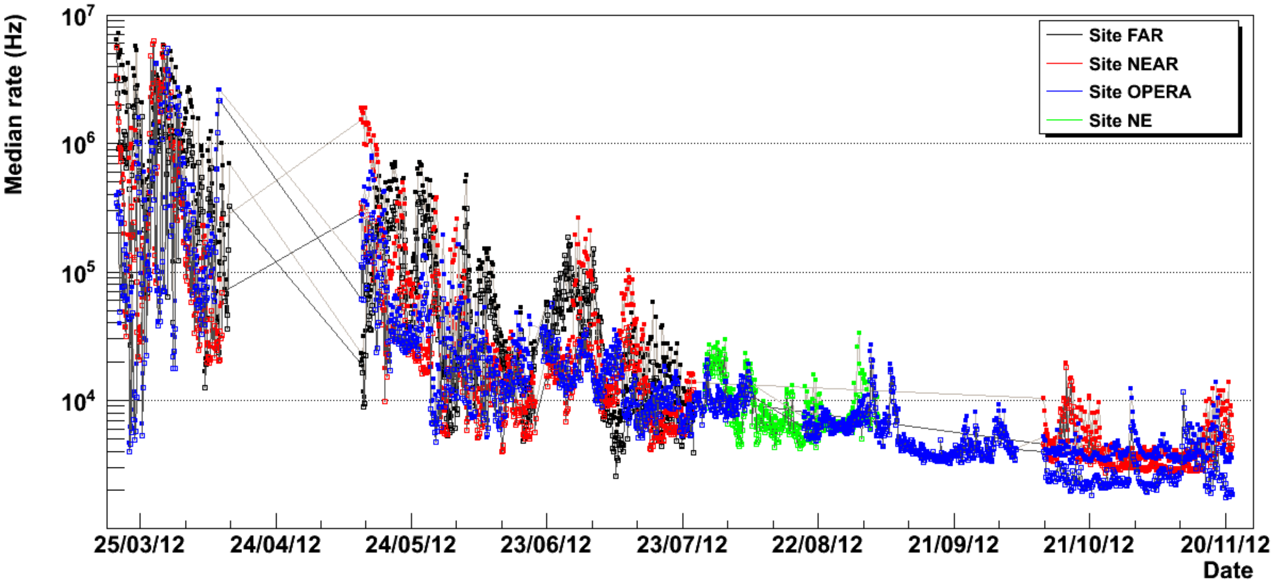


Figure 3.4: variations of the optical activity (median counting rates of the 2 PMTs) for 4 sites.

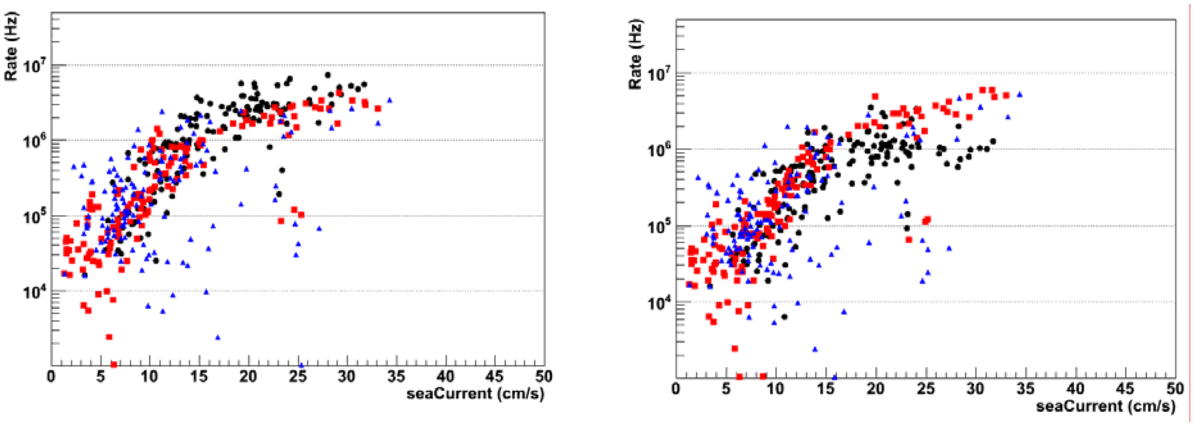


Figure 3.5: correlation between the sea current intensity and the optical median counting rates measured for a period of 1 month for PMT1 (left) and PMT2 (right) of the 3 autonomous OMs (colours).

c) Antares long term measurements

As a reference for long term evolutions and fluctuations, figure 3.6 shows the variations of the sea current intensity measured on the Antares site in the past 5 years. The regularity of the winter activation is clearly visible, except in 2008 where it did not happen, in coherence with a non-observation of winter convection in the Gulf of Lion this year.

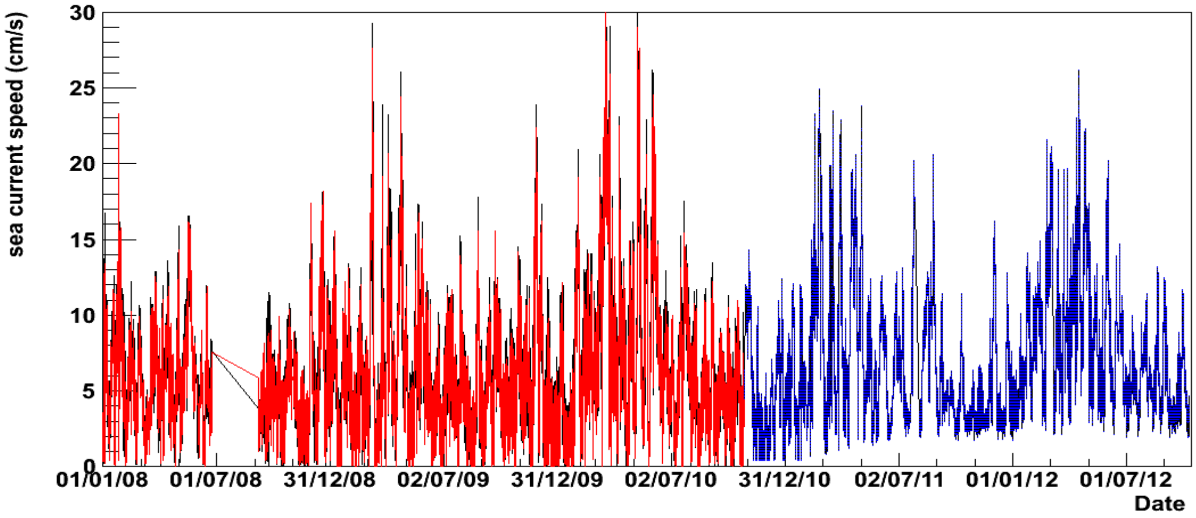


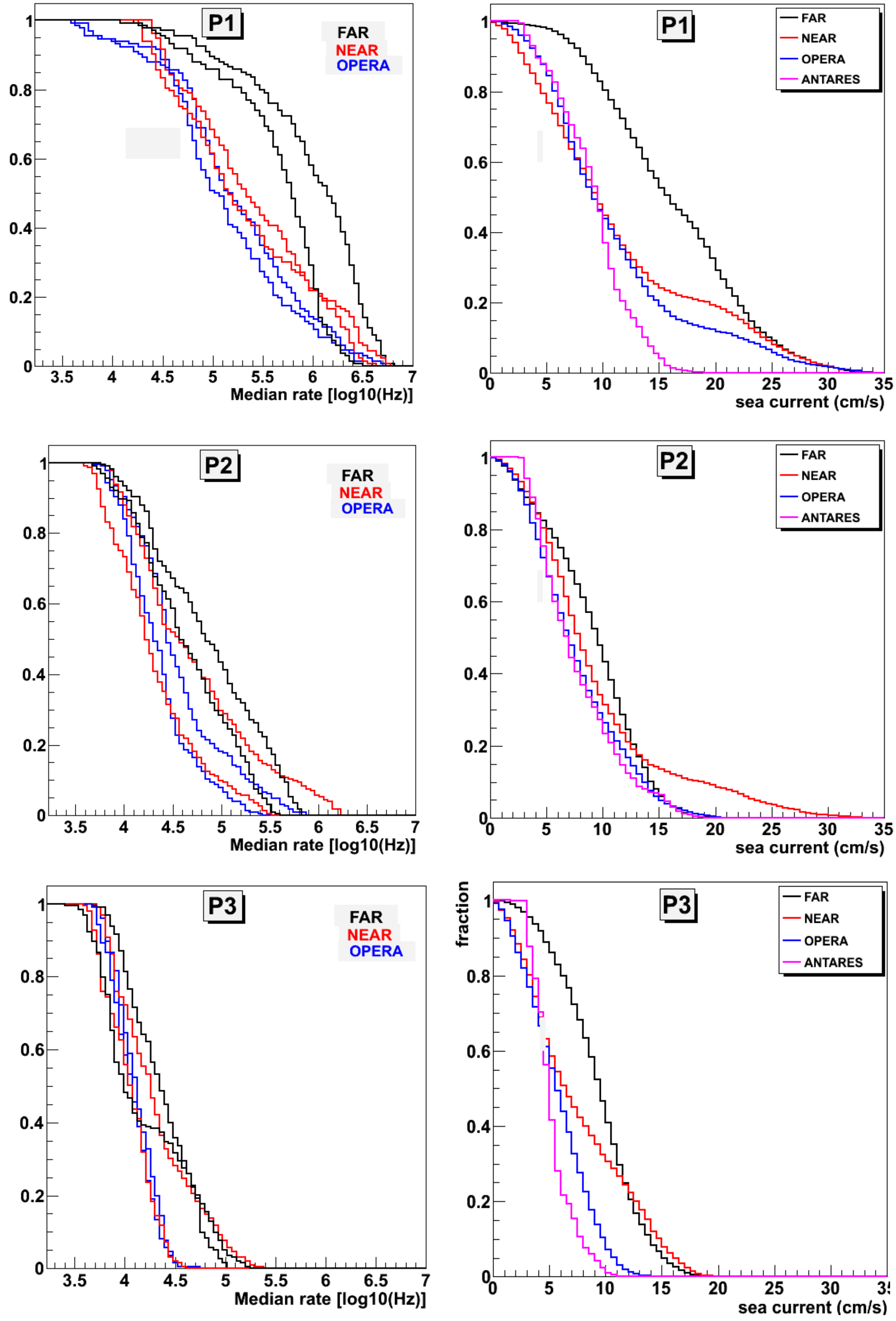
Figure 3.6: evolution of the sea current intensity measured by Antares on a 5 years period directly with a current meter (red) and from the detection lines deformations (blue)

4) Results of investigations

For a given time period and a given activity indicator, the quality of a site can be quantified by the fraction of the period where activity exceeds a given threshold. This is done for the 5 periods of decreasing activity, P1 to P5, defined in figure 3.1. Figure 4.1 summarizes the results. Both indicators, optical counting rates and sea current intensity, are studied separately. They are found to provide similar insights, as expected from section 3b).

In general, during the investigated period, the FAR site shows a higher activity than the coastal sites. This may be due to a larger exposure to the influence of the Gulf of Lion winter phenomena. This observation led to discard the FAR site as a viable option at an early stage, to stop its evaluation after period P3 and to start studying site NE instead.

The four coastal sites have a similar behaviour. Some periods of higher activity are visible on the NEAR site in periods P1 to P3, corresponding to a few bursts of high current lasting a few days (fig. 3.2 top). When comparing to Antares one must keep in mind the fact that, as regards currents, high values are damped by the measurement method on the Antares site in 2012 (section 2c). One can attempt to qualitatively assess the significance of the observed bursts. For example, the high activity observed on the NEAR site in period P3 is mainly due to 2 bursts of few days of current > 15 cm/s not present in the other sites (figure 3.1 top). For comparison, 8 such bursts are observed on Antares in the 15 quiet months of 2008-2010 where a current meter was operational, corresponding to 0.5 burst / month. It is therefore considered that the differences observed between the coastal sites within the rather short 2012 evaluation period are not significant.



<u>Figure 4.1</u>(first part): see second part for legend.

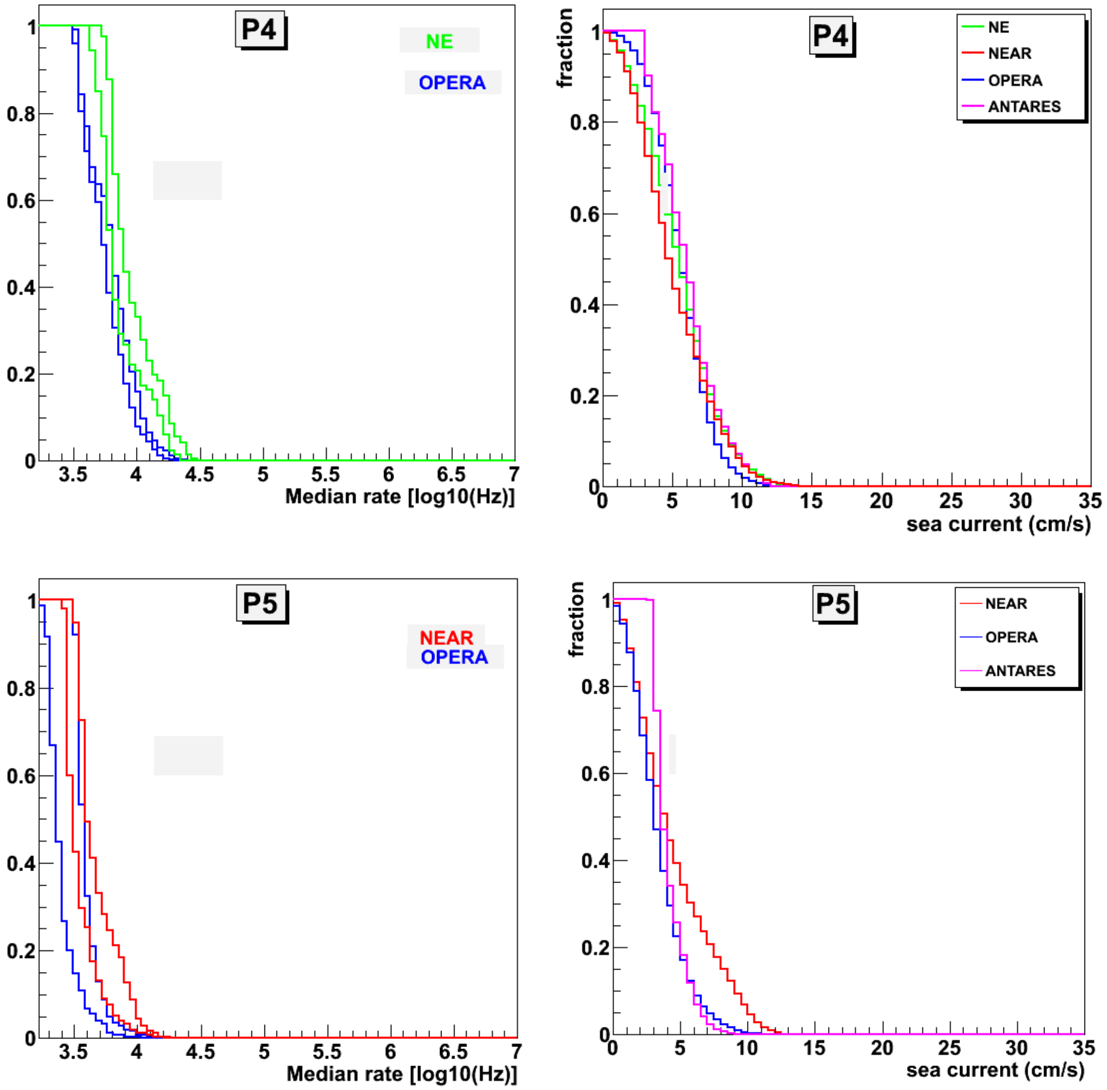


Figure 4.1(second part): Site quality indicator: fraction of time with activity higher than a given threshold as function of the threshold value, for optical counting rates (left) and sea current intensity (right). On the left the counting rates of the 2 PM of an optical module are shown separately, the differences between the 2 rates being mainly due to different orientation and sensitivity to sea current. The 5 pairs of figures from top to bottom correspond to the 5 periods P1 to P5 defined in Fig. 3.1, respectively.

5) Logistic constraints

In addition to its intrinsic qualities, the potential geographical and operational limitations of a site are important ingredient to make a choice.

As already mentioned, the available space on the sea floor in the vicinity of Antares is limited by: the CC5 telecommunication cable on the South and West; the break shelf on the North; and the Tremail acoustic military array on the East (figure 1.1). Southwards, westwards and northwards about 3 km of free space are available. Eastwards the distance to the Tremail is about 10 km, but at most 5 km could be usable since the acoustic transponders needed for detector positioning would start affecting the Tremail operation within a distance of 5 km. Approaching the Tremail limit is also likely to increase the fraction of time when marine operations will not be permitted by the military authorities. Finally, positioning the MEUST MEOC and first node close to Antares may be a risky operation for the Antares telescope.

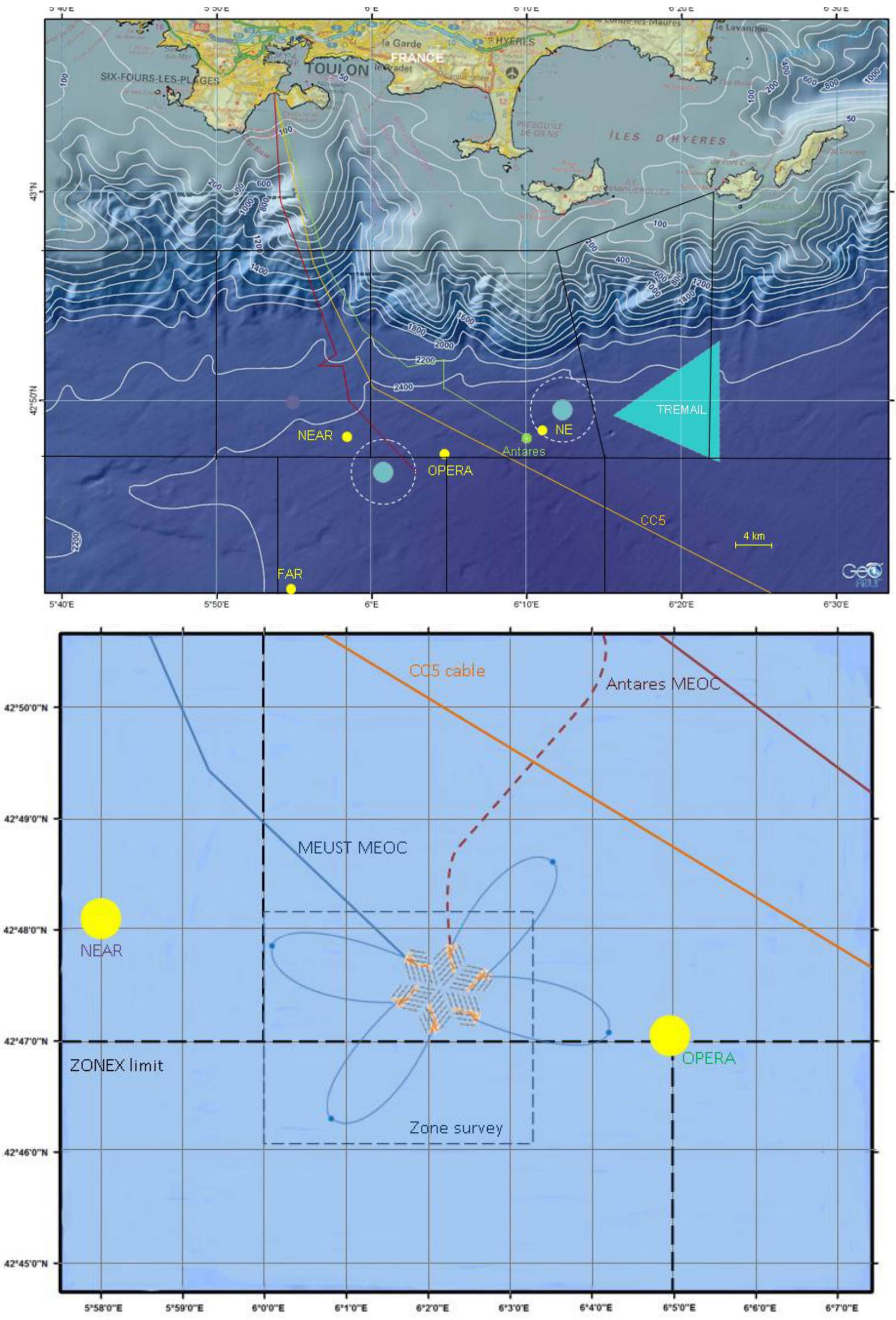
6) Site choice and next steps

As mentioned in section 4), the observation that the FAR site is more sensitive to seasonal activation has led to discard this option at an early stage.

As regards the coastal sites, the observed differences have such a low significance that logistics and operational aspects become primordial for the choice. It was therefore decided to select the site in the intermediate region between the NEAR and OPERA sites. The MEUST site will therefore be at similar latitude as Antares but on the western side of the CC5 cable. A preliminary high precision bathymetric survey performed by IFREMER on a 4x2 km^2 portion of the area has revealed a very flat and clean zone which should be suitable for the KM3NeT telescope.

The foreseen implantation of the MEUST submarine infrastructure is shown in figure 6.1. The route of the MEUST MEOC was defined by France Telecom Marine. There remains some flexibility to tune the position of the final end point both during the construction phase of the cable and after its deployment. Bathymetric and visual surveys of the foreseen MEUST detector area will be performed in 2013 and the final location adjusted accordingly. At a later stage, after Antares descoping and provided the cable suits the KM3NeT specifications, it will also be possible to redirect the end of the Antares MEOC to the MEUST site in order to complete the second half ring of the marigold network of a full KM3NeT Building Block.

In the coming months the quality of the chosen site will be further monitored by continuously keeping 2 autonomous lines in operation on the NEAR and OPERA sites. On one of the lines 2 optical modules will be fixed at different heights in order to monitor the environment on the whole 800m water column needed for a KM3NeT DU.



<u>Figure 6.1</u>: Top: route of the MEUST MEOC (red line) defined by France Telecom Marine. Bottom: zoom on the foreseen MEUST detector area with a sketch of the full Marigold network. The zone to be surveyed is indicated as a dashed rectangle. The dashed red line shows a possible future re-direction of the Antares MEOC towards the MEUST area to complete the full detector ring.