

Study and characterization of a deep sea site for a km³ underwater neutrino telescope

The NEMO Collaboration

December 2002

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Summary

The Mediterranean Sea offers optimal conditions, on a worldwide scale, to locate an underwater neutrino telescope. The choice of the location is such an important task that careful studies of candidate sites must be carried out in order to identify the most suitable one.

The NEMO Collaboration has performed, since 1998, a long term research program to select and characterize a deep-sea site that could be appropriate for the installation of a high-energy neutrino detector.

This activity has allowed to demonstrate that a site in the Ionian Sea close to the southernmost cape of the coast of Sicily (Capo Passero) with a depth of about 3500 m shows excellent characteristics to host the km^3 underwater neutrino detector.

The long term characterization of the site, presented in this report, has been performed by studying a large number of oceanographical properties, like deep-sea water optical properties (absorption and diffusion), water environmental properties (temperature, salinity), biological activity, optical background, water currents, sedimentation and seabed nature.

The study of optical properties in the selected site is very important and requires long term measurements in different periods of the year to evidence possible seasonal dependences. The water transparency can be parametrised in terms of its absorption and scattering lengths. These parameters have been measured *in situ* by means of a suitable device. The one used by the NEMO collaboration is based on a commercial instrument that allows the measure of the absorption and attenuation lengths in nine different wavelengths that span all the spectrum of visible light from 412 to 715 nm. Measurements have been performed in Capo Passero in different seasons showing that at all wavelengths deep waters have an absorption length close to pure seawater, reaching a maximum of 68 m at 440 nm, which is the wavelength that corresponds to the spectral region where seawater has the maximum transparency. The same experimental device has also been used to characterize other sites, including the Antares one (this measurement was performed in July 2002 during a joint NEMO-ANTARES campaign). The absorption length measured in the Antares site at 440 nm is considerably shorter, 48 m, than in Capo Passero. Light attenuation length in the blue-green region of the spectrum results shorter than in pure sea water, due to the occurrence of scattering effects, caused by the presence of dissolved particulate, that are more important for shorter wavelengths. No seasonal variations of the light transmission properties of the deepest waters in Capo Passero have been observed.

Optical background noise in the detector comes mainly from two natural causes: the decay of ^{40}K , which is present in seawater, and the so called “bioluminescence” that is the light production by biological entities (bacteria or larger size organisms). Of these two effects the first one shows up as a constant rate background noise on the optical modules, while the second one induces fluctuations in the noise rate. This optical noise has been measured, by means of a set up consisting in two 8" photomultipliers and the associated electronics, both in the Capo Passero site and in the Antares site near Toulon (this last measurement was performed during a joint NEMO-ANTARES sea campaign). In the Capo Passero site a constant rate of about 29 kHz has been measured, with rare

high rate spikes due to bioluminescence. In the Antares site a rate of about 58 kHz has been measured with a large occurrence of instant rate increases above 200 kHz that can be attributed to bioluminescence.

Deep sea currents have been continuously monitored in Capo Passero since 1998. The analysis points out that the behaviour of the deep sea currents in the area is almost homogeneous on the part of the water column that has been monitored (bottom 500 m) with very low average values (around 3 cm/s) and peaks not exceeding 12 cm/s.

The study of the downward flux of sediments yields qualitative and quantitative information about the suspended matter in deep sea waters. The amount of matter, which is both of lithogenic or biogenic (like remains of planktonic organism) origin, falling down towards the sea bottom, is of particular relevance, since it deposits on the top surface of the photon detectors reducing their efficiency. Moreover, the particulate in suspension in the water contributes to the scattering of the photons propagating in the water. The quantity and nature of the sedimenting matter in Capo Passero has been studied by collecting samples of these sediments by means of a so called "sediment trap". The annual average value of material sedimenting at the sea bottom is about $60 \text{ mg cm}^{-2} \text{ day}^{-1}$, a rather low value as expected for an oligotrophic environment such as the Ionian Sea. This nature of very low biological activity area has been also evidenced by the results of a series of sea campaigns aimed at characterising the chemical, physical and microbiological features of the water mass in the region.

The nature and structure of the seabed has to be studied in detail in order to design the mooring structures of the neutrino detector. The flatness and the absence of any evidence of recent turbidity events, which occur when sediments of the continental shelf slide down the continental slope and are therefore of potential great danger for the detector, must be assessed. The Capo Passero site is located in a wide abyssal plain and is sufficiently far from the shelf break to consider this risk to be negligible. A geological survey of the site has been performed and bathymetric and seismic analysis of the sea bottom has evidenced that it has a very flat topography with slopes that, with few exceptions, do not exceed 0.5° and a nature of a deposit of pelagic sediments. Several cores, about 5 m long, have been sampled in the area and analysed to study their stratigraphic features. All the cores show the same stratigraphy, demonstrating the homogeneity of the area. A dating of the different layers of the cores is possible by the recognition of some features that are associated to well known geological events. An evaluation of the average sediment accumulation rate has been performed based on this dating, giving a value of 3-4 cm/kyr, which is in agreement with the mass flux measured with the sediment trap. Only one evidence of an ancient turbidity event has been found at a depth of about 2.5 m that corresponds to a dating of 65000 years before present.

Introduction

The Mediterranean Sea offers optimal conditions, on a worldwide scale, to locate an underwater neutrino telescope. Close to the Italian coasts several sites exist, at depths beyond 3000 m, that are potentially interesting to host an undersea neutrino telescope. The choice of the km³ scale neutrino telescope location is such an important task that careful studies of candidate sites must be carried out in order to identify the most suitable one. The NEMO Collaboration has performed a long term research program to characterize deep-sea Italian sites that could be appropriate for the installation of a deep sea high-energy neutrino detector. Deep-sea water optical properties (absorption and diffusion) and the sites environmental properties (water temperature, salinity, biological activity, optical background, water currents and sedimentation) have been studied.

The site has to fulfil several requirements:

- *It has to be deep.* Thickness of the overlaying water has to be enough to filter out the down-going atmospheric muon background to allow the selection capability of up-going tracks (originated from up-going neutrino interactions in the Earth and/or the water near the detector). The needed background rejection is a function of the muon angle, of the muon energy and also depends on the capability of the muon reconstruction algorithm to correctly distinguish up-going tracks from down-going ones. At a depth of more than 3500 m the vertical atmospheric muon flux is reduced by 5 orders of magnitude with respect to the flux at sea level.
- *It has to be close to the coast.* The data transmission to the on-shore laboratory, as well as the transmission of power from the laboratory to the offshore detector, will be performed via an electro-optical multi-fibre cable. At distances closer than 100 km from the coast, commercial systems allow data and power transmission without special hardware requirements (e.g. amplifiers) which would increase the cost and reduce the reliability of the project. Moreover, the proximity to the coast and to shore infrastructures simplifies the access to the site for deployment and maintenance operations.
- *It has to be located some tens of km far from shelf breaks and canyons.* Catastrophic submarine events, well known to oceanographers, such as *turbidity* and *density currents* may occur in the proximity of those structures.
- *The sea bed has to be flat and stable.* The nature of the seabed should allow the mooring of the telescope structures.
- *It has to show good optical underwater properties.* The detector effective area is not only directly determined by the extension of the instrumented volume but is strongly affected by the light transmission in the water. Mainly two microscopic processes affect the propagation of light in the water: absorption and scattering. Light absorption directly reduces the effective area of the detector, the scattering worsens the detector track reconstruction performance, which is based on the measurement of the photon arrival time on the photon detectors.
- *The optical background has to be low.* The background directly affects the detector performances, in particular the quality of muon track reconstruction. In a high

background environment severe cuts to the photon detector data must be applied, hence reducing the detector effective area.

- *The sedimentation rate in the selected region must have very low values.* The presence of sediments in the water can affect seriously the performances of the detector. Sediments increase the light scattering and so worsen the track reconstruction angular resolution. Moreover a deposit on the sensitive part of photon detectors, i.e. large surface photomultipliers, reduces the global detector efficiency.
- *The site has to be “quiet”.* The underwater currents have to show low intensity and stable direction. This is important for several reasons:
 - it does not imply special requirements on the mechanical structure;
 - the detector deployment and positioning is easier if the water current is limited;
 - the optical noise due to bioluminescence, mainly excited by variation of the water currents, is reduced.

Site characterization activities of the NEMO collaboration

Since July 1998 we have started a series of campaigns (see appendix B for a complete list) of study in three sites close to the Italian coast. The sites were selected according to the geographical constraints of depth, proximity to the coast and nature of the seabed, listed in the previous section, to qualify the water optical properties.

These sites, shown in fig. 1, are:

- **Capo Passero**, located in the Ionian Sea South-East of Sicily at $36^{\circ} 16' N$, $16^{\circ} 06' E$, about 40 NM from the coast, with a depth of 3350 m;
- **Ustica**, located in the Tyrrhenian Sea North of Sicily at $38^{\circ} 55' N$, $13^{\circ} 18' E$, about 15 NM from the coast, with a depth of 3500 m;
- **Alicudi**, located in the Tyrrhenian Sea North of Sicily at $38^{\circ} 56' N$, $14^{\circ} 16' E$, about 25 NM from the coast, with a depth of 3500 m;

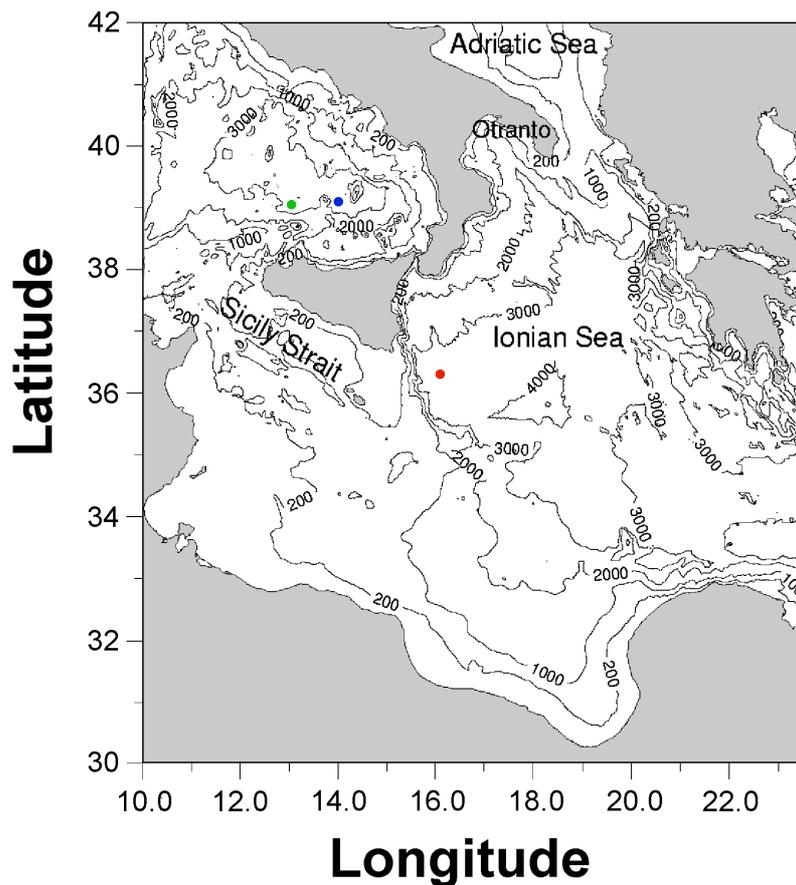


Figure 1 – Bathymetry of the central Mediterranean region. The sites explored by the NEMO collaborations are shown: Capo Passero (red dot), Ustica (green dot), Alicudi (blue dot).

In the Capo Passero region, which shows a wide plateau at more than 3000 m, two locations have been investigated: one located at $36^{\circ} 16' N$, $16^{\circ} 06' E$ at about 40 NM from the coast, that has been denoted KM4, and a second one closer to the coast (20 NM), denoted KM3, located $36^{\circ} 30' N$, $15^{\circ} 50' E$.

From these measurements and from other considerations based on oceanographical properties of the Ionian region from the literature, we arrived at the decision that a large region close to Capo Passero (figure 2) is appropriate for the construction of the Neutrino Telescope. Therefore, our research effort in the following has been concentrated in this area.

The selected site presents also the advantage of being close to well equipped shore infrastructures:

- the ports of Siracusa, Augusta and Catania;
- the international airport of Catania;
- the I.N.F.N. Laboratori Nazionali del Sud in Catania.

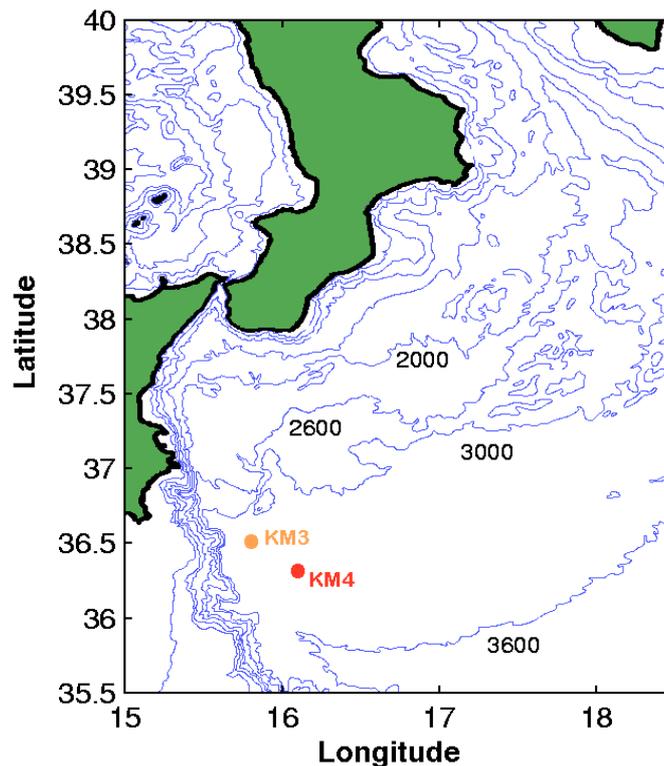


Figure 2 – The Capo Passero site. Both the explored sites, KM3 and KM4 are shown.

Measurements of water optical properties have also been carried out in the Laboratori Nazionali del Sud Underwater Test Site, that is located 15 NM offshore Catania, in the ANTARES Site and in Lake Baikal.

Details of the instrumental setups are given in appendix A.

Water optical properties

Optics in deep sea

The study of optical properties in the selected site is extremely important and must be completed with a long term program of characterisation carried out in all different seasons. Seawater, indeed, absorbs and scatters photons as a function of water temperature, salinity and concentration, dimension and refraction index of dissolved and suspended, organic/inorganic particulate. These parameters are different in different marine sites and change as a function of time.

In order to describe the transparency of natural waters, as a function of photon wavelength, it is necessary to measure *in situ* the so called *Inherent Optical Properties* (IOP) of the water, such as the absorption $L_a(\lambda)$, scattering $L_b(\lambda)$ and attenuation $L_c(\lambda) = L_a(\lambda) + L_b(\lambda)$ lengths [1]. Each of these lengths represents the path after which a photon beam of intensity I_0 and wavelength λ travelling along the emission direction, is reduced of a factor $1/e$ by absorption or diffusion phenomena. These quantities can be directly derived by the simple relation:

$$I_{a,b,c}(x) = I_0 \exp(-x \cdot L_{a,b,c})$$

where x is the optical path traversed by the beam and I_0 the source intensity. In the literature the absorption $a = L_a/L_a$ and the scattering $b = L_b/L_b$ coefficients are extensively used to characterize the light transmission through matter. The sum of scattering and absorption coefficients is called attenuation coefficient $c(\lambda)$.

In pure water, light absorption and scattering are strongly wavelength dependent. In particular light transmission in pure water is extremely favoured in the range 350-550 nm, overlapping the region in which photomultiplier tubes usually reach the highest quantum efficiency. In the visible region of the electromagnetic spectrum light absorption steeply decreases as a function of wavelength and reaches its minimum at about 420 nm [2]. Scattering refers to processes in which the direction of the photon is changed without any other alteration. Scattering phenomena in which the photon wavelength changes (e.g. Raman effect) happen less frequently. Scattering can take place either on molecules (Rayleigh scattering) or on dissolved particulate (Mie scattering).

Another parameter commonly used in the literature is the effective scattering length $L_b^{eff} = L_b(\lambda) / [1 - \langle \cos(\theta) \rangle]$, where $\langle \cos(\theta) \rangle$ is the average cosine of the scattering angle. The estimation of the last parameter is extremely difficult since it needs the knowledge of another IOP, the volume scattering function $V(\lambda, \theta)$, that must be measured with appropriate devices [3].

Comparison of optical properties of the sites close to the Italian coast

The optical properties of the four pre-selected sites (Ustica, Alicudi, Capo Passero KM3 and KM4) have been studied during two oceanographical campaigns in December 1999. Part of the data have already been published in [4], while a comprehensive report on all the results is presented in [5]

Two profiles of the water column have been carried out in each site. In figure 3 we report, as an example, the two profiles of sea temperature, salinity and the values of a and c coefficients for $\lambda = 440$ nm measured, as a function of depth, in KM4.

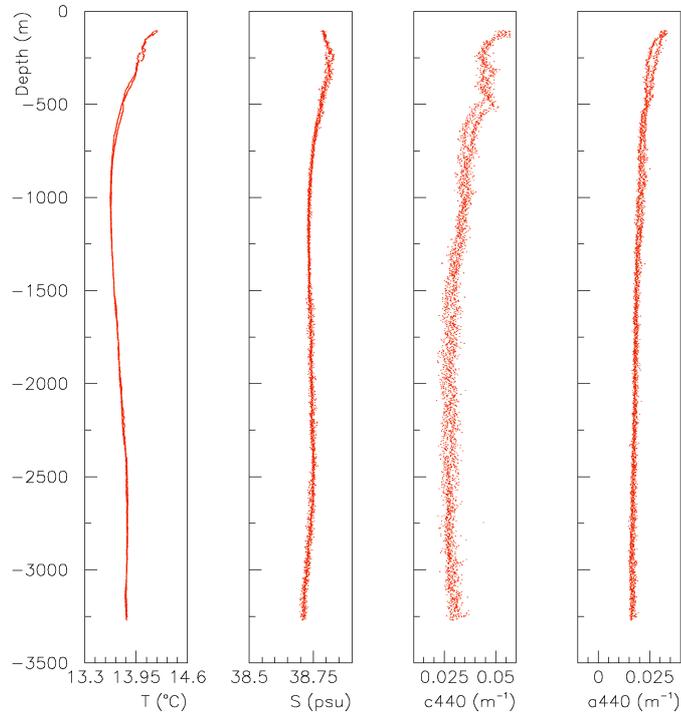


Figure 3 - Profiles of temperature (T), salinity (S), attenuation coefficient $c(440)$ and absorption coefficient $a(440)$ measured in KM4.

In order to compare the properties of the deepest waters in the different sites, the value of the absorption and attenuation coefficients a and c have been determined for each measurement by averaging the data over depths greater than 2850 m. Moreover, the data have also been averaged between the two measurements performed in each site. The statistical errors associated are negligible. Systematic errors have been estimated to be of the order of $\pm 0.0010^{-3} \text{ m}^{-1}$ for all the wavelengths.

The results are summarized in figs. 4 and 5, where the average values of absorption and attenuation lengths measured in the four sites, are shown as a function of λ . In the figures we show the values of $L_a(\lambda) = 1/a(\lambda)$ and $L_c(\lambda) = 1/c(\lambda)$ in order to allow the reader to immediately evaluate the effect of water optical properties on the detector design.

We also show for comparison light transmission data for optically pure sea water (microfiltered water) taken from [1,6]. **It is clearly observable that at all wavelengths, deep waters in KM4 have an absorption length compatible with pure water. In comparison with the other sites, KM4 also shows the best values of L_c .**

The value of the light attenuation length is obviously worse than the one measured for microfiltered sea water, due to the dependence on the scattering coefficient, which is a function of the concentration of scattering centres dissolved in natural waters.

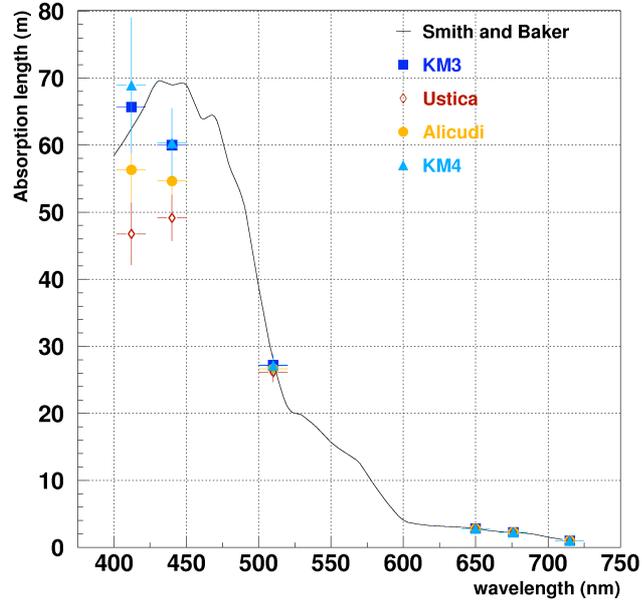


Figure 4 – Comparison between average absorption lengths, measured at depths greater than 2850 m, in KM3, KM4, Alicudi and Ustica (December 1999). The curve relative to optically pure water [6] is plotted in black.

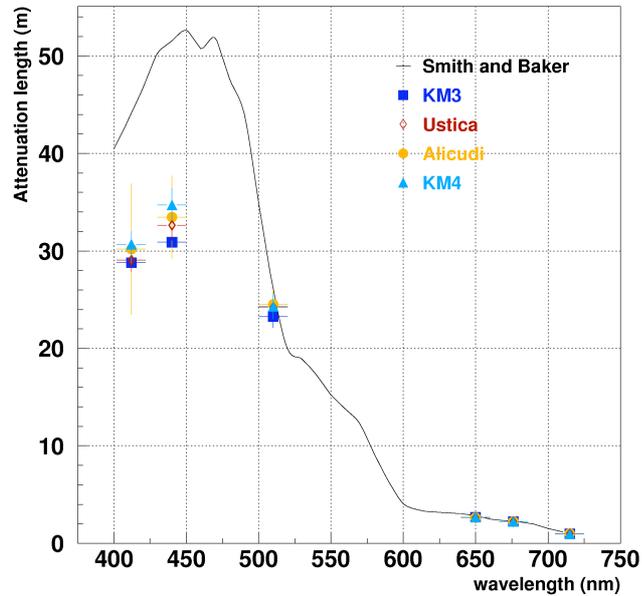


Figure 5 - Comparison between average attenuation lengths, measured at depths greater than 2850 m, in KM3, KM4, Alicudi and Ustica (December 1999). The curve relative to optically pure water [6] is plotted in black.

Long term characterisation of optical properties in Capo Passero

Having chosen KM4 as the best site among the four pre-selected, the collaboration started a series of campaigns aiming to study the long term behaviour of optical properties in KM4. In particular three campaigns were performed during 2002 (March, May and August), in order to verify the occurrence of seasonal effects in optical properties. It is expected, in fact, that during the periods of major biological activity (like springtime) the concentration of dissolved and suspended particulate increases, worsening water transparency.

In figure 6 we show the profiles recorded with the AC9-CTD setup in the cruises of December 1999 (light blue), March 2002 (yellow), May 2002 (Blue) and August 2002 (red). The values of temperature, salinity and the coefficients $a(\lambda)$ and $c(\lambda)$ for the 440 nm wavelength are reported as a function of depth.

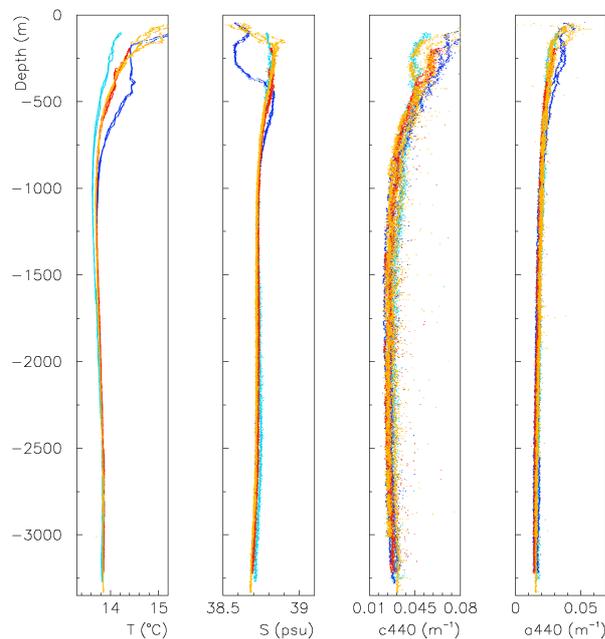


Figure 6 – Profiles of temperature (T), salinity (S), attenuation coefficient (c) and absorption coefficient (a) at 440 nm, measured in the Capo Passero KM4 site. The profiles refer to different campaigns: March (yellow), May (blue), August (red) and December (light blue).

Appreciable variations are observed in the temperature and salinity of shallow waters (first 500 m). These effects are also reflected in the optical properties. At the depths of interest for the telescope (more than 2500 m) **seasonal variations are negligible and, for blue-green wavelengths, compatible with the instrument experimental error** ($\Delta_T \sim 10^{-2} \text{ }^\circ\text{C}$, $\Delta_S \sim 10^{-2} \text{ psu}$, $\Delta_{a,c} \sim 2 \cdot 10^{-3} \text{ m}^{-1}$).

The absorption and attenuation lengths, averaged for depths greater than 2850 m, are shown, as a function of λ , in figures 7 and 8. There is no evidence of a seasonal dependence of the optical parameters.

We can therefore conclude that optical properties in Capo Passero KM4 are constant over the whole year.

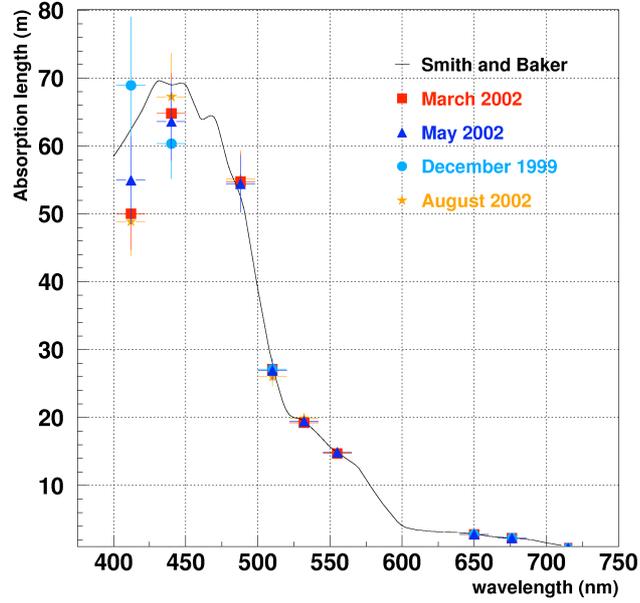


Figure 7 - Values of average absorption lengths as a function of wavelength, measured during four periods of the year in Capo Passero KM4.

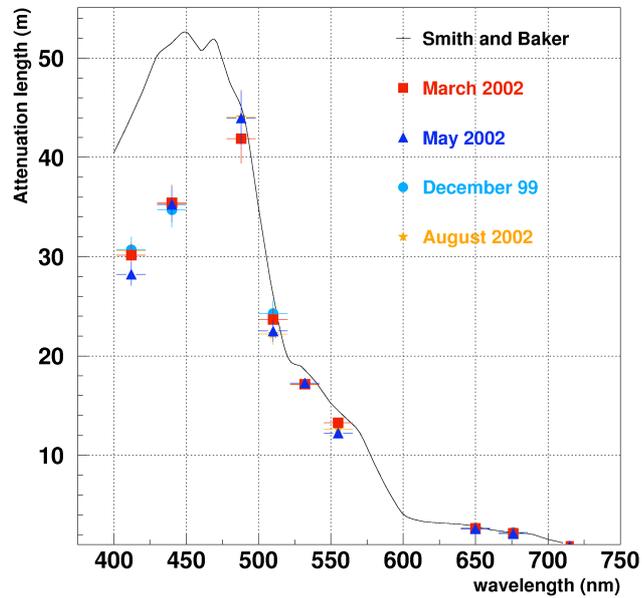


Figure 8 - Values of average attenuation lengths as a function of wavelength, measured during four periods of the year in Capo Passero KM4.

Optical properties in other sites

Water optical properties have also been measured with the AC9 device in other sites. In particular the *Test Site* of Catania (15 NM offshore Catania, 2000 m deep) has been investigated in March and August 2002 and the ANTARES site (40 NM South-West of Toulon, 2400 m) in July 2002. A campaign has also been performed in Lake Baikal in March 2001. Results of the Lake Baikal campaign have already been published in [7]. The July 2002 campaign on the ANTARES site was performed jointly by the NEMO and ANTARES Collaborations onboard the *R/V Thetis*.

The blue light attenuation coefficient profile (figure 9) obtained with the AC9 in the ANTARES site shows a variability typical of coastal waters such as the Catania Test Site, down to ≈ 800 m. The values of the absorption coefficients are larger than the ones measured in the 3400 m deep Capo Passero site, and, on the other hand, compatible with the ones measured in Catania site, which has both distance from the coast and depth similar to the ANTARES site.

In figures 10 and 11 the average absorption and attenuation lengths as a function of the wavelength measured in the deep waters of the Capo Passero KM4 and ANTARES sites are compared. In order to show the AC9 accuracy in the same figure we also show the data measured in Lake Baikal in a different environmental situation. Data measured in the Catania Test Site are also reported.

The first plot shows that KM4 site has blue light absorption length close to the optically pure water one [6] and considerably better than the ones measured in the other sites.

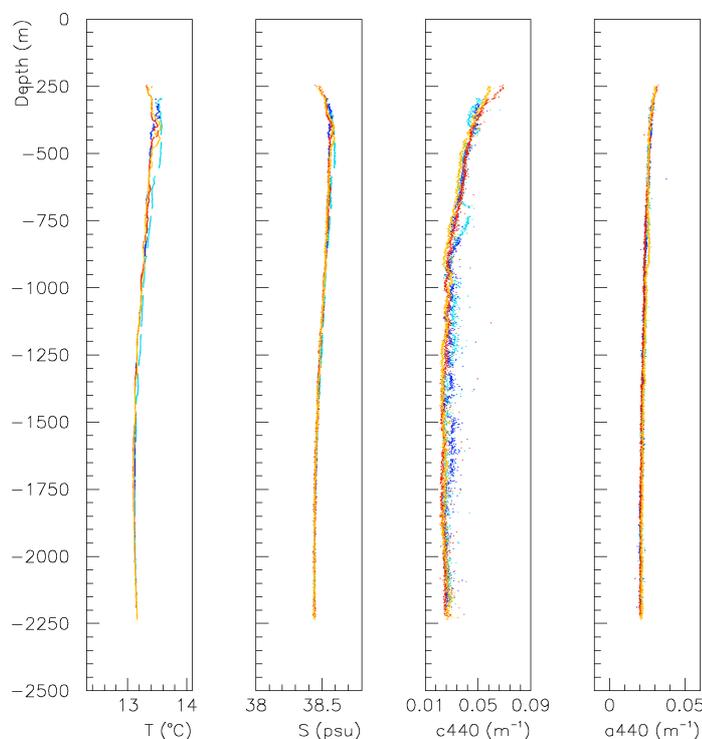


Figure 9 - The four profiles of temperature, salinity, $c(440)$ and $a(440)$ as a function of depth, measured with the AC9 during the cruise in the ANTARES site in July 2002.

The $L_a(440\text{nm})$ measured in Capo Passero is 1.4 times larger than $L_a(440\text{nm})$ measured in ANTARES site and 3 times larger than $L_a(440\text{nm})$ measured in Lake Baikal.

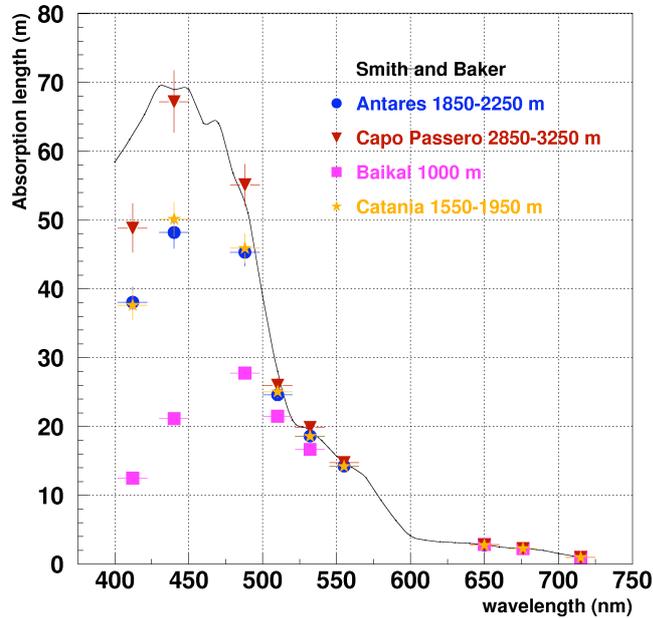


Figure 10 - Comparison between the absorption length average values measured in the sites of Capo Passero KM4 (red triangles), ANTARES (blue circles), Baikal (purple square) and Catania Test Site (yellow stars). The curve relative to optically pure water [6] is plotted in black.

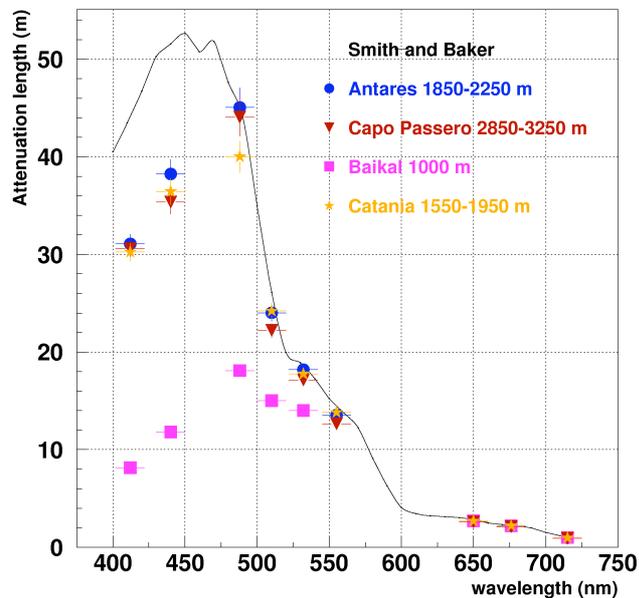


Figure 11 - Comparison between the attenuation length average values measured in the sites of Capo Passero KM4 (red triangles), ANTARES (blue circles), Baikal (purple square) and Catania Test Site (yellow stars). The curve relative to optically pure water [6] is plotted in black.

Figure 11 shows that average values of $L_c(\lambda)$ almost similar for both KM4 and ANTARES site. This could imply that the density of scattering centres is extremely low in the Antares site. This result may be also explained in a different way. It is known from literature that waters with a large concentration of organic particulate may show a narrow forward-peaked volume scattering function for visible light (Petzold coastal waters [1], figure 12). In this case the AC9 angular acceptance in the c channel (0.7°) does not allow to discriminate between non interacting photons and photons scattered inside the detector acceptance angle. The $c(\lambda)$ coefficient would be, in this case underestimated.

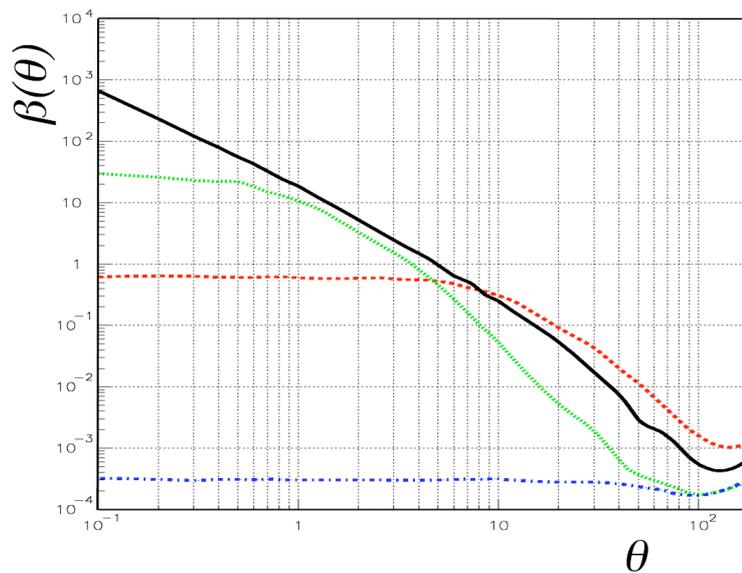


Figure 12 – Volume scattering function for pure water (Rayleigh scattering) (blue dash dotted line), Petzold coastal waters (black solid line). The red dashed line and the yellow dotted line are theoretical calculations for water samples with small and large scattering centres, respectively.

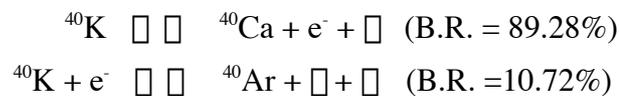
Measure of the optical background

Sources of optical background in seawater

The Optical Modules counting rate in an undersea neutrino detector is strongly affected by two kind of natural causes: the decay of radioactive elements diluted in water and the luminescence produced by biological entities (we will refer to this contribution simply as “bioluminescence”).

Background from radioactive decay

Of all the radioactive isotopes present in natural sea water ^{40}K is by far the one that contributes the most to its total radioactivity. Both ^{40}K decay channels



contribute to the production of optical noise. A big fraction of electrons produced in the first reaction is above threshold for Cherenkov light production. The photon originated in the second reaction has $E_\gamma \approx 0.46$ MeV and can therefore originate electrons over threshold for the Cherenkov effect.

For obvious reasons the flux of Cherenkov photons originated by ^{40}K radioactive decays depends mainly on ^{40}K concentration in sea water. The very small variations of salinity in the Mediterranean Sea suggest that we have to expect very small variations of the luminescence produced by radioactive isotopes from site to site. In the Capo Passero site the salinity at 3300 m amounts at $S \approx 38.7$ g/l. Knowing the contribution of potassium to the total salinity (ρ_K), the relative abundance of ^{40}K isotope ($\rho_{^{40}\text{K}} \approx 0.17 \cdot 10^{-4}$) and its mean life time ($\tau_{^{40}\text{K}} = 0.277 \cdot 10^{10}$ y) we can evaluate the total number of radioactive decays per unit of sea water volume:

$$N = \frac{\ln(2)}{\tau_{^{40}\text{K}}} S \cdot \rho_K \cdot \rho_{^{40}\text{K}} \cdot \frac{N_A}{40} = 13600 \text{ m}^{-3} \text{ s}^{-1}$$

The volume of water seen by an optical module has a radius ≈ 10 cm. Therefore; we expect a huge number of photon hitting the PMT photocatode. Several measurements carried out by DUMAND, NESTOR, ANTARES have shown that the contribution of ^{40}K to the “optical noise” on PMT with large photocatodes (8”÷13” diameter) can rise up to 40÷80 kHz. The evaluation of the total flux of photons produced by ^{40}K in seawater can be carried, from direct measurements with Optical Modules, only taking into account photons propagation (in water, glass, optical gel, ...), detector properties (photocathode sensitivity and quantum efficiency), geometrical acceptance, etc...

Bioluminescence

Bioluminescence is mainly produced by bacteria emitting light at the level of single photon intensity. A high level of bacteria concentration can give rise to an optical noise several orders of magnitude more intense than the one due to ^{40}K .

Not too much is known about bioluminescence at high depth. Data reported in the literature show the typical spectra (see fig. 13) of the emitted radiation, centred in the region where the water transparency is maximal and, unfortunately, of interest for undersea Cerenkov neutrino telescopes.

From a campaign of measurements in the region of Capo Passero, carried out in collaboration with the Istituto Sperimentale Talassografico di Messina (CNR), important information about the distribution of luminescent bacteria in a vertical column of water was determined.

As it appears from fig. 14 the presence of these bacteria depends on the depth and their presence at more than 2500 m is negligible.

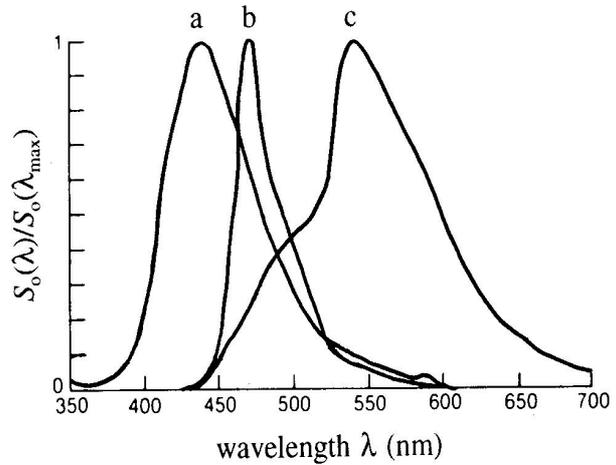


Fig. 13 – Emission spectrum for three biological organisms: a) the arthropod *Scine*; b) the *Dinoflagellata Pyrocystis*; c) the bacterium *Vibrio fischeri*.

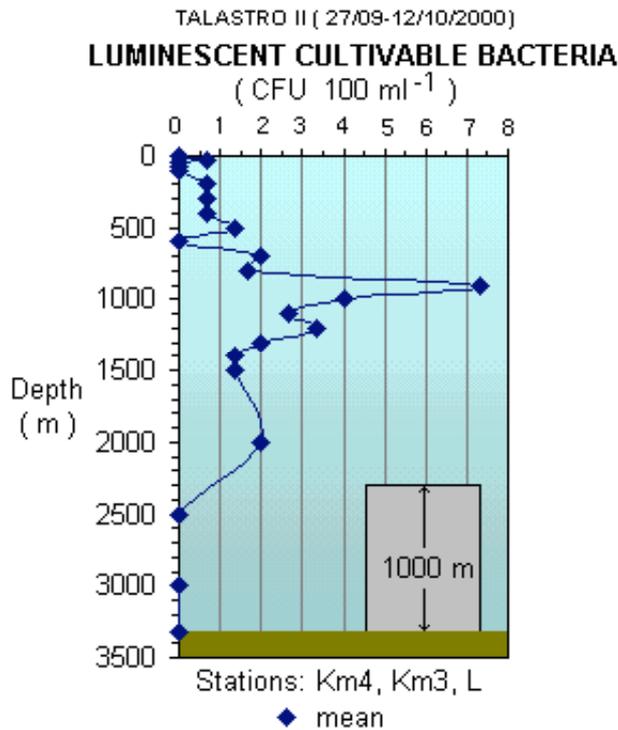


Figure 14 - Amount of luminescent cultivable bacteria in Capo Passero as function of depth.

Measure of the optical background in Capo Passero

Data in Capo Passero were collected during a campaign in March 2002. The setup, that consisted in two 8" photomultipliers and the associated electronics, was moored at 3400 for about 4 days and took data for about 60 hours. A detailed description of the setup is given in Appendix A.

During data acquisition the anode pulses of each PMT are digitized each 5 ns and compared with a threshold set at 1/3 of the most probable signal amplitude produced by a single photo-electron. This threshold was characterized in laboratory for each PMT before and after the deployment of the apparatus. Fig. 15 shows the pulse height distribution for one of the two PMT for pulses collected during the deployment, and the threshold corresponding at 1/3 of the single photo-electron signal. Fig. 16 shows the charge distribution for all pulses collected with the same PMT. Both figures are compatible with an optical noise intensity mostly at the level of single photo-electron.

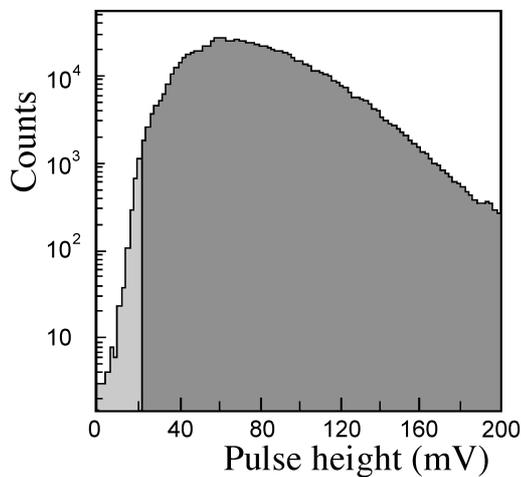


Figure 15 - Pulse height distribution, pedestal subtracted, of signals collected, with PMT n.1, during immersion in KM4 at 3400m depth. The darker region corresponds to pulses over threshold.

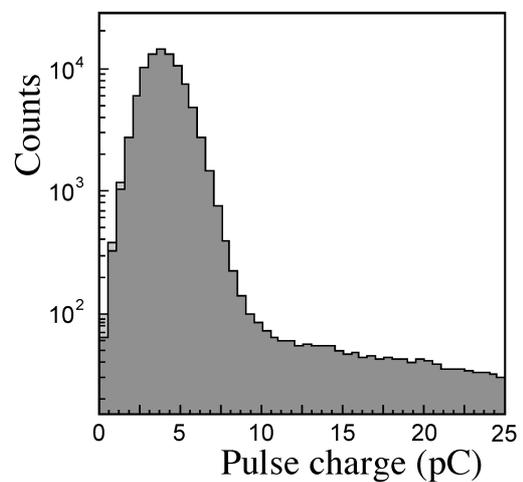


Figure 16 - Charge distribution for signals collected, with PMT n.1, during immersion in KM4 at 3400m depth. The darker region corresponds to pulses over threshold.

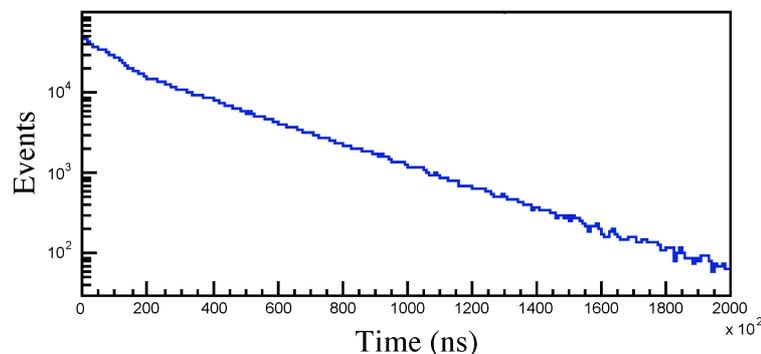


Figure 17 - Distribution of time, in ns, between two consecutive pulses, relative to data collected in KM4, Capo Passero region.

The data taking system records, for each event, also the “time over threshold” information. This allows to build the distribution of the “time between two consecutive events” shown in fig. 17. In order to evaluate the rate due to the “optical noise” (i.e. signals from ^{40}K decay or “bioluminescence”) we have to subtract the PMT “dark current” noise. This subtraction can be done only statistically from the measured total rate. We could evaluate the “total instant rate” on an event per event basis as $f_{\text{Total}} = N / \Delta t$, being Δt the time between two consecutive events.

This method would give the correct average value for the “total instant rate” but with large fluctuations on its value. To reduce the fluctuations we evaluated the “total instant rate” on the basis of N consecutive events as

$$f_{\text{Total measured}} = N / (t_{i+N} - t_i)$$

and fixing $N = 10$. In figure 18 the total instant rate as a function of the time is shown.

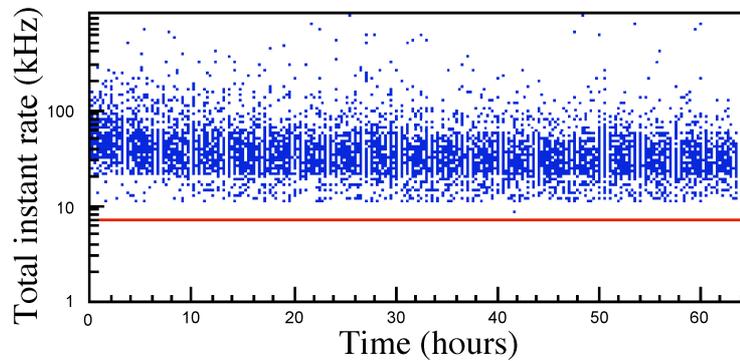


Figure 18 - Total instant rate, as function of time, for data collected in KM4. The red line indicates the level of "dark current noise", due to the PMT, to be subtracted.

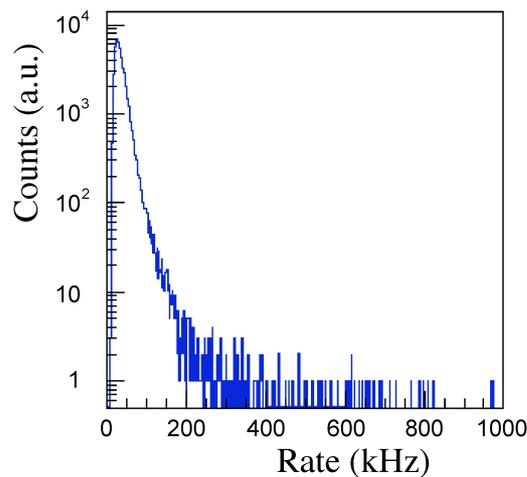


Figure 19 - Total instant rate distribution for data collected in KM4. The contribution to the total instant rate due to the PMT "dark current noise", that amounts to ~ 7 kHz, is not yet subtracted.

In figures 18 and 19, we can easily see that the total measured instant rate value fluctuates from 20 kHz to 200 kHz and very rarely exceeds this higher value.

The average “total measured rate” amounts to ~ 35 kHz. Therefore, taking into account that the PMT “dark current” rate amounts to 7 kHz we obtain the rate due to optical noise (^{40}K plus bioluminescence). A compatible value is obtained analyzing data collected with the second PMT.

As final results we can say that the optical noise induced on a 8” PMT (355 cm² sensitive photocathode area) in Capo Passero KM4 site amounts then to

$$f_{\text{optical noise}}^{KM4} \approx 28.5 \pm 2.5 \text{ kHz}$$

This noise is quite constant and shows only rare emissions of light in bursts, typical of “bioluminescence”.

Comparing this result with the expectations of a MonteCarlo simulation, that includes all our knowledge about the PMT behaviour and the optical properties of deep sea water in KM4 site, we can conclude that in average the flux of photons due to “optical noise” in Capo Passero, that can be detected by a bialkali PMT, amounts to

$$\Phi_{\text{optical noise photons}}^{KM4} = 360 \pm 40 \text{ photons} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}.$$

Measure of the optical background in the ANTARES site

Data was taken, with the same setup, also in the ANTARES site in July 2002. The set up was moored for about 60 hours, at a depth of about 2000 m. The mooring line also hosted a setup of the ANTARES collaboration for the measure of the optical background.

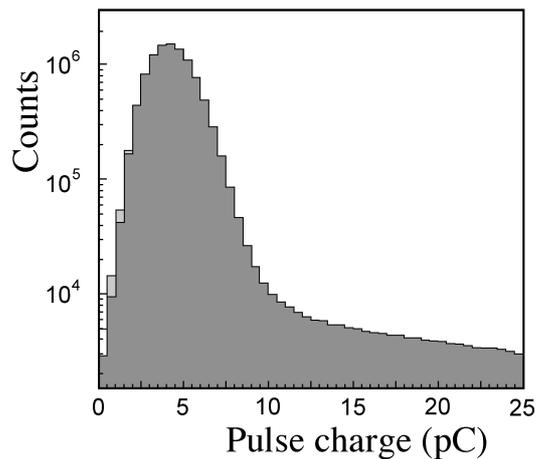


Figure 20 - Charge distribution for signals collected during immersion close to ANTARES site, at 2000m depth. The darker region corresponds to pulses over-threshold.

After the measurement in Capo Passero and before the deployment in the ANTARES site the dark current rate of two PMTs was checked in the laboratory and showed to be stable. The two PMT settings were exactly identical so the results obtained in the two sites can be directly compared.

Fig. 20 shows the charge distribution of pulses collected by the PMTs in the ANTARES site and is directly comparable with fig. 16 that shows the same distribution for data collected in Capo Passero. In both sites the optical noise is mainly due to single photons hitting the PMT. Figure 21 shows the total instant rate, defined previously as the average over 10 consecutive pulses, as a function of time. This distribution, that can be compared with the one relative to Capo Passero in fig. 18, shows that the instant rate

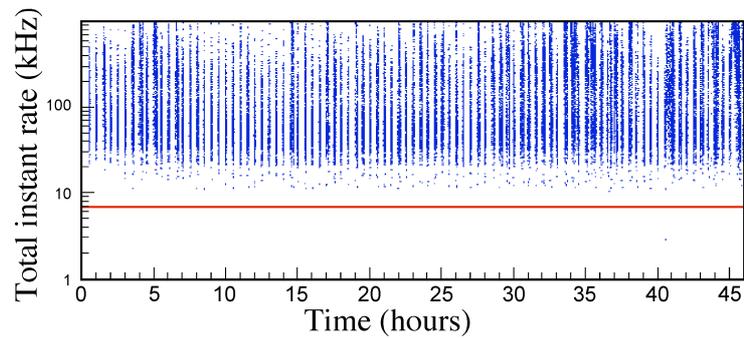


Figure 21 - Total instant rate, as function of time, in a region close to ANTARES site at 2000m depth. The red line indicates the level of "dark current noise", due to the PMT, to be subtracted.

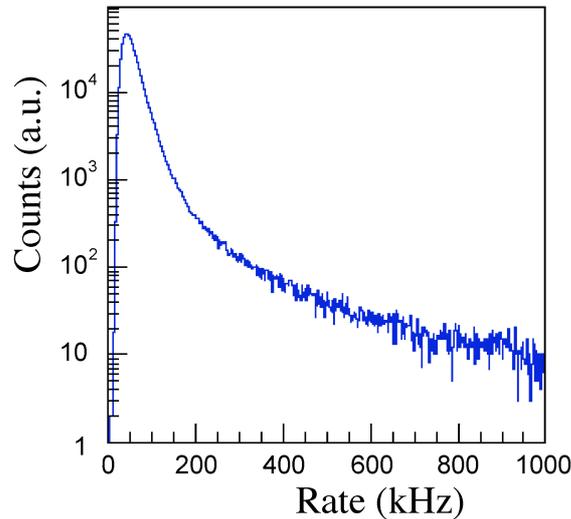


Figure 22 - Total instant rate distribution for data collected in a region close to ANTARES site at 2000m depth. The contribution to the total instant rate due to the PMT "dark current noise", that amounts to ~ 7 kHz, is not yet subtracted.

often exceeds 200 kHz, indicating a contribution to the optical noise due to bioluminescence. From figure 22, that shows the distribution of the total instant rate measured in ANTARES site at 2000 m depth, we get the average “total measured rate”: of about 65 kHz. Subtracting the PMT “dark current” rate we obtain the rate due to optical noise (^{40}K plus bioluminescence).

$$f_{optical\ noise}^{ANTARES} \approx 58 \pm 3 \text{ kHz}.$$

Study of deep sea currents

Current-meter chains have been moored in the region of Capo Passero since July 1998 to measure the current intensity and direction in a range of ~300 meters above the seabed.

In the period July-December 1998 a mooring line has been positioned in the site denoted KM3 (36° 30' 00" N, 15° 50' 00" E). The line was equipped with two current meters located at 10 m and 100 m above the sea bottom, respectively. The KM3 site was investigated up to December 1999.

Over 36 months the instruments measured currents stable both in direction and intensity: the average value is about 3 cm/s, and the maximum value is close to 12 cm/s. At the two depths the current velocities measured by the instruments were in good agreement: the water flows from SE to NW and the average angle is 38° NW.

Since August 1999 a new mooring line has been positioned in the site denoted KM4 (36° 18' 52" N, 16° 04' 42" E). This line was equipped with two current meters located at 100 m and 460 m above the sea bottom, respectively. The set of data from this second mooring line show values comparable, and slightly smaller, than in the KM3 mooring (about 10 cm/s maximum and about 2.5 cm/s average).

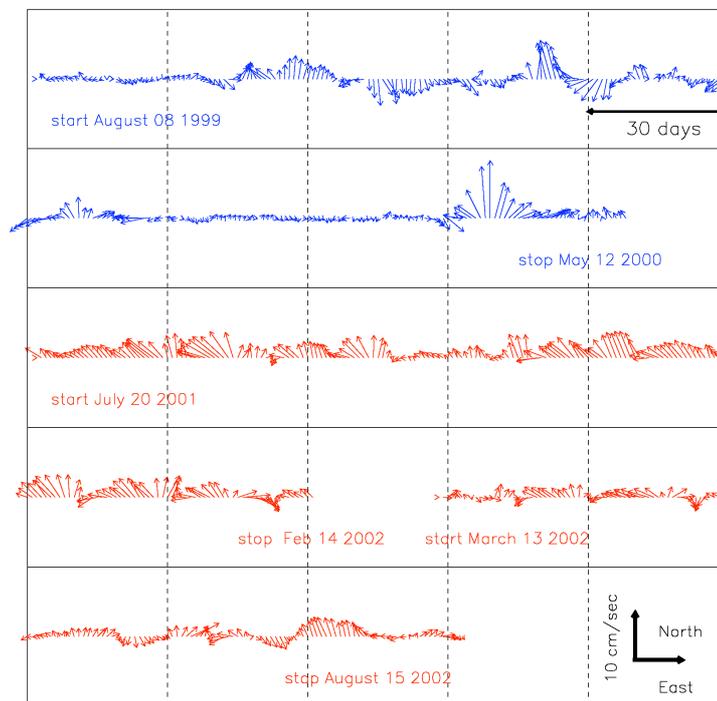


Figure 23 – Stick plot of the current intensity and direction recorded in the Capo Passero KM4 site.

A complete analysis of the current meter data for the period July 1998 – December 1999 is reported in [8]. **This analysis confirms that the behaviour of the deep sea currents in the region of Capo Passero is almost homogeneous on the part of the water column covered by the current-meters (≈ 500 m) with very low average values and peaks not exceeding 12 cm/s.** The analysis of the complete set of data, that covers the period from 2000 to august 2002 is under way. Raw data of the current intensity recorded in KM4 for the complete data taking period (August 99 to August 2002) is shown in fig. 23. Data taking is still continuing on the KM4 site.

Study of downward sediment fluxes

The analysis of the particulate material collected by a sediment trap can yield qualitative and quantitative information about the suspended matter in deep sea waters. The aim of this study is to estimate the amount of downward sediment flux in deep waters, its composition and dimensional distribution and to have information on its time variability.

Samples were collected using the sediment trap installed on the KM4 mooring chain described in Appendix A. The trap was located at about 110 m above the seabed and programmed to collect sediment samples over periods of ≈ 15 days. Two periods of samples have been analysed: August-December 1999 and January-May 2000.

Experimental methods

In the laboratory, samples were processed according to [9]. The main steps of the procedure were (1) manual removal of swimming organisms under a dissecting microscope and (2) subsampling using a precision wet splitter.

A small fraction (100-200 μl) was filtered on 0.4 μm Nuclepore filters for Scanning Electron Microscope (SEM) observation.

Subsamples for total mass flux (TMF) determinations were filtered through 0.45 μm Millipore filters, rinsed with distilled water and dried at 60 $^{\circ}\text{C}$ for 24 h, then weighed. For total and organic carbon (C_{tot} and C_{org}) and total nitrogen (N_{tot}) content, samples were filtered through precombusted 25 mm GF/F glass fibre filters, then they were analysed by a Perkin-Elmer 2400 CHN Elemental Analyser. For C_{org} analysis, the inorganic carbon was removed by HCl vapours [10]. The total amount of organic matter is assumed as $2C_{\text{org}}$.

Carbonate content was calculated assuming that all inorganic carbon (obtained from $C_{\text{tot}} - C_{\text{org}}$) was represented by CaCO_3 , using the carbonates/carbonate carbon ratio of 8.33. Biogenic silica (Si_{bio}) was determined by a dissolution with 2 M Na_2CO_3 solution at 85 $^{\circ}\text{C}$ for 5 h [11,12]. The lithogenic fraction was computed as the difference between the total mass and the sum of the biogenic components: organic matter + CaCO_3 + Si_{bio} .

Grain size spectrum of particles, in the range 0.8-128 μm , was determined with a Coulter Counter MULTISIZER 3, utilising the two-tube methodology.

Till now, the complete set of analysis is available only for the first deployment period (August-December 1999), while TMF data are available for both periods.

Results

The Total Mass Flux (TMF) measured is reported in fig.24. The particle flux shows rather constant low values (average 20 $\text{mg m}^{-2} \text{d}^{-1}$) from August 1999 to February 2000, while an increase during the March-June period was observed (average 156 $\text{mg m}^{-2} \text{d}^{-1}$).

For comparison in figure 24 similar data, collected by Istituto di Biologia del Mare of CNR (Venice), in the Ionian Sea (station I1, at ≈ 300 m depth and about 200 km North of Capo Passero) in 1997 and 1998, are also shown [13]. These data show the same seasonal behaviour as in KM4 station and they **confirm the extremely low**

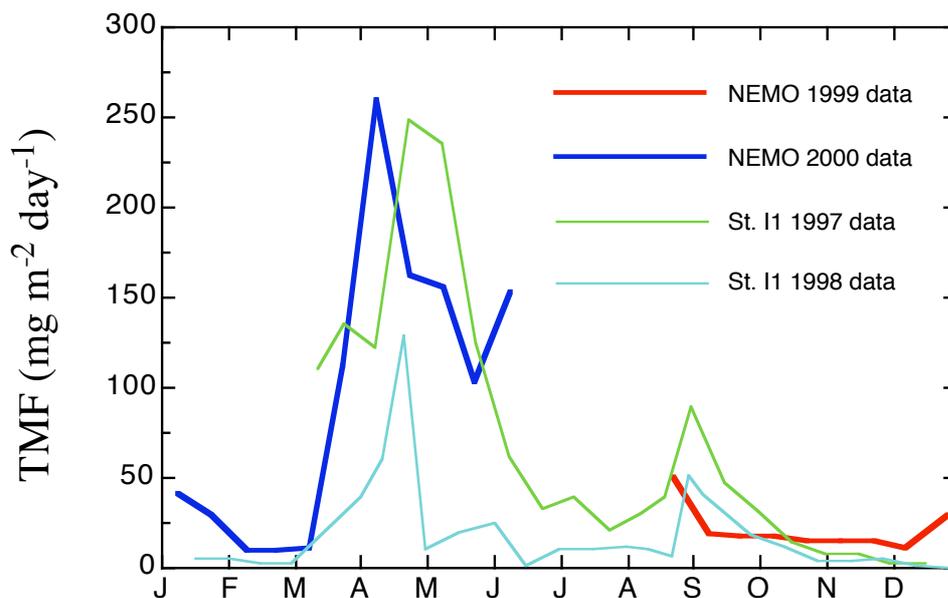


Figure 24 - Annual cycle of vertical fluxes in the Capo Passero site (thick blue and red lines). Data of the Northern Ionian II station are also shown.

sedimentation values in the Ionian plateau. However, although the annual cycle observed in the I1 station seems to be reproduced in Capo Passero, the data of the I1 station show marked variations from year to year, suggesting that the monitoring of the sedimentation rate should be carried out for long periods. The mass flux averaged over the year of observation is $62 \text{ mg m}^{-2} \text{ d}^{-1}$. Data of the July 2001 – August 2002 period are under analysis, while the collection of samples is still going on.

From optical observation (optical microscopy and SEM), the trapped material during the first low-flux period is essentially constituted by diffused particles of small dimensions with rare small aggregates. The biogenic component is essentially represented by faecal pellets and remains of planktonic organisms (Radiolarian, Foraminifera, Pteropods). During the period of higher flux (spring 2000) the presence of flocks of various dimension and mucous aggregates with several faecal pellets, phytoplankton cells (mainly diatoms), and again remain of planktonic organisms was observed.

In the Ionian Sea, vertical fluxes of particles are considered highly correlated with the biological productivity, and show the same seasonality as confirmed by the direct relationship between carbon flux and primary production [13]. The autumn and spring peaks of fluxes are associated with phytoplankton blooms and match with the beginning and the end of the cooling period, in relation with the increase of inorganic nutrient concentration in the photic zone during the thermal mixing. Microplankton even in low abundance in the water column (in Ionian Sea diatoms are 3-10 % in number), might play an important role in assimilating exportable biomass in oligotrophic oceanic habitats with gelatinous aggregate formation. Particle settling velocity (about 150 m d^{-1}) permits a strict link between upper and deep sea layers [13].

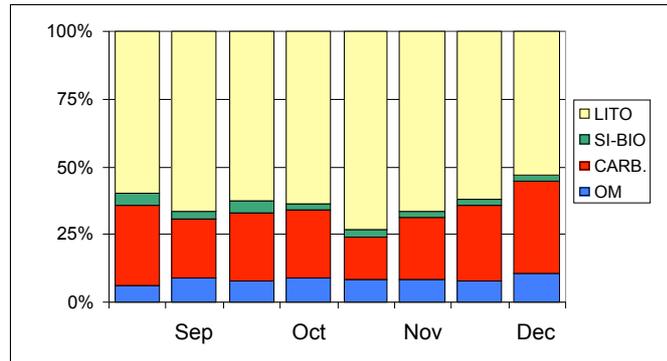


Figure 25 - Composition of the material collected during the first sampling period (August-December 1999).

In summer the prevalence of organic nutrients in the photic layer [14], enhances regenerated production processes. In this layer the pico and nano-plankton fractions are predominant in the autotrophic communities, as reported also in [15], but the role of these organisms as source of sinking material is relatively unimportant [16].

The chemical analysis of the material collected by the trap has been carried out for the samples collected during the first deployment period (August-December 99). The composition of the sedimented material is shown in fig. 25, while the average values over the first collecting period are reported in Table. I. The main component is represented by the lithogenic fraction and the high percentage of carbonates reflects the importance of coccolithophorids and foraminifera in plankton communities.

August– December 1999	Flux	
	<i>(mg m⁻² d⁻¹)</i>	<i>% of TMF</i>
Organic Matter	1.5 ± 0.6	8.2
Carbonates	5.2 ± 3.9	25.4
Biogenic silica	0.7 ± 0.7	3.1
Lithogenic	12.4 ± 7.3	63.3

Table I – Chemical composition of sedimented material.

The dimensional analysis of particles determined for the first sampling period (August 1999 - December 1999), in the range 0.8-128 μm, showed a general peak in the grain size distribution (expressed as volume percentage) around 3.5-6.5 μm, with a secondary mode in some samples around 30-68 μm (fig. 26).

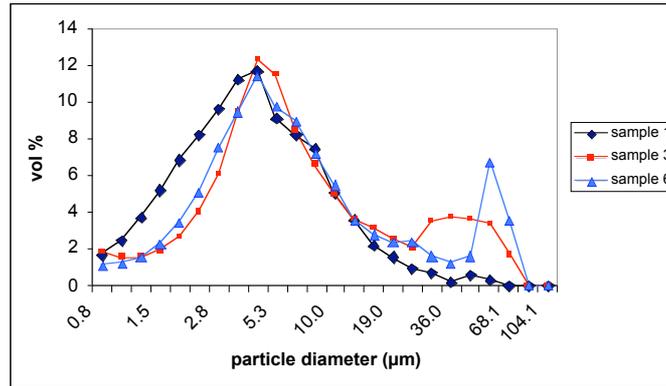


Figure 26 - Particle size distribution in 3 samples of the first sampling period (sample 1= 16 Aug-1 Sep99; sample3 = 16 Sep-1 Oct 99; sample 6= 1 Nov-16 Nov 99).

Geological survey of the area

A preliminary geomorphological characterization of the Capo Passero region has been performed in March 2002 with a study of an area of about 1100 km² around KM4. This study, performed by means of the Sub Bottom Profiler installed onboard the RV Urania, has evidenced that the sea bottom has a rather flat topography with slopes that, with few exceptions, do not exceed 0.5°. The bathymetry remains also flat for hundreds of km² around the region. The nature of the sea bottom is that of deposit of sediments of pelagic or emipelagic environment of sedimentation, characterized by absent or very weak bottom currents, that has permitted the formation of basin deposits (pelagic carbonates).

In a following campaign, still with the R/V Urania, eight sediment cores have been sampled in various locations close to KM4. The average length of the cores was about 5 m (fig. 27).

All of the cores have been analysed, showing the same stratigraphic features (fig. 28). Along their whole length the cores are essentially composed by clay sediments. Only two layers, one located at about 3 m below the sea-bottom and the second one at about 4.5 m, with different composition (silty sand) have been found. Layers of volcanic ash (tephra), that can be associated to ancient (more than 70 kyr) pyroclastic events, are also present.

Some feature observed in the cores, that can be associated to well known geological events, allow for a dating of the different layers of the cores. In particular, levels with a

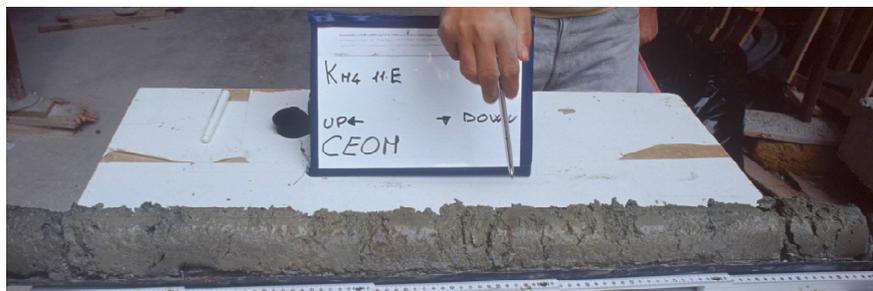


Figure 27 - One of the KM4 cores.

high concentration of organic material have been evidenced. These levels can be associated with anoxic events known as Sapropel, caused by the presence of a highly layered structure of the water column with a strong reduction of the oxygen exchange in the deepest waters. The presence of a strongly reducing environment favoured the preservation of organic substance on the sea-bottom. The most recent event, known as Sapropel S1, has been found in the cores at a depth of about 80 cm and can be dated between 9 and 6.5 kyr before present (BP).

A qualitative analysis of the Nannoflores, and in particular the relative abundance of Emiliana Huxley and Gephyrocapsa Muellerae, allows to associate the bottom part of the cores (below 3 m depth) to the Tirrenian (Mediterranean Isotopic Stage 5), dated between 125 and 75 kyr BP. At about 3 m depth the increase in the presence of

Emiliana Huxley has been evidenced. This event is chronologically calibrated at about 60-70 kyr BP.

The association with planctonic foraminifera and nannoplancton allows to evidence the isotopical stages 2 and 1. The isotopical stage 2 is recognizable from the high ratio $^{18}\text{O}/^{16}\text{O}$ and corresponds to the Last Glacial Maximum, occurred between 24 and 14 kyr BP. The isotopical stage 1, which is characterized by a lower value of the $^{18}\text{O}/^{16}\text{O}$ ratio, corresponds with a warmer interglacial period dated between 13 and 14 kyr BP.

Based on these data an evaluation of the sediment accumulation rate has been performed, giving a value of 3-4 cm/kyr. This result is in agreement with the mass flux measured with the sediment trap.

The only evidence of turbidity events, which occur when sediments of the continental shelf slide down the continental slope, has been found in the previous mentioned dark layer at a depth of 2.5 m. This leads to a date of about 65 kyr BP.

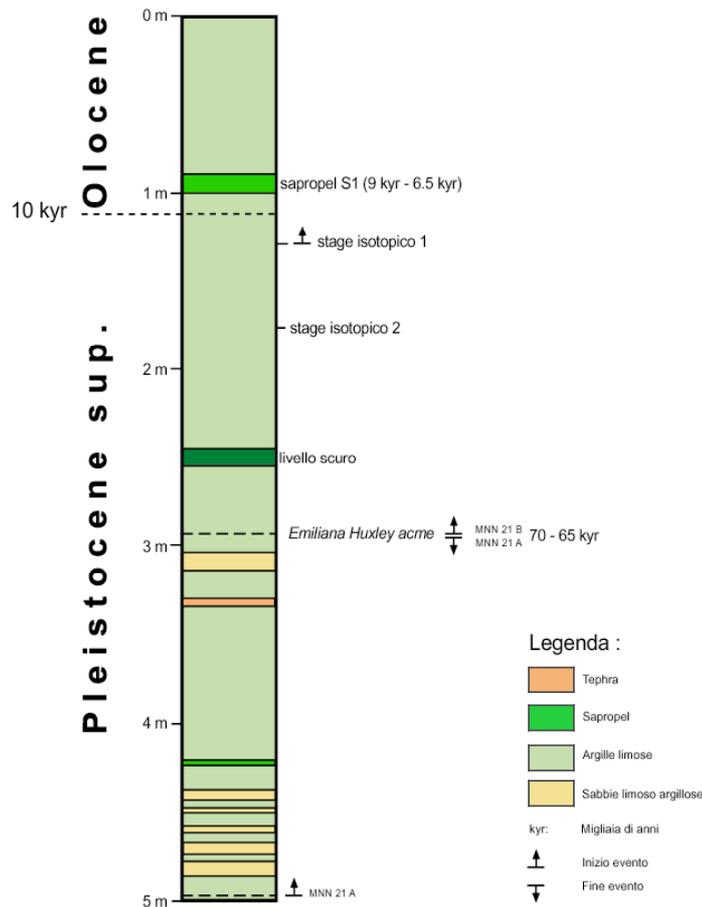


Figure 28 - Stratigraphy of the KM4 cores.

Effects of biofouling on optical surfaces

Materials that are kept in a marine environment for long time are subject to the growth on their surfaces of a bacterial film or to the settling of marine organisms: this is called “bio-fouling”. The degradation of the light transmission properties of the glass spheres that are used to host the optical modules due to bio-fouling has to be studied since it is determines the operational lifetime of the optical modules.

A deep sea station to study this phenomenon was deployed at 3000 m in Capo Passero KM4 site in late December 1999. The measuring system, that is described in more detail in appendix A, is basically composed by an array of photodiodes placed inside a benthos glass sphere and illuminated by pulsed blue LEDs.

The measurement technique consists in studying the time evolution of the ratio between the pulse amplitude of each photodiode inside the sphere over the pulse amplitude of a reference photodiode placed inside the vessel containing the LED. If fouling is formed on the sphere surface, a reduction of the ratio is expected as a function of time.

A short term measurement (40 days in the period January-February 2000) has been performed. Data measured with photodiodes placed at different polar angles are shown in fig. 29. No effects of bio-fouling on optical surfaces on this time scale have been evidenced.

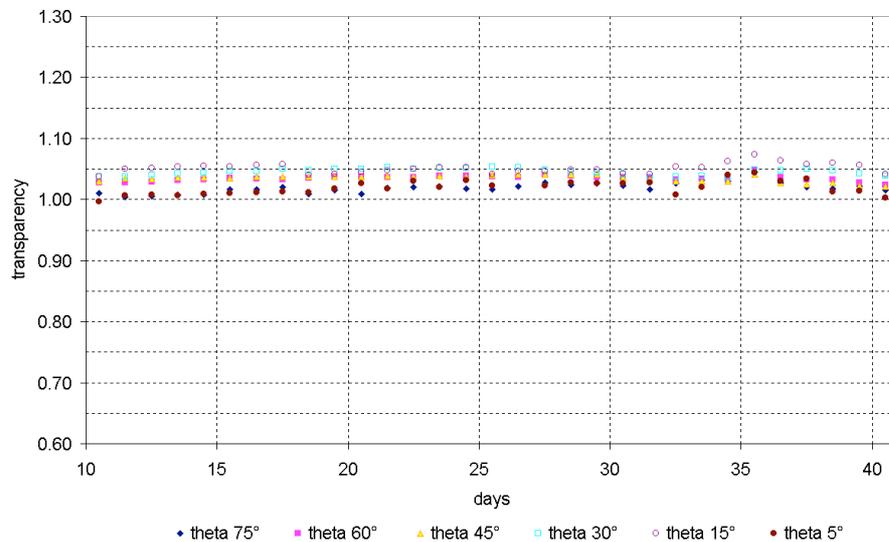


Figure 29 – Time dependence of the response of photodiodes placed at various polar angles inside the glass sphere of the apparatus. Data are normalized to the first day of operation of the setup.

Hydrobiological survey of the area

To evaluate the possible interference on the efficiency of the detector, the area characterization has also been performed through an interdisciplinary analysis of the main chemical, physical, trophic and microbiological features of the water masses. Particular attention was put on the bacterial compartment that plays a dominant role in the organic matter transformation in the marine ecosystems. The seasonal evolution of trophic rate in the water masses was investigated in four oceanographic cruises (December 1999, September 2000, July 2001, April 2002).

The investigated area shows typical oligotrophic conditions and a marked water stratification, which influences the distribution of planktonic communities.

Four main water masses were identified: Atlantic Ionian Stream (0-200m), Levantine Intermediate Waters, Eastern Mediterranean Deep Waters and Cretan Deep Waters. Seasonal variability of selected parameters was observed in each water mass and in whole water column.

Different vertical patterns were found for each parameters, but the prevailing trend was characterized by a decrease in activity and abundance values with increasing depth. In the shallow water photic zones microbial processes are particularly intense and subject to strong seasonal variations, also in relation with photosynthetic activity. With increasing depth only low levels of biological activity and a marked decreasing vertical gradient were observed.

The trophic load was very moderate during all investigation cycle, and appreciable differences between photic and deep zone were observed, with the highest levels in the first one.

The highest levels of biomass were noticed at the superficial layer and generally decreased from surface to the bottom. Also the higher microbial activity levels were registered in these layers suggesting the presence of an efficient microbial food chain in this oligotrophic environment and confirming the key role of enzymatic activity to mediate the organic matter flux in the whole water column.

Particularly relevant for what concerns the effects on the water Cherenkov detector is the absence in the deepest waters of luminescent bacteria, already presented in fig. 14.

The presence of Particulate Organic Carbon (POC) and Particulate Organic Nitrogen (PON) is very low in agreement with the known oligotrophic condition of the area [13,15]. The lowest values have been observed during the summer campaign.

The measurements of biological parameters confirms the sedimentation and biofouling data, showing that deep Ionian Sea waters are comparable with oceanic waters. The extremely low values of the bacterial concentration could represent a double advantage both for the expected growth of biofilm and for the optical noise level induced by bioluminescent organisms.

Conclusions

Results of the site survey activity performed since 1998 by the NEMO Collaboration suggest that a large region located ~ 80 km SE of Capo Passero (Sicily) is excellent for the installation of the km³ underwater neutrino telescope.

- The site is close to the coast (about 80 km) but sufficiently far from the shelf break to be considered "safe". The proximity of several infrastructures (including the ports of Catania, Siracusa and Augusta) facilitates the access to the site for the installation and maintenance of the detector. Moreover, it is also close to of the INFN Laboratori Nazionali del Sud in Catania.
- The bathymetric profile of the region is extremely flat over hundreds km², with a depth of about 3500 m. The seabed nature of sediment deposit is perfectly suitable for the mooring of the telescope structures. No evidence of recent turbidity events, of potential danger for the detector, is present.
- Water optical properties are the best observed in the sites explored, including also the Antares site. Blue light absorption length is close to 70 m and attenuation length is 35 m. No seasonal effects on the light transmission properties have been observed.
- The optical background induced in the optical modules is low with an average rate compatible with the decay of ⁴⁰K. Only rare events due to bioluminescence are observed.
- The sedimentation rate is very low, as expected for a low biologically active environment as the Ionian Sea, with an average value of about 60 mg m⁻² day⁻¹.
- Deep sea currents have very low intensity, of the order of 3 cm/s, with maximum peaks that never exceed 10-12 cm/s.

Appendix A – Details of the instrumentation used

Several types of instruments were used to characterize the oceanographical and optical properties of the selected site. In some cases the instruments were connected to the surface by means of an electro-mechanical cable and deployed with a winch operated onboard the surface vessel. This arrangement allows to perform real time measurements deploying the instruments from the surface to the sea bottom obtaining a profile of the whole water column. Long term measurements were instead performed by mooring the instruments on the sea bottom. These moorings were recovered from time to time to allow for data downloading and instrument maintenance.

Schematically a mooring line is composed by a dead weight, which ensures the anchoring on the sea bottom, a release system and the instrumentation. The line is kept vertical by an appropriate buoy. Recovery is possible by remotely activating an acoustic release system, that, releasing the dead weight, allows the buoy to float to the surface with the instrumentation.

AC9 profiler

Light attenuation and absorption measurements in deep seawater were performed by means of a set-up based on a commercial transmissometer: the AC9 manufactured by Wetlabs [17]. The device compactness (68 cm height \square 10.2 cm diameter) and its pressure resistance (it can operate down to 6000 m depth) are excellent for our purposes. The AC9 performs attenuation and absorption measurements independently, using two different light paths and spanning the light spectrum over nine different

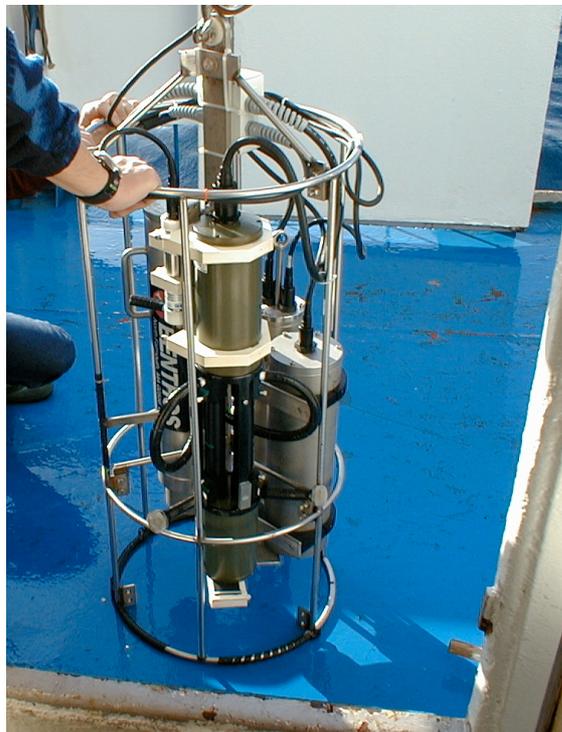


Figure 30 – The AC9 assembled together with the CTD probe on a stainless steel cage, ready for deployment.

wavelengths (412, 440, 488, 510, 532, 555, 650, 676, 715 nm). Following an accurate calibration procedure we obtained an accuracy in $a(\lambda)$ and $c(\lambda)$ of about $1.5 \times 10^{-3} \text{ m}^{-1}$. Using AC9 data, the scattering coefficient can be calculated subtracting the absorption coefficient value from the attenuation coefficient one at each given wavelength. During deep sea measurements the AC9 was connected to a standard oceanographic CTD (Conductivity–Temperature–Depth) probe: the Idronaut Ocean MK317. The instruments are assembled on an AISI-316 stainless-steel cage (fig. 30). The data acquisition set-up is designed to acquire the *profiles* of a set of 20 parameters that characterise the water column (temperature, salinity, nine absorption coefficients and nine attenuation coefficients) as a function of depth. In order to estimate systematic errors at least two profiles at short time distance (~ 6 hours) were carried out in each site. Further details about the measurement procedure and data analysis can be found in [4].

KM3 mooring line

A scheme of the mooring line used in the location denoted as KM3 ($36^\circ 30' \text{ N}$, $15^\circ 50' \text{ E}$) is shown in fig. 31. This mooring hosted two Aanderaa RCM 8 mechanical recording current meters, one positioned at 10 m and a second one at 110 m above the seabed. The mooring was first deployed in July 1998 and recovered several times until December 1999.

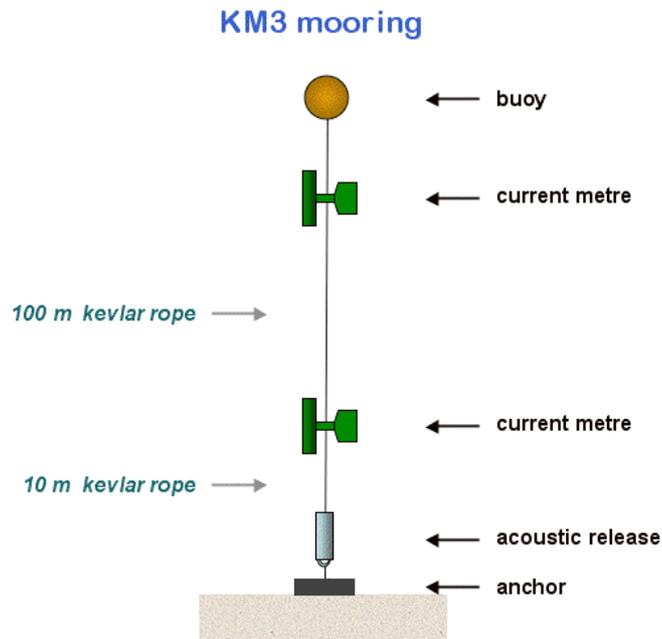


Figure 31 – Scheme of the KM3 mooring line.

KM4 mooring line

A scheme of the mooring line used in the location denoted as KM4 (36° 16' N, 16° 06' E) is shown in fig. 32.

Two slightly different versions of this mooring have been deployed. A first one, denoted KM4a, hosted two Aanderaa RCM 8 mechanical recording current meters, one positioned 100 m and a second one 460 m above the seabed. The mooring was first deployed in August 1999 and operated until July 2000. During this period it was recovered once (December 1999) while an attempt for a recovery using the remote release system in July 2000 failed. The mooring was dragged and recovered in August 2002.

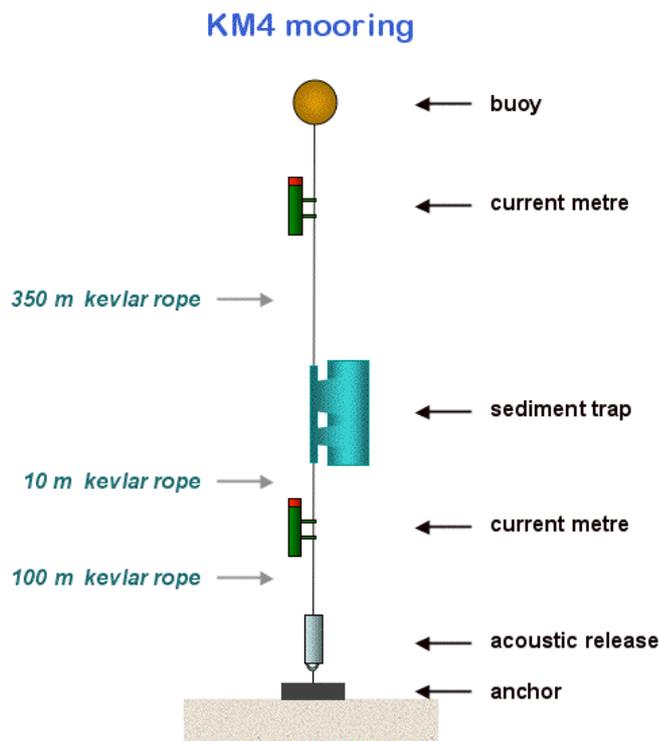


Figure 32 – Scheme of the KM4 mooring line

The mooring was also equipped with a sediment trap, mounted at about 110 m above the sea floor, to collect suspended particles and measure the downward fluxes. The sediment trap used (Technicap mod. PPS3/3), basically consists of a cylindro-conical funnel with a collecting area of 0.125 m² and a height of 1.8 m, equipped with a series of 12 bottles that can be automatically changed by means of a programmable motor. The sample bottles were filled with a 4% formaldehyde solution buffered in filtered sea water, to prevent organic degradation during the deployment. The top of the trap was protected by means of a 0.5 cm meshed net, to avoid the entrance of large size organisms.

In a further improvement of the mooring, denoted KM4b, the RCM8 current metres were replaced by two two Aanderaa RCM 11 doppler recording current meters, which

allowed for a lower threshold in the current measurements. This mooring was first deployed in August 2001 and is still in operation. During this period it was recovered for data downloading and maintenance in February and in August 2002.

Data measured with the RCM8 and the RCM11 current meters have been checked for consistency. The velocity distribution measured with the two types of current meters is

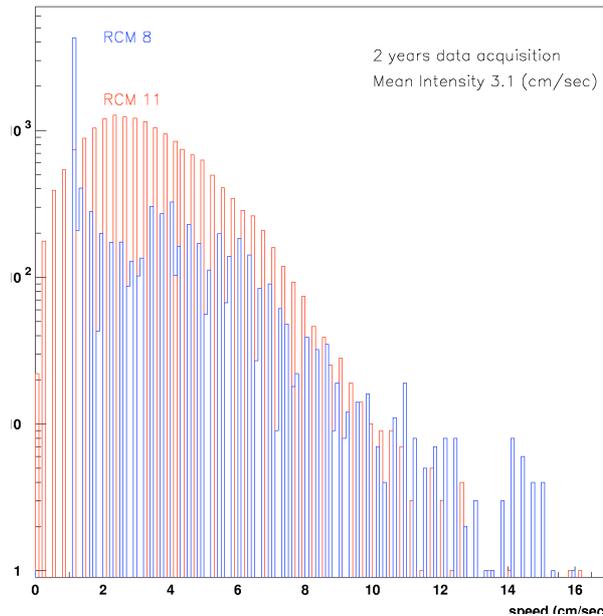


Figure 33 – Distribution of the current intensities measured with a RCM8 mechanical current meter (blue) and with an RCM11 doppler current meter (red).

shown in fig. 33. The data are fully consistent for current velocities above 5 cm/s, while for lower values the threshold presented by the RCM8 introduces a distortion in the distribution. However, the average value of the two distribution is equal.

The “Optical Background” mooring chain

Background “optical noise” was measured directly in deep sea water by means of an autonomous detection system, equipped with two Optical Modules, a digitization electronics, a slow control electronics and a data collection system. This set-up was mounted on a mooring line (fig. 34) that can be positioned on the sea bottom for a period of time sufficient to characterize the “optical noise” and, eventually, its daily variations.

Each optical module consists of an 8” hemispherical PMT (the “low noise” EMI 9356KA) protected by a 17” glass sphere (BENTHOS). The optical contact between the PMT and the sphere is obtained by means of a two components optical silica gel. Each PMT is equipped with a custom produced μ -metal cage to reduce the effect of the Earth magnetic field (the residual magnetic field has been measured to be 0.12 ± 0.2 Gauss). By means of a Spectrophotometer (Carry 500) we characterized the optical properties (absorption length, refractive index, ...) of the sphere glass and of the silica gel in order

to be able to fully simulate the acceptance of the Optical Module as function of the wavelength.

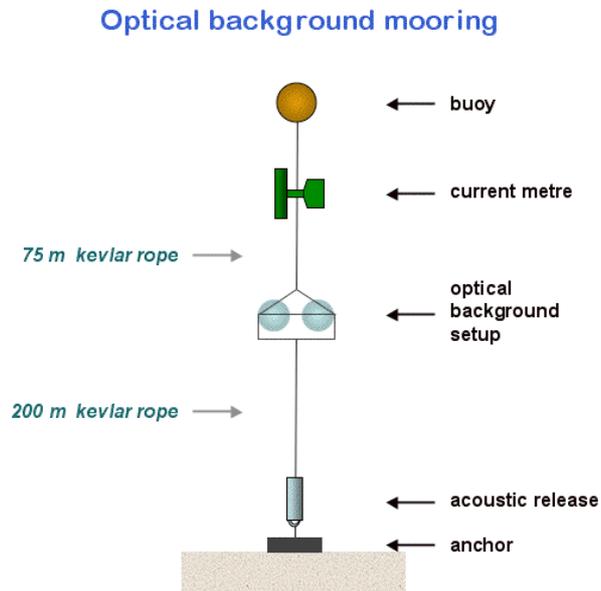


Figure 34 – Layout of the mooring line used for optical background measurements.

The response of the PMT was studied by means of a LED source (460 ± 10 nm) producing single photo-electrons. The Q.E. of the PMT photocathode has been studied as a function of the impact point of light. The gain of the two PMTs was set to allow the detection of single photo-electron signals (7.3×10^7 and 8.4×10^7).

During data taking the PMT pulses are continuously digitized, at 200 MHz, and data are stored on disk only if the signal is greater than 1/3 of the one given (as most probable) by one single photoelectron. This threshold defines the PMT dark currents. The counting rate of both PMTs due to dark current, at 1/3 of p.e. level, and its evolution with the temperature has been characterized over a long period of time. In deep sea working conditions the dark-current counting rates amount to ~ 7.1 and 6.9 kHz, for the two PMTs respectively.

Typically the setup was moored for periods of 5-7 days. A microprocessor takes care of switching on the PMTs high voltage a couple of hours after the deployment. The same microprocessor starts a data taking cycle (5' data taking, 25' stand-by) only after a period of time (6 hours) sufficient to reduce to the minimum the PMT dark current. Data are written on a 10GB disk and downloaded after the mooring line recovery.

Biofouling mooring chain

The measuring system is composed by an array of 14 6×6 mm² Hamamatsu S1337-66BR photodiodes (PD) coupled with custom pre-amplifier cards. The array is placed inside a 43 cm diameter Benthos sphere. The PDs are positioned at different angles

ranging from upward vertical (0°), to downward vertical (180°). Two blue high luminosity LEDs, placed inside an external housing, are used as light sources.

The measurement technique consists in studying the time evolution of the ratio between the pulse amplitude of each PD inside the sphere over the pulse amplitude of a reference photodiode placed near the LED. If fouling is formed on the sphere surface, a reduction of the ratio is expected as a function of time.

Moreover, the station is equipped with a CTD probe Idronaut Ocean MK-317, which measures water temperature, conductivity, salinity and depth, and a current metre Aanderaa RCM-8, which gives information of current direction and intensity.

Data can be downloaded from the surface by means of an acoustic modem Datasonics ATM-877.

Appendix B – List of the sea campaign performed

List of the oceanographical campaigns performed by the NEMO Collaboration

July 1998

Vessel: R/V Thetis

Departure / Arrival: Catania / Catania

Locations: Capo Passero

Activities performed: Deployment of KM3 mooring

August 1998

Vessel: R/V Urania

Departure / Arrival: Bari, august 18 / Ravenna, august 31

Locations: Capo Passero

Activities performed: Test of AC9
Recovery-Maintenance-Deployment of KM3 mooring

October 1998

Vessel: R/V Urania

Departure / Arrival: Civitavecchia, october 10 / Ponza, october 12

Locations: Ponza

Activities performed: Two profiles with AC9

December 1998 - January 1999

Vessel: R/V Urania

Departure / Arrival: Bari, december 28, 1998 / Catania, january 18, 1999

Location: Capo Passero

Activities performed: Profile with AC9 (KM2 site)
4 CTD profiles (Capo Passero)

Location: Matapan (Greece)

Activities performed: Profile with AC9

February 1999

Vessel: R/V Urania

Departure / Arrival: Catania, february 9 / Catania, february 11

Location: Capo Passero

Activities performed: Profile with AC9 (KM3 site)
Recovery-Maintenance-Deployment of KM3 mooring

August 1999

Vessel: R/V Urania

Departure / Arrival: Civitavecchia, august 6 / Catania, august 12

Location: Capo Passero

Activities performed: Profile with AC9 (KM2 site)
Recovery-Maintenance-Deployment of KM3 mooring
Deployment of KM4 mooring

Location: Catania Test Site

Activities performed: Profile with AC9
4 CTD profiles

December 1999

Vessel: R/V Urania

Departure / Arrival: Messina, december 4 / Messina, december 10

Location: Ustica

Activities performed: 2 profiles with AC9
4 CTD profiles

Location: Alicudi

Activities performed: 2 profiles with AC9
4 CTD profiles

December 1999

Vessel: R/V Urania

Departure / Arrival: Messina, december 12 / Pozzallo, december 17

Location: Capo Passero

Activities performed: Profile with ⁴⁰K assembly

December 1999

Vessel: R/V Urania

Departure / Arrival: Pozzallo, december 19 / Messina, december 23

Location: Capo Passero

Activities performed: 2 profiles with AC9 (KM3), 2 profiles with AC9 (KM4)
Recovery-Maintenance-Deployment of KM3 mooring
Recovery-Maintenance-Deployment of KM4 mooring
Deployment of Biofouling mooring (KM4)

Location: Catania Test Site

Activities performed: 2 profiles with AC9 (Test Site)

March 2000

Vessel: R/V Urania

Departure / Arrival: Catania, march 20 / Naples, march 22

Location: Capo Passero

Activities performed: 2 profiles with AC9 (KM4)
Profile with ⁴⁰K assembly

June 2000

Vessel: R/V Georges Petit

Departure / Arrival: La Seyne sur Mer, june 8 / La Seyne sur Mer, june 12

Location: Toulon

Activities performed: mission aborted due to problems on the electro-mechanical winch

June 2000

Vessel: R/V Thetis

Departure / Arrival: Catania, june 26 / Catania, june 28

Location: Capo Passero

Activities performed: Attempt to recover KM3, KM4 and Biofouling moorings

August 2000

Vessel: R/V Thetis

Departure / Arrival: Siracusa, august 11 / Siracusa, august 14

Location: Capo Passero

Activities performed: Recovery of Biofouling mooring
Attempt to recover KM3 and KM4 moorings

March 2001

Departure / Arrival: march 25 / march 31

Location: Lake Baikal

Activities performed: 2 profiles with AC9

August 2001

Vessel: R/V Thetis

Departure / Arrival: Catania, august 19 / Catania, august 28

Location: Capo Passero

Activities performed: 2 profiles with AC9 (KM4)
Test of DEWAS
Recovery-Maintenance-Deployment of KM4 mooring

Location: Catania Test Site

Activities performed: profile with AC9 (Test Site)

November 2001

Vessel: R/V Thetis

Departure / Arrival: Siracusa, november 5 / Siracusa, november 9

Location: Capo Passero

Activities performed: mission aborted due to problems on the electro-mechanical winch

December 2001

Vessel: R/V Thetis

Departure / Arrival: Catania, december 10 / Siracusa, december 12

Location: Capo Passero

Activities performed: mission aborted due to bad weather conditions

February 2002

Vessel: R/V Thetis

Departure / Arrival: Siracusa, february 13 / Siracusa, february 15

Location: Capo Passero

Activities performed: Recovery-Maintenance-Deployment of KM4 mooring

March 2002

Vessel: R/V Urania

Departure / Arrival: Messina, march 1 / Catania, march 4

Location: Capo Passero

Activities performed: Sub Bottom Profiler (KM4)
Recovery of Biofouling mooring

Location: Catania Test Site

Activities performed: Sub Bottom Profiler

March 2002

Vessel: R/V Urania

Departure / Arrival: Messina, march 13 / Catania, march 18

Location: Capo Passero

Activities performed: Profile with AC9
3 profiles with AC9+DEWAS
Recovery-Maintenance-Deployment of KM4 mooring
Deployment and recovery of the ⁴⁰K mooring
Collection of core samples

Location: Catania Test Site

Activities performed: Profile with AC9+DEWAS

April-May 2002

Vessel: R/V Alliance

Departure / Arrival: Siracusa, april 29 / Siracusa, may 2

Location: Capo Passero

Activities performed: 2 profiles with AC9 (KM4)

June 2002

Vessel: R/V Thetis

Departure / Arrival: La Seyne sur Mer, june 4 / La Seyne sur Mer, june 10

Location: Toulon

Activities performed: 2 profiles with AC9
2 profiles with AC9+DEWAS
Deployment and recovery of the ⁴⁰K mooring
Measures with the Antares ⁴⁰K mooring
Measures with the Antares TEST-3 assembly

August 2002

Vessel: R/V Alliance

Departure / Arrival: Catania, august 11 / Catania, august 17

Location: Capo Passero

Activities performed: 3 profiles with AC9

Test of NERONE

Recovery-Maintenance-Deployment of KM4 mooring

Deployment and recovery of the ⁴⁰K mooring

Measures with the Antares ⁴⁰K mooring

Measures with the Antares TEST-3 assembly

Location: Catania Test Site

Activities performed: 4 profiles with AC9

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