Measurements of optical properties in deep seawater for a Mediterranean km-cube Čerenkov Telescope

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Abstract. The NEMO collaboration is performing a feasibility study for the construction of a km^3-scale underwater Neutrino Telescope in the Mediterranean Sea. The selection of an optimal marine site has a great importance in the determination of both the performances of the detector and of the project costs. For Čerenkov detectors, the knowledge of light transmission properties in deep seawater is extremely important. The collaboration has measured optical properties in several marine sites near the Italian coasts, at depths >3000 m, using a set-up consisting of a trasmissometer and a CTD probe. The results obtained during two years of sea campaigns demonstrate that deep seawater of a large area located about 80 km SE of Sicily shows optical properties comparable to those of the clearest waters.

1 Introduction

The reconstruction of neutrino tracks in km^3-scale telescopes is based on the detection of Čerenkov photons radiated in water (or ice) by relativistic charged leptons. The selection of an adequate site for the deployment of a Neutrino Telescope (especially for gigantic structures like the km^3) is extremely important and must be completed with a long term program of characterisation of the candidate sites carried out in all different seasons. Moreover the continuous monitoring of water optical properties is mandatory for the right interpretation of the telescope data. Seawater, indeed, absorbs and scatters photons, as a function of water temperature, salinity and as a function of concentration, dimension and refraction index of dissolved/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) such as the absorption ($a(\lambda)$), scattering ($b(\lambda)$) and attenuation ($c(\lambda) = a(\lambda) + b(\lambda)$) coefficients (Mobley, 1994). Another parameter commonly used in literature is the effective scattering length $L_b^{eff}(\lambda) = \frac{1}{(b(\lambda)\cdot(1-<\cos(\vartheta)>)}$, where $< \cos(\vartheta) >$ is the average cosine of the scattering angle. The estimation of this last parameter is extremely difficult since it needs the knowledge of another IOP, the volume scattering function $\beta(\lambda, \vartheta)$, that must be measured with appropriate devices (Pappalardo *et al.*, 2000).

At the beginning of its activity the NEMO collaboration has identified a number of potential sites in Southern Italy, selected on the basis of the average depth ($\sim$ 3500 m) and the proximity to the coast ($<$ 100 km). In this paper we report measurements of optical properties for the deep marine sites corresponding approximately to the coordinates (figure 1):

- 35° 50 **N** 16° 10 **E** in the Ionian Sea, South-East of Capo Passero, Sicily;
- 39° 05 **N** 13° 20 **E** in the Tyrrhenian Sea, North-East of Ustica island, Sicily;
- 39° 05 **N** 14° 20 **E** in the Tyrrhenian Sea, North of Alicudi island, Sicily.

The criterium chosen for site selection was based on seawater optical properties (absorption and attenuation) measured with the trasmissometer *AC9* (see section 2). Once the collaboration had demonstrated the optimal quality of seawater in the region of Capo Passero, we started an intense programme of site characterization, as discussed elsewhere in these proceedings (Riccobene *et al.*, 2001).

2 The *AC9* trasmissometer

Light attenuation and absorption measurements in deep seawater were performed by means of a set-up based on a trasmissometer: the *AC9* manufactured by WETLabs (see AC9 manual). The device compactness (68 cm height × 10.2 cm

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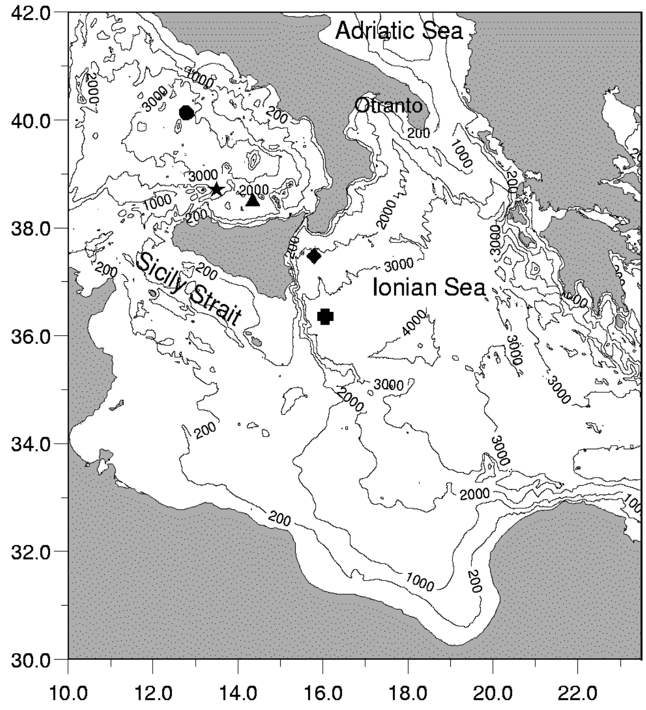

Fig. 1. Locations of the sites investigated by the NEMO collaboration. Alicudi (triangle), Ustica (star), Capo Passero (cross), Ponza (circle). The data measured in *Ponza* need further analysis and are not presented. In figure we also show the location of the *Test-Site* of Catania (diamond) discussed elsewhere in these proceedings (Riccobene *et al.*, 2001).

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 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 $1.5 \cdot 10^{-3}$ 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 we connect the *AC9* to a standard oceanographic CTD (Conductivity Temperature Depth) probe, the Idronaut-*Ocean MK317*. Figure 2 shows the whole set-up mounted on an AISI-316 stainless-steel cage before a deployment. The DAQ set-up is designed to acquire, as a function of depth, the *profiles* of a set of 20 parameters that characterise the water column (temperature, salinity, nine absorption coefficients and nine attenuation coefficients). In order to estimate systematic errors we carry out at least two profiles at short time distance ($\sim$ 6 hours) in each site. Further details about the measurement procedure and data analysis can be found in (Capone *et al.*, 2001). As an example, in figure 2 we show, as a function of depth, water salinity and temperature together with the absorption and attenuation coefficient for $\lambda = 440$ nm measured during the first (black dots) and the second (red dots) deployment in Alicudi site. As it appears in the figure, the layer composition of Tyrrhenian Sea, well studied by oceanologists in terms of salinity and temperature, is also observed in the measurements of water optical properties: the *AC9* sensitivity permits to distinguish layers of water where absorption and attenuation coefficients vary of $\sim 1 \cdot 10^{-3}$ m^{-1}.

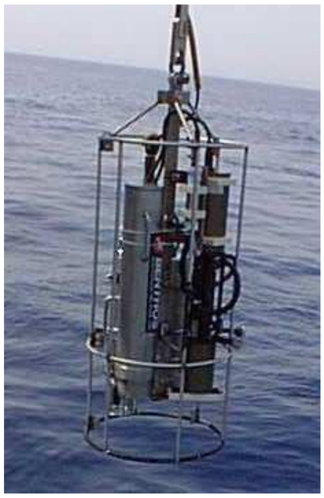

Fig. 2. Deployment of AC9 deep-sea setup.

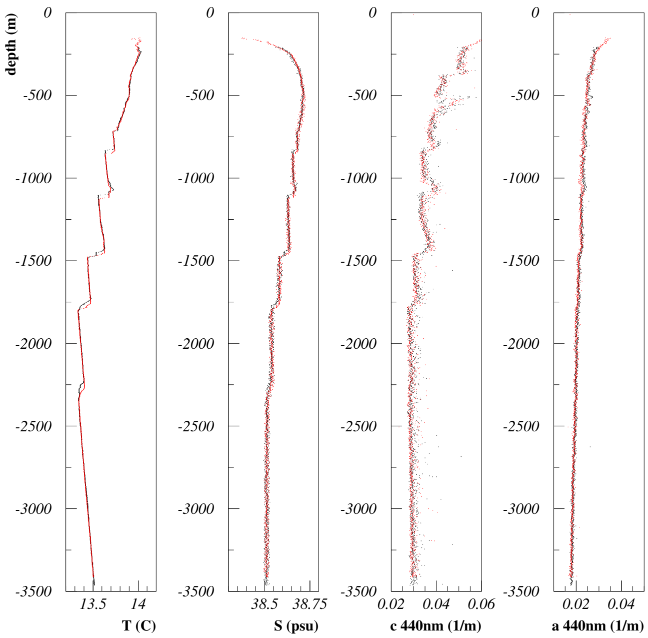

Fig. 3. Temperature, salinity, attenuation and absorption coefficients (at $\lambda = 440$ nm) as a function of depth, measured in the first (black) and in the second (red) deployment in *Alicudi* site. The values measured in the two deployments are nearly superimposed in the figure.

3 Results

In figures 4 and 5 we plot the attenuation and absorption lengths, as a function of λ, measured with the *AC9* during December 1999 in *Alicudi* and *Ustica* (published in (Capone *et al.*, 2001)) and the preliminary results for Capo Passero. In the region of Capo Passero we have explored 2 sites named respectively KM3 ($\sim$60 km far from the coast) and KM4 ($\sim$80 km far from the coast).

The absorption and attenuation lengths shown in figures, are obtained averaging the values of $L_a(\lambda)$ and $L_c(\lambda)$, measured at each site, in the range of depths interesting for a km^3 neutrino detector: a $\sim$ 500 m wide interval, with its base $\sim$ 150 m above the seabed.

In the same figure we also included, for comparison, the optical properties measured in the vicinity of the NEMO *Test Site* (28 km East offshore the port of Catania, depth 2050 m); plotted data refer to the average in the interval 1500 $\div$ 1900 m.

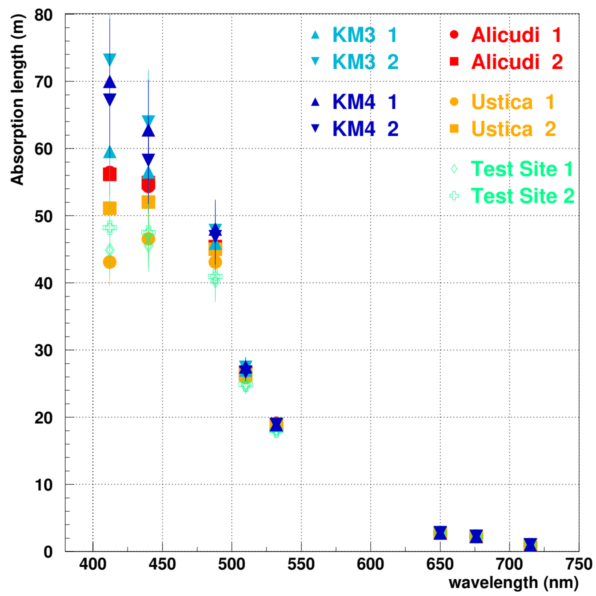

Fig. 4. Absorption lengths ($L_a = \frac{1}{a}$) measured in Ustica, Alicudi, Capo Passero KM4 and KM3. The average value is calculated in the interval 2850 $\div$ 3250 m. For the optical properties measured in Catania, the average is calculated between 1850 and 2050.

4 Discussion

The used instrumentation is optimal to determine the evaluation of light absorption and attenuation *in situ*. We, in fact, carry out profiles of optical parameters as a function of depth and wavelength (in the range 412 $\div$ 715 nm). This allow a cross check with the profiles of oceanographic parameters. We have also demonstrated that our calibration procedure allows to obtain an accuracy in the evaluation of $a(\lambda)$ and $c(\lambda)$ of the order of $1.5 \cdot 10^{-3}$ m^{-1}.

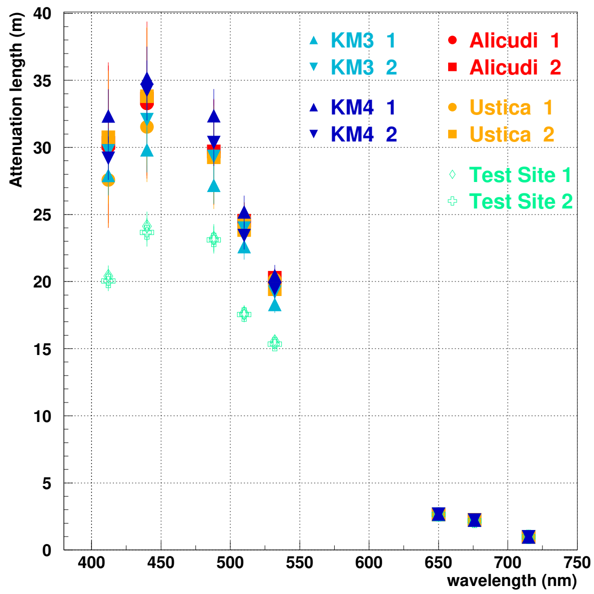

Fig. 5. Attenuation lengths ($L_c = \frac{1}{c}$) measured in Ustica, Alicudi, Capo Passero (KM4 and KM3) and Catania

The values of $L_a(\lambda)$ measured in the depth interval of interest are very close to the ones reported by Smith and Baker for *pure seawater* absorption (Smith and Baker, 1981). The best results were measured in Capo Passero region, where the average absorption length for blue light ($\lambda = 412$ and $\lambda =$ 440 nm) is $\sim$ 70 m and the average attenuation length is $\sim$ 33 m, in the month of December. These values are extremely good when compared to attenuation values of seawater published by the NESTOR collaboration (Kanaev, Kuleshov and the NESTOR collaboration, 1993). A direct comparison of our measurements with measurements carried out in conditions of not collimated geometry published by other experiments (Bardner *et al.* for the DUMAND Collaboration, 1981), (Anassontzis *et al.* for the NESTOR collboration, 1994), (Palanque-Delabrouille for the ANTARES collaboration, 1999) is possible only knowing the used experimental geometry ant the volume scattering function $\beta(\lambda, \vartheta)$. In the latter cases, in fact, the quantity measured is the *effective attenuation coefficient* $c_{eff}(\lambda)$. This quantity (an *apparent optical property*) is defined as the sum of absorption and a fraction of the scattering coefficient:

$$c_{eff}(\lambda) = a(\lambda) + (1 - \langle \cos(\vartheta) \rangle) \cdot b(\lambda) \qquad (1)$$

where $\langle \cos(\vartheta) \rangle$ is the average cosine of the volume scattering function. The function $\beta(\lambda, \vartheta)$ strongly depends on the amount, dimensions and refraction index of the dissolved/suspended particulate and must be directly measured. In order to measure it the NEMO collaboration has designed and constructed a new device, *DEWAS* (Deep water Scattering-Meter) able to measure the volume scattering function in the range $0° < \vartheta < 180°$ $430 < \lambda < 590$ nm (Pappalardo *et al.*, 2000). Measurements with the *AC9* and *DEWAS* will be carried out in Capo Passero in the next future.

5 Acknowledgements

This work has been been conducted in collaboration with: Department of Physical Oceanography of Istituto Nazionale di Oceanografia e Geofisica Sperimentale (Trieste), Istituto Sperimentale Talassografico (CNR, Messina) and Istituto di Oceanografia Fisica (CNR, La Spezia).

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AC9 manual available at `www.wetlabs.com`.