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On-line monitoring of underwater acoustic background at 2000 m depth

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The NEMO (NEutrino Mediterranean Observatory) Collaboration is constructing, 25 km E from Catania (Sicily) at 2000 m depth, an underwater test site to perform long-term tests of prototypes and new technologies for astrophysical HE neutrino telescopes. In this framework the collaboration deployed an electro-optical cable equipped with several e.o. terminations. An experimental apparatus for the measurement of underwater acoustic background was also installed and connected on 22 Jan 2005, allowing continuous on-line monitoring of deep-sea noise. The station is equipped with 4 hydrophones operational in the range 30 Hz - 40 kHz. This interval of frequencies matches the range suitable for acoustic detection of HE neutrino-induced showers in water. Hydrophones signals are digitized (96 kHz - 24 bits) underwater and continuously transmitted to shore via optical fibre. Underwater noise spectra were produced and classification of transient signals is under way. The NEMO-test site is also equipped with an on-line seismic observatory developed by INGV (the Italian National Institute for Geophysics and Volcanology).

1. Introduction

Askarjan firstly suggested that at $E_\nu \geq$ EeV, neutrino interactions in water could produce detectable acoustic signals [1]. Showers, originated by ν, release instantaneously a macroscopic amount of energy in the volume of matter traversed by the cascade. Ionization and sudden heating of water produce a bipolar pressure pulse which propagates (in a homogeneous medium) perpendicularly to the shower axis. The wave peak frequency is estimated to be in the range of $\sim$ 10 kHz. At these frequencies the sound attenuation length in the sea is of the order of km. The expected pressure wave amplitude scales linearly with the deposited energy density and as inverse power law (roughly from $r^{-0.5}$ to r^{-2}) as a function of distance. Theoretical models foresee wave amplitudes of order of $1\div10$ mPa for 10^{20} eV showers at 1 km distance [2, 3]. The measurement of ambient acoustic background is, therefore, fundamental in order to carry out a feasibility study for an underwater acoustic neutrino detector. Noise in the sea have different origins: biological (fishes, marine mammals, crustaceans), seismic, mechanical (wind, rain and waves on sea surface), thermal agitation of molecules (at frequencies $>$ 40 kHz), human activities (navigation, fishing, military operations, oceanographical instrumentation, oil exploration) [4]. Biological and human noises could reach very high pressure level (up to 250 db re 1μPa at 1 m), but they are, generally, produced by local and impulsive sources. In the frequency range of interest, average noise is due to surface agitation and to navigation that, close to ports or commercial ship routes, generates a diffuse acoustic background. At present only few data of acoustic noise at large depth are available in literature. For this reason the NEMO Collaboration [5] deployed and is operating the OνDE (Ocean Noise Detection Experiment) station in the NEMO underwater test site, 25 km E offshore the port of Catania (Italy). The station is devoted to perform real-time monitoring of the level of acoustic noise at depth $\geq$ 2000 m, where underwater detectors should be presumably located. Recorded data are used to model underwater noise as a function of time, a useful information to implement algorithms for acoustic neutrino detection.

2. The NEMO test site

NEMO (NEutrino Mediterranean Observatory) aims at installing a km^3 underwater neutrino telescope in the Mediterranean Sea [6, 7]. The collaboration is presently conducting an intense activity to select and monitor abyssal sites for the installation of the detector. Data strongly indicate that a large marine region $\sim$ 80 km SE off the Sicilian Coast of *Capo Passero*, is optimal [8, 6]. In the same time the Collaboration is conducting technological R&D for submarine instrumentation and operations for the km^3. In this framework NEMO installed an underwater test site at 2000 m depth, a deep sea facility to perform long term tests for technologies and experimental techniques in the field of neutrino astronomy. The facility consists of a shore infrastructure, a 28 km long electro-optical cable, connecting the shore to the abyssal test site, and the underwater laboratory. The shore building hosts the land termination of the cable, mechanics and electronics workshops, the data acquisition room and power supplies for underwater instrumentation. The 28 km long electro-optical (e.o.) cable that connects the DAQ room to deep sea is a telecom cable, containing 10 optical fibers and 6 electrical conductors (3 mm^2) protected with external steel armor, specifically designed for high bandwidth data transmission and power feeding of deep sea installation. At about 20 km E from the shore, the cable is divided into two branches, roughly 5 km long. The Test Site North (TSN) branch has 2 conductors and 4 fibres directly connected to shore, the Test Site South (TSS) branch has 6 fibers and 4 conductors. A sea campaign was conducted on January 2005 to install, on the cable, submarine terminations with electro-optical connectors mounted on titanium frames. The frames were deployed on the seabed at $\sim$ 2050 m depth (see figure 1). The installed connectors permit to plug and unplug underwater experimental instruments by means of Remotely Operated Vehicles (ROV) avoiding further operations on the main e.o. cable. During the sea campaign two experimental devices were deployed and connected. On TSN termination the INGV (Istituto Nazionale di Geofisica e Vulcanologia, Italy) attached the seismic monitoring station Submarine Network 1, which is the first node of the ESONET project [9]. On TSS (coordinates 37°30' N 015°23 E) the NEMO Collaboration attached the OνDE station, described in the following paragraph. During 2006 the collaboration plans to install, on the TSS termination, the NEMO-Phase One detector, a prototypal basic module of the architecture proposed for the km^3 telescope [7, 6].

3. The OνDE acoustic station

OνDE is designed to perform the on-line monitoring of the acoustic noise at 2000 m depth in the NEMO test site. The station is equipped with four hydrophones, whose signals are digitized and translated into optical by underwater electronics. Data are sent to shore through optical fibers, then re-converted into electrical and acquired on a PC. The hydrophones come from a special series, TC-4042C, manufactured by *RESON* for NEMO to operate at 250 bar pressure. The TC-4042C are piezoelectric omnidirectional sensors with a nominal receiving sensitivity of -193$\pm$3 dB re 1V/μPa, linear over a wide range of frequencies: from few tens Hz to 50 kHz. Each detector (hereafter H1,H2 H3 and H4) is mounted on an Al-alloy vessel, pressure resistant, which also contains the hydrophone preamplifier (20 db gain). Two preamps (for hydrophones H2 and H4) where modified applying a hi-pass filter ($>$ 1 kHz, 6 db per octave) to reduce most of the ambient noise which has a $1/f$ spectrum. The detectors are fixed on the TSS frame to form a tetragon of $\sim$ 1 m side. The analog signals are brought, through underwater electric cables, to a 17" diameter glass housing, that hosts the digitization, data transmission and power distribution electronics. In figure 1 we show the station set-up: hydrophone H3, mounted in the uppermost position ($\sim$ 3.2 m above seabed), is placed close to the frame apex; H1,H2 and H4 are attached at the same height ($\sim$ 2.6 m above seabed) on the top frame edges. H2 is visible in the picture behind the the instrument housing (the orange spherical shell), H1 is hidden on the right with respect to the shell, H4 is on the left. Analog signals are fed into two stereo A/D Boards *Crystal* CS5396. H1 and H3 (large bandwidth) reach the same A/D stereo board, H2 and H4 (hipass filtered) the other one. The two A/Ds are driven by the same clock: the four signals are, then, synchronized. The CS5396 samples the analog data at a rate of 96 kHz with 24 bit resolution. The digital outputs of the two A/Ds (in standard SPDIF) are sent to two fiber optic data transmitters. A tilt-meter and compass board is also installed inside the glass sphere to measure the absolute orientation of the frame and continuously monitor possible movements of the station. Optical data are reconverted, on shore, into SPDIF protocol by two fiber optic receivers and, then, acquired using two PCI audio boards *RME DIGI96-8 PAD* (96 kHz, 24 bits) mounted on a PC, Pentium4 3GHz. Power is supplied from shore using stabilized 220 VAC supplier and transformed to ∼405 VAC in order to feed the underwater station constantly at 380 VAC. The station power consumption is roughly 30 W. On January 22^{nd} 2005 OνDE was deployed together with the TSS frame and then connected and switched on. The orientation of the frame front with respect to North is $\sim 110°$, measured both by the ROV and the on-board compass.

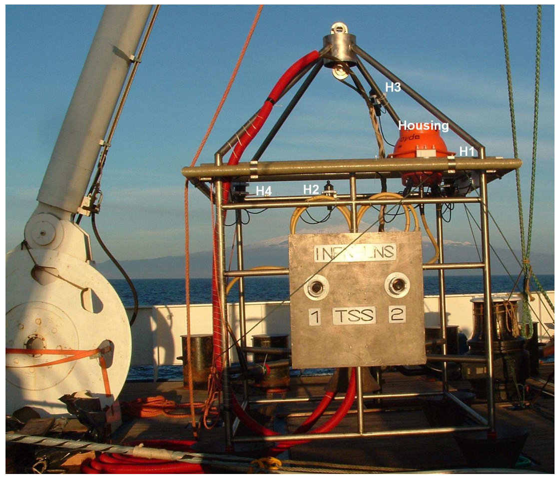

Figure 1. The titanium frame installed on TSS. The ROV operable electro-optical connectors are visible on the front panel. The hydrophones and electronics housing of the OνDE station are also shown (see text). The frame height is about 3.5 m)

4. Preliminary results and discussion

OνDE continuously transmits to shore some MB of data per sec, the present data acquisition strategy is to record the acoustic data stream for 5 minutes every hour. This permit to limit the data storage on disk and to record enough statistics to measure the noise level as a function of time. In figure 2 we plot, as an example, the power spectral density of noise measured from April 10 to May 12 at 4:00 am using channel H1. For this channel (hydrophone with electronic chain) the calibration curve was preliminary measured to be -175 ± 2db re V/μPa, in the interval 4÷22 kHz, the value is consistent with data provided from RESON. This value of response sensitivity is used for the whole frequency range plotted (1 ÷ 40 kHz). Further data analysis is anyhow required for frequencies lower than 4 kHz and higher than 22. Data recorded by the other hydrophones are consistent with H1. The periodogram shown in figure is obtained calculating the 2048 points FFT of data sample (2 minutes per each day), windowed using a Hanning window, shifting by 1024 points. Plot shows that ambient noise is strongly variable at frequency below 20 kHz, depending on sea state and biological and human activity. It is important to note that even for rough sea conditions, happened in the first half of April 2005, the measured noise at 2000 m depth is below sea state 2 curve [4]. A more detailed correlation with sea state data is in progress. The highest noise level was observed on April 28, probably generated by the passage of a large ship, and on April 22, due to the presence of several marine mammals in the area, clearly identifiable in the data files. The plateau observed at high frequency during the most quiet days is unexpected and could be generated by instrumental noise. Further analysis is in progress.

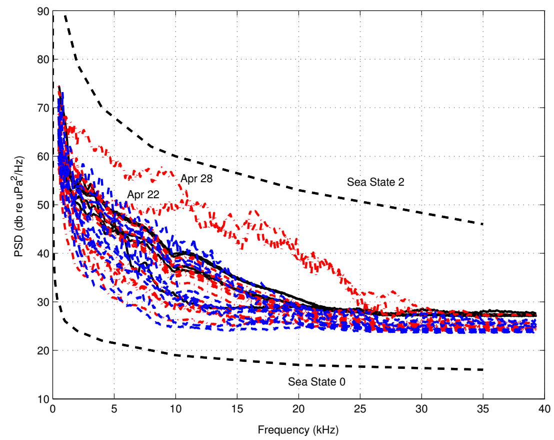

Figure 2. Average power spectral density of underwater noise measured by OνDE for April 10 to May 12 2005 at 04:00 am. Black solid curves refers to April 10-15, red curves to April 16-30, blue curves to May 1-12 (see text). Expected noise due to sea surface agitation is plotted (black dashed line) for comparison [4]

5. Conclusions

The OνDE station is fully operational at NEMO test site of Catania since Jan $22^n d$ 2005. The station transmits high data 24h/24h. Data analysis is presently addressed to characterize noise variations as a function of time. Several impulsive signals were also found in the data sets, most of them connected to human or biological activities. These are anyhow background sources for ν detection. Localization of noise sources using the 4 hydrophones data together is presently under development. Recorded data set is also extensively used for interdisciplinary studies mainly addressed to search for cetaceans in the region.

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