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14 Sub-sea environmental observatory integrated with the KM3NeT neutrino telescope infrastructure in the Mediterranean Sea

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14.1 Introduction

The concept of fiber optic cabled environmental observatories on the seafloor with real time data transmitted to shore is now being developed in a number of projects around the world (NEPTUNE 2012, MARS 2008, DONET 2008, ESONET 2012). However, the first attempt at deploying an optical cabled system in the deep sea was not directed towards study of the marine environment but to astronomy. In order to detect high-energy neutrinos originating from cosmic sources it was realized during the 1970s that the detector would have to be much larger than could be built in any laboratory. The solution was to instrument a large volume of seawater in the deep sea with photo-detectors that could monitor the flashes of light generated by high-energy particles passing through the planet. This could only be achieved through the use of the then novel underwater glass fiber optic cables, and the first such undersea observatory attempting to use the new cables was the DUMAND (Deepwater Underwater Muon and Neutrino Detector) project off Hawaii (DUMAND 2003). Sub-sea observatory elements were tested in 1982 and a fiber optic cabled system was deployed in 1993, only to be abandoned in 1995 owing to technical difficulties. With a location close to the equator (latitude 19.5°N) DUMAND would have been capable of scanning the entire universe every 24 hours as a result of the rotation of the Earth (Roberts,

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1992). This concept has now been replaced by international projects to build two neutrino telescopes, one in Antarctica (using the southern polar ice-cap as an alternative to seawater) and a second observatory in the northern hemisphere. Such a dual system can monitor the entire sky continuously in contrast to a single observatory at the equator which relies on rotation of the Earth to gain complete coverage.

In the absence of a continental ice cap in the Arctic, the northern hemisphere telescope will be built in seawater. The Mediterranean Sea (locations at latitudes 36–43°N) has been chosen as an appropriate site for the European KM3NeT project and overcomes some of the problems of open ocean location that frustrated DUMAND. KM3NeT will be complementary to the US ICECUBE (ICECUBE, 2014) project in Antarctica. With a large sub-sea infrastructure, including power and data transmission, it is proposed that KM3NeT should also encompass earth–sea science studies at the chosen location in the Mediterranean Sea. This will complement and augment the large quantity of marine research that has already taken place in this region investigating phenomena such as bioluminescence (production and emission of light by a living organism as the result of a chemical reaction).

In this chapter we consider the integration of oceanographic, climatological, geological and biological applications into the astro-particle physics infrastructure.

14.1.1 Neutrino astronomy

Our knowledge of the universe has primarily been derived from the observation of electromagnetic waves throughout the spectrum from long wavelength radio waves, the light spectrum (infrared to ultra violet), to very short wavelength X-rays and gamma rays. Traveling in straight lines, electromagnetic waves provide an accurate image of the universe but are susceptible to absorption so there are inevitably parts of universe that cannot be viewed by earth-bound telescopes. Cosmic rays, which are mostly composed of protons or atomic nuclei minus their orbiting electrons, provide an additional means of understanding the cosmos beyond the solar system. However, due to their positive charge, their paths are affected by the galaxy's magnetic fields and therefore these particles cannot be used to establish the source of cosmic rays. Neutrinos are weakly-interacting particles which travel in straight lines, penetrate even the interiors of stars and enter our atmosphere unhindered at very close to the speed of light. This makes neutrinos an ideal candidate for detection by a telescope to accurately map the universe. High-energy neutrinos originate from supernova remnants, pulsars and micro-quasars in our Galaxy and from extragalactic sources such as active galactic nuclei and γ-ray burst emitters. As a neutrino traverses through the mass of the Earth, interactions may occur whereby a muon is released and emerges upwards from the seafloor in the antipodal location traveling at more than the speed of light in closely the same direction as the parent neutrino. The passage of the muon through water produces Cherenkov radiation which at a fixed point consists of a short flash of light analogous to an electromagnetic version of a sonic boom. The detection of Cherenkov light is achieved using an array of light detectors housed in glass spheres known as optical modules (OM), deployed in the deep sea. Knowing the arrival time and the position of the OMs enables the reconstruction of the muon track to a precision of a few tenths of a degree.

The European Union agreed to fund the design study and preparatory phase of a cubic kilometer neutrino telescope, KM3NeT, in the Mediterranean Sea. Its infrastructure will be

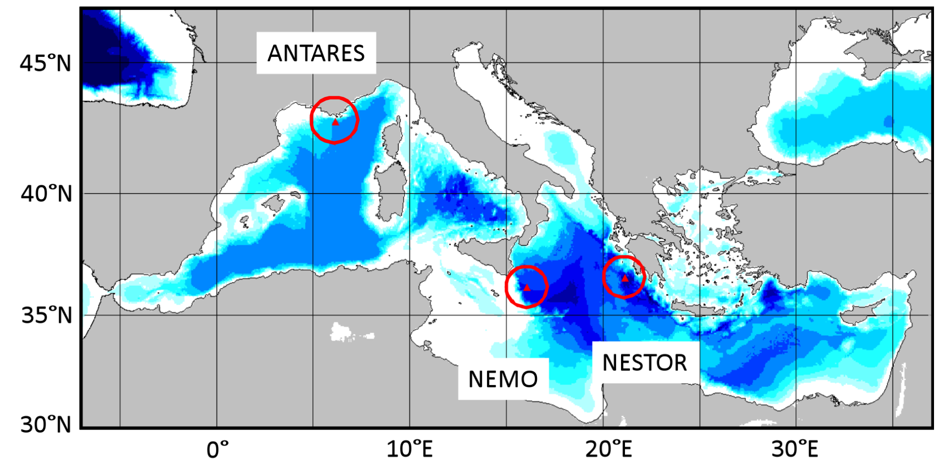

Figure 14.1 The Mediterranean Sea showing the location of the three KM3NeT neutrino telescope pilot projects ANTARES (2475m depth) in the Ligurian Sea and NEMO (3350m) and NESTOR (4500–5200 m) in the Ionian Sea. The circles indicate 100km radius around each location that could be instrumented via the Km3Net junction box. Shading indicates depths at 1000m intervals.

shared with multidisciplinary undersea observatories, making continuous long-term measurements in the area of oceanography, climatology, geophysics, geohazards and marine biological sciences.

14.2 Scientific case for a cabled infrastructure in the Mediterranean Sea

With the transparency of its water the Mediterranean Sea provides the large mass necessary in which to house a large array of light sensors to detect Cherenkov light emissions. The geographic location is perfect since the area of the sky covered includes the center of our Galaxy and, due to the rotation of the Earth, a telescope situated at a latitude (λ) 36º and 43º north can observe upwards-going neutrinos from most of the sky (about 3.5 π sr). Declinations below $-90°+\lambda$ are always visible, while those above $+90°-\lambda$ are invisible. Most of the Galactic plane, including the Galactic center, can be observed for most of the sidereal day.

In addition, the Mediterranean deep sea is of prime interest for marine and earth sciences research. The earth–sea sciences infrastructure, which has been included in the design, will enable the development of a permanently cabled deep-sea observatory with potential for important discoveries. This infrastructure will form part of a wider global environmental monitoring system for investigating climate change issues and enabling the provision of early warning systems regarding earthquakes and tsunamis.

Studies into the possibility of constructing a neutrino telescope in the Mediterranean Sea have been ongoing for more than a decade. Three pilot projects, ANTARES, NEMO and NESTOR, situated at different locations identified in Figure 14.1 have been used to explore different configurations and techniques.

14.3 KM3NeT conceptual design

Based on the experience gained from the three pilot studies, a generic conceptual design (KM3NeT, 2008) has been proposed for the Mediterranean Sea cubic kilometer neutrino telescope, KM3NeT, and its marine science observatories.

This neutrino telescope will be composed of a number of vertical structures known as Detection Units, anchored to the sea bed and kept vertically upright with buoys. Each detection unit consists of a series of mechanical structures, called storeys, supporting the necessary sensors, electronic components, power and data line interfaces. In contrast to previous designs in which each OM housed one large photo-multiplier tube (PMT), KM3NeT is evaluating designs with multiple small PMTs within each glass sphere, including the high-voltage bases and data acquisition interfaces. Therefore the complete detector may have in the order of 100,000 PMTs. Each detection unit "string" or "tower" is likely to have 20 storeys spaced at intervals of 40m with the top buoy at over 800m above the anchor on the seafloor. A practical telescope will have over 150 such detector units with spacing of 150–200m between them depending on the final configuration chosen. An electro-optical

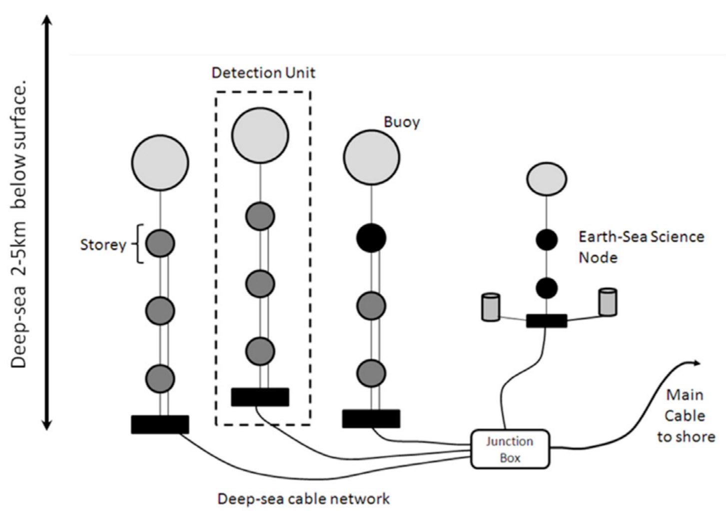

Figure 14.2 Schematic diagram of a KM3NeT junction box to which are connected detection unit strings anchored to the seafloor and an earth–sea science node. In practice, there are many more detection units and storeys as well as multiple earth–sea science nodes.

cable connected via the anchor to a deep-sea cable network runs through the detection unit supplying power and retrieving data from each storey. This network typically contains one or more junction boxes and electro-optical cables, through which all data are transmitted to shore and configuration data sent to the detector. A shore station equipped with substantial computing power collects the data, applies online filter algorithms and saves the data onto mass storage devices.

Earth–sea science nodes are connected to the neutrino telescope cable infrastructure, thus providing electrical power and data links to a series of sensors, moorings and platforms. These may be positioned under the sea-floor, on the sea-floor and reaching up through the water column to the mixed layer below the sea surface as shown in Figure 14.2. Some small earth–sea science sensors may be incorporated into the neutrino telescope detection units.

These nodes are to be positioned at optimal places around the detector providing environmental data relevant to the neutrino telescope and also allowing the marine science communities to perform continuous long-term monitoring experiments and implement earthquake and tsunami early warning systems. Assembly of the telescope sub-sea infrastructure will probably take a number of years. The system could start functioning with a small number of detector units and gradually be expanded over time. Planning of the earth–sea science nodes should allow for possible changes to, or extension of, the telescope infrastructure.

Typically the earth–sea science junction boxes will have connections to one or two mooring strings with profilers or fixed sensors, a suite of seafloor sensors such as seismo-

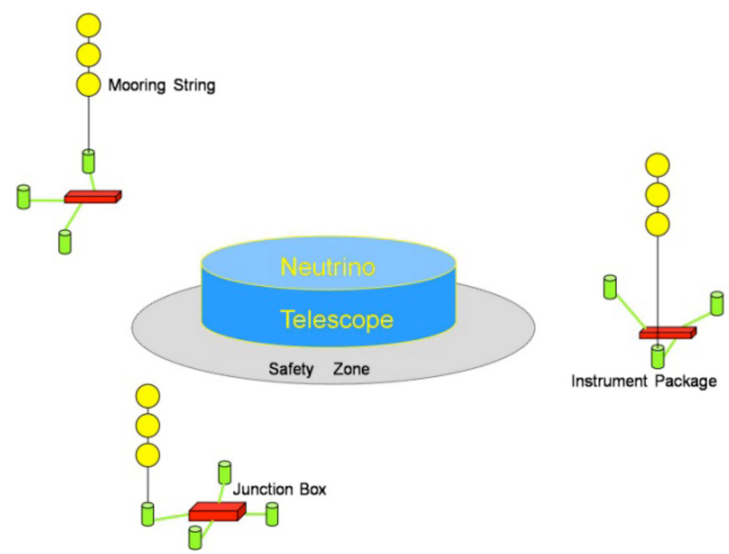

Figure 14.3 KM3NeT conceptual design with the volume of water instrumented for the Neutrino telescope surrounded by a safety zone outside which are located the earth–sea science nodes, each comprising a junction box, a mooring string with sensors in the water column and sensors on the seafloor.

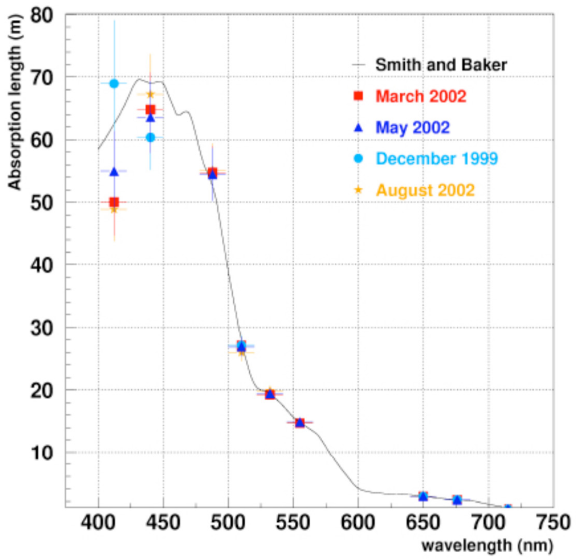

Figure14.4 Average absorption length as a function of wavelength, for four seasons at the NEMO site. Measured using WETLABS AC9 sensor ~25cm path length.

graphs, cameras and acoustic instruments built into modular frames that can be inserted in fixed platforms on the sea-bed (Figure 14.3). Data will be transmitted to shore in real time for processing and dissemination, whilst instruments may be controlled via commands sent from the shore station.

14.3.1 Site criteria

The Mediterranean Sea offers optimal conditions to host an underwater neutrino telescope. Several sites have been identified for such a telescope, with the following criteria driving the final choice:

- Optical properties of sea water for light in the wavelength range 350 nm to 550 nm;
- Distance to the coast for ease of deployment, risk reduction and cable costs;
- Sufficient depth to reduce background noise from atmospheric muons;
- Level of bioluminescence;
- Rates of bio-fouling on optical surfaces;
- Rates of sedimentation;
- Sea current velocities at those depths.

Careful studies of all three candidate sites have been carried out in order to identify the most suitable one. These results are discussed in the following sections.

14.3.2 Water optical properties

The optical properties of water are important when deciding where to construct an underwater neutrino telescope. Much data have already been gathered from the pilot sites and the results are discussed in the following sections.

14.3.2.1 Light transmission

The study of deep-sea water optical properties has been carried out at each site through a long-term programme across all seasons (Riccobene et al., 2007, Capone et al., 2002, Anassontzis et al., 2010). Seawater absorbs and scatters light depending on the water temperature and salinity, as well as the characteristics and concentration of the suspended particulates. These parameters vary between marine sites and possibly as a function of time. Measurements of absorption length show that typically in the Mediterranean Sea (Figure 14.4) there is a maximum at wavelengths around 450 nm and values are close to those recorded for optically pure sea water (Smith & Baker, 1981).

14.3.2.2 Optical background

Decay of radioactive elements in the water and bioluminescence produced by organisms can influence the background counting rate of OMs.

14.3.2.2.1 Potassium 40

The dominant radioactive particle in natural sea water is potassium 40 (^{40}K) and the following 40K decay channels contribute to the production of optical noise:

$^{40}K \rightarrow {}^{40}Ca + e^- + \bar{\nu}_e$ (BR = 89.3%)

$^{40}K + e^- \rightarrow {}^{40}Ar + \nu_e + \gamma$ (BR = 10.7%)

A large fraction of electrons produced in the first reaction is above the threshold for the production of Cherenkov light. The second reaction produces photons with energies of 1.46 MeV and therefore can lead through Compton scattering to electrons above the Cherenkov light production threshold. The intensity of Cherenkov light from 40K radioactive decays depends mostly on its concentration in sea water. Since the salinity in the Mediterranean Sea has small geographical variation, this noise effect is largely site independent.

14.3.2.2.2 Bioluminescence

Bioluminescence forms an important part of the optical background of the deep sea. It can be categorized into two types: a steady background glow produced by bioluminescent bacteria, and intermittent flashes produced by bioluminescent organisms. The organisms that produce the bioluminescent flashes range in size from sub-millimeter to several meters. Flash intensities range from 10^9 to 10^{13} photons flash^{-1} (Heger et al., 2007) Emission maxima of most species range from 450–490 nm (Herring, 1983), corresponding to maximum light transmission in seawater. Although it is estimated that up to 90% of deep sea animals are bioluminescent (Herring & Morin, 1978), background flash rates are very low (Widder et al., 1989) . However, defensive bioluminescent responses can be stimulated when planktonic organisms are carried by currents past underwater structures. Flow of 5.5 ± 3.4 mm

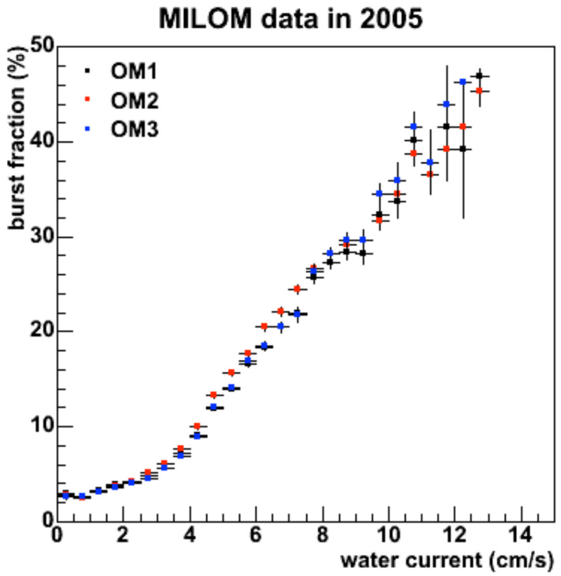

Figure 14.5 Correlation between water current velocity and bioluminescence burst rates around optical modules at the ANTARES site. The burst fraction is the fraction of time with count rates exceeding 120% of the baseline rate.

s^{-1} can be sufficient to generate the necessary shear force (Hartline et al., 1999).

Priede et al. (2008) modeled the frequency of bioluminescent events resulting from organisms impinging on a submerged sphere, such as the OM of a neutrino telescope (Eq. 14.1):

$$impacts\ s^{-1} = \pi\left(\frac{\phi_{sphere}}{2} + \frac{\phi_{animal}}{2}\right)^2 \times \nu \times \rho \qquad (14.1)$$

where $Ø_{sphere}$ is the sphere diameter, $Ø_{animal}$ the animal diameter, ρ the density (bioluminescent sources m^{-3}), and ν the current velocity. If it is assumed that each impact results in a bioluminescent response, the flash rate is directly proportional to the density of bioluminescent animals, the water current velocity and the cross-sectional area of the sphere and the organism.

Flashes, or bursts, of light have been detected by the array lines of OMs installed at prototype neutrino telescopes. At the ANTARES telescope site, data from the MILOM line showed a correlation between sea-current velocity and the bioluminescent burst rate (Naumann-Godo et al., 2007, Bertin 2009) (Figure 14.5).

Individual flash characteristics vary between species, but do share a common pattern of intensity. Typically, after stimulation there is a delay, followed by a rapid rise in intensity

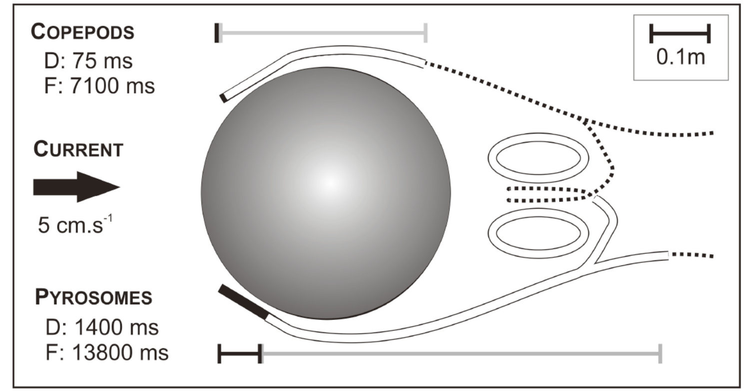

Figure 14.6 Expected pattern of stimulated bioluminescence around a KM3Net detector unit, 43cm-diameter glass sphere. Hypothetical bioluminescence field produced by a copepod and a pyrosome advected by a current of 5 cm.s-1. When an organism encounters and is stimulated by the sphere there is a delay (D – solid bar) before start of the flash duration (F – open bar). The mean flow is indicated by dotted lines. The result is an asymmetric stimulated bioluminescent field with most photons emitted downstream.

and a slower decay. Craig et al., (2009). showed that although organisms impinge on an OM on the upstream side, most light would be produced on the downstream side as a result of the flash delay and further stimulation in the eddy vortices (Figure 14.6).

The number of bioluminescent organisms in the water column ($N.m^{-3}$) has been measured using profiler systems based on an ultra-low-light camera focused downwards on a rectangular mesh. The system is mounted on a frame and records during vertical descent through the water column from the sub-surface to the seafloor. The mesh stimulates bioluminescence flashes which are counted and converted to a density with depth. Values in the Mediterranean Sea are an order of magnitude lowerthan previous data recorded in the Atlantic Ocean and show a general decrease with increasing depth (Priede et al., 2008; Craig et al., 2009, 2011) (Figure 14.7). Seasonal changes have been detected but these are not significant at depths >2500m where the neutrino telescope is likely to be installed.

14.3.2.3 Deep-sea currents

Deep-sea currents have been monitored at all three sites over long periods of time. At the Toulon site measurements were performed during the investigation phase using autonomous mooring lines. Since integration of the instrumentation line in 2005, real-time measurements have been performed continuously. The current speed average was ~5cm.s^{-1} with peak flow occasionally exceeding 35cm.s^{-1} (Aguilar et al., 2006; van Haren 2011) .

Deep-sea current measurements in the Capo Passero region have been recorded using stand-alone current-meter moorings. Current intensity and direction have been monitored

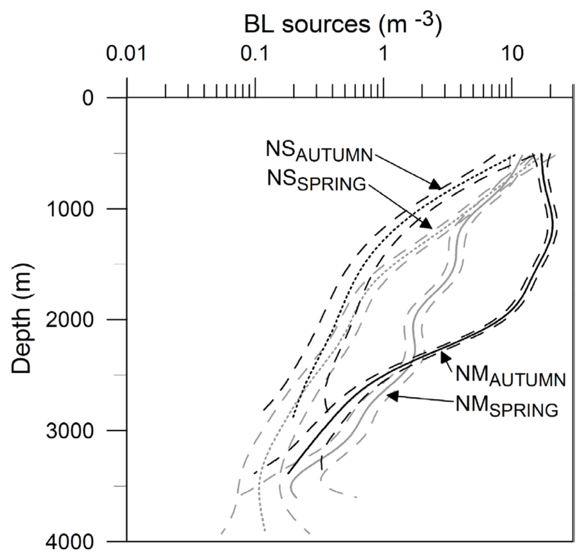

Figure 14.7 Density of bioluminescent animals as a function of depth in the Ionian Sea during different seasons. Curves (GAM, generalized additive modeling, smoothers) show the depth trend at the NEMO (NM) and NESTOR (NS) sites, in autumn 2008 and spring 2009, detected using the ICDEEP profiler. Dashed lines: 95% CL.

almost continuously since 1998 to within 500m of the seabed. Data for the period July 1998–December 1999 have been analyzed and the results presented in (Migneco et al., 2004). This analysis shows that deep-sea currents are unaffected by depth and were stable in both direction and intensity with an average value of about 3cm.s^{-1} and peaks not exceeding 12cm.s^{-1}. These results were confirmed for the period August 1999–August 2002.

At the Pylos site the deep-sea currents have been monitored since 1989 with different moorings and stand-alone current-meters (Aggouras et al., 2006). These studies show that velocities rarely exceed 6cm.s^{-1}. In general, the flow at the 4500m site is northward and is below 4cm.s^{-1} 90% of the time and at the 5200m site it is southward and substantially weaker, with a speed below detection threshold 95% of the time.

14.3.4.2.4 Sedimentation

The rate of sedimentation in these three regions has been obtained using sediment traps deployed at each site in different years. Records at the Capo Passero site (KM3NeT, 2008), and the Toulon site (Amram et al., 2003) during the late winter/spring indicate that the highest mass flux values occurred during the autumn/early winter period as shown in Figure 14.8. The mass fluxes were recorded at the Pylos site during 2006–2008 and low sedimentation rates confirmed the oligotrophic character of the area (Stavrakakis & Lykousis, 2011).

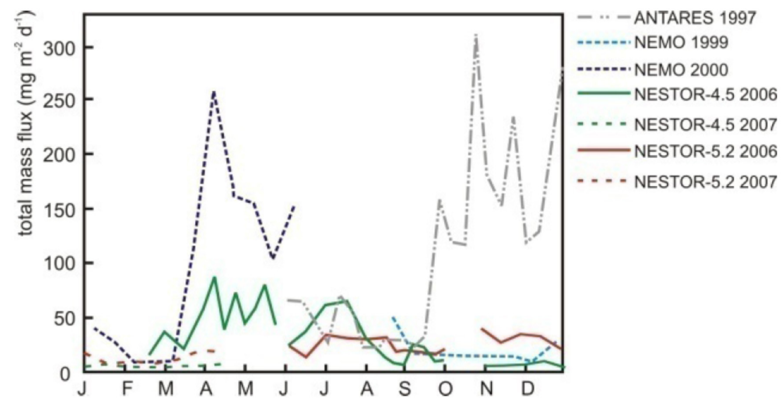

Figure 14.8 Downward total mass fluxes of particulate matter as recorded from sediment traps at the three KM3Net neutrino telescope sites.

14.3.2.5 Biofouling

Fouling is classically considered to progress in five main stages (DeLauney et al., 2010):

1. Formation of a primary film by adsorption of organic and inorganic macromolecules immediately after immersion.
2. Transport of microbial cells to the surface and the immobilization of bacteria on the surface.
3. Attachment of bacteria to the substratum through extracellular polymer production, forming a microbial film.
4. Development of a more complex biological community with the presence of multicellular species, microalgae plus debris, sediments, etc.
5. The final stage is characterized by attachment of larger marine invertebrates such as barnacles, mussels and macro-algae.

Biofilms may form on any solid structures in a pelagic environment and in the case of a neutrino telescope can lead to degradation of the transparency of the surface of the OMs and presence of bioluminescent bacteria in the film will likely increase optical noise. Studies at the ANTARES site (Amram et al., 2003) indicated that growth of fouling is very slow at depth with loss of light transmission for a vertical glass surface estimated to be ~2% after one year. Fouling appears not to progress beyond stage 3 on this time scale and at the depths of interest for neutrino telescopes. A piezophilic luminous bacterium Photobacterium phosphoreum strain designated ANT-2200 has been isolated from 2200m depth at ANTARES and it was demonstrated that the light output from this organism is five times higher at 22 MPa pressure than at atmospheric pressure (Ali et al., 2010). It is assumed that the presence of this bacterium on aggregates around the telescope can contribute to bioluminescent background but this and other marine luminous bacteria may also be capable of growing on the biofilm coating OMs. In the Ionian sea at the NEMO site a maximum of potentially luminescent bacteria was found between 900 and 1200m depth (De Domenico, 2003).

Research at the NESTOR site has concentrated on the metabolic activity of bioluminescent bacteria in the water column, and on the influence of various materials on the settlement of bacteria colonies and biofouling. A colonisation experiment has been developed, providing surfaces for bacterial growth and a protective mechanism preventing wash-off during retrieval. It has been deployed at various depths ranging from 1500m to 4500m carrying sample surfaces of aluminium, titanium, glass, limestone and slate facing both upwards and sideways. After 155 days during 2007 there was no evidence of macro-fouling and only a loosely adhered biofilm could be observed. Scanning Electron Microscopy of surfaces revealed presence of attached bacteria and molecular biological techniques detected some bacteria at all depths (Bellou et al., 2011).

14.3.2.6 Distance offshore

Distance offshore is a major determinant of capital cost of a neutrino telescope; the further offshore the greater the cost of cable. Ship time required for installation and operations also increases owing to longer passage times and greater time loss if bad weather intervenes. Costs increase with increasing depth of installation, winches with longer cables become heavier, support vessels consequently increase in size and time required for any sub-sea operations become longer. The basic engineering of the telescope hardware also becomes more challenging with increasing depth. The Mediterranean Sea offers a choice of sites with different distances offshore and depths. NESTOR offers several locations from a depth of 3000m at 20km offshore to 5200m depth at 60km offshore, ANTARES has a depth of 2475m at 45km offshore and NEMO 3350m at 100km offshore. All the factors relating to costs, telescope performance, seafloor slope, depth and distance offshore can be weighted to select an optimal location in a GIS (Geographic Information System) environment (Niedzielski et al., 2009).

14.3.3 Scientific opportunities in the Mediterranean Sea

In general, observations in the deep sea have until now been made by autonomous measuring systems, deployed for up to a year and requiring recovery in order to retrieve the data. Data storage and battery energy capacity have data sampling rates in such systems limited to once every 10 minutes or every hour and there are inevitable breaks in data collection.

The proposed KM3NeT deep-sea infrastructure, permanently cabled to the shore, will enable continuous data to be collected without interruption over long periods. Data capture rates will be orders of magnitude faster than used hitherto and will allow new phenomena to be investigated with sampling rates of the order of 1 Hz. For instance, it will be possible for the first time to investigate phenomena such as internal waves and short time-base oscillations in the water column using sensors distributed throughout the telescope array. Real-time tracking of bio-acoustic emissions or vertical migrations of organisms will also be possible. Both the spatial and temporal scale of measurements will be transformed and real-time availability will revolutionise data applications. The system will also provide

continuous vigilance in the face of transitory hazardous events such as earthquakes, slope failures and tsunamis.

Sensors placed on the seafloor and in the water column that are cabled to shore will ensure efficient tracking of environmental change on longer daily, annual and decadal time scales. The earth–sea science infrastructure within KM3NeT will form the basis for the Mediterranean section of the EU plan for long-term monitoring of the ocean margin environment around Europe. It is part of the Global Monitoring for Environment and Security (GMES) system and will complement oceanographic networks such as GOOS (Global Ocean Observing System), EuroGOOS and DEOS (Dynamics of Earth and Ocean Systems), and will be multidisciplinary, with stations monitoring the rocks, sediments, bottom water, biology and events in the water column.

The KM3NeT infrastructure will incorporate reconfigurable junctions boxes to which new associate sciences instruments can be connected. For example, it will be feasible to connect elements of the new Ocean Tracking Network that will be capable of tracking fishes and other animal equipped with implanted transmitters (OTN, 2014).

Geologically, the Mediterranean Sea is at a pivotal point between the African and Eurasian tectonic plates and some authors have argued that it contains some of the oldest ocean floor on the planet, recognisable as remnants of the Tethys Sea that was an embayment of the single proto-continent, Pangaea. The present day Mediterranean area is still tectonically active with 23 active volcanoes in Italy and six in Greece associated with subduction of the African plate beneath Eurasia. Vesuvius on the mainland and Etna on the island of Sicily are the best known in Italy and the island of Santorini in Greek waters erupted most recently in 1950. Hydrothermal activity is also seen around volcanic islands. Earthquakes occur regularly in this region, particularly in the eastern basin despite relatively slow motion of the tectonic plates. The Hellenic trench and the parallel Mediterranean ridge which extends across the Ionian Sea to Cyprus are important sea-floor features associated with subduction and accretion (Ambriola et al., 2012). Emissions of methane from the sea-floor due to deep sea mud volcanoes also occur in the Eastern Mediterranean. Slope failures have been detected capable of generating turbidite flows and tsunamis.

Biologically, the Mediterranean Sea has been re-colonised after the formation of the modern ocean basins with limited time for evolution of new species but very special conditions and partial isolation of basins that give opportunities for endemic species to appear. Colonisation and re-colonisation have occurred from the Atlantic Ocean. It is estimated that 50.2% of species are of Atlantic origin, 16.8% Atlantico-Pacific and 4.4% of Indo-Pacific origin (Emig & Geistdoerfer, 2004) and of all species in the Mediterranean 28.6% are endemic or unique to this area. Owing to the direction of colonisation and stagnation events in the east there is a general impoverishment of fauna from west to east. It is estimated that the Mediterranean Sea contains about 8500 species of which only half are generally represented in the Eastern Basin (Bianchi & Morri, 2000). The east is therefore impoverished not only in productivity but also in biodiversity. Despite apparent sparseness of life in the Mediterranean it contains between 4 and 18% of world marine species in 0.32% of the world ocean volume. Numbers of species decrease rapidly with depth so that at 1000m there is 8% of the shallow water number and only 3% at 2000m.

The Mediterranean supports a wide range of fishing activity including pelagic (near surface) such as tuna, sardine and anchovy, demersal species (bottom living), crustacean and molluscs. Generally, the Mediterranean is less productive than other seas reflecting its oligotrophic status. However, there is evidence that production of fish has increased over time. The Western Basin has moved from below the world average to above average production in sea shelf fishery production. This increase may be attributable to fertilisation by run-off from human activity on land. The main increase has been due to small inshore pelagic fishes whereas bottom living fishes have declined. So whilst catches have increased, the quantity of big valuable fish has decreased.

There are 19 species of cetaceans in the Mediterranean Sea of which eight are considered of common occurrence, and only one species of pinniped, the Mediterranean Monk Seal (*Monachus monachus*) which is listed as endangered. Colonies are now confined to the Alboran and Aegean Seas. Public interest in cetaceans of the Mediterranean Sea is great and there is support for research activity. Recently, a Cuvier's beaked whale, *Ziphius cavirostris* (Tyack et al., 2006), was recorded to a depth of 1900m during a dive lasting 85 minutes in the Ligurian Sea. This is the world record for deep diving in mammals.

14.3.3.1 Physical oceanography

An array of the order of 10,000 sensors in a cubic kilometer of deep sea such as KM3NeT offers the opportunity to study water motions in the ocean in unprecedented temporal and spatial detail. Specifically, scientific questions can be addressed on 3D-variations of physical processes on meso-scale (10km) horizontally and smaller scales including those of nonlinear internal wave propagation. This will not only renew our knowledge of some of the relevant physical processes of the ocean, but also of their effects on the distribution of suspended geological, chemical and biological materials.

The redistribution of matter, momentum and heat in the ocean interior depends crucially on turbulent mixing to overcome the otherwise stable vertical density stratification. The impact of this mixing affects not only redistribution of fine grained sediment and possibly associated pollutants, but also life, due to the flux of nutrients up and into the photic zone. It also affects the distribution of plankton in the deep sea and, crucially, the large-scale meridional overturning circulation. It is thought that a major part of the mixing is generated via breaking of (nonlinear) waves in the interior and especially above sloping bottoms. These waves are supported by the self-same density stratification.

Other processes that may be important for the redistribution of materials are small- and meso-scale eddies, which show rather large, preferentially downward vertical motions of up to several 10^{-2}m s^{-1}, or 1000m day^{-1}, so that near-surface materials can be transported to the bottom within a day (van Haren et al., 2006). Such eddies can be associated with meso-scale meandering variations in boundary or along-frontal currents. Recent custom-made high-resolution temperature T-sensors that can be moored at a specific site down to 6000m whilst measuring at a rate of 1 Hz show details of such internal waves up to 40m high and breaking as depicted in Figure 14.9 (van Haren et al., 2005, 2009) .

Most present-day moored physical oceanographic (internal wave) observations are limited by the following dimensions: 10m vertically, typically 10km horizontally and 10–30 minutes in time when sampled over ranges of 500m vertically and durations of one year. An exception was a tri-moored internal wave experiment, in the 1970s (Briscoe, 1975) . This limitation is due to battery and memory constraints as the measurements are made by

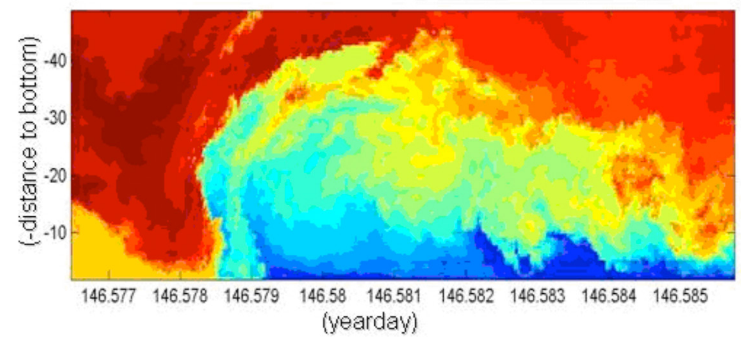

Figure 14.9 Example of data obtained from a vertical array of temperature sensors. Fourteen minutes detail of a backwards breaking, 40m-high wave measured using 100 NIOZ-2 temperature sensors at a depth of 550m near the top of Great Meteor Seamount, North Atlantic Ocean. Temperature ranges from 12.4°C (blue) to 14.2°C (red). Such vigorous process is unlikely to occur in the deep Mediterranean interior but, at a slower rate by about a factor of 3–10, such waves can occur near deep topography.

self-contained instrumentation, while financial constraints restrict the number of simultaneously operated moorings to about 5–10. Within the set-up of KM3NeT, novel oceanographic possibilities arise by sampling at least one decade faster and across one order of magnitude smaller horizontally over the above ranges for the period of at least 10 years. It will enable the operation of an internal wave/small-scale processes antenna, which will resolve amplitude and phase distributions in so far unresolved detail.

In the deep Mediterranean Sea, where the neutrino telescope is planned, the weak stratification supports internal waves having typical periods of 1–24 hours with typical vertical and horizontal wavelengths of 10–1000m. These are very slow waves indeed, but even to properly sample linear, sinusoidal waves, a sampling rate is required that is at least 10 times faster than the shortest period available. If one wants to study internal wave induced mixing via nonlinear steepening and eventual wave breaking into large, not yet even dissipative turbulence scales, one needs to sample 100 times faster, or about once per 10–100s (Figure 14.9 is sampled at 1 Hz for waves of period 20 minutes, occurring once every 12.4 hours; semidiurnal lunar tide).

We envisage the use of the photon detectors PMTs to compare variations in their data with those obtained from conventional oceanographic instruments. It would be beneficial if high-precision T-sensors are installed on each PMT. The high sampling rate of such T-sensors, typically 1 Hz, allows sampling of the larger turbulence overturning scales but does not compare with the somewhat cruder vertical and horizontal spacing between PMTs of 15 and 100m, respectively. In addition, some of the PMT lines will be equipped with acoustic current meters, to resolve directly the flow field. Furthermore, the plan is to equip at least one line in the earth–sea science section outside the neutrino array with some 100–200 densely vertically spaced (1m) high-sampling rate (1 Hz) temperature sensors. These sensors will be moored in conjunction with turbulence velocity sensors and a 300 kHz ADCP covering the lower 100–200m of the water column and focusing on near-bottom (nonlinear internal wave) motions. Another line will hold a continuously profiling yoyo-CTD which will monitor the entire vertical density structure at cm-scale.

14.4 Infrastructure management and operation

There will be need for joint operations management of the earth–marine science infrastructure and the neutrino telescope which would be responsible for coordinating deployment, maintenance, data sharing between the two communities and emergency situations.

14.4.1 Neutrino telescope operations

The telescope will have an operations control center situated either in the shore station or at one of a limited number of remote centers and be operated by a small group of operators on a 24-hour, seven day a week basis. Technicians will be based locally for maintenance operations and emergency situations. The operations center will provide continuous monitoring of the status of all major components such as optical cable, junction boxes, detection units, power supply, data links and local environmental variables. The system will alert the operators when anomalies are detected and predefined procedures will be in place to resolve these problems.

14.4.2 Marine science observatory operations

It is expected that neutrino telescope operations will have priority over the marine science operations, except when agreed in advance, in order to limit any interference.

Three categories of observatory operation are recognized:

- Operational and Civil Protection
  - Earthquakes
  - Tsunamis
  - Oceanography – GOOS (Global Ocean Observing System) contribution
- Ocean & Geosciences Research
- Engineering trials.

In the first category, a high standard of reliability and real-time availability is required with significant down-time being unacceptable. In the second category, a certain amount of service interruption is acceptable but continuity is a priority albeit at low data rates or via data buffering. In the third category, performance and availability are negotiable.

The earth–marine science user community will need some kind of coordinating body with operational staff tailored according to the size and complexity of the earth–marine

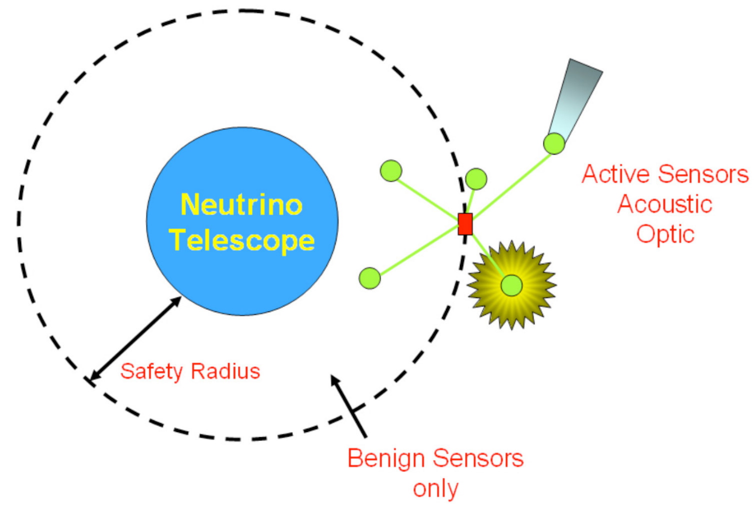

Figure 14.10 Schematic plan of the KM3Net neutrino telescope and an earth–sea sciences junction box on the seafloor. Active sensors with sonars and strobe lights must be outside a safety radius so that telescope functions are not affected. Benign sensors might be placed with that radius.

science nodes. This could be managed according to the rules and methods established in ESONET NoE (ESONET, 2012).

The management team will ensure efficient integration between the KM3NeT associated science communities, environmental agencies and organizations at the national, regional and international level including ESONET, EMSO, GOOS and ORFEUS, thus maximizing dissemination and use of data.

14.4.3 Safety requirements

The experience gained during the integration of the associated science node at the ANTARES site demonstrated the need to define a safety radius between the telescope and the science node to reduce the cost of sub-sea intervention whilst minimising the risk of collisions during such interventions.

A safety zone around the neutrino telescope has therefore been agreed between the astrophysics and the marine science communities. The position of an associated-science node relative to the array, as shown in Figure 14.10, will need to take into account this safety distance and the optimum position for the best scientific results. This will have the added advantage of ensuring independent deployment, operations and maintenance of both installations as the marine science observatories will be serviced regularly every 12 months whilst the neutrino telescope will be serviced on a needs-be basis. This safety zone is defined to avoid interference between the earth–sea sciences activity and the astrophysics infrastructure; it lies within a general exclusion zone protecting the overall subsea infrastructure.

14.4.4 Data management and access

In the marine sciences standardized methods for information management are becoming established to ensure better accessibility and traceability of datasets and ultimately to increase their use for societal benefit. A further important aspect is the connection of ocean observatory effort into larger frameworks including the Global Earth Observation System of Systems (GEOSS) and the Global Monitoring of Environment and Security (GMES) (Ruhl et al., 2011).

The neutrino telescope data acquisition system will filter the data in real-time before archiving and distributing it to users around Europe and beyond. If possible, an existing data center will be used; however, if necessary, a data center similar to those used by astronomical observatories may be implemented for KM3NeT with a dedicated data manager.

Management of the earth–marine science data was made possible by the use of the ESONET NoE data management system (DMAS with reference to the NEPTUNE concept) allowing access to:

- Generic sensor data by a large community for model assimilation and warning for civil protection
- Specific experiment data by their principal investigators
- Images and associated data by the public at large
- Test data by engineering teams.

14.4.5 Public relations and outreach program management

It is important that the observatory results are made available in a simple and visual manner to the citizens of the European Community and beyond. In order to achieve this, all KM3NeT observatory activities will be publicized on a regular basis and links to outreach programs made available at all the institutes involved in the project. All KM3NeT results will be posted on the KM3NeT website. The site will be split in two sections: one for the layman and a more advanced one for scientists. Real-time data will be displayed on the website, whenever possible, for the general public to access. An aim of the layman's site is to get young people interested in all aspects of KM3NeT science and allow the general public to understand how funds are being used to enhance scientific and technical knowledge. The advanced site will aim at generating scientific and technological knowledge among European scientists.

14.4.6 Users and stakeholders

It is envisaged that access to the system and its data will be granted to:

- Scientists from member institutes
- External scientists from within the EU
- Scientific institutions external to the EU
- EU government departments and organizations.
- Non-government organizations.

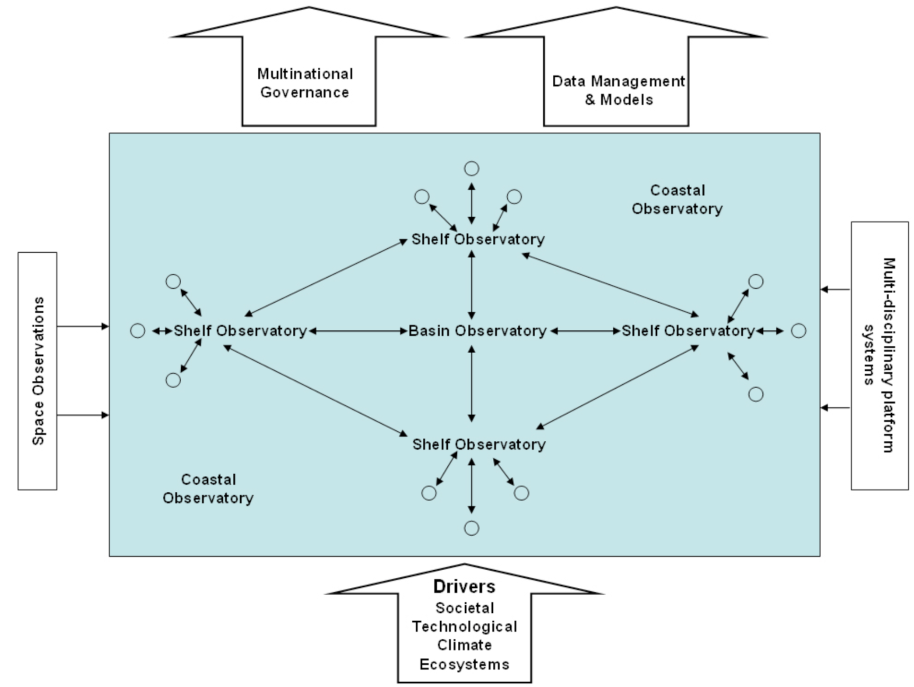

Figure 14.11 The CIESM (Mediterranean Science Commission, or Commission Internationale pour l'Exploration Scientifique de la Méditerranée) scheme for an integrated system of Mediterranean marine observatories into which KM3Net facilities should be incorporated.

14.5 Marine observatory integration in the Mediterranean

At a workshop held in La Spezia in January 2008 (CIESM, 2008) the Mediterranean Science Commission (2012) stated that the Mediterranean is characterized as a miniature ocean and was therefore an ideal model to study oceanic processes and land–ocean–atmospheric interaction. Geological records have shown that this ecosystem amplifies climatologic signals and makes this an ideal test bed for climatic studies.

The Mediterranean environment is facing extreme pressure from an ever-increasing population, climate change and over-exploitation. Recent observations have shown large-scale changes to deep ocean circulation, heat and regional climate, sea level rise, deterioration in water quality, increased number of algal blooms and the collapse of regional fisheries. Such changes have a profound impact on the ecosystems.

Sustainable development will depend more and more on intelligent management of the marine environment in order to protect marine ecosystems and minimize the impact of climate change whilst maintaining the economic benefit to the region. As a result, the formulation of policies must be based on informed decisions which in turn will depend on intelligent support systems, relying on real-time sensing platforms and numerical modeling.

The concept of an Integrated Mediterranean Marine Observatory, as depicted in Figure 14.11, includes instrumentation placed on satellites, sea-buoys, moorings, ships, drifters, profilers, gliders and coastal systems such as arrays of weather stations and marine sensors such as ADCPs.

Complex networks and clusters of distributed activities such as ESONET NoE and KM3NeT will enable access and sharing of data from many diverse sources. Together, this data can then be used and transformed into information and knowledge increasing the economic value of ocean data. These observatories should be designed to provide appropriate spatial and temporal coverage with new generation of sensors, adaptive sampling capabilities and linked to state of the art 3D models capable of predicting future changes and assessing the effects of mitigating actions.

These multipurpose observatories represent the way forward and combining this data with economical, environmental and social parameters will provide the required integrated management approach (Commission of the European Communities, 2007).

Data management and analysis functions must be integrated in such a way as to rapidly and systematically apply all data quality control procedures and disseminate the marine data with all its derived products to the user community at large. This in itself will be a major challenge for data providers involving high volumes of data consisting of disparate data requiring rapid integration and presented in a user-friendly format.

The KM3NeT sub-sea telescope infrastructure will form an important component of the Integrated Mediterranean observatory system. The decision to build in the Mediterranean Sea and the precise site chosen are determined by the requirements of neutrino astronomy; the challenge for the Earth–Sea–Science community is to make the best use of this opportunity to intensively instrument part of the Mediterranean Sea.

Acknowledgments

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15 ANTARES neutrino telescope and deep-sea observatory

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15.1 Introduction

The ANTARES detector consists of a multidisciplinary undersea observatory associated with a neutrino telescope. The neutrino telescope, with 12 mooring lines holding light detectors, was completed in May 2008 and is destined for research in the field of astroparticle physics, in particular in neutrino astronomy. Instruments for research in marine and Earth

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9 The results presented in this chapter are the work of the whole ANTARES Collaboration whose members are given in Ageron et al., (2009).