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Cruise Report

KM3NeT14

R/V Pelagia cruise 64PE389

06 – 11 June 2014
Malaga – Malaga (Spain)

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(with contributions from participants)

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0. Contents

1. Summary of R/V Pelagia KM3NeT14 cruise

In June 2014 R/V Pelagia (Royal NIOZ, the Netherlands) sailed to the north-central Alboran Sea (Western Mediterranean Sea; south of Spain), to perform several tests for the future cubic kilometer neutrino telescope ‘KM3NeT’. The research cruise was commissioned by Nikhef, the Dutch National Institute for Subatomic physics, Amsterdam. Nikhef is the main contributor to European Project KM3NeT in the Netherlands, with minor contributors NIOZ and KVI (Groningen University). The Dutch contribution to KM3NeT is funded via a large investment program in the realm of ESFRI by NWO, the Netherlands Organization for the advancement of scientific research.

Neutrinos are to be captured via very faint light signals in the deep-sea using highly sensitive optical Photo Multiplier Tubes (PMTs), moored at the sea bottom and connected to an underwater cabled network. As part of the future mechanical structure, NIOZ proposed to build a low-drag mooring-string holding pressure-resistant glass-spheres containing the PMTs. As KM3NeT will comprise of a large number of these strings, a compacted mooring launcher is proposed, for efficient deployment via ‘self’-unrolling of the string.

As a follow-up of unrolling tests of a compacted mooring-string in December 2009 and February 2011 in the Ionian Sea and in April 2013 in the Alboran Sea, a further two tests were performed in 910 m water depth some 20 nautical miles south of Motril (E) during 4 days. Therefore, a Launcher of Optical Modules (LOM), a 2.02 m diameter sphere holding 35 glass spheres of 17″-diameter, unrolled two 680-m lines with 18 glass spheres in between. The LOM surfaces freely after emptying its contents (the string of 18 digital OMs). The LOM was tested twice with a realistic optical fibre cable but without optical sensors. The tests was monitored via the mounting of motion sensors and underwater video inspection.

As support information three shipborne Conductivity Temperature Depth (CTD)-profiles were obtained, as well as some moored current measurements.

The cruise was successful. During both deployments the sea-operations and LOM-unrolling worked well mechanically. Some minor problems associated with the optical cable attachment occurred during the first deployment. The string was standing vertically upright as planned after both deployments.

2. General research aim.

KM3NeT

KM3NeT, a European deep-sea research infrastructure, will host a neutrino telescope ('NeT') with a volume of at least one cubic kilometer ('KM3') at the bottom of the Mediterranean Sea that will open a new window on the Universe. The telescope will search for neutrinos from distant astrophysical sources like gamma ray bursters, supernovae or colliding stars and will be a powerful tool in the search for dark matter in the Universe. An array of thousands of optical sensors will detect the faint light in the deep sea from charged particles originating from collisions of the neutrinos and the Earth. The facility will also house instrumentation from Earth and marine sciences for long term and on-line monitoring of the deep-sea environment and the sea bottom at depths of several kilometers. Recently, an EU-funded prepatory phase ended to design the KM3NeT-structure. Presently, about 40 MEuro is available from various national funds to start construction. Eventually, 150-250 MEuro is needed to build the entire telescope. Proposed sites are in the Northern Hemisphere, to compliment the IceCube-telescope in Antarctica. The sites are all in the Mediterranean Sea where sufficiently deep (below 1500 m) waters are found within several tens of kilometers from coasts. This facilitates the huge data transport to shore. Three sites are selected: south of Toulon France, east of Sicily Italy, west of Pylos-Peloponessos Greece.

KM3NeT-Esfri

The NWO investment program for large European Structures has granted Nikhef-Amsterdam, NIOZ-Texel and KVI-Groningen 8.8 MEuro to set-up the dutch part of KM3NeT. This national funding was followed by funds from France, Romania and Italy (with a present-day total sum of about 40 MEuro). Hopefully, many more will be brought in soon within the KM3NeT-consortium.

Building the KM3NeT: the underwater mechanical structure

The construction of a cubic kilometer telescope at great depths demands special mooring techniques. Standard single line oceanographic taut-wire moorings, consisting of an anchor, acoustic release and instrumented cable, all below a sub-surface buoy, cannot be used easily in a construction with, say, 600 detection units (DU), each about 700 m high and 100 m apart horizontally. Deploying standard moorings with optical sensors in unprotected glass spheres, 'digital optical modules (DOMs)', requires high precision in handling. Furthermore, the entire telescope needs to be operational within 4 years after the start of production. Thus, it is proposed to use compacted moorings that unfold upon acoustic command. The new techniques have the advantage that they can be prepared in the laboratory prior to going to sea.

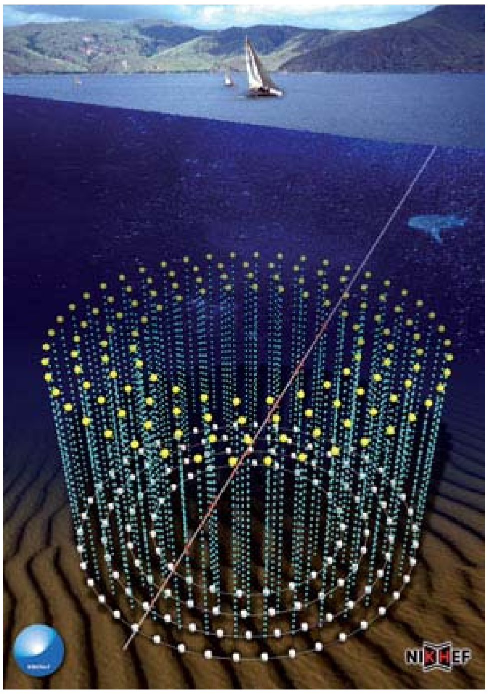
One of the compacted mooring techniques proposed by KM3NeT during the technical design study is the 'Tower'. It consists of 6 m long aluminum frames (bars) holding 4 DOMs.

Twenty of such bars will be placed under a 1500 kg buoy (the whole structure weighing about 7000 kg). In March 2013, a successful deployment of an 8-bar test-tower was done near Capo Passero, Sicily (I).

Another proposed compacted mooring technique is the ‘String’, with two 4 mm diameter Dyneema lines (almost neutrally buoyant in water) holding 18 DOMs between them under a 135 kg buoy. This low-drag single mooring is wound-up in a re-usable 2-m diameter aluminum sphere, the Launcher of Optical Modules (LOM). The loaded LOM weighs about 1200 kg, its anchor 950 kg. It could be mounted on a 1-km ground-line, to become deployed as a multiple (~10) string deployment.

KM3NeT14 cruise a/b oceanographic research vessel Pelagia

The purpose of the KM3NeT14 cruise in the Alboran Sea was to perform 2 technical test-deployments of a single string using the LOM holding 18 DOMs (with dummy weights replacing optical sensors), with realistic data communication cable. Each deployment test was followed by a visual under-water inspection of the mooring by a Remotely Operated Vehicle ‘ROV’. Some environmental conditions on temperature and current variations were monitored simultaneously for proper interpretation of the mooring tests.



3. KM3NeT14 area.

The working area of the R/V Pelagia was approximately five hours sailing south-east of the harbour of Malaga (E), see Figure 1. In 2013, the bottom has been mapped using Pelagia's Multibeam system. A 910 m deep, flat and muddy site suitable for LOM-test-deployments was found around 36°24'N 03°30'W. For water-mass inventory, shipborne Conductivity-Temperature-Depth 'CTD'-profile were made locally. Currents were monitored using a short stand-alone acoustic Doppler current profiler (ADCP) mooring in the same area.

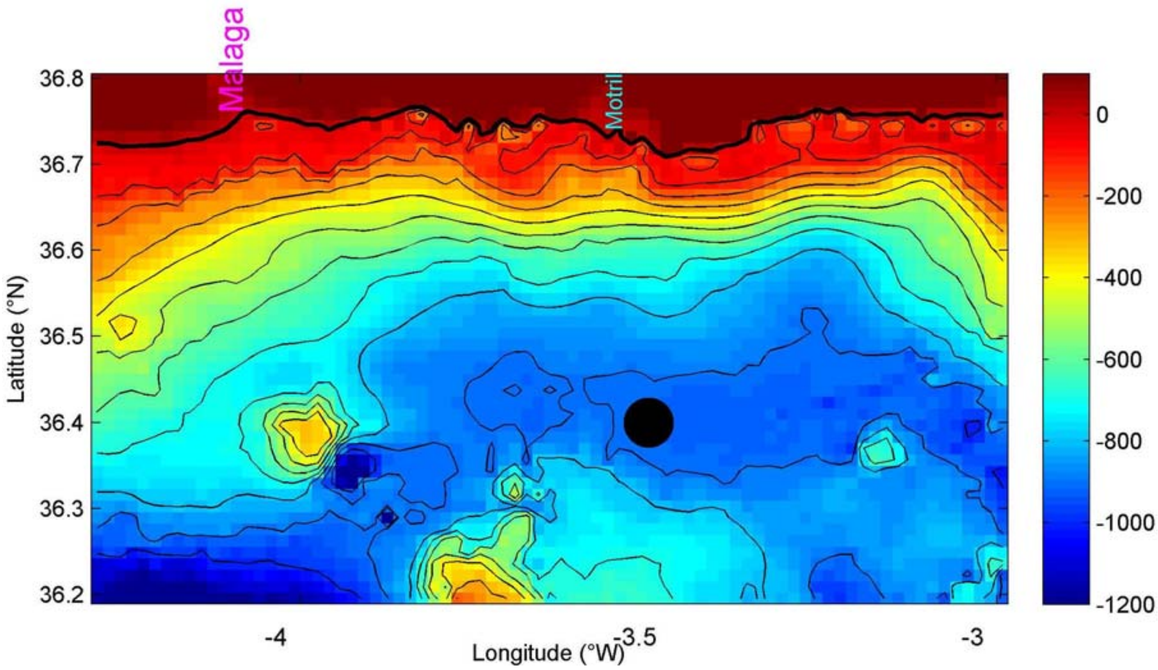


Fig. 1. Map of the north-central Alboran Sea, with LOM-testing site 'working area' indicated by black dot. Depth contours every 100 m.

4. Participants.

1	NIOZ	Hans van Haren	Dutch
2	NIOZ	Andrea Cimatoribus	Dutch
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7	NIOZ	Roel Bakker	Dutch
8	NIOZ	Ruud Groenewegen	Dutch
9	VLIZ	Wim Versteeg	Dutch
10	Nikhef	Paul Kooijman	Dutch
11	Nikhef	Dimitri John	Dutch
12	Nikhef	Edward Berbee/Els Koffeman	Dutch
13	CPPM	Sylvain Henry	French
14	CPPM	Jean-François Drogou	French
Observ	Inst Hyd Cadiz	Rodolfo Ramos	Spanish

Nikhef	National institute fro subatomic physics, Amsterdam (NL)
CPPM	Centre de Physique des Particules de Marseille (F)
VLIZ	Vlaams Instituut voor de Zee (B)

Most cruise photos by R. Ramos

5. Data acquisition and instrumentation (see Appendix A for mooring diagrams).

a. Launcher Optical Module (LOM) compact mooring test

Like the three previous cruises, the key-purpose of this cruise was to further perform in-situ tests of a compacted string-mooring launcher.

NIOZ/Nikhef built a compact string-mooring, which eventually is designed to be launched with 5-10 strings on a single ground-cable. The entire design is to minimize the number of underwater-connectors, to quickly deploy multiple mooring-strings and to have minimal deflection of a string from the vertical under drag by horizontal currents. A single string has two 4-mm neutrally buoyant Dyneema lines for support and a 6 mm tube, the Vertical Electrical Optical Cable (VEOC), holding all power and data communication cabling. The VEOC is a pressure-balanced oil-filled cable in which optical fibres and copper conductors operate under an ambient hydrostatic pressure that is much reduced with respect to the in situ under-water pressure. As no tensile loading is allowed on the VEOC, it is made 10% longer than the Dyneema lines. (From tensionless new, pre-stretched lines to a load of 2000-3000 N typical mooring tension, the verified lengthening is 3-4%). A string holds eighteen 17″ glass spheres and about 60 anti-torsion sticks (which also function as cross-over for extra length of the VEOC). Eventually, each glass sphere will hold 30 small Photo Multiplier Tubes as optical sensors. Together they form a DOM and the entire ~700 m long string makes a DU.

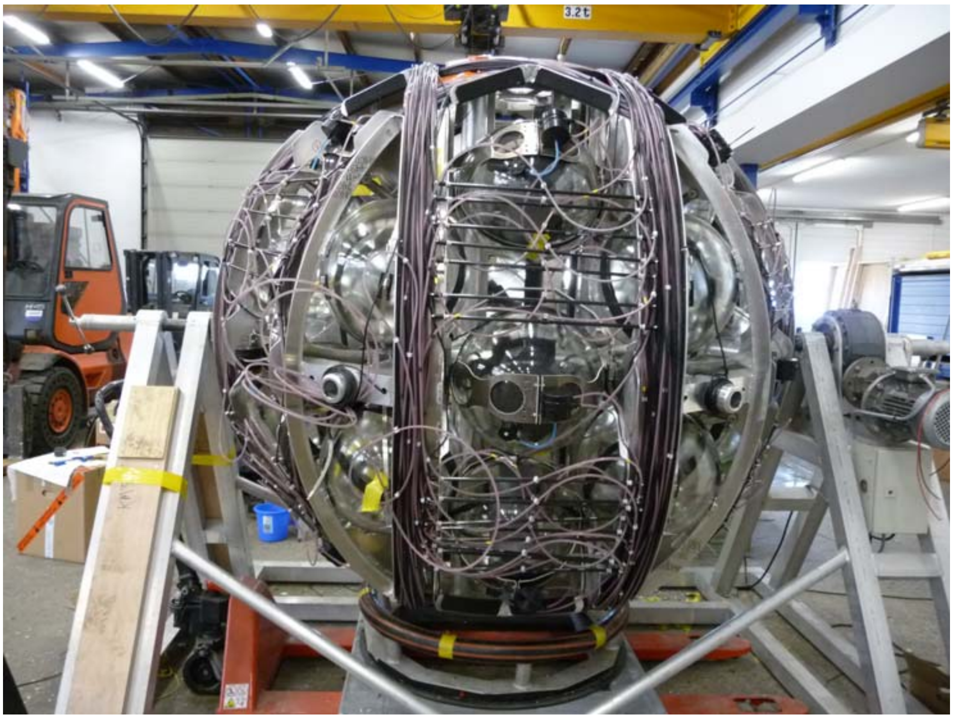


Fig. 2. Launcher of Optical Modules (LOM) in its winding 'rotator', with Dyneema lines (black) and data cable (purple). The OMs are loaded with dummy weights.

18 DOMs are separated by approximately 36 m. The DOMs are mounted 'naked' in between the two Dyneema lines, with a support-ring to keep its two half-spheres tight-closed.

This ring supports the data-communication splitter or Break-Out Box (BOB) and, here, one test-instrument monitoring the motions at 10 Hz. At each BOB one bidirectional fibre and two power conductors are branched out to a Break-out Electro-Optical Cable (BEOC) connector. The BEOC is connected to the DOM via a penetrator (glass feed-through). Between the DOMs (and in the lower 60 m above the anchor-weight) 'line-separators' are mounted between the Dyneema lines, about every 9 m. They primarily function to stiffen the mooring, to provide torque to counter-act precession and to prevent a twist-knot. Secondarily, they are used to store excess-VEOC and switch-over from one Dyneema line to the other, so as to retain symmetry of the DU.

For compact-mooring deployment, the entire DU-string and top-buoyancy are mounted in and on the 1.9 m inner-diameter (2.1 m outer-diameter) sphere, the LOM, see Fig. 2. Six DOMs plus line-separators, cable and lines are mounted in a 'lane', the three of them oriented at respective angles of 60°. A fully loaded LOM is mounted directly above a bottom-weight, with three 0.007 m diameter steel cables feeding through vertical pipes. These cables are looped into the release-hook sitting in its top-buoy above the LOM. Upon release, acoustically from the research vessel, it will unroll along its lines and release the DOMs due to its positive buoyancy. After releasing the 135 kg syntactic foam top-buoy (Figure 3), the LOM detaches itself and surface freely. Its acoustic release-buoy surfaces separately and earlier.

Fig.3. Syntactic foam topbuoy inside the (empty) LOM (left). Top-buoy release mechanical mechanism (right).

The stand-alone test-instruments are modified NIOZ4-thermistors, which in this case only register their compass-tilt (acceleration) data, at a rate of 10 Hz. Three such sensors are also mounted inside the LOM, one on each of the three rotational axes. The anchor holds an upward looking video system. (A remotely operated vehicle 'ROV', see further under c., is launched for video inspection of the entire string once deployed.)

As the above string-mooring (**KM3NeT14_LOM_#, #=1,2**) is recovered to read the stand-alone sensors, it is deployed in a U-fashion mooring (see Appendix), with a 1.3 km long steel ground-line and separate surface marker. The fully equipped LOM with bottom anchor and release have a total mass of about 2.2 tonnes.

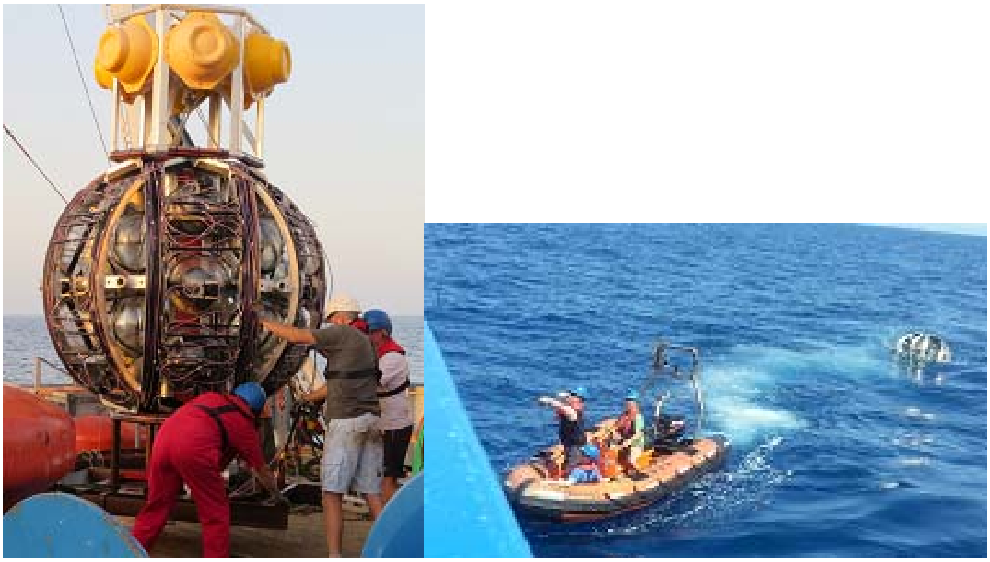


Fig. 4. (left): Fully laden LOM just before deployment. Below the LOM the bottom weight and video camera are partially visible. Above the LOM, its own acoustic release is between six plastic-capped glass spheres. (right): recovering the 'empty' LOM after surfacing.

In order to accomplish two test-deployments in only 4 days, two complete LOMs have been assembled at NIOZ and transported to Malaga. A LOM is deployed one day and recovered the next day. Deployment was done from the stern, separate surface marker going out first, followed by spooling out the 0.014 m diameter ground cable before the LOM package is lowered all the way to the bottom by the stern-winch. The LOM-package includes the separate acoustic release in a beacon above the LOM (Fig. 4,left) and another acoustic release for detaching the winch-cable once bottom was hit (not visible above Fig. 4,left). To move this cable away from the LOM two 17″ glass spheres are attached to it, some 20 m above the release. The entire deployment took 2.5-3 hours.

Fig. 5 (left): The first of a sea-strait of glass spheres. (middle): a DOM is lifted on board (right): tool for lifting a DOM (©Dutch cheese-carriers).

Empty LOM and release-buoy were recovered with assistance of the MOB-boat (Fig. 4, right). The recovery of the U-shaped mooring starts again with the surface buoy. Once the DU-anchor was off the bottom, Pelagia moved forward at a speed of 0.5 knots with continued winching to stretch the string at the surface (Fig. 5, left), which prevented the glass spheres from colliding into each other. On deck, DOMs and VEOC remained attached, but they were separated from the Dyneema lines (Fig. 5, middle). The DOMs and VEOC were stored in custom-made boxes (Fig. 5, right). The entire recovery took about 4 hours.

b. Short-term mooring

Short-term mooring MED**14** is a free-falling mooring 40 m long. It was deployed to monitor the environmental conditions from temperature and current variations with time at the LOM test-site, for proper interpretation of mooring movements.

c. Shipborne sampling

The NIOZ CTD/Rosette system contains a Seabird 911 Conductivity Temperature Depth sensor. The CTD samples at a rate of 24 Hz. Its data provide information on the environmental, water mass and turbidity, conditions for LOM-tests.

ROV “Genesis” (Fig. 6), a 1500 m depth-rated ROV Cherokee manufactured by SubAtlantic and operated by VLIZ (B) is deployed every LOM launch. It is used for visual (video) inspection of the DU.

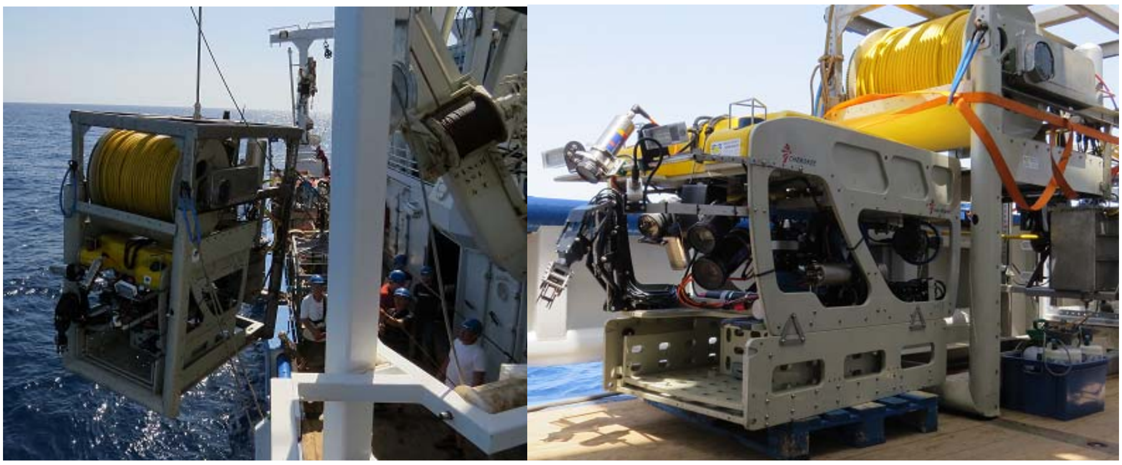


Fig. 6. ROV Genesis (VLIZ).

6. Daily summary of KM3NeT14.

Friday 06 June

WNW3. 13 UTC Departure from Malaga harbor. 18 UTC lowering of LOM1 to about 700 m for a pressure test.

Saturday 07 June

W6-3. 06 UTC CTD in the Alboran Sea test-area; 08 UTC deployment current meter mooring. Have to postpone LOM1 deployment, because of too much wind. 12:30-15 UTC LOM1-deployment. Smooth operation, except perhaps that the lowering is somewhat tricky as the cable tension varies between 0.2 and 4 tonnes. However, this provided no damage to the any of the hoist-cables (with modified 3-point attachment to the anchor). Normal surfacing of empty LOM and release beacon. 21 UTC Malaga pilot station; exchange people.

Sunday 08 June

W4. 06 UTC CTD. 09-11:30 UTC ROV inspection of VEOC1 (string). The optic fiber is very tight near the anchor and it is broken between DOMs 15 and 16 (3 and 4 from below). Many clips lose. Otherwise, the DU is standing perfectly upright, untwisted, with spreaders all in place and DOMs quasi-horizontal. 12-16:45 UTC recovery LOM1. Smooth operation. No DOMs leaking, all penetrators ok. VEOC inspection shows a strong tearing before breaking, probably because clips were loose and a loop was caught by the LOM during unrolling.

Monday 09 June

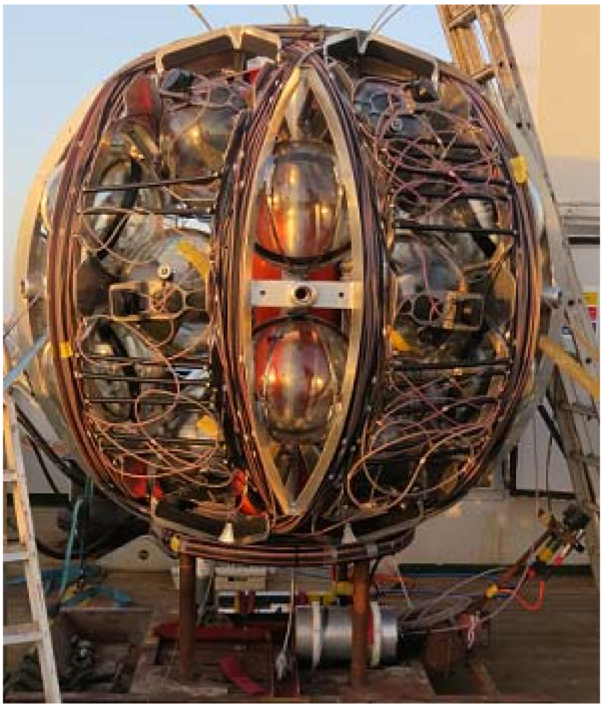
WNW2-4. 06 UTC CTD. 06:30-11 extra tightening of cable-clips on LOM2. 12-14:15 UTC deployment LOM2. Smooth operation. One LOM-glass sphere leaking. 16:30-18:30 inspection of VEOC2 with ROV: all well, nearly all clips in place holding the optic fiber cable. Nowhere a tight cable and string perfectly upright, untwisted.

Tuesday 10 June

Var2. 06:30-11:15 UTC Recovery LOM2. Normal and smooth operation. One DOM (#2, or number 17 from below) leaking, probably through the equatorial tar-band. 12:00-12:30 recovery current meter mooring. 19 UTC arrival in Malaga harbor.

Wednesday 11 June

Disembarkment, port of Malaga (E).



7. Scientific summary and preliminary results

Test-mooring **KM3NeT14_LOM** was deployed in about 910 m water depth on a smooth muddy and flat bottom just south of Motril. The bottom texture turned out perfect, a clean silt bottom without large rocks, as is interpreted from video camera observations and residue at the bottom-weights after recovery. The clarity of water was less good: 5-10 m visibility. The overboard deployment and recovery operations of the U-shaped mooring were handled well: four times a smooth operation. The 1300 m long ground-line was long enough for the ship to move gently away from the surface marker/ADCP and allow ample time to transfer this cable from the stern to the LOM-anchor.

The double testing of the LOM-deployment was successful, in so far that most of the improvements recommended after April 2013 have worked and only a few last flaws came to light. During both deployments, the unrolling worked without problems and the mechanical structure stood upright as planned (Fig. 7). All bars were in place, unbroken. The accelerometer sensors all worked, during LOM2 only. ROV and anchor video systems all worked flawlessly.

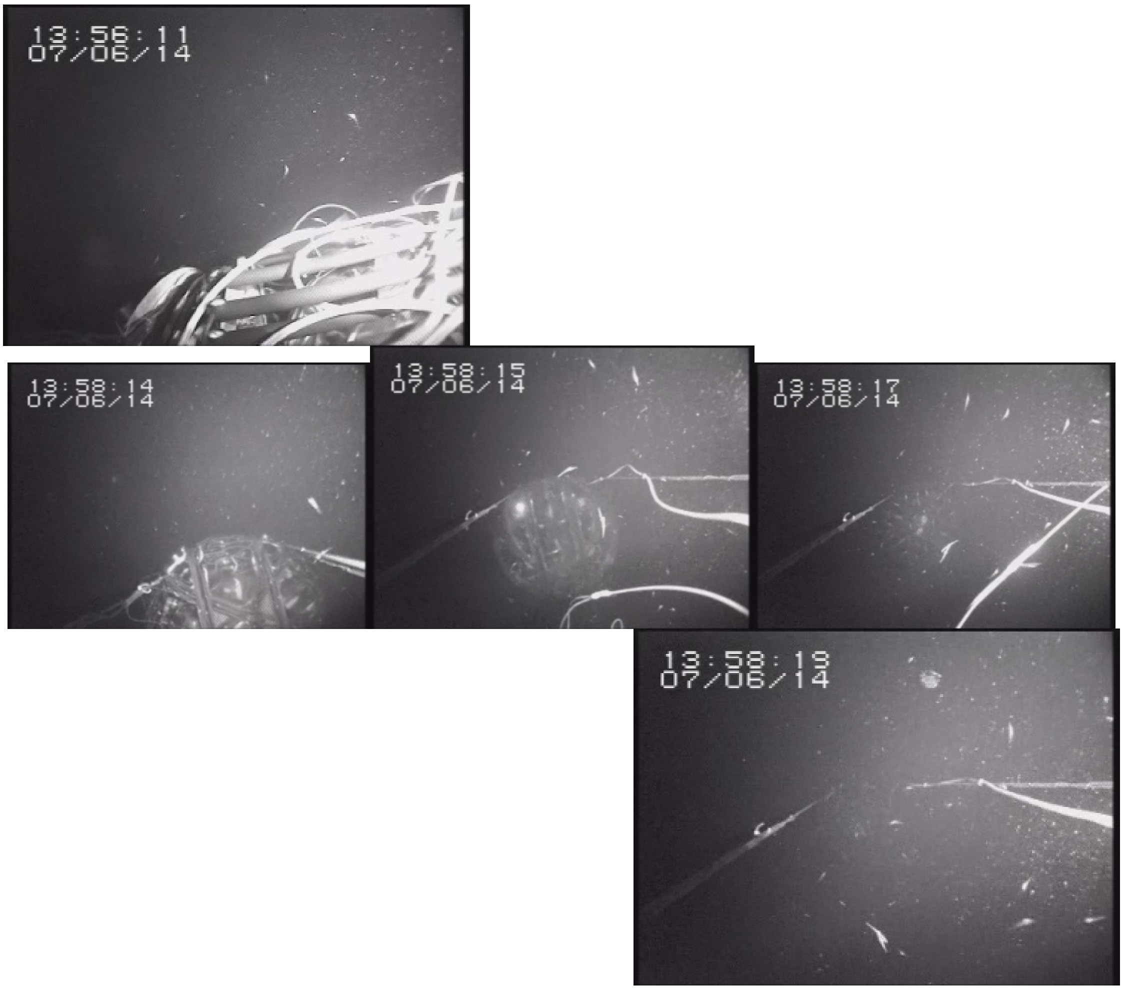


Fig. 7. Underwater anchor video stills of LOM1 just prior and after its release.

During LOM1, many clips were loose, so that the VEOC was hanging lose. Once, this loose VEOC caught the turning LOM so that it broke between DOMs #15 and #16 (and also near the anchor due to improper tightening to the weight). The lower VEOC, thicker than the upper, seemed too stiff.

During LOM2, the clips were reinforced with tape and they worked nearly perfectly. Now, the VEOC was intact, albeit somewhat overly long. One DOM leaked (#2, probably due to a shifted tar-band around its equator during its mounting into the LOM) as well as one empty glass sphere of LOM2 (also due to an improper placement of the equator-tar-band?).

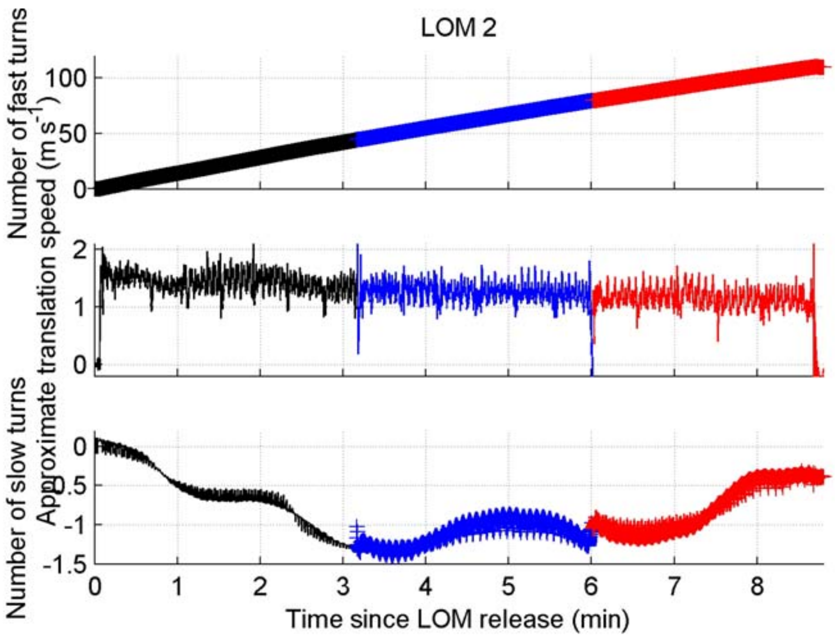


Fig. 8. Unrolling of LOM2 as a function of time: (upper panel) number of 6 m (LOM circumference) turns, (middle panel) approximate vertical translation speed, computed from the data in the upper panel, (lower panel) number of precession turns: due to glass-sphere and separator-bar torque the LOM precedes back after 3.5 min from its start.

During the unrolling, no glass spheres were damaged and the surface buoy worked again excellent, not hampering the LOM to surface. The unrolling took 8.7 minutes for a 680 m string (an average unrolling speed of 1.3 m/s; Fig. 8, middle). The slowing down of the LOM-translation speed during the exiting of each of the 18 DOMs is clearly visible. The hick-up/slow-down during both lane-switches is partially artificial, due to the particular mounting of the accelerometers. In the figure of the precession (‘slow-turns’ Fig. 8, lower; see detail in Fig. 9) an apparent nutation is seen, especially during the blue lane unrolling when the LOM was most asymmetrically laden. This nutation has a period of exactly one LOM-turn, and may also be partially due to the way of the accelerometer mounting, which was not perfectly axi-symmetric. Per LOM-period, the precession and Dyneema line showed 6-8 0.1 s short vibrations, in two groups (Fig. 9). These ‘ticks’ are thought to be caused by the scratching of the Dyneema line by the line-separator-bars that were stored on the front- and back-sides, but not on the poles (*cf*. Fig. 4,left).

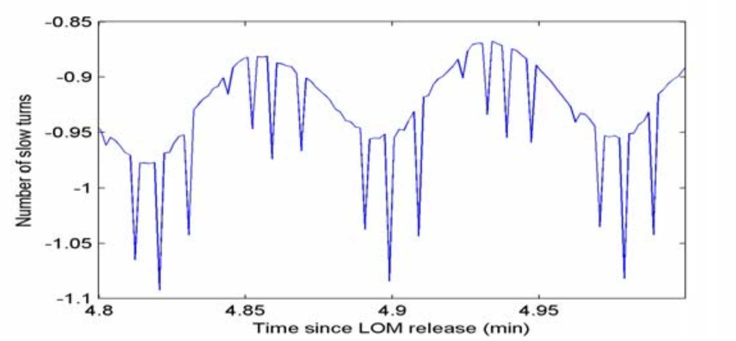


Fig. 9. Detail with time of the precession during the unrolling of the blue lane of LOM2..

After deployment, the tension was virtually equal on the two cables, the string stood upright (Fig. 10). The spheres tilted <10° from the horizontal (Fig. 11, middle and lower; Fig. 12, middle and right). Here, the tilt-sensor data are split in values relative to their mean (Fig. 11) and the means (Fig. 12). From the latter it is seen that some unresolved bias remained after the mounting 'by eye' of the sensors to the DOMs. All spheres have more or less the same heading-direction (Fig. 11, upper), with a slight vertical string-rotation of about 20° remaining (Fig. 12, left). In the relative heading time series of Fig. 11, the DOMs are seen to precession-rotate by maximum ±2° (top-DOMs) around their mean value also after the DU is completely unrolled and the LOM has surfaced. This is understandable, as the top of the DU is moving most, especially when current is strongest, as in this case in the early hours of day 160 (Fig. 13).

Fig. 10. ROV underwater video stills of upright LOM2-DU. The white line is the VEOC, which switches the barely visible black Dyneema lines every two out of three bars (right), and goes in and out a DOM (left).

After release, the mooring remained at the bottom for at least 12 hours before retrieval. Relative current speeds were measured up to about 0.15 m s^{-1} over the ADCP/DU-range (Fig. 13). This current is dominated by the tide, due to the proximity of the Atlantic Ocean via Gibraltar. The current ellipse is almost degenerated, causing a near-rectilinear motion directed

East-West. Basically, the tidal motion is vertically uniform. However, a considerable part (~50%) makes a vertical structure, with lower values closer to the bottom and relatively thin (~100 m) layering in current and direction in the upper 400 m. In a <50 m thin surface layer currents were considerably larger, ~0.5 m s^{-1} (rough visual estimate from ship's drift not measured by the ADCP due to sidelobe reflection at the sea surface).

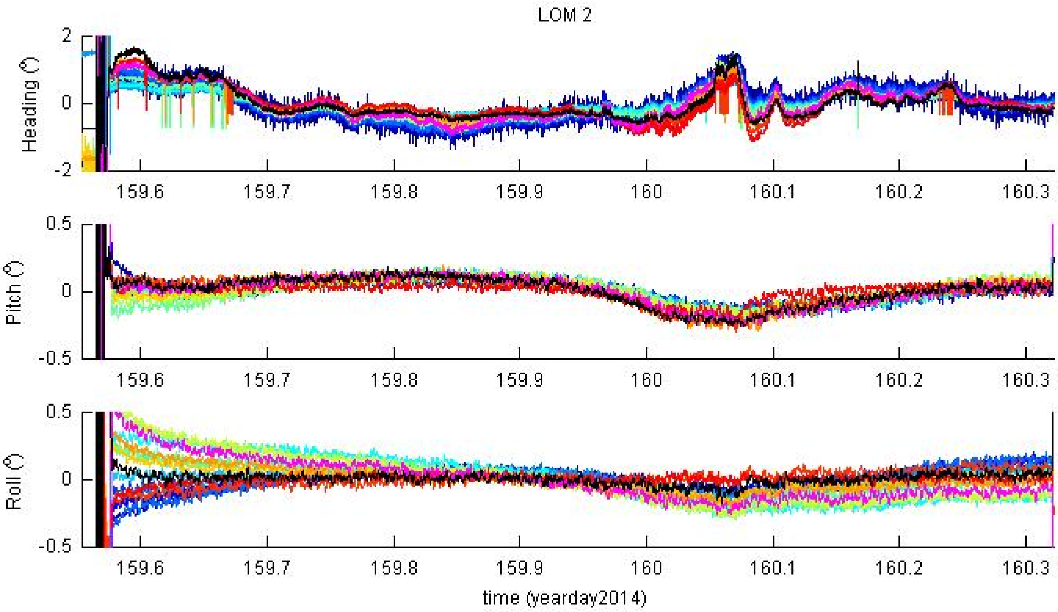


Fig. 11. Heading and tilt directions, relative to their mean values (cf., Fig. 12), of LOM2 DOMs after unrolling, when the DU is upright. The spikes in some headings are due to electronic problems of the 10 Hz data. The tilt data are smoothed to 1 s, for clarity.

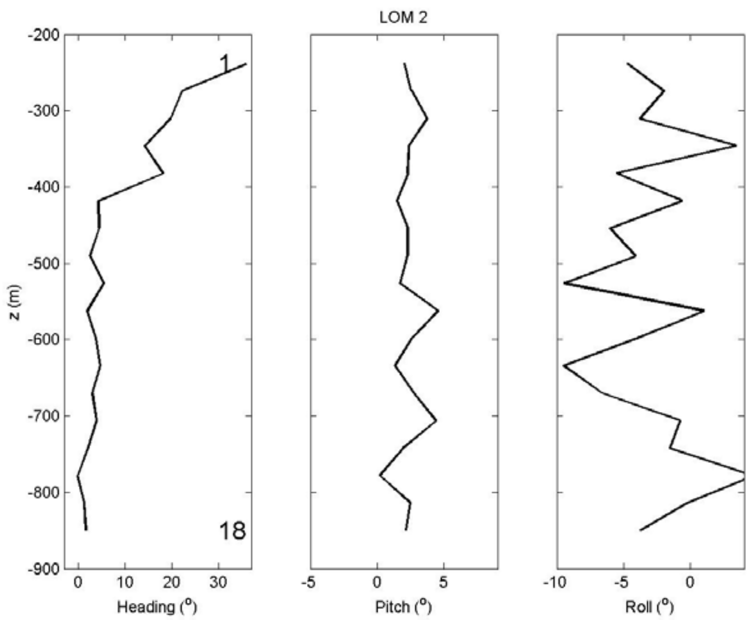


Fig. 12. Time averages between days 159.6 and 160.3 of original heading and tilt sensor data.

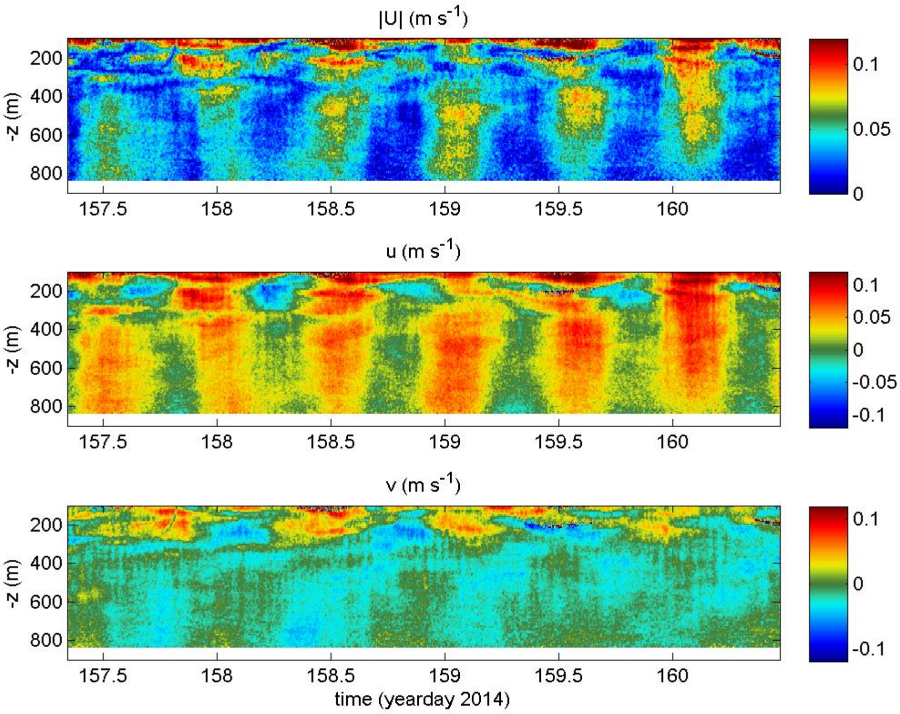


Fig. 13. ADCP-current data, smoothed over 10 min, as a function of time and depth of: (upper) total current amplitude, (middle) East-West, (lower) North-South component.

8. Achnowledgments

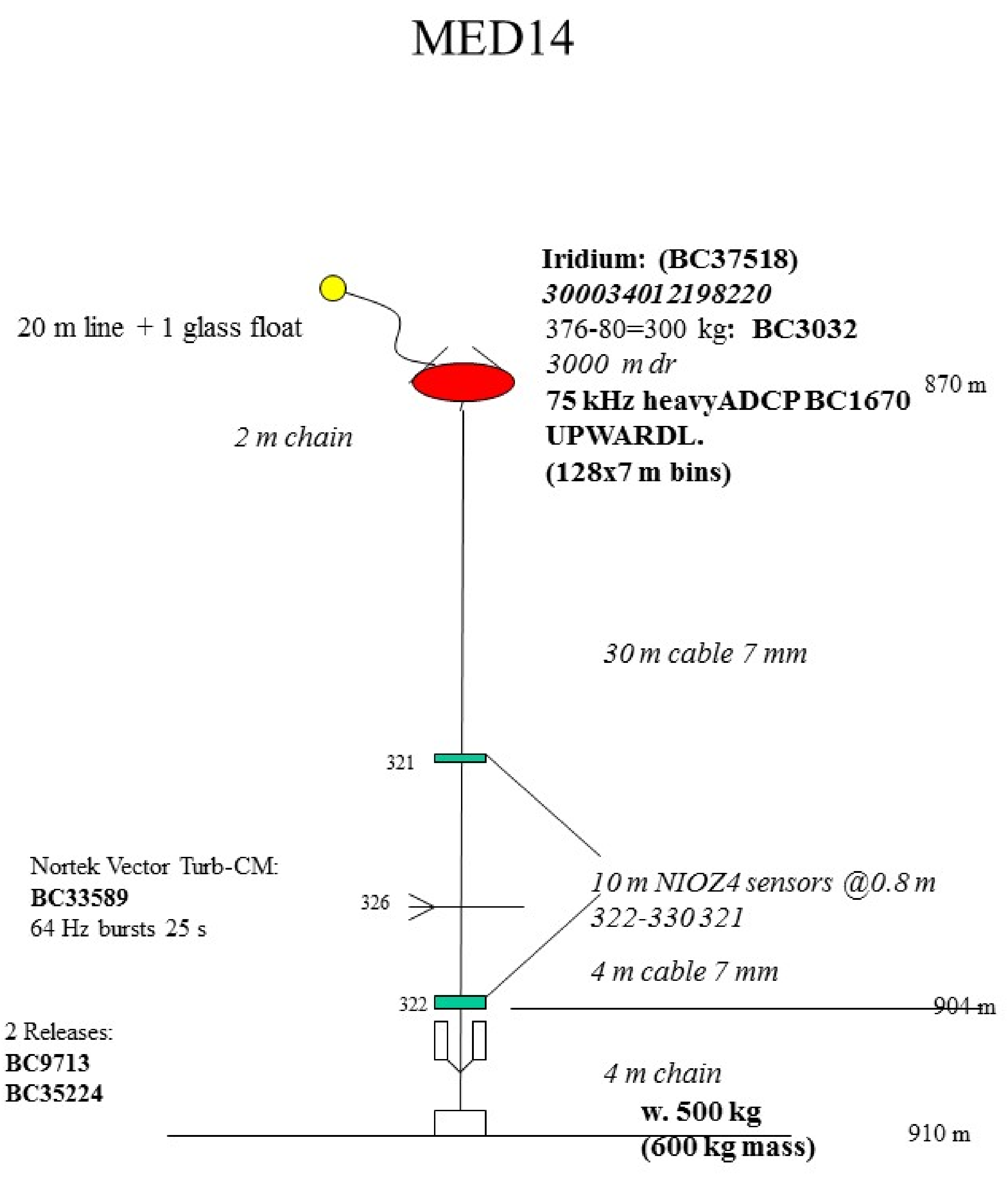
On behalf of all participants, I would like to thank captain Pieter Kuijt and the crew of R/V Pelagia for the very pleasant cooperation. Funding by the Netherlands Organization for the advancement of Scientific Research is gratefully acknowledged.

July 2014,

Hans van Haren

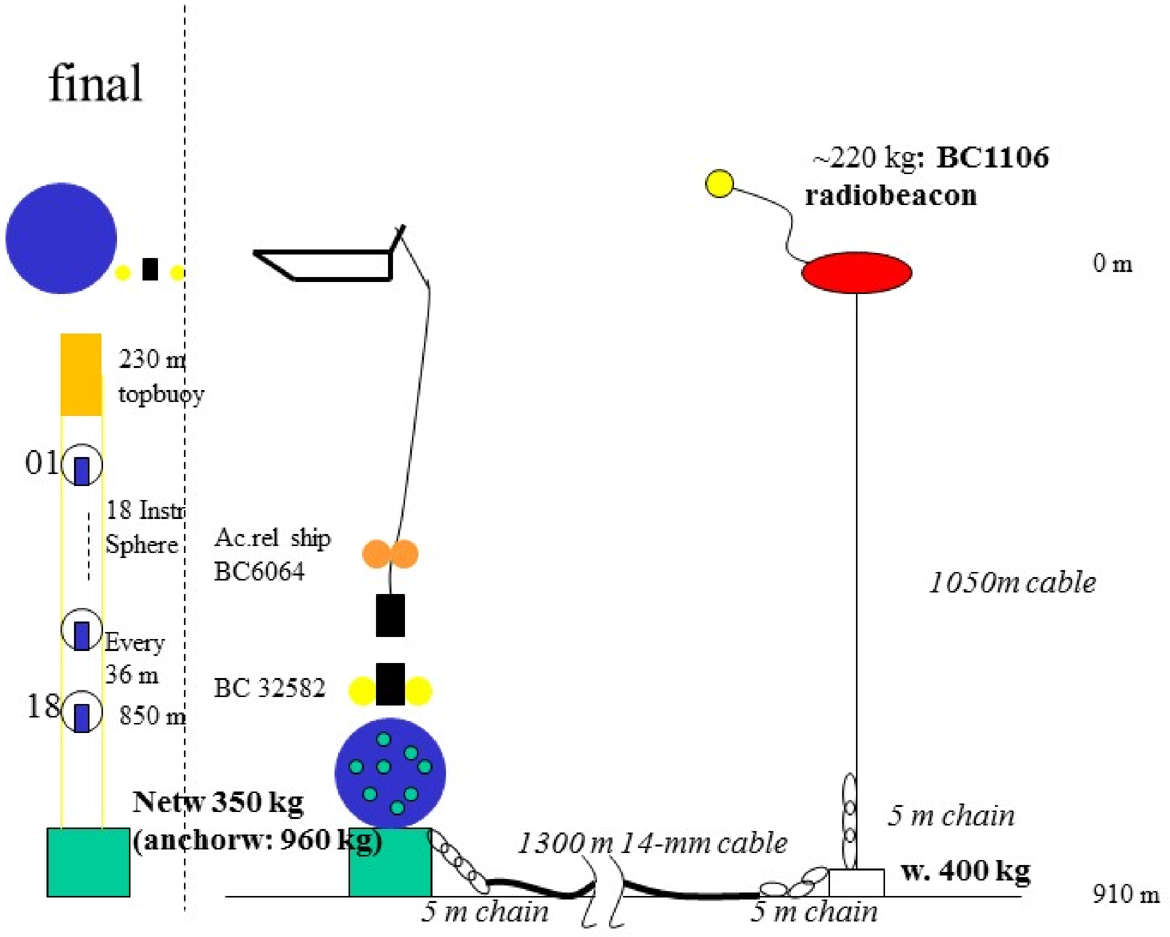
Appendix A Mooring diagrams KM3NeT14

Bottom short mooring MED14
(for monitoring environment near LOM-test site)



U-shape mooring

KM3NeT14_LOM2



Sensors:
LOM: black(252), blue(253), red(254)
DOMs 1-18: 281-288 290-297 289 310

Appendix B Cruise summary of stations (activities) of KM3NeT14

Date	(UTC)	Latitude	Longitude	Device name	Action name
07/06/2014	6:06:33	N 36– 23' 59.629''	W 3– 29' 59.165''	CTD_C02	Begin
07/06/2014	6:24:10	N 36– 23' 59.226''	W 3– 29' 59.042''	CTD	Bottom
07/06/2014	6:42:03	N 36– 23' 59.928''	W 3– 29' 57.188''	CTD	End
07/06/2014	8:06:34	N 36– 24' 36.137''	W 3– 29' 57.991''	Mooring_MED14	Deployment
07/06/2014	12:35:53	N 36– 24' 22.09''	W 3– 30' 55.998''	Mooring_LOM1	Deployment
07/06/2014	13:40:49	N 36– 24' 25.337''	W 3– 31' 5.336''	Mooring	Deployment
08/06/2014	6:04:00	N 36– 24' 52.085''	W 3– 30' 11.984''	CTD_C05	Begin
08/06/2014	6:20:46	N 36– 24' 52.722''	W 3– 30' 16.369''	CTD	Bottom
08/06/2014	6:39:22	N 36– 24' 52.373''	W 3– 30' 16.085''	CTD	End
08/06/2014	9:09:44	N 36– 24' 30.449''	W 3– 31' 1.063''	ROV—LOM1	Deployment
08/06/2014	11:24:14	N 36– 24' 28.339''	W 3– 31' 1.859''	ROV	Recovery
08/06/2014	11:54:47	N 36– 24' 35.06''	W 3– 31' 1.978''	Mooring_LOM1	Recovery
08/06/2014	13:54:32	N 36– 24' 43.164''	W 3– 31' 6.161''	Mooring	Surface
09/06/2014	6:01:25	N 36– 24' 34.754''	W 3– 30' 41.328''	CTD_C09	Begin
09/06/2014	6:16:59	N 36– 24' 31.727''	W 3– 30' 40.752''	CTD	Bottom
09/06/2014	6:35:40	N 36– 24' 29.923''	W 3– 30' 41.555''	CTD	End
09/06/2014	12:04:00	N 36– 24' 31.9''	W 3– 27' 37.307''	Mooring_LOM2	Deployment
09/06/2014	13:17:23	N 36– 24' 28.861''	W 3– 28' 7.518''	Mooring	Deployment
09/06/2014	16:30:18	N 36– 24' 28.681''	W 3– 28' 8.713''	ROV—LOM2	Deployment
09/06/2014	18:22:16	N 36– 24' 29.434''	W 3– 27' 59.731''	ROV	Recovery
10/06/2014	6:22:45	N 36– 24' 34.927''	W 3– 27' 57.697''	Mooring_LOM2	Recovery
10/06/2014	8:46:46	N 36– 25' 38.575''	W 3– 27' 45.814''	Mooring	Surface
10/06/2014	11:53:08	N 36– 24' 37.256''	W 3– 29' 29.807''	Mooring_MED14	Recovery