Reference:
van Haren, H., 2024. Cruise report MED24: R/V Pelagia cruise 64PE532 (25 February-06 March 2024), NIOZ, 18 pp.

Cruise report

MED24

R/V Pelagia cruise 64PE532

25 February – 06 March 2024
Toulon-Toulon (F)

10 April 2024

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0.Contents:

1. Cruise summary

End of February 2024 research vessel ‘R/V’ Pelagia (NIOZ, the Netherlands) sailed to the Liguro-Provençal Basin in the Western Mediterranean. The purpose of the cruise was to recover most of a large-ring mooring array that was deployed in October 2020 in 2458 m water depth. The mooring array holds 2925 high-resolution temperature (T-)sensors distributed over 45 mooring lines that are 125 m tall and 9.5 m horizontally to its nearest neighbour. At their bottom, the lines are attached to a grid of steel cables that is held in a 70-m diameter ring of 0.6-m diameter steel pipes. This set-up is aimed to provide a three-dimensional (3D) view of the development of internal wave and sub-mesoscale eddy turbulent overturning above a flat seafloor about 6 km from the foot of the steep continental slope. The recovery used assistance of a deep-water Remotely Operated Vehicle (ROV) from the Irish Marine Institute, first, to cut the vertical lines holding the T-sensors, and, second, to cut the grid of cables between the large ring that fixes the vertical lines. The first impression was a perfectly upright mooring array, still mechanically well after 3.5 years underwater. Phase 1 of the operations consisted of ROV cutting the 5-mm diameter steel vertical lines near the seafloor. The top-floatation buoy brought each line holding 65 sensors to the surface. An inflatable working-boat assisted to bring each buoy with mooring line to the Pelagia for recovery. This day-time operation was accomplished in 2.5 days, under moderately good weather conditions. The sensors performed extraordinary well, with 97% data recovered not counting a blocking of data storage at 30MB (half the expected file sizes) resulting in about 20 months data records. Phase 2 involved ROV cutting the 12-mm diameter cable network at the seafloor to be able to bring it to the surface. A custom-designed recovery-mooring was deployed from the Pelagia and connected by ROV to the cut network. This phase was done within 1 day. Phase 3 after demobilization of the ROV consisted of recovery of the mooring line with the entire attached seafloor grid material. Under 2-m swell and otherwise good weather conditions this phase failed as the material slid out of the hoisting hook whilst only 130 m below the surface. It sunk to the seafloor at 1.2 km NNE from the empty large steel ring.

2. General research aim.

The purpose of this physical oceanographic study is to characterize the development in three dimensions ‘3D’ of internal wave motions and turbulent exchange in a deep-sea, *i.c.* over a 2458 m deep flat seafloor near the continental slope in the Liguro-Provençal Basin, Western Mediterranean.

For 15 years, very sensitive, low-noise, underwater temperature (T-)sensors have been developed at the Royal Netherlands Institute for Sea Research (NIOZ) to gain more insight in physical processes for the dispersion of substances in shallow and very deep seas and oceans. The T-sensors are used to measure the energy-rich large eddies of turbulent flows. In the stably density stratified waters, mainly established by solar heating from above, such turbulent eddies are mostly generated by the breaking of internal waves (e.g. Eriksen, 1982; Thorpe, 1987).

The measuring method works best if sufficient T-sensors are attached to a mooring line, say 100 sensors at a distance of 1 to 2 m from each other. The mooring line is held in place by a heavy weight and almost vertically taut by a heavy top-floatation buoy. Until a few years ago, such mooring lines were deployed separately in the sea at various locations: This provided one-dimensional (1D) depth/time information. Such deployment was done in free fall, in the order buoy-line-anchor weight, with an accuracy of about 100 m horizontally around a target position per 3 km depth.

Since internal waves and turbulent eddies are essentially 3D (e.g. LeBlond and Mysak, 1978), there has been a desire for years to place multiple mooring lines next to each other in the sea to study the development processes of turbulence in a volume of water. Research showed that lines would then have to be approximately 10 m apart horizontally, also in the deep sea, to resolve large turbulent and nonlinear internal wave lengths. Such distance is impossible to achieve from free-fall deployment of single lines. In addition, the clocks of the T-sensors are synchronized every 4 hours to be able to measure simultaneously within 0.02 s. A deep-sea robot would therefore be necessary to electrically connect the individual lines: An expensive and difficult operation. Therefore, it was decided to develop new mooring techniques whereby several lines can be released into the sea in free fall at the same time.

The first version, which was successfully used twice, consisted of 5 lines at 4 (and 5.6) m apart horizontally, 100 m high vertically and contained approximately 500 T-sensors (van Haren et al. 2016a). The lines were folded on four arms of a "rotary clothesline", in collapsed form on board a research vessel, and unfolded overboard once at sea using a heavy weight and a second rotary clothesline. The whole mooring array was under such a tension by the top-buoys that it did not twist and could sink in free fall. This ‘small’ five-line 3D mooring array provided information about the transition from flattened 2D turbulence on slower, large scales to fully uniform 3D turbulence on faster, smaller scales (van Haren et al. 2016b).

However, deep-sea eddies of more than 100 m in vertical and horizontal directions were not fully mapped with this version.

Based on the five-line mooring and on ideas and technology of astrophysical project KM3NeT, short for "cubic kilometer neutrino telescope", half a cubic hectometer T-sensor array ‘3D-T’ was devised. This ‘large-ring’ mooring array consists of 45 lines, 125 m high and 9.5 m to the nearest neighboring line, each line holding 63 temperature and 2 temperature/tilt sensors (van Haren et al., 2021). The total of 2925 sensors measure roughly half a million cubic meters, or half a billion liters, of deep-sea with a precision of <0.0005°C once every 2 s, intentionally for a period of 3 years. The location is off the coast of Toulon (France) in the vicinity of KM3NeT-ORCA. This is not only to have the ability to combine the temperature data with optical data from the telescope, but also because the area is known for deep-sea internal waves in very weakly stratified waters, and for contrasts due to general geothermal heating, (continental slope) boundary layer currents, deep dense-water formation and eddies that transport fresh biological material within a day from surface to the 2500-m deep seafloor (van Haren et al., 2011). Logistically, the location is attractive, because a flat deep-sea bed is reached only 25 km from the coast, 40 km from the nearest harbor, and because ocean swell is relatively low, to ease the technically difficult sea operations.

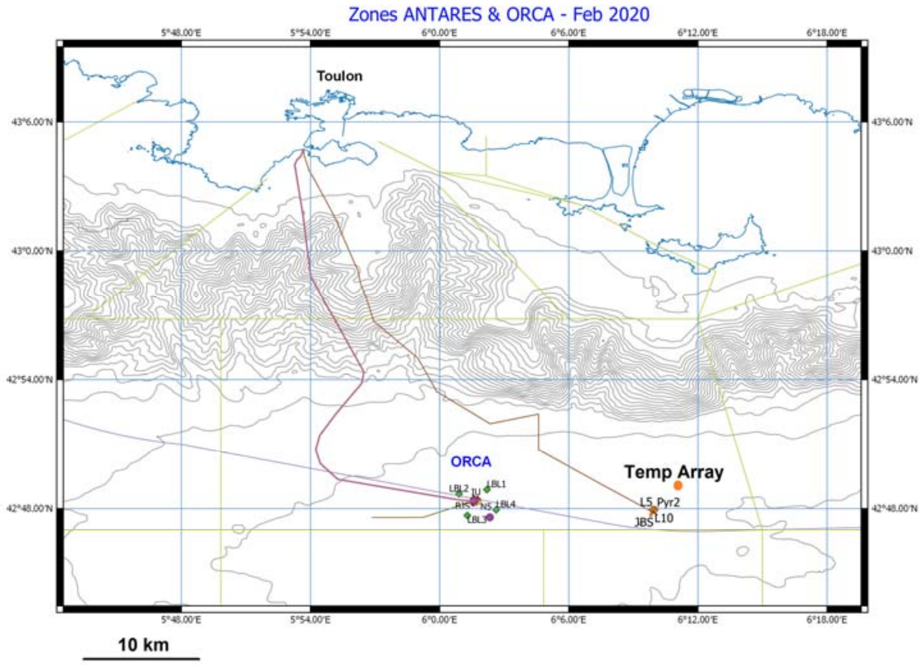

Figure 1. Location "Temp Array" for the large-ring mooring, just inside the French 12-miles zone. The mooring is well East of main neutrino telescope (NT) site “ORCA” and just Northeast of the former ANTARES NT-site. NB: horizontal and vertical axes have different scales (no spherical curvature correction). The scale is correct for the latitude (vertical axis).

3. Site.

In October 2020, the large-ring mooring was deployed at 42°49.50′N 006°11.78′E, 2458 m water depth (Fig. 1). The site is about 15 km East of the main French KM3NeT-ORCA site and about 3.5 km Northeast of the former neutrino telescope site ANTARES. The mooring is on a flat seafloor plain with mainly sand-silty texture. About 6 km northward is the foot of the steep continental slope leading up to Ile de Porquerolles 20 km, or just under 12 nautical miles, from the mooring site. An exclusion zone is 6 km to the East.

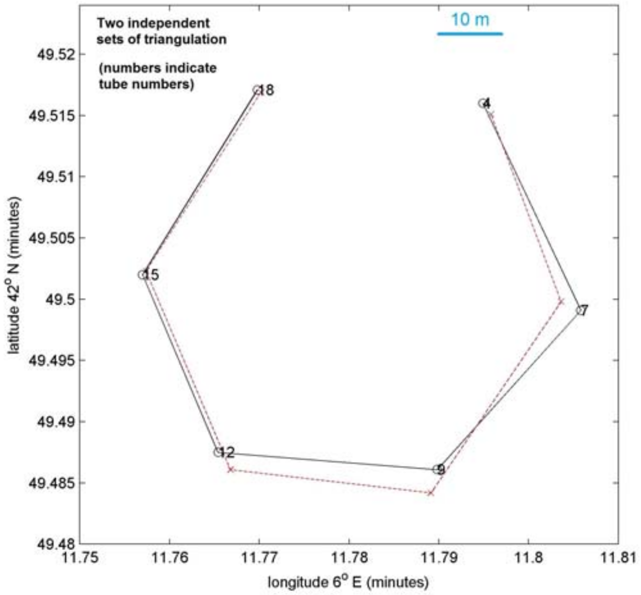

Figure 2. Position detail of large-ring mooring from triangulation using acoustic releases at the bottom of 6 drag-parachute lines for positioning of the large ring at the seafloor. Two independent sets of data are used. The numbers refer to steel tubes to which the acoustic releases were attached (cf. steel-grid plan in Fig. 4).

4. Instrumentation.

4.1 Large-ring mooring

The large-ring mooring consists of a 70-m diameter large ring of 0.6-m diameter steel tubes. Inside the steel-tube ring, a 12-mm diameter steel-cable grid is mounted at 9.5 m intervals (Fig. 3). At each cross-section of cables a 2.5-m diameter aluminum “small-ring” is mounted. Prior to deployment each small-ring held in fold-up form a 125-m long 5-mm diameter steel cable (6-mm diameter with plastic coating) to which 63 high-resolution NIOZ4 self-contained T-sensors (van Haren, 2018) were taped at 2-m intervals. About 0.5 m from top and bottom sensors, two T-tilt sensors were also taped to the cable. The stacked lines were kept in place by a 1.45-kN float under a chemical release strap. A total of 45 lines and 2925

T-sensors were within the large ring. Construction and deployment are described in some detail in van Haren et al. (2021).

After sinking in free-fall that was controlled by a custom-made drag-parachute, the ring was found to have landed completely horizontal and to be sunk only about 0.07 m into the seabed. The vertical lines unfolded automatically via chemical releases 3-7 days after deployment. Underwater inspection by ROV showed the lines perfectly upright (Fig. 3).

Figure 3. After deployment and unfolding of vertical lines: (left) Part of large ring with a few small rings near seafloor, (right) Several top-buoys.

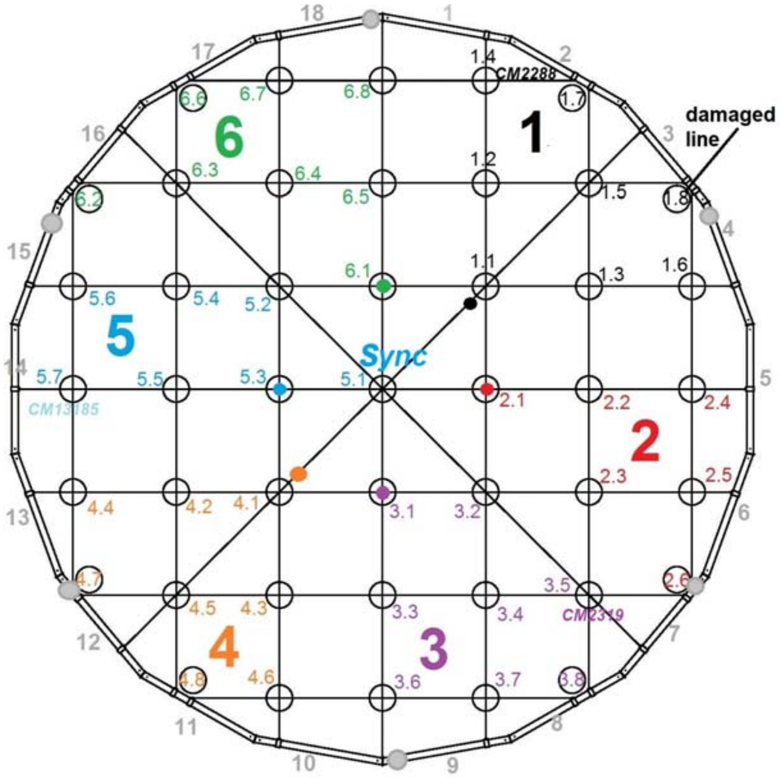

Figure 4. Schematic of large ring including 16 12-mm cables, with tube numbers given in gray and gray dots indicating the 6 acoustic release positions to the former drag-parachute lines. The 45 small rings are divided in 6 synchronization groups. From synchronizer 'Sync' on small ring 5.1 10-m long pig-tails lead to coloured dots for connection to each group. 'CMxxxxx' indicate the numbers of three current meters at their respective top-buoys. One sensor-line was damaged by a looped drag-parachute line.

All vertical lines are interconnected via electric wire taped to the steel-cable grid, for synchronization of the T-sensors' clocks (Fig. 4). The synchronization is done in 6 groups of 5-8 lines, for energy saving. Every half hour a group is synchronized, a sequence that is repeated every 4 hours.

Three floats held a Nortek AquaDopp single point acoustic Doppler current meter. The current meters measured for 60 s storing data every 600 s.

As no acoustic releases are mounted to the bottom of the 45 vertical lines, these lines have to be cut by ROV. This ROV-cutting is the primary goal of the present cruise to recover instrumentation and recorded data.

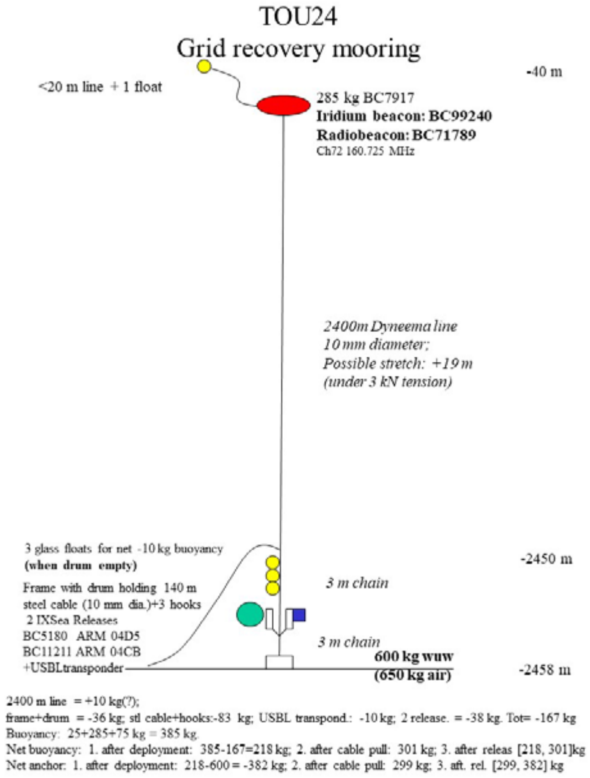

Figure 5. Sketch of mooring to recover the steel-cable grid.

4.2 Additional recovery mooring

A secondary goal of the present cruise is to bring the cut steel-cable grid including the 45 small rings to the surface. For this purpose, a single 'recovery mooring' (Fig. 5) has been designed. During this cruise it will be deployed just outside of the large-ring, on the downstream southwest side of the large ring. The mooring consists of 100-kN breaking strength members, the main one being a 2400-m long, 10-mm diameter Dyneema line. The recoverable steel-cable grid weighs approximately 17 kN. The delicacy of the sub-surface mooring lies in its short distance below the surface, to avoid surface wave action and ship disturbance during the approximately two days of absence of the Pelagia for demobilization of the ROV.

To connect the recovery mooring to the cut steel-cable grid, a custom-made drum with 140-m steel cable is attached to a frame also holding two acoustic releases (Fig. 6). Near its front-end, the 140-m long cable has one easy attachable fixing hook for attachment to the grid. At its back-end the cable has a hook hidden in the drum, which is to be attached to the main mooring line, just above 3 glass spheres to partially compensate for weight (Fig. 5). For location positioning during the lowering, the frame is equipped with a USBL-transponder beacon.

Figure 6. Frame with acoustic releases, drum to hold the 140-m steel cable with friction strip to avoid self-unrolling. One of 3 hooks to attach to cables is mounted inside the drum hold. The transponder beacon (red cap) is visible behind the acoustic releases (right image).

4.3 Remotely operated vehicle Holland 1

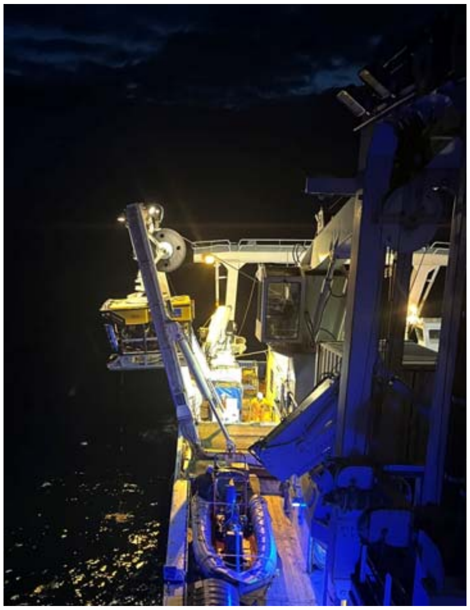

Figure 7. ROV Holland I, Marine Institute, Rinville, Oranmore, Co Galway. Image shows its deployment from R/V Pelagia.

The Irish Holland 1 is a scientific deep-water ROV system (Fig. 7). The system is designed for deployment from the Irish Marine Institute vessel R/V Celtic Explorer as well as from other vessels of opportunity such as R/V Pelagia. The system consists of a SMD Quasar work class Hydraulic ROV, Tether management system (optional), A-frame launch and recovery system and a deepwater (3000-m rated) winch. The system is controlled from a 20′ container and comes with a fully equipped 20′ workshop container. The ROV has seven and five function manipulators to enable a wide variety of intervention and sampling procedures to be completed. For the present purpose one of the arms is equipped with a steel-cable cutter.

Its starboard-side launch A-frame is mounted on a custom-made frame (Fig. 8). On port-side a rental 600 kVA power generator is located.

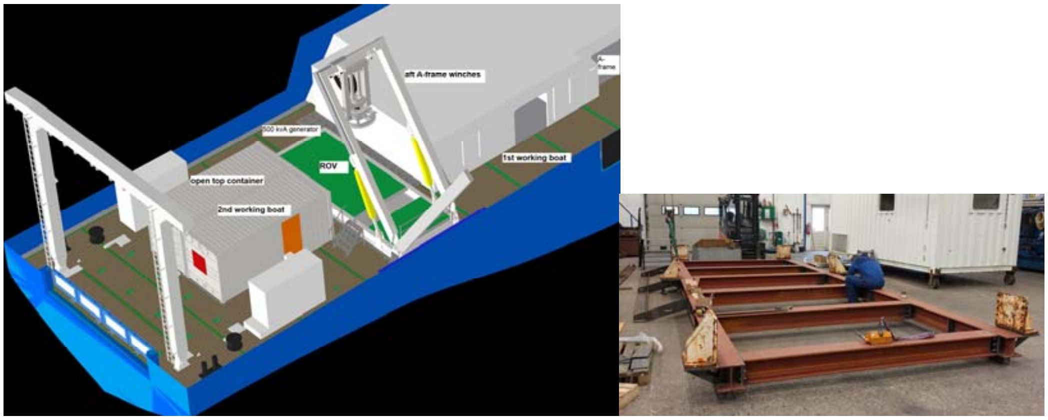

Figure 8. left: Pelagia's aft-deck outlay, with ROV A-frame placed on a custom-made frame (right). The spare inflatable working-boat is stored on top of ROV-container.

5. Sea operations.

Figure 9. ROV-video screen image at the moment of cutting of a vertical line.

5.1 Phase 1: Vertical line recovery

The ROV was operated from the Pelagia's starboard side, using the ROV's A-frame (Fig. 8). During Phase 1, the ROV cut each of the vertical lines under the lowest T-sensor, just above its small ring (Fig. 9). The lines went up at a speed of 2.0 m/s due to the top-float and surfaced after 20 minutes.

A working boat was launched by Pelagia's aft crane. An (unused) spare working boat was available and stored on the ROV's workshop container. The working boat towed floats with cut mooring lines along the sea surface to a line floating from the Pelagia's stern (Fig. 10). The floats were stored directly in the open-top container located besides ROV's control container (Fig. 11). T-sensors were detached by cutting the tape from the plastic-coated steel cables and stored in small cases. The cables were spooled via the capstan winch on deck.

Figure 10. Working boat attached a surfaced float to the line floating from Pelagia's stern.

Figure 11. (left) Float hoisted on deck, spooling of line and grey case ready on the table to host the T-sensors to be cut from the mooring line. (right) Open-top container loaded with floats and mooring cables towards the end of the Phase-1 sea-operation.

5.2 Phase 2a: Steel-cable grid cutting

For rubble removal, the freeing of the 12-mm steel grid from the large ring, including the 45 small rings and the synchronizer in ring 5.1 but excluding the 16 cable-tensioners and safety bands, a minimum of 32 cable-cuts were required by the ROV. This cable cutting was made just inside the large ring (Fig. 12).

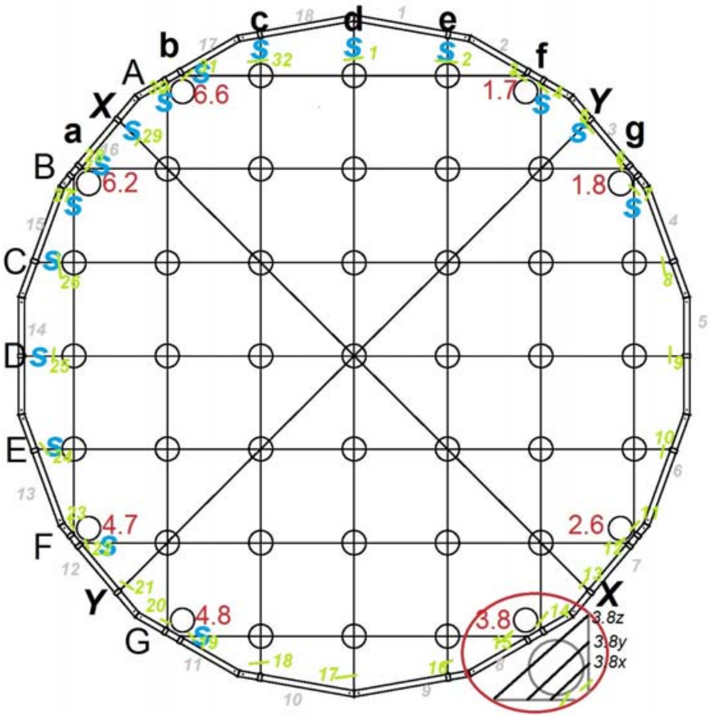

Figure 12. Schematic of large ring including 16 12-mm cables named a-g, A-G and X, Y, with tube numbers given in light-grey. Cable tensioners are in light-blue 'S'. In green, the minimum 32 cable cuts with a roughly indicated stripe. The enlargement shows a special 3-line attachment of a small ring in a corner between two steel cables.

5.3 Phase 2b: Deployment and attachment of the recovery mooring

To bring the cut steel-cable grid including the 45 small rings to the surface, a single 'recovery mooring' (Fig. 5) was deployed just outside of the large-ring. The mooring could not be deployed in free-fall for required high precision location. Instead it was lowered with USBL beacon from the Pelagia down to about 50 m from the seafloor before a short final drop in free-fall.

ROV's final task before demobilization was to connect the 140-m long steel cable of the recovery mooring to the cut steel-cable grid. The ROV pulled the cable from the drum, brought it inside the large ring and attached a hook to the cut steel-cable grid (Fig. 13). After attachment, the ROV completely unrolled the cable from the drum, so that the cable's end-hook could be connected by the ROV to a ring directly under the upright Dyneema mooring line.

Figure 13. ROV attaching recovery mooring hook to the steel cable grid.

5.4 Phase 3: Recovery of the steel-cable grid

After demobilization of the ROV in the port of Toulon, Pelagia's aft deck was emptied to salvage the 17-kN weighing steel-cable grid plus small aluminum rings. Following acoustically releasing the anchor weight and rapid surfacing of the float of the recovery mooring, the mooring line was lifted over the large ring by a combination of hoisting and Pelagia manoeuvring before spooling the 2400-m long Dyneema line.

6. Participants.

	Institute	Name
1	NIOZ	Hans van Haren (PI)
2	NIOZ	Yvo Witte
3	NIOZ	Roel Bakker
4	NIOZ	Barry Boersen
5	NIOZ	Jesper van Bennekom
6	NIOZ	Henk de Haas
7	NIOZ	Zeynep Erdem
8	ROV-Irl	Paddy O'Driscoll
9	ROV-Irl	George Findlay
10	ROV-Irl	Robert Carpenter
11	ROV-Irl	Colin Ferguson
12	ROV-Irl	Karl Bredendieck
13	ROV-Irl	Paul Benjamin

7. Narrative of sea activities (daily summaries)

Sunday 25 February

S5-6. Around 19 UTC R/V Pelagia leaves Toulon harbour for the large-ring mooring location. Weather predictions for the next day are reasonable for the sea-operations.

Monday 26 February

N4-5. After first trials, the ROV is launched around 11 UTC. In the afternoon, 5 vertical lines are recovered.

Tuesday 27 February

W3, <2 m swell. A very productive day. At a regular pace of once per 15 minutes a total of 27 vertical lines are cut by the ROV, picked-up and towed by the working boat, and recovered and stored at Pelagia's stern deck.

Wednesday 28 February

N4-5. After easing of the swell, in the afternoon continued recovery of remaining 13 vertical lines. By 16 UTC the last of 45 vertical lines is on deck. Around 20 UTC the ROV is launched again for cutting the grid. However, a black-out of the rental container caused the ROV to be powerless and thus steering-less. It drifts to the stern of the Pelagia. Luckily due to swift handling of ROV team and ship's crew and officers the ROV comes back on deck safely. During the night the rental equipment service is not responsive.

Thursday 29 February

WNW3-5. After a change of power-supply for the ROV from the rental generator the Pelagia-supply, the ROV is launched around 12 UTC. All 16 cables of the grid are cut on both sides (32 cuts) within 2 hours. After surfacing of the ROV, the recovery mooring is placed flawlessly 40 m SW outside the large ring. The ROV is launched for the final dive and connects the mooring cable to a grid-cable (Fig. 13). R/V Pelagia sails back to Toulon to demobilize the ROV and its team. During the weekend weather conditions are unfavourable for sea-operations.

Monday 04 March

WNW4, <2 m swell. Around 07:30 UTC R/V Pelagia leaves Toulon harbour to recover the insides of the large-ring: the steel-cable grid including aluminum rings and synchronizer. At 11:15 UTC the mooring is acoustically released and surfaces almost instantaneously. The floats are picked up smoothly from Pelagia, and with a hoisting line the mooring is brought to a stern’s winch. With the line attached, Pelagia moves over the large-ring mooring prior to lifting the grid from the seafloor. Hoisting procedes slowly, because the tonnage indicator stays fixed at 1388 kg. During the entire operation the USBL-beacon provides useful information on the position of the release frame with respect to Pelagia. After spooling the 2400-m Dyneema line, the release frame is retrieved and the remaining steel cable is attached to the starboard side winch. The tonnage indicator of this winch works normal and shows large variation in tension due to drag of the hoisted materials and motions of the ship’s stern. Soon, tension is gone and the mooring grid has slipped off the hook. The hook’s safety pal turns out to be damaged. The cable-grid is lost at 42 50.10′N, 006 12.04′E, i.e. 1165 m NNE from position of the (empty) large-ring.

8. Scientific summary and preliminary results

Despite the failure of salvage of the steel-cable grid and aluminum small rings, the cruise was very successful. All 45 vertical lines were flawlessly recovered, Mechanically, all lines were vertical. One line was partially damaged by the parachute release failure in 2020. One other line was looped around a small frame top-buoy support and about 0.5 m lower than planned. All other lines stood upright.

Electronically, the T-sensors worked very well, except for one thing. The 8 GB micro SD-cards did not allow more storage than 30 MB. This translates to about 20 months of temperature data, and 5.5 months of temperature&tilt data. Remaining power was still 3.3 V, well above 3.0 V minimum power level. This severe software, I/O or formatting error is yet to be determined. A slight unfortunate poor functioning of the small Sandisk card reader caused about 25 files to be misread and potentially corrupted before we switched reading cards using a docking station. Nonetheless, these files were readable after conversion. For the rest, after reading all cards and converting the data, the result is really good.

Some statistics of the T-sensors:

We deployed 45 lines with 63+2 sensors = 2925 sensors.
45 lines were recovered.
43 lines were mechanically good, line 1.8 hit by drogue parachute, line 6.5 was about 0.5 m lower due to a loop.
3 sensors leaked, of which of 2 data could be salvaged.
? (<15) sensors missing/fallen off
? (<10) sensors shifted along the cable because of loose tape (new tape, old always holds).
44 lines synchronized typically within 50 ms, only line 3.6 is not.
All sensors stopped before filling 30MB of memory = 20 mo (only T), 5.5 mo (T+tilt).
2902 sensors raw data, of which 2901 remain after conversion providing:
2891 sensors complete data of 105MB (incl. 3 90-95% good)
10 too small (<60kB)

Preliminary result before inspection of data: 97% score (if the 30-MB blocking is not taken into account).

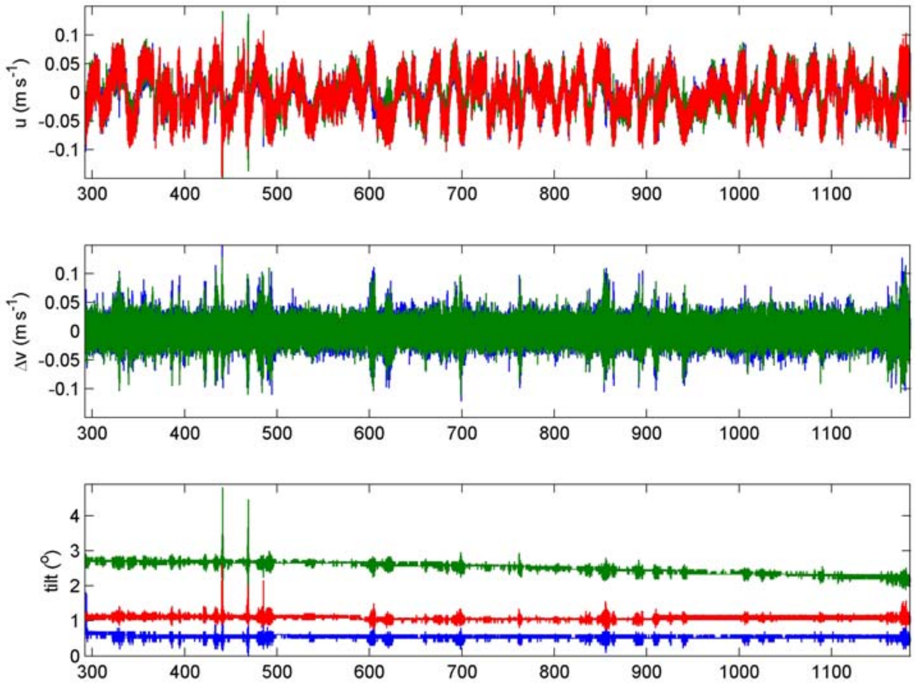

Figure 14. Two-and-half years of current meter data. (Top) East-west current component. (Middle) North-south current component differences. (Bottom) Tilt.

All 3 current meters provided data, for almost 2.5 years before their batteries ran out. This was the expected lifetime. Two records showed some checksum errors resulting in 9 and 24 missing records, respectively. These are manually interpolated.

The current speeds seldom exceeded 0.1 m/s (Fig. 14, top), with variations on seasonal and especially about monthly days intervals. The latter are attributable to (sub-)mesoscale variations in the boundary flow. Shorter-scale current variations are hidden in the thickness of lines in Fig. 14, and follow a rough sequence of visible inertial motions, increasing shorter scale variations culminating in a peak and collapse to quiescence. Between the current meters, short-term variations of spiky data are visible in the middle panel of Fig. 14. These associate with short-term internal waves of several hours duration, and which also shake the tilt of the mooring float (Fig. 14, bottom).

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Declaration

Cruise participants consented to use photos and names included in this document.

Acknowledgments

I am grateful to have worked with all on board. It was such a pleasant and professional team, which made the above mentioned excellent result possible. I thank you all, it was a great pleasure.

Texel, 10 April 2024, Hans van Haren