Project	AtlantOS – 633211
Deliverable number	D3.7
Deliverable title	Technical enhancement of TMA sites for data safety & cost efficiency
Description	Current developments of deep sea data telemetry system (capsules, inductive, acoustics) will be reviewed and further developments performed. Technical enhancement will be demonstrated at selected sites and with different platforms (e.g. Myrtle-X lander)
Work Package number	WP3/task 3.3
Work Package title	Enhancement of autonomous observing networks/OceanSITES transport
Lead beneficiary	GEOMAR, DSS, HAV, NERC
Lead authors	J. Karstensen, M. Motz, B. Hansen, K. M. H. Larsen, D Rayner
Contributors	Svein Østerhus, UniRES
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Due date	PM 36
Comments	Deliverables was delayed to consider the community reporting at the OceanSITES general assembly (taking place every 1.5 years) and some recent developments and testing activities by the partners. Further delay because of formatting issues

Last updated: 12 November 2018

Stakeholder engagement relating to this task*

WHO are your most important stakeholders?	☐ Private company If yes, is it an SME ☐ or a large company ☐? x National governmental body x International organization ☐ NGO x others Please give the name(s) of the stakeholder(s): …scientists
WHERE is/are the company(ies) or organization(s) from?	x Your own country x Another country in the EU x Another country outside the EU Please name the country(ies): …
Is this deliverable a success story? If yes, why? **If not, why?**	x Yes, because an SME developed and constructed a system that is now commercially available ☐ No, because …..
Will this deliverable be used? **If yes, who will use it?** **If not, why will it not be used?**	x Yes, the system that was developed is on the market and will be used by the customers buying it ☐ No, because …..

NOTE: This information is being collected for the following purposes:
1. To make a list of all companies/organizations with which AtlantOS partners have had contact. This is important to demonstrate the extent of industry and public-sector collaboration in the obs community. Please note that we will only publish one aggregated list of companies and not mention specific partnerships.
2. To better report success stories from the AtlantOS community on how observing delivers concrete value to society.

*For ideas about relations with stakeholders you are invited to consult D10.5 Best Practices in Stakeholder Engagement, Data Dissemination and Exploitation.

Executive Summary

In the Ocean Observing Value chain the timely access to data is of key importance. Only data that is available in a timely fashion can be used for downstream integration and services. What "timely" means depends very much on the type of service that is targeted: for a deep sea time series that aims to monitor multiannual temperature or oxygen trends/variability that might be related to climate variability a data retrieval every 6 month, or even every year, could be "timely". In contrast, for upper ocean observations that are utilized in operational oceanographic downstream services daily (or even higher, e.g. for SAR applications) access to data might be needed.

Here we report on technology that target the "real-time" data access to survey climate variability aspects. This data is of particular use for verification of numerical model simulations but likewise for initializations of the deep ocean compartments of such models. It particularly addresses data from the region below the "Argo depth" (2000m) and data from energetic boundary currents. More specifically technology for data from Transport Moored Arrays (TMA) is considered. TMA are assemblages of moorings that are designed to monitor volume and property transport. The moorings are complex constructions and in particular the costs for the servicing of the moorings (ship time, staff time, consumables) is significant. Multiyear long deployment periods at TMA sites are desirable - to save costs and also to minimize variations in the experimental setup. The timely and safe data retrieval from such moored instrumentation serve three equally important requirements: (1) Data safety – periodic data retrieval from moored sensors will serve as a backup for the data. (2) Data verification – periodic data retrieval will ensure functioning of the sensors. (3) Cost saving – periodic data retrieval will facilitate in some cases a longer deployment period, thus less personnel and operation costs will be spend. Data access via telemetry is relevant for many real time but also climate observations.

In AtlantOS task 3.3 we looked into existing data telemetry for TMAs. The implementation of subsea real-time data telemetry systems (*DW.SRB*) was proposed by one SME (Develogic) and task 3.3 partners contributed with component tests. Furthermore, two other system that were already under development, the *Myrtle-X* and the *Expendable trawlproof bottom temperature logger*s) were further tested and refined. A waveglider based acoustic modem solution was also tested. This deliverables reports on the remarkable progress on the data transmission technology for moored installations during the AtlantOS lifetime. We acknowledge the demand (market) for such technology documented by the institutions involved in developing and testing. We appreciate that systems exists that are commercially available (Develogic & the KTH Royal Institute of Technology, Stockholm, Sweden) and which will ensure more reliable and save data transmission for long term monitoring activities.

1. Introduction

Oceanographic data telemetry systems allow to access data from sensors that are in a sampling mode installed at sea. The data access may serve at least two purposes, first to evaluate and analyze data in a quasi-continuous way, and second to create an "off-site backup" while the instruments are still deployed and recording.

Considering differences in technology and design two types of telemetry systems are addressed here: systems that are permanently at the surface and thus can provide data in a quasi real time stream (**surface telemetry systems**), and systems that collect sensor data and store it a subsurface module and occasionally releases data messengers or is read-out from ships or other surface(ing) vehicles (waveglider, electric underwater glider) (**subsurface data telemetry systems**).

Surface telemetry systems allow rapid data access to data and as such are in use where analysis and predictions of "ocean weather" or "hazards or ocean extremes" are targeted (comprising periods from sub-hourly to several days; e.g. CMEMS products, El Nino state analysis and forecast, SAR applications or DART "Deep-ocean Assessment and Reporting of Tsunamis" buoys, Meinig et al. 2001). A typical surface telemetry system requires a buoy that stays permanently at the ocean surface and transmits data to shore at defined time intervals. Commercially available surface telemetry system on the market include the SEAWATCH from Fugro, Data.Buoy SB.600/1000 by Develogic or Surface Buoy Systems by Mooring Systems, Inc.). A surface buoy on top of a conventional subsurface mooring not only adds substantial costs but also increases stress, wear-and-tear and exposure to fishing activity and ice drift. Moreover, various mooring installations target observing of the deep ocean and an extension to the surface is in many cases not envisioned.

Subsurface telemetry systems are used in cases were no surface buoy can/shall be installed but still a need for data retrieval exists. Typically these systems feature a subsurface data collection and storage unit to be accessed via data messenger buoys (sometimes called "pop-up" buoys) that rise to the ocean surface and commence data transmission to shore via satellite or other telecommunication or via underwater acoustic communication between the data collection unit and a ship or another suitable platform (glider, waveglider). (Note, we are leaving here aside any deep sea cable solutions.) Subsurface data telemetry systems have been sparsely used, mostly in bottom lander installations.

The most frequently used system is probably the PIES (Pressure Inverted Echo Sounders, Howden et al. 1994, Watts and Rossby, 1977) system. The system uses low bandwidth underwater acoustics to read out data from a bottom lander at occasional ship visits at the mooring location. Belonging to the same family, is a data retrieval system of the "Multi Year Return Tide Level Equipment" (MYRTLE; Spencer and Foden 1996, Spencer and Vassie 1997). The scientific mission of the PIES and Myrtle instruments benefit from least possible movement of the equipment during the deployment and the telemetry systems are exclusively designed for a stable seafloor installation ("lander installation").

A system that was specifically designed for integration into a mooring line (away from the seafloor), is the "Data Capsule Magazine" (DCM), developed during the ULTRAMOOR project (Fyre et al. 2002, 2004). The ULTRAMOOR project started in 2000 with the purpose of designing and testing multiyear (5 years was the target) mooring deployments. The DCM consists of an acoustic receiver that collects data from moored instruments which in turn are all equipped with acoustic transmitters. A module in the receiver unit uploads the data into expandable data capsules

(original design was up to 10 capsules), each holding up to 4Mbyte of data. The capsules are released (via burnwire) at pre-defined time intervals (Fyre et al. 2002, 2004). DCM system never reached a routine use and also is not commercially available (reasons are unknown to the author group).

In the context of EU projects some development activities have on subsurface telemetry systems been undertaken (FP7 THOR; FP7 NACLIM; H2020 Blue-Action). In THOR two systems, one based on underwater acoustic ("Bergen System") and one being a pop-up system (OPTIMARE system) were further developed and tested. However, both systems are not commercially available.

Here we specifically report on three other systems: one developed at the SME Develogics with input from the AtlantOS partners, one developed and tested by partner NERC/NOCS (Extended Myrtle system) and one developed and tested by partners HAV and UniRES (Expendable trawlproof bottom temperature loggers). For completeness, the results of the former EU efforts (THOR and NACLIM) are included in the systems description below.

2. Systems

Any telemetry units comprise essentially three components/compartments: (i) a data assembly and collection compartment, (ii) a compartment that ensures data transmission to the sea-surface (pop-up, acoustic or permanent surface module), and (iii) a compartment that transfer data from the sea-surface to the data centres (surface platform such as buoys, ships, underwater gliders or wave gliders or pop-up modules that contain a data telemetry unit e.g. Iridium satellite link).

The functioning of all three compartments AND the seamless interfacing of the three compartment is of critical importance for the successful transmission of data to the data centres and subsequently to the data users.

2.1 THE DEVELOGIC SYSTEMS

Develogic subsea systems (called here "Develogic") is a German-based company founded in 2000 with a focus on developing and manufacturing turn-key customized data-acquisition and telemetry solutions for marine monitoring applications. Develogic develops and sells a wide range of ocean observing products for multiple applications. Of relevance for this deliverable are telemetry buoys (MI.SAT I & II) and the PopUp buoy technology implanted in the product "Satellite Recovery Beacon – DW.SRB". MI.SAT and the DW.SRB allow downloading data/exchange (bi-directional) data via a satellite link from equipment that is drifting at the surface.

The main characteristics of the MI.SATII modules are:
- Integrated GPS Trimble I
- Iridium SBD satellite link
- LED flasher
- Exchange with sensors via inductive link
- Surface pressure sensor integrated (main difference to module MI.SAT I)
  - Initial accuracy 0,3mBar
  - Pressure resistant (no hysteresis) to 300 m (30 bar)
  - Accuracy of temperature sensor integrated into air pressure: +/-0,2°C
- LED Flasher
- External configuration and testing (MCBH6F)
- Integrated Data logger

- Position-alarm
- Remote configuration
- Rating:
  o Buoy made of syntactic foam; pressure resistant to 1100m (110bar)
  o System housing; pressure resistant to 6000m (600 bar)
  o Antenna dome; pressure resistant to 400m (40 bar)

The main characteristics of the DW.SRB modules are:
- Integrated GPS
- Iridium SBD satellite link
- LED flasher
- Surfacing detector
- Ambient brightness sensor
- Backup battery (keeps system alive for up to 2 weeks when external power supply fails)
- Depth rated antenna and sensor module
- Integrated data logger
- Plug and play with other develogic modules

For the DW.SRB modules, once at the surface (released from the bottom unit) the standard operation mode is the periodic transmission of the GPS position via IRIDIUM SBD and activation of the integrated flasher. In addition, it is possible to communicate bi-directionally with the module – e.g. for downloading only part of the sensor data, reconfiguring the pop-up e.g. for recovery. So far, the lander based system has been used by NOC (Southampton, UK), Trianel (wind farming), the German Navy, UNC (Chapel Hill, USA), NIVA (Oslo, Norway), TechnipFMC (Houston), StatOil/Equinor, ABB, Total, Petronas, Sintef, Interwell and numerous other customers. The MI.SAT buoy has been used by GEOMAR, NIVA, Ocean Institute Monaco and various other customers.

The expendable pop up buoy system consists of two components: a mechanical release with integrated wireless data and power transmission interface and the actual popup buoy that locks into the release (Fig. 1) and can be triggered based on a pre-programmable schedule, violation of thresholds in the acquired data or by sending a command via acoustic communication from the surface.

Fig. 1: Release mechanisms of the DW.SRB

The operating principle is that sensor data from the lander or mooring installations data logger is periodically forwarded into all remaining popups of the installation in parallel. During the data forwarding phase, the electronics in the popups are powered via the wireless power transmission from an external power supply – the internal battery pack is disconnected.

Immediately prior to ejection, the popup internal battery pack is connected, the satellite transponder activated and then the popup is released.

Upon surfacing the popups periodically transmit the position and system health status. Selective data transfer of the data stored in the popup has to be initiated from the remote side by sending corresponding download commands.

In addition, if actual retrieval of the unit is possible, a LED strobe can be activated via a satellite command to support the recovery by a vessel.

2.1.1. System Tests with the Develogic Systems

Surface telemetry tests

A critical component for surface telemetry systems is the surface element (a buoy or a pop-up) that broadcast the data either being stored (in the pop up case) or retrieved via inductive links (in the real-time case MI.SAT). Some limitations in the performance have been reported in rough seas were the antenna is not fully exposed to the sky.
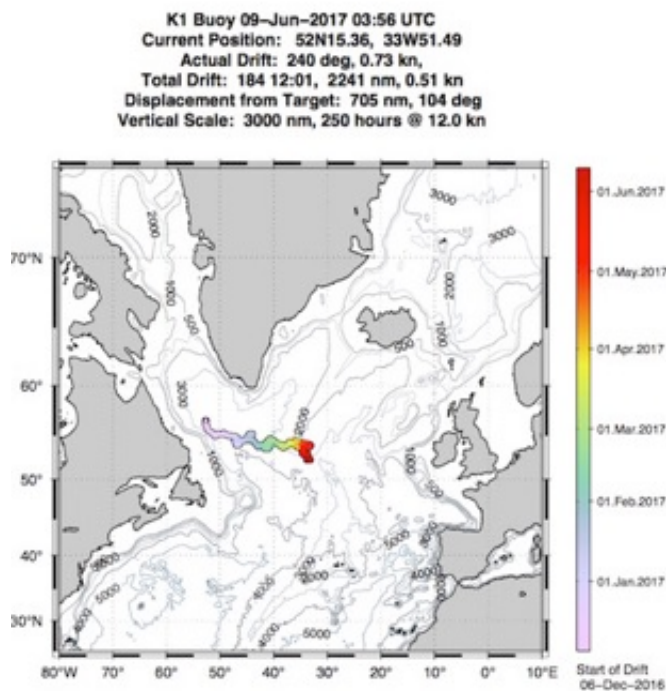

Fig. 2: Drift path map (automatically generated via the GPS positions)

GEOMAR has performed several transmission tests for the surface telemetry using the MI.SAT/DW.SRB system that is sending data via an Iridium SBD satellite link. The systems were deployed in the North Atlantic in contrasting areas – an area in the trade wind region (at 17°N/23°W) with steady wind and wave conditions and high wind /wave installations in the Labrador Sea (56°33'N/52°39'W) and Irminger Sea (59°31'N/39°47'W). Endurance time and functionality of the "port.8" is a key component for long installation with MI.SAT/DW.SRB.

Mechanical problems for the MI.SAT system led to a break off of the surface element in December 2016 from the mooring in the Labrador Sea (see map Fig. 2) In June 2017 a vessel was identified that could eventually rescue the drifting buoy. However, the attempt failed and shortly after the batteries were empty and no further rescue possible. The manufacturer improved the design and now the system only requires 33% of the power allowing much longer deployments to be realized.

North Sea Installation in NOC Lander (contributed by Mario Esposito, GEOMAR)

The Pop-up system release and data communication in an NOC-Lander (develogic SSL.150c Shallow Water Seafloor Lander) was tested in the North Sea in 2017 (Fig. 3). The lander was deployed during the POSEIDON POS518 cruise and the responsible on board was Mario Esposito

(GEOMAR). This installation was not in any case financially supported by AtlantOS but we feel that the information is of relevance for the report here.

The NOC lander (Figure below) is composed of four main parts:
- A trapezoid shape trawl resistant frame
- A fully integrated solution with all mechanical and electrical components accessed and configured via interface connection or acoustic telemetry
- A recovery subsystem with 250 m tether reel connected to a ballast plate through a DW.R1000 titanium release
- A surface hydro-acoustic modem with a 35 m rugged Kevlar reinforced cable for real-time communication

The system has an integrated acoustic modem HAM.Base VHF for communication and data logging, a satellite recovery beacon DW.SRB for transmission of GPS position via IRIDIUM satellite telemetry at surface, an integrated Sono.Vault II HF acoustic recorder, an integrated depth sensor Keller PA33Xc, a conductivity and temperature sensor Seabird SBE37-SM and a set of 6 ECB popup telemetry units (Popup Data Ferry DF.2000) for data transmission via IRIDIUM satellite telemetry. The units contain an additional Port8 data logger fully integrated with a Seabird SeapHOx pH and O_2 sensor, 3 NOC Lab-on-Chip chemical sensors for inorganic nutrients (nitrate, phosphate) and pH and an Acoustic Doppler Current Profiler Nortek Signature 250.
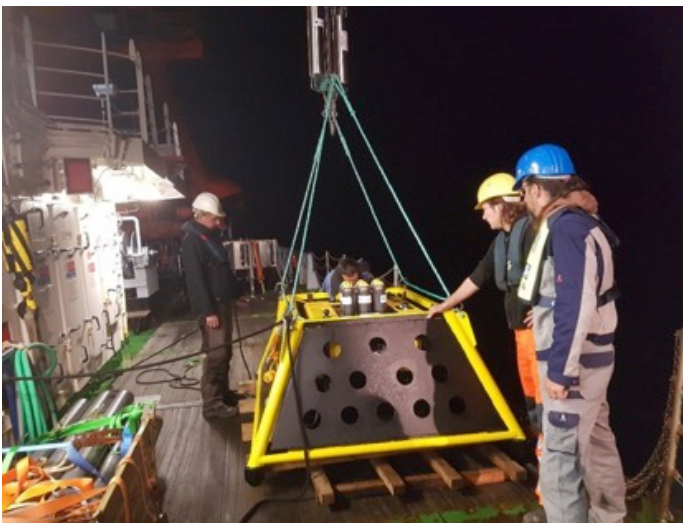

Fig. 3: Lander deployment during POS 518

The ECB Popup Launcher can host up to 6 Popup Data Ferries (DF.2000/6000) or Expandable Communication Beacons (ECB.500) (see photo on the right). The launcher units host an integrated release and an opto-inductive ECB/DF interface. The data from the Port.8 data logger can be mirrored into the individual popups. The Popup ups are rated to 2000m, and are equipped with an Iridium SBD transponder. They can be configured for push or pull transmission, include a Trimble 32ch GPS receiver (positioning) and a bright, configurable LED flasher with ambient light sensor. They are made from hard anodized Aluminium, can carry 8 size D batteries (e.g. LSH20). Total storage is up to 128Bbyte. They are available in 2000 and 6000m depth rating (DF.2000 or DF.6000). Diameter is 100mm and the length is 1015mm.

For the North Sea tests the Pop-ups release scheduled event
1st pop-up on 01/12/2017 at 08:00 UTC
2nd pop-up on 01/03/2018 at 08:00 UTC
3rd pop-up on 01/06/2018 at 08:00 UTC

None of the three popup initially reported data after ejection. One popup initiated satellite communication after being washed ashore in Scotland – unfortunately the popup was taken by

the sea again before recovery was possible. Another popup was found by chance in Norway and recovered (see picture below).

What has been identified as cause for the communication problem a plastic protection grid over the glass sphere that – after longer submerging – got saturated with seawater that lead to shielding the high frequency satellite communication (see yellow protection cap Fig. 4).

Fig. 4: Original DW.SRB before improvement (plastic cover possibly degraded antenna performance)

A revised popup design fixing the shielding problem and taking into account several improvements regarding the data uplink and the popup release was implemented and recently successfully tested offshore Rügen in the Baltic sea during various lander deployments together with the FWG/Kiel (Fig. 5).
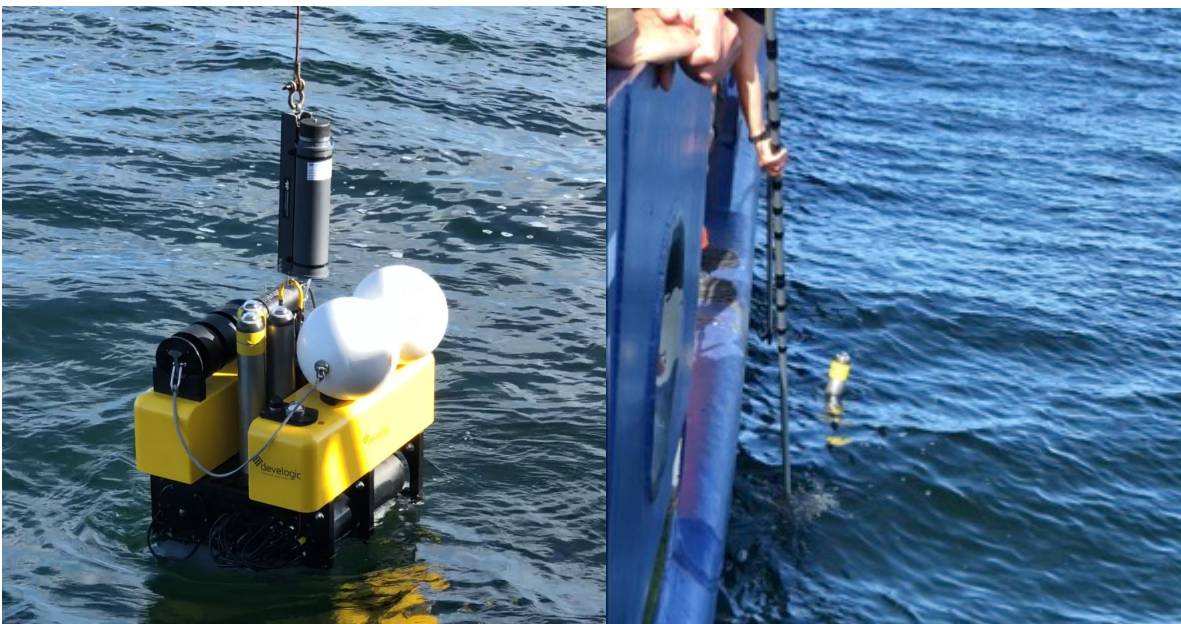

Fig. 5: Develogic Lander with DW.SRB popups - deployment

2.2 THE NATIONAL OCEANOGRAPHY CENTRE SYSTEMS

The National Oceanography Centre collects data from an array of moorings that span the subtropical Atlantic from the Bahamas to the continental slope of Africa. Data from the RAPID 26°N array is used to calculate a time series of the Atlantic Meridional Overturning Circulation (AMOC) that is widely used by ocean and climate scientist. Interannual variability of the AMOC, and the associated northward heat transport, has been identified as a possible precursor of regional climate variations (e.g. Buchan et al. 2014, Blaker et al., 2014), and it has been suggested that AMOC variability could be used to predict sea surface temperature anomalies in the North Atlantic with a 5-month lead time (Duchez et al., 2015). For these reasons, the RAPID 26°N team would like to increase the frequency at which the data is made available to the scientific community. Additionally, as the length of mooring deployments increases so does the risk of data loss. To address the needs for more frequent data return and improved data security, the RAPID 26°N team have been working on two telemetry systems, both of which will be deployed operationally for the first time in Autumn 2018.

Initially telemetry systems were developed that were housed in surface buoys. However, these suffered significant damage and increased the risk of damage to the moorings too. Therefore, the development of a lander-based system (MYRTLE-X) was started in 2012. In 2016 work began on a second telemetry system using an autonomous surface vehicle, the Liquid Robotics Wave Glider. For both of these systems it is possible to telemeter data from moorings that do not have a surface expression.
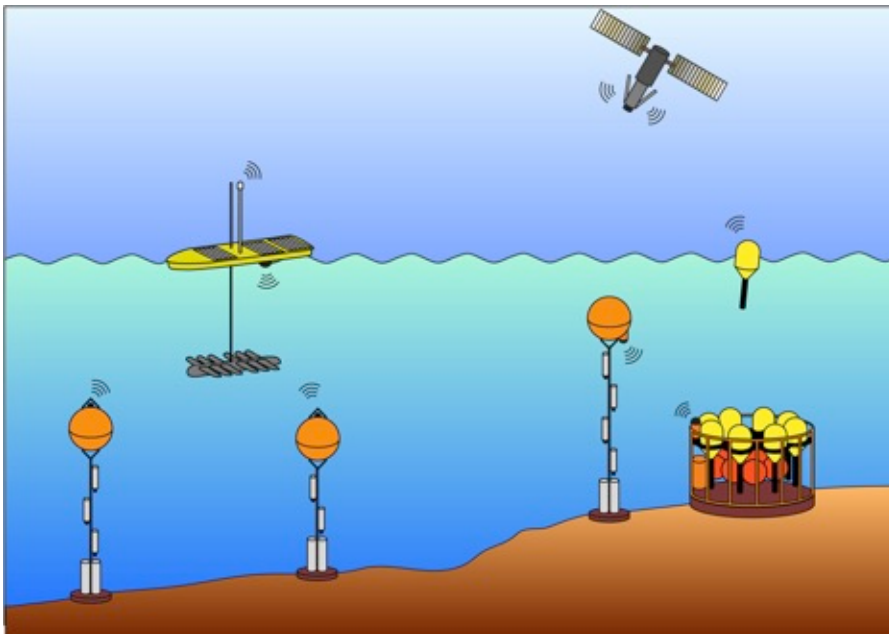

Fig. 6: Schematic of the two NOCS telemetry systems. The Wave Glider (left side) can service multiple moorings. One MYRTLE-X lander (right side) is required for each mooring.

The two NOCS telemetry systems (Fig. 6) share a common telemetry buoy on each mooring from which data is telemetered. The mooring controller gathers, using inductive communication via the mooring wire, and processes data from the instruments. The data are then transmitted acoustically, either downwards to the MYRTLE-X sea floor lander or upwards to an autonomous surface vehicle. The MYRTLE-X lander periodically releases data pods that rise to the surface and transmit data via Iridium satellite communication. In the case of the Wave Glider, data are sent directly from the vehicle via Iridium.

The telemetry buoy (Fig. 7) is a bespoke 1.2 m diameter syntactic float with cut-outs and clamps to hold the mooring controller, acoustic modem, modem battery and mooring beacons. The float can

withstand submergence to 5000 m allowing flexibility on where it is deployed on the array, where the choice of deployment depth varies depending on the mooring height, seabed depth and whether the modem is pointing down to the MYRTLE-X lander near the base of the mooring or pointing up towards the Wave Glider on the surface.

Benthos ATM-960 series acoustic modems with a low-frequency omni-directional transducers are used in both systems. Typical ranges with this modem and transducer are stated as between 2-3 km for horizontal ranges, but up to 6 km vertically. The Benthos modem has a memory card which is used to store data. The mooring controller writes the compressed instrument data and some diagnostic information to the modem memory card. The partner modem, controlled by the lander or Wave Glider, initiates the connection to the moored modem using a pre-set address number and then pulls the data off the moored modem's memory card before onward transmission.

The inductive communication worked successfully throughout the 18-month deployment of a telemetry buoy on mooring EBHi of the RAPID 26°N array from autumn 2015 to spring 2017.

Fig. 7: (Left) - The syntactic float telemetry buoy following recovery from trials in early 2018 (left). Right – a close up showing the components. The dark grey pressure case on the left houses the mooring controller electronics; in the black central clamps is the Benthos moored acoustic modem and batteries; in this float the acoustic modem transducer is mounted opposite the mooring controller (just visible behind the float metalwork) and is therefore pointing down for use with the MYRTLE-X lander; mounted to the cross bars of the float metal work is the Sea-Bird inductive coupler through which an electrical cable passes – this cable is connected to the inductive swivel mounted to the framework at the bottom of the picture with the other end of the swivel connecting to the mooring wire.

2.2.1 The MYRTLE-X lander telemetry system

MYRTLE-X (Fig. 8) is a seabed lander that was originally designed for the deployment of pressure sensors (Spencer & Foden, 1996). The design has been changed to add electronics necessary to control the acoustic modem so that the lander controller can receive data from a mooring and write it to each data pod. The data pods are 17-inch diameter glass spheres with an infrared

modem to receive data from the lander controller, and an Iridium satellite modem to relay data to shore once at the surface.

Fig. 8: The MYRTLE-X lander following recovery from trials in early 2018. The orange painted aluminium frame provides the structure with orange, hard-hat covered glass spheres in the middle of the frame providing buoyancy. The MYRTLE electronics are housed in smaller glass spheres spread around the bottom

Following an unsuccessful trial on the RAPID 26°N array, from autumn 2015 to spring 2017, the system electronics and software were re-engineered in 2017. In Spring 2018 a deep-water trial was conducted off-shore of Gran Canaria. The two-month deployment showed successful unattended operation of the mooring controller and inductive communications part of the system and partial success with the acoustic transfer and automatic data pod release. Following the trials, faults were traced to firmware on the data pods and on the lander controller. These faults have now been fixed and the system is scheduled for deployment on the western boundary of the RAPID 26°N array in November 2018.

2.2.2 The Wave Glider system

A Wave Glider (Fig. 9 a) is an autonomous surface vehicle developed by Liquid Robotics. It uses the difference in wave motion experience by a surface unit and an 8m-deep sub unit to provide propulsion, with solar panels and rechargeable batteries powering the on-board computing, sensors and communication systems. An Iridium satellite modem allows control of the both the vehicle and the payload sensors remotely with data from the sensors relayed to shore as required.

Figure 9: a) Wave Glider Sennen following recovery from trials off Gran Canaria in early 2018. The yellow float unit sits on its troller with the bladed propulsion sub-unit beneath and the umbilical connection the two laying on the floor to the left. A second NOCS Wave Glider (Waimea – not equipped with the RAPID telemetry system) sits behind on the quayside. B) The Benthos acoustic modem transducer as mounted in the hull of the Wave Glider.

The telemetry system we use with the Wave Glider builds on a system called "Hotspot" that was developed at the Monterey Bay Research Institute (MBARI) (O'Reilly et al., 2015) (Fig. 9b). The telemetry components are housed in a separate payload box, which contains a processing computer and the acoustic and Iridium modem electronics. An acoustic modem transducer has

been integrated into the hull of the Wave Glider (Fig. 9b) and a second Iridium antenna fitted alongside the one used for Wave Glider communications. The second Iridium antenna allows direct communication with the Hotspot payload without having to go through the Wave Glider controls systems.

The system completed successful deep-water trials off-shore of Gran Canary early in 2018 and a mooring buoy is scheduled for deployment on the eastern boundary of the RAPID 26°N array in October 2018. The first collection of data from the RAPID 26°N array via a Wave Glider is scheduled for December 2018.

2.2.3 Operating scenarios

The Wave Glider system

There are three advantages of the Wave Glider system:
- With two-way communications to the Wave Glider there is the possibility to try and rectify any issues that might be encountered when communicating with the mooring controller.
- A single vehicle can be used to communicate with multiple moorings.
- It is possible to gather near-surface data that can be used to improve the extrapolation of mooring data to the surface.

The disadvantages are:
- The operating costs are relatively high when compared with a lander. It is possible that the costs could be reduced in the future as new piloting systems are developed that make less demands on human pilots.
- Operation in strong currents could be challenging. Before deploying on the western boundary of the RAPID 26°N array, it would be advisable to conduct some model simulations to determine how well the vehicle could be navigated.

This system is well-suited for operation on the eastern boundary where data from multiple moorings is needed.   It would also be possible to extend the Wave Glider missions to visit the mid-Atlantic ridge array. However, a round trip would take about 4 months from Gran Canary.

The MYRTLE-X lander system

The advantages of the lander-based system are
- Low operating costs. Excluding the costs of cruises for deployment and recovery, operating costs are significantly less than for the Wave Glider.
- Once successfully deployed, it is not affected by surface currents.

The disadvantages are
- Large capital cost of additional systems.
- There is little that can be done to address any issues that arise until the system is recovered.

MYRTLE-X is well suited for deployment on the western boundary of the RAPID 26°N array where currents are strong but only two moorings are required to be telemetered. It would also be suitable for use over the mid-Atlantic Ridge.

2.3 Expendable trawlproof bottom temperature loggers

In addition to surface wave and wind impacts, the ocean observing installations are often hampered by heavy fishing activity in the monitoring region, as exemplified by the currents transporting warm and saline Atlantic water across the Greenland-Scotland Ridge into the Arctic Mediterranean. In these regions, traditional mooring arrays eventually get caught and lost in fishing gear, especially trawling is a serious threat. For observations using upward-looking ADCPs (e.g. volume transport) which are moored below the depth of trawls or deployed in trawlproof frames on the bottom the risk is minimized but observing properties along with the currents to estimate heat and freshwater transport the situation is different as T and S observations are required to be recorded at different depth. For an oceanic set up where currents flowing over a slope region, a partial solution is to monitor bottom temperature at several depths on a monitoring section crossing the slope. Such Bottom Temperature Loggers (BTLs) need to be protected by robust frames, which easily become heavy and recoverable systems tend to be expensive. An alternative strategy, using expendable BTLs, was initiated in FP 7 NACLIM and has been used and further developed within AtlantOS WP3.3. and other projects by partners HAV and UniRES. Two versions have been developed (Fig. 10). Both versions are designed to be deployed onto the bottom where they record bottom temperature at the site at hourly (programmable) intervals for a period of years. The main difference lies in the method of data recovery – one is using acoustic telemetry the other a pop-up system.
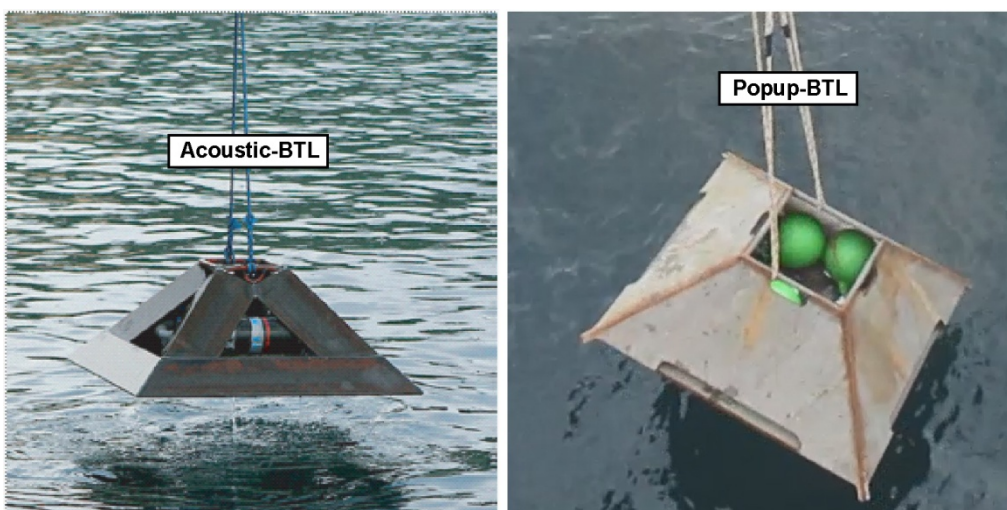

Fig. 10: The two different types of trawlproof bottom temperature loggers (BTLs).

The first BTL version, here termed Acoustic-BTL, consists of a temperature recorder (SeaBird SBE39) connected to a LinkQuest underwater modem (UWM2000). Both of these are powered by external battery packs with alkaline D-cells in two LinkQuest battery housings. Data are recovered by acoustic communication between the underwater modem of the BTL and a surface modem lowered from a vessel over the site. Establishing contact, uploading data, and restarting data logging typically requires 15 minutes for half a year of hourly temperature records. A prototype of this version was deployed on the section of the TMA that monitors the Faroe Current (Hansen et al., 2015) in October 2014. From this test deployment, data were successfully recovered twice, the last time after 11 months, but since then, it has not been possible to establish contact with this prototype. Based on this, the design was modified to provide better mechanical protection of the instrumentation and four new systems have been built and deployed. Two of these were deployed on the Iceland-Faroe Ridge together with an ADCP in a trawlproof frame to measure the overflow through a passage (the Western Valley) close to the Icelandic end of the ridge. The two BTLs in this experiment performed optimally and delivered the planned data (Hansen et al., 2018). In addition

to this, two Acoustic-BTL systems have been deployed in the Faroe shelf/slope region in October 2015. These two systems have so far delivered 34 months of data each and were fully operational at the last data upload in August-September 2018.

The other version of BTL, here termed Popup-BTL, is based on the LoTUS buoy developed by the KTH Royal Institute of Technology, Stockholm, Sweden (commercially available at http://www.lotussensing.com). The LoTUS buoy is designed to stay submerged for periods of months/years, during which it measures in situ temperature at regular intervals, before surfacing at a pre-programmed time for satellite communication with land based stations. The Popup-BTL is then designed simply to provide a protective frame, from which the LoTUS buoy can escape at the pre-programmed time. In the present version, the frame can contain up to four buoys (green spheres inside the Popup-BTL frame, see Fig. 10), which are programmed in this case to be released after periods of 1, 2, 3, and 4 years, respectively. This provides redundancy since each buoy contains the data of the buoys planned to be released previously. A prototype version of Popup-BTL containing only one LoTUS buoy, funded by AtlantOS, was deployed in October 2017 on the section of the Faroe Current TMA and is planned to be released in November 2018. A new system with four buoys was deployed at the same site in June 2018. At the same time, an additional Popup-BTL system with three buoys was deployed on the monitoring section of the TMA that is monitoring the Faroe Bank Channel overflow (Hansen et al., 2016).

Both of these two different BTL versions have similar production costs (20-25 k€) and are designed to deliver hourly temperature measurements over similar length of time (≈4 years). Only time can show, how well they will perform in long-term operation. The performance of the Popup-BTL funded by AtlantOS will be reported in the final progress report.

2.4 Earlier systems

For completeness we also mention here briefly the earlier systems that also showed some promising results but could not be further developed due to different reasons.

The OPTIMARE® Mooring PopUp system

The system goes back to a PIES system but was modified to be installed in a conventional steel wire mooring. The initial tests of the OPTIMARE® Mooring PopUp system as part of the FP7 NACLIM addressed the stability of the messenger buoys mounting rack and the fixation of the buoys within the burnwire release brackets on the frame (Fig. 11). For the typical "anchor-last" deployment of a mooring, the frame (along with other instrumentation) must be capable of handling a tow behind the ship for several hours, steaming at 3-4 knots.

Several communication tests of the Iridium RUDICS system where performed, on land and in shallow water. In August 2011 the first long-term deployment of the OPTIMARE® Mooring PopUp system was made. This time, the system was incorporated into a full water depth (2700m) mooring. The collection of data as well as the launch of the four buoys worked as programmed. Unfortunately the communication with the base station did not work and as such no data was transmitted.
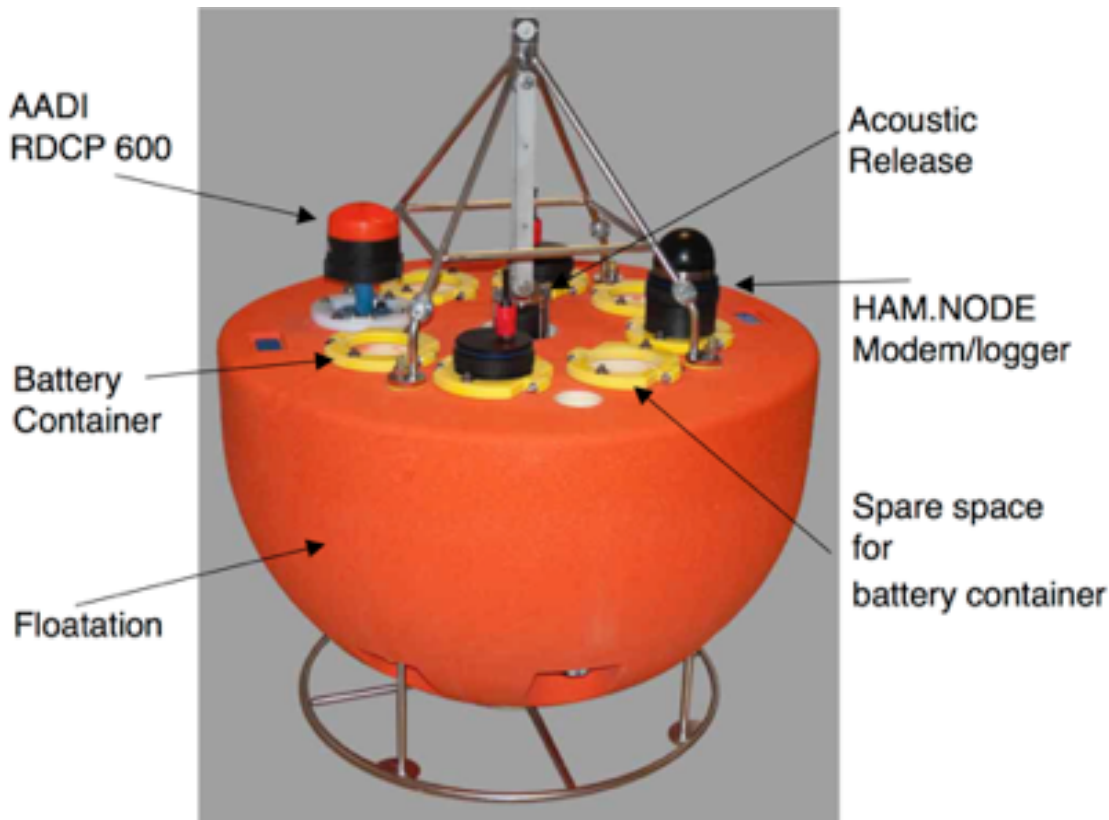
Fig. 11: The OPTIMARE Mooring PopUp system ready to be launched for a test deployment.

The Bergen AADI® SmartSub System

The Bergen AADI® SmartSub System (Fig. 12) used a central data collection node mounted in the buoy and recoverable via acoustic telemetry e.g. from a ship. Tests were conducted in Fanafjorden, (Norway) at a water depth of approx. 200m. Data from an AADI R-DCP600 current profiler with additional sensors (temperature, conductivity, pressure) were successfully retrieved via reception modem lowered over the side of the ship. An open ocean test in the Faroe Bank Channel and Barents Sea in 2010 were made. Data from all deployed platforms were retrieved acoustically via ship-based receiver modems. The sensor payload configuration of all of these systems included an AADI R-DCP600® current profiler with additional sensors (temperature, conductivity, pressure, oxygen), connected to a serial port (RS422) of the HAM.NODE®-based Develogic® hydro-acoustic modem and data logger device.

The hydro-acoustic modem multi-carrier modulation scheme allowed bandwidth efficiency. To minimize the degrading effect of noise on the data transfer, the ship was adrift during the readout and periodically steamed back upwind of the nominal position. For the data retrieval at the Faroe Bank Channel (800m water depth) we observed 4000bps data transfer rates for shortest distance (ship was over the instrument) and rates degrading to 800bps when being about 1nm horizontally off the position, and which prompted us to steam back, upwind of the instrument position.
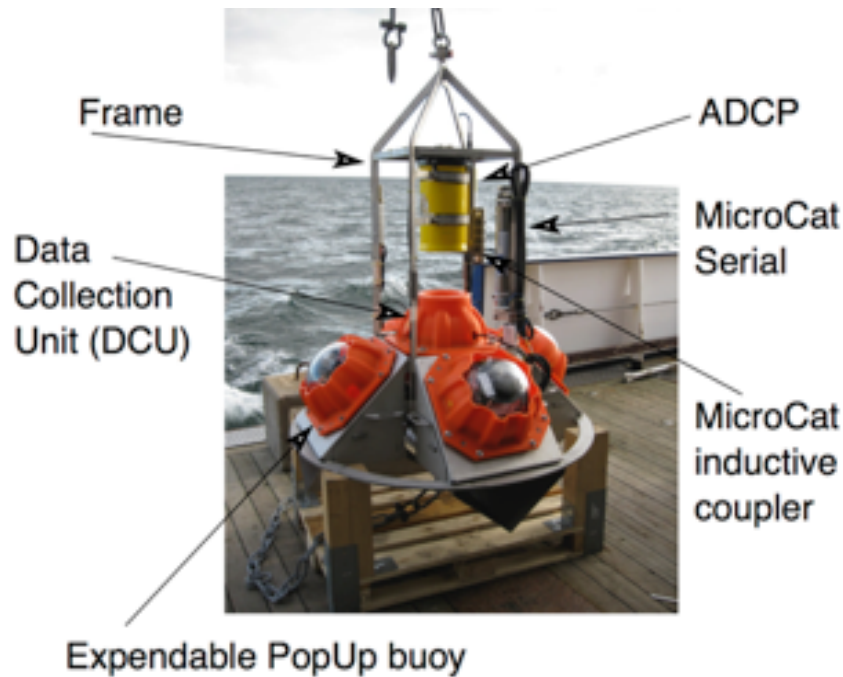
Fig. 12: The Bergen AADI® SmartSub system.

3. Conclusion

Data telemetry systems for climate monitoring applications must serve different purposes than real-time data telemetry systems for operational applications. While for real-time in an operational framework rapid integration (e.g. assimilation) of the data into model system is the most important, the climate data telemetry applications serve three equally important issues: Data safety – by constantly retrieving and storing the data from connected instruments a data backup is compiled. Data verification – by getting access to the data in regular intervals, the existence and the functioning of the installation can be verified. Cost saving – by prolonging the deployment time of the instrumentation significant personnel and operation costs can be saved.

Three systems have been tested and partially developed in the framework of the AtlantOS project – The implementation of subsea real-time data telemetry systems (*DW.SRB*) was realized by our SME partner (Develogic) and further task 3.3 partners contributed with component tests. Furthermore, two other system that were already under development, the *Myrtle-X* and the *Expendable trawlproof bottom temperature logger*s were further tested and refined. A wave glider based acoustic modem solution was also tested. Overall a remarkable progress on the data transmission technology for moored installations during the AtlantOS lifetime can be reported. It can be reported that the three systems marched from a technological readiness level (TRL) 4 ("Trail"; in reference to the Framework for Ocean Observing TRL categories; UNESCO 2012) via TRL 5 ("Verification") to TRL 6 ("Operational").

We acknowledge the demand (market) for such technology documented by the institutions involved in developing and testing. We appreciate that now data retrieval systems exists for subsea data transmission which are commercially available (Develogic & the KTH Royal Institute of Technology, Stockholm, Sweden). More reliable and save data transmission for long term monitoring activities is ensured.

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Dissemination so far is presentations and posters at meetings:

Telemetry Solutions for Realtime Data from Mooring Arrays. Darren Rayner, Stephen Mack, Peter Foden, Hannah Wright, John Walk, Chris Balfour and MARS. Poster at 2018 International AMOC Science Meeting

Development and Field Trials of Two Autonomous Telemetry Systems for Transferring Data from the RAPID 26°N Array. Presentation at the Marine Autonomy & Technology Showcase, Southampton UK November 2018.

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