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A strategy for meeting the needs for marine-based research in the Arctic

Deliverable 6.5. Key technologies for an improvement of ship-based and autonomous measurements in the Arctic Ocean

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1. Introduction

The Arctic region plays a fundamental role in the climate system and responds rapidly to climate change. The associated warming has strong impacts on the region and its communities, with the loss of sea ice and endangered ecosystems and species. Long term climate predictions are still unreliable, due to the lack of systematic in-situ observations and measurements in the Arctic region of and beneath the sea ice.

The exploration and study of the areas Arctic Ocean is technically challenging. Extreme conditions such as low temperatures, together with the presence of ice and strong winds make the Arctic Ocean a complex site to work at.

The equipment used in polar regions is very specialised, as some environmental parameters are intrinsic to the polar regions and need instruments and sensors specifically developed for this purpose, such as sensors to measure parameters related to ice, its extension, thickness and color, among others. The deployment of any equipment in the Arctic Ocean requires a complex infrastructure that involves platforms such as icebreakers and it is logistically complicated. The performance of the science operations is also limited by the ice coverage and the need of complementary technologies such as sensors on satellites or onboard aircraft.

Several technologies have recently evolved leading to an improvement of data ship-based and autonomous measurements in the Arctic Ocean; other technologies and sensors are still missing or in need of further developments. These technologies are reviewed in detail in this report.

In selecting the technologies to address, two perspectives have been considered:

A – **Processes:** complex interactions between atmosphere, hydrosphere, cryosphere and biosphere take place at the air-sea interface. Observations of this interface are important to monitor and understand occurring changes and generate better climate projections of future scenarios. In addition,, a better knowledge of these processes is crucial for marine operations. Satellite and remote sensing techniques are constantly developing, but there is still a need for *in situ* measurements providing information on the vertical column extending from sea surface until, at least, the top of troposphere/stratosphere.

B – **Critical variables:** Some variables are essential to define the earth climate and its changes, and must be taken into account in the design and manufacture of new equipment and sensors. A short overview of the World Meteorological Organization (WMO) Essential Climate Variables (ECVs) is shown below.

2. Variables

The World Meteorological Organization (WMO) defines an ECV as:

> "... a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate."

- **Relevance**: The variable is critical for characterizing the climate system and its changes.
- **Feasibility:** Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.
- **Cost effectiveness:** Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

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Through a long process, the Global Climate Observing System (GCOS) co-sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO), the United Nations Environment Programme (UN Environment), and the International Science Council (ISC), developed a matrix with ECVs needed to systematically observe the Earth's changing climate. A list of important ECVs and products for the context of marine based Arctic research is shown in the table below. For some ECVs the product list is slightly modified to take into account what can be realistically accomplished now from an observing marine platform. The Global Observing Systems Information Center (GOSIC) provides further background, definitions, requirements, network information, and data sources for the ECVs.

Table 1: Essential climate variables in the context of marine based Arctic research (modified from WMO).

ECVs	Products
Atmosphere	
Pressure	*Surface air pressure*
temperature	*Surface air temperature*
Water vapour	*Surface air relative humidity*
Surface wind speed and direction	*Surface wind speed; surface wind direction*
precipitation	*Estimates of liquid and solid precipitation*
Surface radiation budget	*Shortwave radiation budget; longwave radiation budget*
Aerosol properties	*Aerosol optical depth; single scattering albedo; aerosol-layer height; aerosdol extinction coefficient; aersol absorption coefficient*
Cloud properties	*Cloud amount; cloud optical depth; cloud liquid water content; effective particle radius*
Greenhouse gases	*Surface air CO2 concentration; surface air CH4 concentration*
Cryosphere	
Snow	*Area covered by snow; snow depth; snow water equivalent*
Ice Sheets and ice shelves	*Surface Elevation Change; Ice velocity; Ice mass change; Grounding line location and thickness*
Ocean Physical	
Ocean Surface Heat Flux	Latent Heat Flux; Sensible Heat Flux
Sea Ice	Sea Ice Concentration; Sea Ice Extent/Edge; Sea Ice Thickness; Sea Ice Drift; sea ice type; floe size; icebergs;
Sea Level	Global Mean Sea Level; Regional Sea Level

Sea State	Wave Height
Sea Surface Salinity	Sea Surface Salinity
Sea Surface Temperature	Sea Surface Temperature
Subsurface Currents	Interior Currents
Subsurface Salinity	Interior Salinity
Subsurface Temperature	Interior Temperature
Surface Currents	Surface Geostrophic Current
Surface Stress	Surface Stress
Ocean Biogeochemical	
Inorganic Carbon	Surface Ocean Partial Pressure of CO2 (p CO2); Subsurface ocean storage of CO2
Nitrous Oxide	Interior ocean N_2O; N_2O air-sea flux
Nutrients	Interior ocean concentrations of silicate, phosphate, nitrate
Ocean Colour	Water Leaving Radiance; Chlorophyll-a Concentration
Oxygen	Interior ocean oxygen concentration
Transient Tracers	Interior ocean CFC-12, CFC-11, SF6, tritium, 3He, 14C, 39Ar
Ocean Biological/Ecosystems	
Marine Habitat Properties	Coral Reefs; Mangrove Forests, Seagrass Beds, Macroalgal Communities
Plankton	Phytoplankton; Zooplankton

Source: https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables

Several of these ECVs and products have been already considered in ARICE D6.3 and recommended for marine observation ship programs, and are based on consolidated technologies that are often suitable for the implementation of automatic measurements. In the following sections, we will discuss new technologies that will led to an improvement of data collection in the Arctic Ocean.

3. Ship-based measurements

3.1. Research vessels

Research vessels are used today for all kinds of sampling and measurements. Although each ship is different, certain convergences or typical designs have been observed in recent times. New technologies are present from the early stages of research vessels' design and construction. Naval engineers and architects apply new technologies in propulsion, Dynamic Positioning and other ship

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control elements. The equipment needed to deploy sampling devices (like winches, cables, gantries, etc.) has changed in the last years, as well as the use ROVs, AUVs and landers, and the keel acoustics equipment.

Research vessels are nowadays multipurpose platforms that allow all oceanographic disciplines to be addressed. In addition, they are excellent platforms to host instrumentation for atmospheric observation.

Research vessels working in the Arctic Ocean are often equipped with autonomous or towed underwater vehicles and aircraft that make exploration under ice or over long distances possible. The incorporation of drones is an important milestone in the study of sea ice and atmosphere, allowing a better picture of the short spatial scale variability of the ocean surface and atmospheric status. It is also very important from an operational point of view, as contributes to safety at sea, i.e. navigation and search and rescue.

From a design point of view, considering oceanographic observations, PRVs need a moon pool to deploy equipment when the vessel is surrounded by ice. The size and layout of the moon pool will define its research capabilities in these conditions. In addition, vessels that operate in the Arctic Ocean are designed with increased efforts in reducing the carbon footprint, in making ships more "green". Green-ship technology must be improved to provide a more efficient, clean and environmentally friendly motorization systems.

Cables. The irruption of fiber ropes or synthetic cables technology, with less weight or even positive buoyancy, have allowed to reach greater depths with less weight in the water and in the winch. This has also allowed the possibility to perform clean and ultra-clean measurements in the ocean, with very low interaction with the marine environment. Especially in the measurements made with CTDs which need a lot of cable in the same area working at high depths.

Winches. New technologies have improved winches allowing a very tight, electronically controlled stowage of the cable, which permits the use of a winch with various cables and extend the life of the cable itself. The slip rings for fiber optic cables have also evolved rapidly and allow the expansion of the use of these cables, increasing the quality of the data that is received through them as well as the bandwidth that allows the transmission of video and images in real time.

The control of these winches and the rapid response of the motor or driver allow the ship's balance compensation and a stable vertical position for the deployed equipment , making maneuvers safer and more precise, especially when working on the seafloor. Another important advance is the use of electrical drivers in winches. Although hydraulic winches continue to be used, the control of electric drivers tends to be more reliable and precise.

Submarine positioning. Ultra Short Base Line (USBL) used in the positioning of equipment such as ROVs or side scan sonars ensures operations and navigation near the seabed. When USBLs are used in all the elements deployed, the overview of all the equipment helps the success and safety of operations. All of these rigs have made working in the deep-sea safer and less uncertain.

A cabled ship. The interconnection of all continuous and automatic measurements carried out on the ship it is important and allows to consider the whole vessel as a very well-integrated multi-domain and multi-disciplinary observing platform. A ship with a centralized distribution and data storage system for all its scientific equipment allows researchers to do pre-analysis and first data integration, with a better quality control, optimizing use and maintenance of equipment.

Communications. The acquisition, storage and dissemination of data from ships is a key issue in the study of the climate system (hydrosphere and atmosphere) over the sea. Equipment that works underway such as measuring sea surface temperature (SST), sea surface salinity (SSS) and meteorological/atmospheric data are stored and automatically transmitted to land or to other vessels to feed databases or repositories. For more complex datasets, the metadata can be created on board and sent to land, allowing "on demand" requests of the raw data from interested parties. Communications have expanded ship laboratories allowing some data to be processed on land and, reciprocally, data from meteorological models or surface chlorophyll values, for example, can be sent to the ship for use. There is still a need to improve the ship-to-shore communication in order to extend the usability of data.

Instrumentation carried on board allows vessels to perform analytics and also *in situ* and *in vitro* experimentation. Thermoregulated chambers allow the incubation of organisms to analyze processes such as respiration and photosynthesis under conditions similar to those of the environment of origin of those organisms. Currently, equipment has also been developed that allow maintaining the pressure of the medium where the organisms are captured and thus analyze their metabolism in real conditions. So far in microorganisms but progress is being made in its use as well with macroorganisms.

3.2. Underwater acoustics

Underwater acoustics is an essential technology in the study of the ocean. Due to the rapid absorption of electromagnetic waves (light, RADAR, ...) in the marine environment, acoustics have become the marine technology par excellence. Although it began being used to determine the seabed and later in fish detection, it has been developed in different objectives such as marine currents (Doppler Effect) or communications (underwater acoustic modem) and positioning (USBL) for determining the position at sea of underwater vehicles.

The latest developments incorporate Chirp technology, (chirp is a signal, pulse, in which the frequency increases or grows as a function of time). This technology makes possible a better determination of echoes and a reduced noise. Also applied to RADAR and LASER, it has revolutionized underwater acoustics both in equipment such as MBE or echo sounders for biomass as well as for communications. Acoustics is also used in ice thickness determination using sled-driven equipment.

3.3. LiDAR, thermovision

In the last decades, LiDAR systems have been used for multiple purposes using their capabilities for detection. Currently there are some applications to use it from ships, especially for the detection of marine mammals and their population study. In this sense, thermal cameras installed on ships also have significant potential in terms of obstacle detection and analysis, which also allows research possibilities for marine mammals in particular.

On the other hand, these technologies can help other systems such as radars in polar operations and increase safety. Additionally, FLIRT type infrared camera installations are very useful in detecting "grumpy" or small ice or hidden by sea conditions.

3.4. Images

Advances in the recording of underwater images for both photography and video are based on improvements in the chips used in digital cameras and in lighting. This type of equipment is fundamental in all mapping and monitoring studies, especially associated with its deployment in ROVs and AUVs.

Range-gated systems are providing also 2D and 3D imaging. These methods which use laser light pulses for range the objective and light it with LED lights are useful also for species recognition. Deep-learning and neural networks are also new and useful tools for species recognition comparing "in situ" pictures with a data set of organism images. Future systems will incorporate this intelligent image sampling methods avoiding in some extend physical sampling (trawls).

4. Autonomous measurements

4.1. Space and air borne sensors

Although not specifically operated from ships, the sensors installed on satellites have an application in aerial vehicles that allows a wider spatial coverage of some parameters.

Remote sensing by satellites and their calibration with in situ measurements, have provided with a very useful synoptic view. Advances in signal processing and satellite sensors are therefore also a key factor in the study of the polar regions.

These systems have been widely used in the study of the atmosphere, but in recent years, they have been proven a very useful tool for the study of the polar regions and the relations between the earth's crust, ice and snow-covered areas in the ocean.

In many cases, polar research vessels carry helicopters equipped with this type of sensors, contributing to the wider study of ice covered areas.

4.2. Drones (RPAS/AUV)

Currently there are many manned and unmanned aerial vehicles that are being used for research in polar regions.

In recent years, sensors that can be installed on drones have multiplied, increasing the drone' usability for observing the ocean and the polar areas.

In general, we could divide drones in two categories: multirotor and fixed-wing. Multirotor units have more than one motor and generally more than three. Their size and weight is highly variable, ranging from tens of grams to hundreds of kilograms. Multirotor drones have their greatest advantage in the simplicity of its mechanics and their easy handling, which implies significant maneuverability. Generally, the work with them is under visual field and the number of hours those instruments are able to operate depend directly on the weight of the equipment plus the sensors, which affects the endurance of its battery.

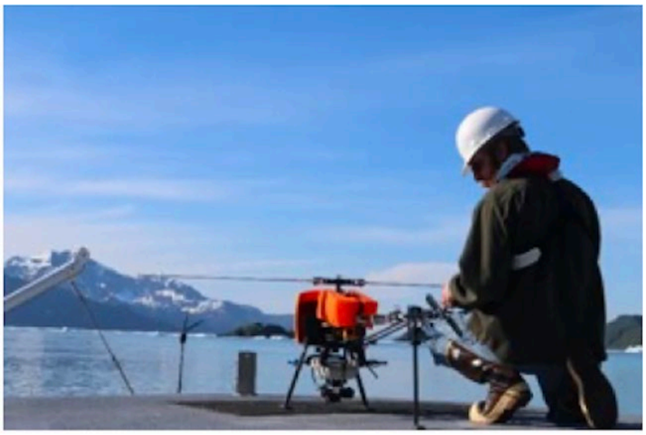

Photo: Operating a multirotor drone from a vessel. University of Alaska Fairbanks

Fixed-wing drones given their bigger size usually have a higher battery capacity and payload. In addition, their more aerodynamic shape makes them more efficient from the point of view of energy consumption. However, fixed-wing drones have the disadvantage that they need a minimum wind speed to fly and a runway or catapult system, a critical factor to consider when working from research vessels. Fixed wing drones can reach greater distances and are able to fly longer, which makes them very useful for missions that require reaching higher altitudes. In recent times, hybrid drones have also been used, which combine the vertical take-off capacity of multirotor drones with the capabilities of fixed-wing drones.

Photo: Fixed-wings drones working in the Arctic. Techsnische Universität Braunschweig

Nowadays there are many examples of the use of these relatively new technologies in polar research, although their use from research vessels is limited due to the difficulties for take-off and landing from the vessel. Nevertheless drones represent a very useful tool for studies of the ocean-atmosphere interface, being able to collect data, or even samples, in the air column above the vessel sampling area.

4.3. Towed vehicles

Traditionally, towed vehicles were equipped with a single sensor (i.e. towed magnetometers for the study of glacial or ice masses). At present times, towed vehicles have been improved and now offer a better capacity to transport sensors (payload), increasing the number of variables they can measure simultaneously. The possibilities of sensors and measurements can be extended to:

- Meteorological parameters
- Aerosol concentration
- Trace gas concentration
- Surface and radiation properties

An example of this type of equipment and its application to polar research is the HELiPOD used in the MOSAiC experiment carried out on board the PRV Polarstern. The HELiPOD has meteorological sensors, sensors to measure the concentration of aerosols, radiation sensors, cameras, radar, altimeter, and sensors for the capture and detection of trace gases. The fully customizable system is thus a multidisciplinary observation platform.

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Photo: HELiPOD vehicle, Techsnische Universität Braunschweig

Some helicopter towed equipment can also be used to contribute to safe navigation. Recent advances in this regard have been developed by the Australian Antarctic Division by using a GPR (ground penetrating radar) for the detection of crevasses in glaciers. This technology could be used in the future, also installed in drones, in order to help ship navigation in ice covered areas, detecting where the sea ice is cracked or where its thickness allows navigation.

This type of system in cooperation with satellite imaginary, such as TerraSAR-X, can improve and expand safety in marine operations and glacier progress, and also contribute to the study of marine dynamics in coastal areas.

4.4. AUV, ROV, USV

The development of unmanned underwater vehicles such as AUVs (Autonomous Underwater Vehicle) and ROVs (Remoted Operated Vehicle) has been fundamental in oceanography.

AUVs have evolved from small platforms with reduced capacities to systems capable of submerging to thousands of meters. ROVs and deep AUVs can only be operated from research vessels that have special capabilities for their deployment and tracking.

AUVs

Large and deep AUVs are fundamentally managed in “tracking” mode, by means of underwater acoustic positioning from “mother” ship constantly following the AUV on the surface.

The sensors and equipment that AUVs are capable of carrying have been increasing and improving over time. Currently, AUVs are able to carry almost any type of oceanographic equipment (such as CTDs, magnetometers and multi-beam) as well as able to take water samples at any given depth. Particularly important is AUVs’ capacity to work near the bottom, which allows acoustic equipment to determine microstructures at the seabed.

Future technologies that should determine the further development of AUVs are related to the durability of the batteries and the possibilities of geolocation, as well as developments in artificial intelligence and communication capabilities. The massive data communication would allow to increase the decision-making capacities in the realization of a mission, adjusting it to the changing characteristics of the marine environment. In the future, this type of massive data communication and the data treatment would allow a better management of sets of AUVs working simultaneously, as the data from each AUV could feed the missions of the others.

Photo: AUV Abyss ©B. Barenbrock, GEOMAR

ROVs

Technological improvements in ROVs have allowed these platforms to reach depths of 6,000 meters or more in the recent years. This has led to important advances in deep ocean research. Most ROV systems are hydraulically powered and an improvement in the powertrains is expected to allow the combination of hydraulic and electric systems. Another important aspect in future technological developments will be the replacement of the umbilical cable or the "tether" by fiber optic cables and the weight reduction of this equipment.

USVs

Since the beginning of the 90s, the development of USVs (Unmanned Surface Vehicle) has been increasing. The USVs can be applied to a variety of studies and research areas thanks to a recent increase in propulsion and communication capabilities. In some cases, these vehicles can incorporate a small winch capable of deploying a CTD or include multibeam transducers with a range very similar to those installed on vessels.

The propulsion systems are key in the design of the USV and today's capabilities have been added to use solar or wave energy, as is in the case of the Wave Glider USV.

The fully autonomous operation of USVs is limited by associated risks, maritime traffic, obstacles at sea, etc. In this sense, this capacity is closely related to the size of the USV. However, risks associated to the operation of USVs increase with the size of the instrument. For this reason larger USVs are currently remotely operated from ships.

The field of application of USVs is very broad but depends on the further development of energy systems, positioning and tracking systems and systems to overcome obstacles. In addition, the rules of Maritime navigation for USV and the recognition of the legal status of USV are both still in a blank stage. As with other fully autonomous systems, the international regulatory framework on maritime traffic will have to take these instruments into account.

Photo: C-Enduro USV, ASV Ltd.

4.5. Gliders

Gliders are a type of robotic underwater vehicle used for measuring oceanographic parameters such as chlorophyll levels, temperature and salinity, which are then transmitted back to the shore. They are very effective tools for gathering data from the ocean with a great variety of instruments. Since the 2000s, technological advances have increased gliders' capacities from being able to operate few hours to allow much longer missions, both in time and distance. Gliders have become a very useful tool for wide-spectrum synoptic studies in the ocean. In general, the data collected is sent via Iridium to land when gliders emerge to the surface, allowing a simultaneous geolocation. In polar regions, and especially in ice-covered areas, since there is no possibility of connection via satellite or GPS, it is necessary to connect through USBL-type acoustic modules. This can greatly expand the range of action of the gliders, especially in real-time missions supported from ships.

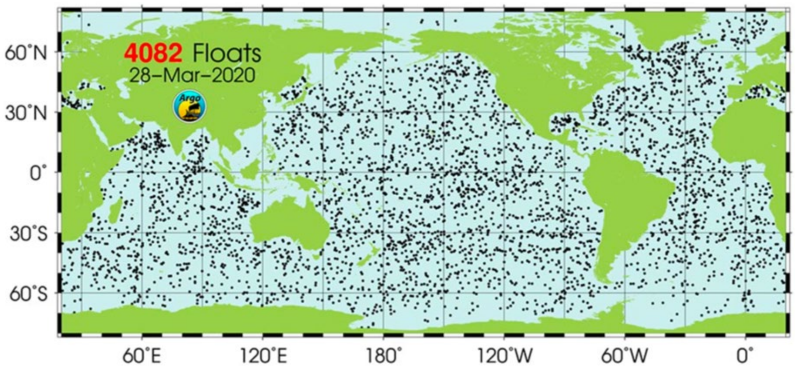
There are several initiatives at a global level for the observation of the oceans such as the "International OceanGliders" within the GOOS program.

The reliability and autonomy of gliders has recently increased, but there are still technological challenges needed to further exploit their potential. Performance in extreme conditions (such as winter conditions and navigation under sea-ice) is improving, and there are very few places on the planet where gliders can't operate. The variety of sensors that gliders can carry is very large, but there are still demands for sensors such as fluorometers for measuring phytoplankton, acoustic systems to detect fish or small marine mammals, among others. In all cases, the limiting factor are batteries, which need to undergo significant technological development in the future to be able to solve the durability challenges. Communications are also a limiting factor, but with the launch of more satellites with polar orbits, this aspect could be improved in the future.

Photo: Webb-Slocum gliders in Palmer Station, Antarctica, USAP

4.6. ARGO floats

Argo is an international program that collects information from inside the ocean using a fleet of robotic instruments that drift with the ocean currents and move up and down between the surface and a mid-water level. Each instrument (float) spends almost all its life below the surface. Since the first launch in 1999 there has been a long advance in the development of ARGO floats. At present, these floats are able to acquire data constantly while operating. In its normal operation the float lowers to a certain depth and guided by the currents resurfaces after a few days, when the data is sent via satellite communication.



ARGO float distribution, www.argo.ucsd.edu/

Although the data contributed by the ARGO floats is very important, there are still challenges to be addressed in terms of coverage (both on the surface and in depth), sensors and maneuverability. While ARGO floats are designed for depths up to 2000m, current developments allow these floats to reach greater depths (4000-6000m), covering part of the deep ocean. Other types of sensors could be added (such as to measure dissolved oxygen, nitrate, chlorophyll, and pH) because the size of these sensors is small and have low power consumption. The maneuverability of this equipment could be improved to avoid equipment concentrations due to the dynamics of marine currents. In the polar areas, these capabilities will be essential to avoid areas covered by ice and with low communications coverage. In addition, the development of pop-up floats will contribute to the simultaneous study of the lower layers of the sea ice and of the water column.

5. Atmospheric measurements over a ship

A ship is a challenging measurement platform for atmospheric measurements. Ships have superstructures and masts causing shadows and distortion of the flow. There are also several sources of heat, moisture and particles. Some instruments require regular maintenance and the optimal site might be a compromise between good exposure and easy access. Movements (pitch and roll) and vibration of the ship require the continuous development of dedicated algorithms to remove noise, and in some cases can limit the amount of accurate results. Furthermore, the marine harsh environment (high humidity, splashing water, sea salt), bring special challenges for the durability of instruments and the accuracy of measurements.

Technological developments offer now possibility to overpass/reduce many of these challenges and largely improve (i) the number of parameters and ECVs that can be continuously monitored with automatic and/or semi-automatic measurements, and (ii) increase the quality of measurements routinely performed up to now on research and ships of opportunity vessels.

Surface radiation budget: in the last years, instruments able to provide components of downwelling flux - even without a tracker equipped with shadow system - have been developed. These instruments, with few or no moving parts, are particularly suitable then to improve information collected from ships. The large improvements and miniaturization of stabilization systems technology on drones, has made possible the design of equipment that minimizes errors connected with the ship pitch and roll movements.

Clouds: information on cloudiness such as cloud fraction and the cloud type can be derived by radiation measurements and by hemispherical sky cameras with dedicated software. Algorithms to determine the cloud fraction from radiation measurements have been developed in the frame of the Baseline Surface Radiation Networks (BSRN) and are now well consolidated and largely used at BSRN stations (Long and Ackermann, 2000; Durr and Philippona, 2004). However, since these instruments have a fix position during the day they need to be adapted for ship-borne measurements, since the relative position of sun and instruments change continuously due to the ship motion.

The identification of the type of clouds with pyranometers is a less consolidated technique with respect to the cloud fraction, but it is still possible (Duchon and O' Malley, 1999).

Cloud base height need active detectors (cloud radar, lidar/ceilometer). Actual ceilometers are quite safe through the use of a pulsed diode laser technology, where short, powerful laser pulses are sent out in a vertical or near-vertical direction. The reflection of light (backscatter) caused by clouds, precipitation or other obscuration is analysed and used to determine the cloud base height. Since the cloud base height is measured along a very defined direction, data interpretation has to consider both ship movement and route.

Visibility: A Visibility meter measures visibility through fog, haze, smoke, sand and all forms of precipitation and generates instantaneous averaged visibility outputs. It consists of a paired transmitter and a receiver used separated by a very short distance. Extinction coefficient of transmitted light is than evaluated on this short path. This measurement is then automatically converted to visibility using established conversion formulae. The most common method of measuring the extinction coefficient is the forward scatter system. A high intensity xenon strobe transmitter directs a beam of light in the visible spectrum. A photo diode at the adjacent receiver is used to detect the amount of light received. The use of transmitted light within the visible spectrum allows this type of instrument to most accurately simulate human perception of visibility.

The use of scattering and extinction coefficient is largely affected by the presence of particles of water, dust, sand or smoke and due to their open path design, these instruments are sensible to the harsh environment. Its use in research vessels implies is limited to finding a location sufficiently undisturbed by splashing water and ship emissions. The installation needs an easy access to allow maintenance.

For normal conditions (no fog), visibility can be estimated with very good accuracy knowing the aerosol content (AOT) and height of the mixing layer. With AOT measurements on-board, an independent evaluation can be achieved to compare with instrumental measurements.

Aerosol optical thickness: Since 2004, a regular programme is supported by AERONET[1] and other agencies to perform aerosol optical thickness measurements on ships of opportunity making use of a manual sun-photometer (MICROTOPS).

Despite several attempts, up to now commercial sun-photometers do not have a marine version that can be used used in vessels. Some companies have tried to develop marinized radiometers, but these projects have been abandoned because better technological developments are needed to improve aerosol optical thickness measurements in vessels. In addition to several efforts by industry, several prototypes have been also developed by research groups, such as the Consiglio Nazionale delle Ricerche (CNR, Italy).

6. Seafloor and water column observatories

Observatories are platforms equipped with multiple sensors, placed along the water column and on the seafloor. They constantly measure different biogeochemical and physical parameters that address natural hazards, climate change and marine ecosystems. Seafloor and water column observatories are highly dependent on research vessels because their deployment, maintenance and recovery, especially of non-coastal observatories, can only be implemented from them.

In addition, the technology and sensors that can be installed in the observatories is the same to the technology shown for other platforms and, without a doubt, seafloor and water column observatories have a great potential in the future of marine and polar research.

6.1. Cabled submarine observatories (CSO)

Observatories of the seafloor and the water column have experienced a considerable increase in the last 20 years. That is due to an evolution of both sensors and communications and energy storage systems. In the case of cabled seafloor observatories (CSO), evolution has also consisted of using existing tools, such as cable ships used in industry to deploy cables and in the extension of fiber optics. By using cables, it is possible to supply electricity without the need of batteries and communicate with land through high bandwidth for real time data. These observatories have a stable infrastructure of stations (nodes) and substations (sub-nodes) interconnected by cable and electro-optical connectors. The connections are usually made with ROVs.

[1] More information and data with respect the Maritime Aerosol Network (MAN) component of AERONET can be found at: https://aeronet.gsfc.nasa.gov/new_web/maritime_aerosol_network.html

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The electrical supply of these CSOs started as alternating current (AC) but over long distances parasitic parameters such as the capacitance and inductance on long cables affected their response and stability. Current CSOs use constant current (CC) or CV (constant voltage) using direct current (DC) with a single conductor and return through seawater. Communications are now robust and can reach 60 to 150 km without interruption.

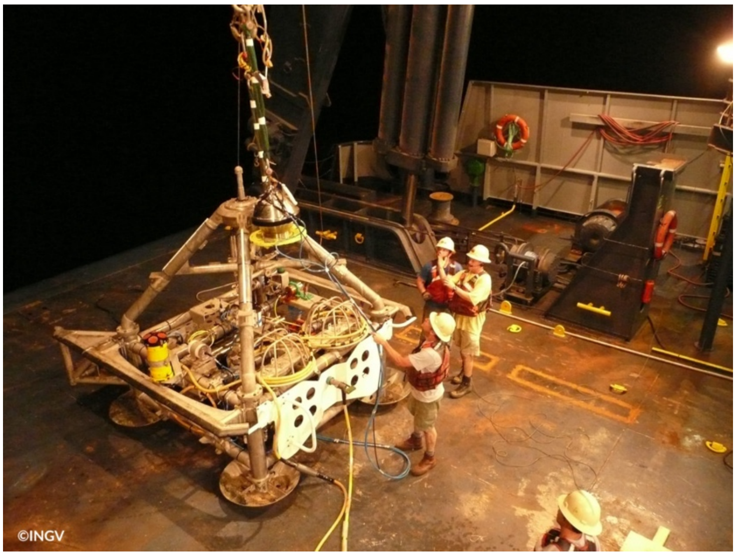


Photo: Western Ionian Sea Observatory, INGV

CSOs are used in tsunami alert systems due to the possibility of real time transmission and their robustness, using geophones and hydrophones to monitor crustal movements and possible tremors. In general, CSOs are used to install other sensors used in other types of projects, such as CTD, cameras, etc. EMSO-DEV (https://www.emsodev.eu/Files/Deliverables/D6.1-Data-management-plan.pdf) proposed some variables and a type of sensors for these observatories as an attempt to standardize the equipment (EGIM).

Taking advantage of disused telecommunications cables, this type of observatories is spreading for the study of deep sea not only in seismic, but also in the study of deep ecosystems.

6.2. Water column observatories

Water column observatories have the objective of studying the pelagic environment. They consist of an anchored line equipped with sensors distributed along the water column. CTDs, acoustic doppler current profilers (ADCP)(), bio-echosounders, hydrophones and sensors for chlorophyll, and photosynthetic available radiation (PAR) sensors (), among others, can be installed along the line. Data is transmitted via GPRS to a station on land or via satellite.

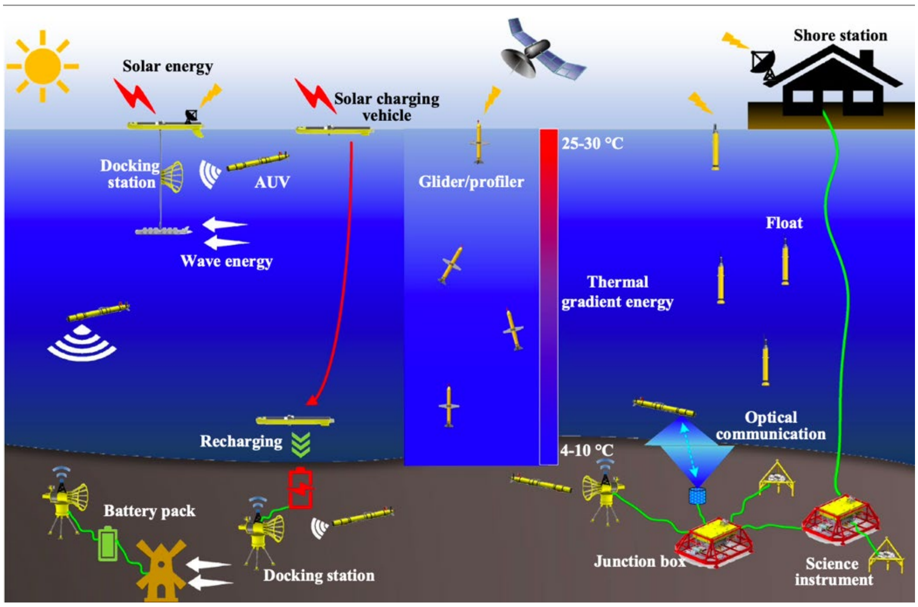
Some moorings are devoted to the study of the behavior of marine species using images or with tracers (tag tracking systems) that are placed on the individuals of the chosen species to monitor their movements. In this case, the equipment is an acoustic transponder that records the information on the movements of the tagged individuals.

6.3. Hadal observatories (Landers)

Landers are platforms that are deployed on the seabed to sample for relatively long periods (months, years) in the abyssal or hadal zone. They are dropped into the desired area with a ballast. The equipment has batteries, usually lithium, and buoyancy material such as foam or glass spheres. Recovery is carried out by activating the acoustic release that lets the ballast go. They usually have a second release system, for example, galvanic erosion that is activated on a certain date and time. The battery system feeds the different equipment with DC-DC converters depending on the needs of sensors and dataloggers. The sensors can be CTD, dissolved oxygen, pH, etc. but landers can also take physical samples of sediment and organisms. A special characteristic in some of these landers is the possibility of raising the samples to the surface at the pressure where the organisms were captured. Some landers, such as NIOZ's Mobile Underwater Vehicle (MOVE) (https://www.nioz.nl/application/files/4214/8775/1791/DeepSeacentreBrochure.pdf), have the ability to move across the bottom at intervals and distances scheduled in advance.

Unwired underwater observatories (autonomous) can be including in the moorings, and then they are equipped with batteries and communicate through aerial antennas on buoys. Submarine communications (acoustic modem) are used as well, but with the speed limitations imposed by underwater acoustics. Acoustic releasers are used to recover the equipment. The use of AUVs to maintain and obtain information from these observatories will be more common with the spread of artificial intelligence applied to this equipment.

The possibility of docking or connecting to power supply through "plugs" in the observatory (in a similar way to how smart home vacuum cleaners charge their batteries) is also a new incentive to extend the missions of these vehicles. Docking technology serves as a "bridge" to connect static and dynamic observations, facilitating expanded coverage in space and time, and greater resilience from ocean observatories. In addition to returning data via satellite, this can be returned by guiding the AUV to a docking station attached to a mooring system or by connecting to a wired seabed observation network. When docked, the AUV returns data, downloads a new mission plan, and recharges the battery for extended periods of work either wired (via a physically connected connector) or wirelessly (inductively). The mooring-based docking station requires the surface buoy to transmit the data returned by the AUV via the Iridium satellite, and the CSO.



Future oceans observing system concept. Lin and Yang *Chin. J. Mech. Eng*

7. Batteries and power supply

One of the key points in autonomous equipment is the duration of the batteries. Due to this, usually a ship must accompany the missions of the AUVs to recharge them and resume the survey. Ascending, recharging and descending, consumes long time and achieving a good autonomy is an objective to reduce costs and time. In missions under the ice, this issue becomes even more important for the safety of the equipment. The same is true for the observatories or moorings and landers. In addition to regular maintenance, the batteries must be replaced in order to have time extensions and a boat must carry out this task.

Nowadays, most underwater equipment uses Li-ion batteries. Li-ion batteries use a liquid electrolyte but they can also use a polymer (solid) and these are Li-ion polymer batteries. We have to distinguish between vehicles, such as AUVs where buoyancy is very important and batteries charge the vehicle and observatories or instrumentation that remains on the bottom where weight does not matter and therefore sets of batteries with a lot of charge can be used.

For underwater autonomous vehicles, Li-ion batteries are a better choice than lead-acid, silver-zinc or nickel-cadmium batteries. Li-ion batteries have excellent energy densities, which gives benefits in weight, volume, and time of mission.

The advantages of Li-ion batteries are:

- Higher energy stored per unit of weight and volume
- Less degradation and greater number of charge-discharge cycles.
- High capacity for fast charging and short charging times (4 times).
- Low level of self-discharge (3% per month compared to 10% in lead-acid).
- Low maintenance and sealed elements.
- Higher average voltage per element (3.5 V vs. 2V in lead-acid).
- Higher useful capacity than lead-acid.

Batteries can be enclosed with oil to balance pressure and to isolate them in seawater. Getting batteries pressure resistant has several advantages. On the one hand, being very heavy, they can be placed in the lower part of the vehicle. Thus, the housing that contains the electronics and the foam can go in the upper part. In addition, there is no need to open the electronics housing to charge or replace the battery. Bluefin develops these types of batteries. One goal is to get battery packs that are pressure resistant. In Li-ion batteries with liquid electrolyte, oil can be used that floats on top of the electrolyte and removes all possible traces of air. However, this can only be done if the battery is in an upright position. In addition, any leakage of the electrolyte can corrode and affect the rest. With polymer batteries this can be solved as it is solid and there is no possibility of leakage.

Nowadays most AUVs use lithium batteries, which present several problems. These batteries can burn and explode, so AUV-sized batteries generally cannot be shipped by flights. In addition, their power density is limited, which means that service ships accompany the AUVs to sea, recharging the batteries as needed. Casings must be used to withstand pressure. This type of batteries has a “batterie management system” (BMS) to avoid accidents.

Advances in battery design are mainly focused on finding other elements or compounds to replace those that are expensive or scarce, such as cobalt. Instead of lithium cobalt oxide, lithium phosphate or lithium magnesium is used. On the other hand, at the cathode, graphene is being used. The automotive industry is pushing hard in the design and manufacture of lighter and more powerful batteries. That matches the same interest in AUV designers.

A current project is OWP, a MIT spinout now acquired by L3. OWP consists of aluminum alloy anode and cathode with an alkali electrolyte in between. “*When an AUV equipped with the power system is placed in the ocean, seawater is drawn into the battery and split at the cathode into hydroxide anions* *and hydrogen gas. The hydroxide anions interact with the aluminum anode, creating aluminum hydroxide and releasing electrons. Those electrons travel back to the cathode, donating energy to a circuit along the way to start the cycle again. Both aluminum hydroxide and hydrogen gas are disposed of as harmless waste".* (https://news.mit.edu/2017/batteries-drink-seawater-long-range-autonomous-underwater-vehicles-0615).

These types of batteries can be the next step in the exploration by allowing autonomies several times greater than those obtained by Li-ion batteries. In addition, there is no fire risk of the above so they can be transported by plane.

8. Conclusions

The key technologies for the study of the hydrosphere, cryosphere and atmosphere domains over the sea, in particular in the polar areas, are evolving very quickly, offering the possibility to largely improve the number of measurable ECVs. These developments are crucial to achieve a global coverage of observation, especially in the oceans. . There is a movement towards:

- The development of increasingly independent autonomous systems. Whether submarine or surface, these platforms will be key in marine and atmospheric research. The miniaturization of the sensors to install in reduced equipment payloads is crucial as well for the installation in drones.
- The application of artificial intelligence and the capacity of communications is essential to allow the use of multiple platforms and receive their feedback in real time.
- The development of technologies to improve battery life and reliability will be key to facilitating longer and more complex missions, providing more energy capacity to have more sensors. In this sense, it will apply to both autonomous teams and observatories.

Especially in the polar areas, the further development of all mentioned technologies is crucial, without forgetting that any equipment developed to work in the polar regions must be able to work in extreme conditions, at very low temperatures and covered with ice.

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