COMMON SENSE
MARINE SENSORS - MARINE MONITORING

# Sensor monitoring strategy

## Deliverable D2.4
## of the COMMON SENSE project

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# Deliverable 2.4

# Sensor monitoring strategy

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## EXECUTIVE SUMMARY

In its overall strategy, COMMON SENSE work packages (11) can be grouped into 3 key phases: (1) RD basis for cost-effective sensor development, (2) Sensor development, sensor web platform and integration, and (3) Field testing. In the Phase 1, within WP1 and WP2, partners have provided a general understanding and integrated basis for a cost effective sensors development. In Phase 2, within the WP3 and WPs 4 to 8, the new sensors have been created and planned to be integrated into instruments for the different identified platforms and how data produced will be processed, organised and saved. During the phase 3, within WP9, partners are deploying precompetitive prototypes at chosen platforms (*e.g*. research vessels, oil platforms, buoys and submerged moorings, ocean racing yachts, drifting buoys). Starting from August 2015 (month 22; Task 9.2), these platforms are permitting the partnership to test the adaptability and performance of the *in-situ* sensors and verify if the transmission of data is properly made and correct observed deviations.

Sensor monitoring strategy (Deliverable 2.4 for Task 2.5) is the last task within Phase 1. As the other tasks in Phase 1 it has to provide a basis for designing field testing activities to be useful. That is how to validate the performance of sensors, integration, data acquisition, transmission, under real conditions in different platforms. Since there is a wide sensor variety, each one with its own characteristics, and several platforms, to prepare a general methodological review and give the corresponding directions as it was initially planned, would be a huge and useless effort.

Given the initially fixed calendar a first version of the present deliverable was presented when most of the sensors were still not developed. The document addressed how projected sensors should be tested, their limitations and conditions for their monitoring and final certification. Now, when D2.2 (Procedures of sensors deployment methodology on physical supports/platforms) has been rewritten (May 2016), all sensors are fully developed and most of them have started their tests at sea, the present new updated version of the deliverable becomes more precise, with much better knowledge on the real sensors and their performance. In addition, a complete new chapter on data transmission –initially proposed but not developed in the previous version– is included.

The information from the six sensor developers in COMMON SENSE on which the initial plan on where and how to test each sensor that was presented in D9.1 (April 2015) has been updated (May 2016). The update includes the final properties of sensors after the respective full laboratory tests and even some of the results from field tests that had been carried out starting August 2015.

This task assesses field testing procedures and deployment specificities. Two tables are presented based on the information of the report for D9.1 delivered in April 2015. One table was created for sensor developers and one for those who will test the sensors at sea. In this report some information from the testers' table is shown and updated according to the new version of D2.2 (May 2016) for platforms.

### *Objectives and rationale*

The objective of Task 2.5 within the WP2 is the definition of sensor monitoring strategy based on the premises for water monitoring, sensor performances and data storage and transmission. For any new sensor, available instruments currently used in the oceanographic studies will be identified to perform comparisons. Suitable transmission technology will be selected according to the test conditions: open sea, coastal areas, remote locations, etc. Sensitivity and stress tests will be designed in order to establish confidence limits under different environmental situations, so that the results obtained in the testing exercises (WP9) will enable to certify the performance of the new instruments.

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# 1. INTRODUCTION

## *1.1 Background*

The Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy, begins with the statement "*Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such*". Indeed, water is one of our most precious and valuable resources. Therefore of utmost importance is that we learn how to adequately use, protect, and preserve water resources. However, the water is a limited and vulnerable resource. The use of water affects the quality of this resource itself as well as the quality of the environment in a broader sense. Water pollution has been a problem that has accompanied human development and the greatest human achievements. New strategies and new radical approaches are needed to improve the management of water bodies, in terms of increasing the quality and efficient use of freshwater, reducing the undesirable effects of land use and human activities on water bodies, and working with local government to identify options and new technologies to assess the chemical and ecological status of water bodies and to develop best practice.

New and efficient methods are needed for monitoring the implementation of various EU agreements and national programmes on reduction of water contamination. Relatively recent advancements in the field of the sensing technologies have brought new trends in the environmental controls. In particular, in micro-electronics and micro-fabrication technologies, that has allowed a miniaturization of sensors and devices, thus opening a series of new and exciting possibilities for environment monitoring. Moreover, robotics and advanced ICT-based technology (in particular, the extensive use of remote sensing and telemetry) is dramatically improving the detection and prediction of risk/crisis situations related to water environment, providing new unmanned tools for control.

The COMMON SENSE project aims to support the implementation of European Union marine policies such as the Marine Strategy Framework Directive (MSFD) and the Common Fisheries Policy (CFP). The project has been designed to directly respond to requests for integrated and effective data acquisition systems by developing innovative sensors that will contribute to our understanding of how the marine environment functions.

The core project research will focus on increasing the availability of standardised data on: eutrophication; concentrations of heavy metal compounds; microplastic fraction within marine litter; underwater noise; and other reference parameters such as temperature and pressure, $pCO_2$ and pH.

This proposal has first provided a general understanding and integrated basis for sensors cost effective development (WP1 and WP2). In particular in WP2 the aim is:

- to obtain a comprehensive understanding and an up-to-date state of the art of existing sensors;
- to provide a working basis on "new generation" technologies in order to develop cost-effective sensors suitable for large-scale production;
- to identify requirements for compatibility with standard requirements as the MSFD, the INSPIRE directive, the GMES/COPERNICUS and GOOS/GEOSS.

To fulfil the above requirements, sea testing of the new instruments (WP9) is crucial to ensure their capability for monitoring ocean waters under different environmental conditions. The final objective of the present report is to bring rules for sensor certification after sea testing. A strategy to design sea testing will thus be developed based on the expected environmental conditions. It involves choosing areas and seasons according to both the monitoring requirements and to the existing

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knowledge of ocean dynamics, sources of contaminants, etc. The instruments' behaviour has also to be tested against different weather conditions that could be found across the ocean. For any new sensor, available instruments or techniques currently used in the oceanographic studies are identified to perform comparisons. Sensitivity and stress tests are designed in order to establish confidence limits under different situations and certify the performance of the new instruments as well as their ranges of operability once sea testing has been performed. Data produced by the instruments have to be stored or transmitted to make them available either in real-time or after processing. For different locations and conditions, available choices for data transmission have also to be tested and intercompared.

Additionally, other essential background information for reference within the present report can be found in released previous deliverables as follows and will not be repeated here:

- About monitoring framework for the European seas, international agreements, and regulations (CS D1.1);
- a very exhaustive assessment of the Implementation efforts, including methodologies, by member stares for MFSD (CS D1.2);
- an inventory of projects having influence on sensors design, measurement and monitoring technologies (CS D1.3);
- a comprehensive list of observation tools, from funded projects and other initiatives to research infrastructures networks and platforms (CS D1.4);
- relevant problems, technical issues and deficiencies in currently existing sensors and on those developed in the Common Sense project (CS D2.1);
- information on standards for managing and accessing sensor data and observations (CS D2.3);
- information on standards for data communication (CS D3.2).

## *1.2 Organisation of this report*

This report provides general information on how sensors should be field tested and how their behaviour has to be monitored and sensor performance be certified. More precisely:

- What kind of sensitivity and stress tests should be applied to analyse the sensor behaviour;
- what reference sensors or analytical methods for every parameter can be used in accordance to the platform characteristics;
- how sensor response has to be analysed;
- how testing sensor integration in instrumented arrays has to be addressed;
- what communications are required for data transmission and how their efficiency has to be analysed;
- which criteria have to be retained for sensor certification after tests.

General procedures for sensor testing can be found in the specialised literature but the methodology described here, although general, will be focused specifically to sensors developed within the COMMON SENSE project: inorganic **nutrien**t concentrations ($NO_2$, $NO_3$, $PO_4$ and $NH_4$), **microplastics**, **heavy metals** (Cu, Pb, Hg and Cd), **underwater noise**, plus new sensors for innovative piro- and piezo-resistive polymeric **temperature** and **pressure**, and nanosensors for **pH** and $pCO_2$ measurements. If not otherwise specified sensors will always be treated in the above mentioned groups (in bold). Note also that according to CS D4.2, $pCO_2$ will not be considered as a different sensor.

Instrumented arrays that will incorporate the above mentioned new sensors exhibit a wide variety of behaviours, ranging from those that are long lived and completely autonomous to those that require

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manual operation or for a limited time or number of samples. Testing methodologies have to be carefully chosen to be addressed to such instruments thus avoiding too general considerations not directly related to the COMMON SENSE project.

The conditions, under which sensors will be tested, are selected according to: the information about the sensors and their behaviour available in the previous reports and proposed by sensor developers. The platforms where sensors are to be used, their range of operability and environmental working conditions (see D2.2) under which sensors are expected to correctly perform, will be under focus for stressing and transmission issues. Places submitted to active monitoring will be described within WP9 and places where previous knowledge on the different variables is yet available to test the sensors at sea will be referred for information.

Worksheets with specific questions have been filled by testers and developers or taken from other COMMON SENSE documents, to collect additional details on the above information.

# 2. INSTRUMENTS AND SENSORS FOR TESTING

## *2.1 Summary of the sensors characteristics*

Characteristics of the sensors developed under COMMON SENSE were initially described in D2.1 as they were planned along the first year of the project (2014). Fully detailed descriptions have been published as sensors were developed in the corresponding deliverables within the WPs from 4 to 8. References for initial descriptions with their publication dates can be found in Table 1. A detailed summary of the situation in April 2015 can be found in D9.1. A slightly more updated short reference for sensors can be found in D4.3 (October 2015) and finally, taking advantage of the new resubmission of the present deliverable, last updated information available for WP9 (May 2016) is presented in Table 2 but adapted and only showing the relevant information for this report. The results shown in this Table are based on the developers' answers to a questionnaire and reflect their points of view on each item, stressing different aspects. In particular the table shows that sensors share several common characteristics in many conditions although they are very different among them both physically and for the kind of measured parameters.

A first important step to design a testing strategy for the wide variety of sensors developed within the COMMON SENSE project is to classify them according to several other aspects in addition to their purpose (parameter observed), the methodology used (physical, chemical, etc) or the properties of each of the sensors. As seen in Table 2 sensor behaviour depends on all them. Table 3 presents a list of those aspects for a sensor classification, some in a binary way (*Y/N*), and the results are included in Table 4. Such procedure will be very useful for testing methodologies in the next chapter, and it's easy to expand if a new aspect would be included or for testing any new sensor, if needed.

## *2.2 Instrumented sensor arrays*

Another aspect not previously mentioned involves the possibility of including a sensor in an instrumented sensor array that may include other commercially available sensors. This concept has been developed in Task 4.2 "Integrated sensor arrays" (D4.3) and is complementary of the sensor data management (D3.2) both from October 2015. It is a very useful tool in order to organise the description of the testing strategies since the concept can be "enlarged" to a single sensor array, so that we can consider every sensor as an instrumented array. Instrumented arrays are also convenient for testing purposes when including both the sensor objective and one or many reference sensors for contrast. Testing instrumented arrays should include testing data transmission and data storage if required.

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## 2.3 Platforms

Another important aspect to be taken into account is the adaptation of a sensor to a platform. A detailed description of the available platforms that can be used for sensor deployments, are already available in the updated D2.2 (May 2016). This document not only describes each one of the actual platforms, which sensors can be deployed in each one of them and their strengths and weaknesses. This is very useful information for the sensor testing strategy, as reported in D9.1 where platforms are classified into 6 categories (Table 5). A summary of the platforms and their availability was initially presented also in D9.1 (April 2015) and is being updated during the development of Task 9.2. Since the purpose of the present report is testing strategy, Table 5 retain the platform categories instead of each individual platform, assuming that differences within each category are not relevant in the general context of the present report.

## 2.4 Sensors and analytical protocols for reference

Testing strategy involves a comparison among sensor output and another, widely acknowledged, reliable information on the sensed parameter. This is the so-called ***validation process***. The reference data may be obtained either from a commercial sensor, being widely used in marine monitoring — and well calibrated— or from a standard analytical protocol on water samples. In many sensor descriptions produced from sensor developers, there are references to these suitable sensors or analytical protocols. In most cases they are being used in the first laboratory tests.

Table **6** summarizes for each parameter, the typical reference sensors to be used for reference or analysis type for samples. A more detailed description can be found in the respective "sensor deliverables" also referenced in the table.

## 2.5 Communications

Monitoring at sea is heavily depending on communications and testing strategies must include a review of the different available communication systems from instrumented arrays in platforms to the data services centres. This is an important issue that has been already mentioned in many Common Sense deliverables, especially D3.2 and D4.3. In those reports protocols of communication have been established but channels are just mentioned. According to the DoW the present deliverable should pay special attention to that point that was not properly addressed in its first version as indicated by the reviewers. For that reason a new complete chapter (4) is fully dedicated to communications. In the present section the main conclusions of Chapter 4 are summarized in Table 7 for testing instrumented arrays in platforms as shown in Table 5.

## 2.6 Stresses

Sensors must be tested according to the real sea conditions that could be found during real monitoring. Sea conditions may exert important stresses on sensors and instrumented arrays, especially in unmanned and long time lasting monitoring. As the previous section this issue has not been addressed in other deliverables although it was already included in the previous version of the present one (April 2015). At this time, sensor developers were asked to fill a table proposing different stressors and indicating the suitability of these sensors as foreseen, having in mind the possible testing conditions. The table has been updated (May 2016) and presented as Table 8. Note that in this new version sensors have been grouped as in Table 1. (see §1.2 sopra) and since none of the developed sensors is supposed to work below 10 m depth, the stressor "depth (pressure)" has been removed from the list. In addition, according to sensors' developers it appears that none of the sensors is susceptible to be affected by environmental light.

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# 3. TESTING PROCEDURES

The goal of testing is to verify the behaviour of an instrument under real conditions. The process involves: to verify *in situ* operability, to validate the data against a known reference, and to look for vulnerabilities from different sources. An example of a test for a temperature sensor is presented in the Annex I, extracted from the testing carried out in June 2016 onboard the S/Y Oceania (*in press*)

## 3.1 Operability

This is the first step of any testing process although not always taken into account. Frequently the design of an instrument involves many specialists in several disciplines that while working as a team each one has its own point of view. After laboratory tests, many problems rise to surface and can be corrected but those tests are not performed in "real" conditions. So that, the first step in field test of a brand new instrument is to verify its operability. This includes but is not restricted to: handling, installation, connexions, protection and communications. In particular, for those instruments powered by batteries it is advisable to control the real consumptions at sea, to ensure enough battery capacity.

The objective of this testing step thus is to find as many failures in the above terms that can be solved with changes in the design. Handling and installation are the mostly ignored problems in some designs because in many cases those who are in charge of these did not participate nor had a secondary role in design process. For this step it is advisable to include the participation of the whole team involved in the design and building the instrument.

## 3.2 Data validation

*In situ* data validation is the most important step in testing any instrument. It is assumed that sensors have been fully tested in the laboratory before starting field testing. This is an important remark to avoid confusions because at this point we are dealing with ***validation, not calibration***. Thus, when we talk about data delivered by an instrument, ***data source***, we will not refer to the direct output from the sensors but to the information on the measured parameter values, expressed in their corresponding units. For example, when talking about data from a nutrient sensor, we are referring to the nutrient concentration (e.g. µMol/L), not to light transmission or absorption, measured by the colorimeter.

According to the above considerations, we assume that when facing data validation we already know the resolution and accuracy of the sensor, the precision of the measure and no offset, since all this was already corrected in laboratory calibration and included in the process from raw data. Then we will look for other aspects affecting the data quality such as long time drifts, changes in resolution or any other problem caused the environmental conditions in the field. The validation to be carried out thus essentially consists on an analysis of the data source versus the values produced by the reference sensors or analytical tools, by means of statistical tools.

There are many choices for statistical tools —not to be described here since there are many manuals available to the reader— but the choice has to be consistent with the nature of the data source and the sampling strategy. These relevant concepts are reflected in Table 4, as previously mentioned.

The nature of the data concept refers to the physical properties of the measured magnitude. For example, it may or act as a concentration of a dissolved matter (*e.g.* temperature, nutrients, heavy metals, and pH), strength, pressure (*e.g.* noise, pressure) or particulate matter (*e.g.* micro-plastics). This is the most important concept in data validation since it involves how to deal with.

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Sampling strategy is a wide concept involving both time and spatial distribution of the measures including data acquisition frequencies and spatial resolution but also space and time span of the validation experiment. Data acquisition frequencies may vary from tenths of Hz, in the case of marine underwater noise, to few data per day, in some of the manually operated sensors such as those for heavy metals or pH. Spatial resolution is directly related to the frequency through the speed of the platform holding the instrument. Sampling strategy also involves the length of the time-series of data either when they are collected at a fixed position (mooring) or if the point is moving along a path (vessel track or vertical profile).

### 3.3 Vulnerabilities

Testing of vulnerabilities is the last but not the least step in the testing process. Every instrument is designed to work under certain conditions as shown in Table 8. It must be tested under the foreseen stressors to reveal the impacts on data and operation (see the above sections) including the electronics and communications. Testing some of the stresses, as sea-state, involve especially devoted exercises in suitable locations where the selected stresses are frequent. In addition, some of the stressors may act after long time exposure such as corrosion or fouling. This also involves a careful selection of locations for testing: high salinity and temperature or highly productive areas that would respectively accelerate the processes of corrosion and fouling.

### 3.4 Summary of suitable locations and conditions for testing sensors

From information gathered from participants knowledge, some locations and conditions have been identified (Table 9) as suitable locations to test the sensors. These locations and conditions have been selected as examples of where and when testing exercises to be done in WP9 can be carried out. Note that shown locations: (i) are under the previously identified stressors, (ii) are relevant according to the variables measured and, if possible, (iii) are being or can be currently monitored in for data validation and (iv) cover different transmission conditions. In the first version of this deliverable some suitable locations were included in an Appendix.

For a robust sensor testing it would be advisable that at least two different locations and conditions could be identified for every sensor+stressor to have more chances in case of any problem or failure.

### 3.5 Testing certification

The final goal of field testing is to certify the behaviour of each one of the sensors; therefore present strategy must end up with a certificate design. Since sensors to be developed in this project are quite diverse, it is not advisable to prepare a “general testing certificate” covering all possible situations, so that we propose a list of several items to include in a certificate and see which apply to every sensor, according to the previous information. These items have been classified in different categories, according to the methodology and sensors on which they will apply (Table 10)

A testing form will be prepared to record the results of all the steps of every trial/sensor during the monitoring exercises on which certificates will be based (WP9).

## 4. COMMUNICATIONS

Communications have a key role in monitoring since they are necessary to get data available and as previously mentioned they must be carefully tested. A deep review of the communication methods fits well on WP2 although there is not a specific task to deal with communication channels. This is the main difference among the other items referred in Chapter 2 of this report and that’s why, as previously mentioned, a special chapter is devoted to communication channels. The present task on

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testing strategies was then designed to include a review of the communication methods, their suitability according to monitoring circumstances and their strengths and weaknesses.

## 4.1 Basic principles

The main goal of communications is to get data from a source (sensor/instrument) from a more or less remote location. Communications can also be required to trigger sampling or modify the working conditions of the instrument. Communications, then, can be uni- or bi-directional and data sent through a communication channel will be referred as ***signal***. As convention, throughout this chapter we will refer the direction of the communication from the point of view of the instrument in charge of the monitoring, thus as to ***send (output)*** or ***receive (input) signals***.

As fully detailed in D3.2 data sent from the instrument have strict rules according to the OGC Sensor Web Enablement (SWE) protocols to be assimilated through the Sensor Observation Service (SOS). Since in that report there is a full description of those protocols, according to each one of the sensors developed within the Project, they will not be repeated here but they have to be taken into account when dealing with the different communication channels. In all cases, however, data transferred is digital, thus the present chapter will only deal on ***digital signal*** transmission disregarding analog signal.

## 4.2 Communication channels

A communication channel is a link between the source of a signal and the receiver. Communication may involve a real physical connection between source and receiver (***physical link***) or it can be established through electromagnetic or acoustic waves (***telemetry***). Physical links are based on cable or optical fibre and telemetry methods will depend on the transmitting medium: acoustic telemetry through water and electromagnetic telemetry through the atmosphere or the space. A first step to select a communication channel involves the distance between source and receiver and the available infrastructure. For instance, if the source is moving (ship, drifting buoy) or in a remote location, there is no possibility to use a physical link. However the reciprocal is not true since fixed locations near the coast not always can be physically linked.

Since we are considering only digital signals, the channel capacity for data transfer will be measured in bits per second (bps) and its multiples (Kbps, Mbps and so on). A second step to select a communication channel involves the capacity required. Other important conditions to be taken into account for the channel choice are: power requirements, reliability and costs, both for installation and transmission (recurring costs).

Telemetry through electromagnetic waves is the most universal communication channel, except inside water. Communication can be established directly between source and receiver or through an intermediate device. There are several choices depending on the kind of wave within the electromagnetic spectrum (Figure 1) and the intermediate: direct radio links (microwaves without intermediates), mobile telephonic links (microwaves with intermediate) and satellite links (VHF, UHF with intermediates). The first two based on microwaves require the source be “at sight” from the receiver (in the same Line of Sight; LoS), thus they cannot work for long distances because of the Earth curvature. The next sections will be devoted to a more detailed description of each one of the channels and the main relevant results are summarized in Table 11.

## 4.3 Physical direct links

Physical direct links are the most efficient, quick and high capacity communication channels. The method consists on connecting the source and the receiver through a cable. Traditionally signal was transmitted through a metallic (Cu) cable, because it has an excellent conductivity, until the optical

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fibre is progressively expanding. As communication channel, optical fibre has a much higher capacity (to 10 Gbps in front of the 0.1 Gbps of the cooper cable). The counterparts are the high cost of installation, only justified for a really huge volume of data such as that generated by underwater noise sensors (in our case), or image transmission. This technology also requires the sensor be located in a fixed platform close to the receiver (mainly in coastal region) and easily serviced as for example OBSEA (see Table 9 and CS D2.2 updated).

## 4.4 Acoustic links

Acoustic links are based on the water sound transmission. Since electromagnetic waves cannot propagate across the water, telemetry within this medium can be achieved through sound waves. In comparison with the propagation of the electromagnetic waves in the air, sound propagates much slower, at around 1500 m/s, and the attenuation of the signal depends on the frequency. The lower are the frequencies longer is the distance.

Typical acoustic links consist in a transducer with a hydrophone and a receiver. Distances covered can reach some km in best conditions and the capacity of acoustic channels is fairly low (up to 2 kbps). In addition, power required and prices use to be quite high. They are used for low rate real-time communications with instruments deployed without cable connexions (*e.g.* Scanmar sensors used in fishing boats). They are not suitable for use within our project.

## 4.5 Direct radio links

This kind of channel is conceptually similar to a direct physical link but through radio telemetry. It is also named as point-to-point radio link and the basic requirement is that source and receiver must share a LoS, without any obstacle between them.

It is a dedicated channel and transmissions can be at no cost (see below). The source and reception communicate in the microwaves band of the spectrum (Figure 1). The suitable frequencies for our purposes would lie within the ISM (Industrial, Scientific and Medical) radio band. Although there must be restricted to medical and scientific use, they are broadly used because no license is required for this band and this causes a risk of interference. The counterpart is that almost everywhere is unlicensed so that instruments and receivers can be used almost everywhere within this band.

Several environmental factors such as mist, rain and clouds can attenuate the signal in direct radio links. This is relevant for testing purposes so that any test for this communication channel should consider the additional power requirements to compensate the environmental attenuation. Higher frequencies also involve more attenuation.

Radio links can be used for coastal regions, even if there are in remote inhabited areas since receiver can be installed in a car, a house or even a provisional settlement such as a camp. This is the preferred option for the fixed buoy in front of Barcelona (see Table 9 and CS D2.2 updated).

Point-to-point transmission can be enlarged in coverage taking advantage of the Tropospheric scattering of electromagnetic waves. In this case some of the scattered radiation emitted by the source can reach a receiver not being is a LoS. This kind of channel is named Troposcatter and is being used for transmission between points well below 1000 km apart with good efficiency and relatively high capacity. The problem however is that high power for transmission is required since only a small fraction of the total emission can actually reach the reviewer,

## 4.6 Mobile phone webs

The unprecedented widespread mobile communication systems from the early 2000’s, has promoted a communication web based on terrestrial nodes with a large coverage in land. The system is based

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on a bidirectional microwave channel from the "user" to one of the nodes. Nodes are usually connected by cable or by direct radio links. Mobile webs are rapidly evolving and changing fast their protocols, from GSM-2G ($2^{nd}$ generation of Global System for Mobile communications) to UTMS-3G ($3^{rd}$ generation of Universal Mobile Telecommunications System) up to the recent 4G. Those systems can be used as communication channels using the standard 2G, which is the most widespread, at low price but there are some important problems to be taken into account as shown below.

The mobile systems are designed and suitable for land but their marine coverage is very limited to the very coastal areas. There are many companies operating using different frequencies and not always compatible. The protocols for data transmission now are evolving. The standard 2G for communications is now starting to be removed in the USA and this policy may propagate quickly to other territories. Therefore for fixed coastal stations direct radio links are preferred.

## 4.7 *Satellite communications*

This is the most "universal" communication link. The intermediate for communication is a satellite in orbit of the Earth who redirects the signal from the source to the receiver. The orbit characteristics are according to the distance from the Earth surface and such distance determines the coverage but also the power required by the sender to reach the satellite. Communications through satellite do not rely on a single one but require several of them (a constellation) to have a reasonable coverage without causing strong delays in data transfer.

Geostationary (GEO) satellites are orbiting the Earth over the Equatorial plane and its period exactly coincides with the Earth rotation thus remaining at a fixed point in the sky from the point of view of any observer lying on the Earth surface. To reach this period, the radius of the orbit is very large so is its altitude (a distance of around 36000 km from the Earth surface). Since the altitude is almost 3 times the Earth diameter, its coverage is almost half of the total Earth surface, although from near the boundary of this coverage the satellite is seen at the horizon. For that reason, three satellites are required to cover the whole Earth instead of two. This coverage then is such as from any point on the Earth surface there is one of these three satellites at least 30° over the horizon, except obviously those points located at latitudes higher than 60°. This is a very good coverage for the whole ocean except some Arctic regions (with latitudes higher than 80°N where those satellites would be seen less than 10° over the horizon). The main problem with these satellites is the high power required for transmission to such a long distance that makes them not suitable for our purposes. VSAT are the most commonly used communication satellites for marine communication purposes.

The lower is the altitude of the satellite, small is the coverage and shorter the orbit period. This means that more satellites are required in the constellation to ensure a simultaneous good coverage. Among those there are the MEO (Medium Elliptic Orbit) and LEO (Low Earth Orbit) with altitudes from 4000 to 15000 km for MEO and around 900 km for LEO. Since MEO satellites are still too high thus requiring too much power for communications, we will focus on the LEO constellations.

LEO satellite constellations are close enough to the Earth surface to ensure good communication quality without exaggerated power consumption (typically around 1 W or less) but a high number (40 to 60) of satellites are required to ensure a reasonable good Earth coverage. Although many of these constellations are designed for land communications (Figure 2), they can ensure a reasonable good global cover without important delays. Among those constellations there are two categories of satellites: Big LEO and Little LEO according to their size and performances. Little LEO satellites are cheaper but they have low capacity (always below 1kbps). Some Little LEO constellations are: Orbcomm, VITASAT, STARNET, etc.

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One of the oldest LEO satellite transmission systems is known as ARGOS, based on the NOAA Earth observation satellites. This constellation has been used since the 1980's to follow wild animals such as migratory birds or marine turtles but also to track drifting buoys and ARGO profilers. The system has a wide coverage but there are very few satellites which mean that there can be gaps in transmission. Before the advent of the GPS coverage for positioning, they were used (and still are in some cases) to find the position of the target (bird or buoy) through a Doppler estimate, and get some information such as temperature, etc. Nowadays drifting buoys and ARGO profilers have a GPS antenna and they transmit the position to the satellite in addition to the other data requested. The ARGOS system is unidirectional, from source to receiver, good for low frequency short data strings but quite expensive for systematic use since nowadays there are other alternatives as described below.

Big LEO satellite constellations appear to be the most suitable to be used for their large capacity and still having a reasonable cost. Some Big LEO constellations are: Globalstar, Iridium, Tedellesic, Ellipso, ICO (INMARSAT-P), etc. Table 12 summarizes the characteristics of Globalstar and Iridium as the most relevant among these constellations for our purposes.

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# 5. TABLES

**Table 1. Documents with basic information on the new sensors developed in the project with their publication dates. Note that sensors are grouped as indicated in Section 1.2**

| Sensor | Document | Date |
|---|---|---|
| Temperature | D4.1 | 31/12/2014 |
| pH | D4.2 | 31/07/2015 |
| Nutrients | D5.1 | 01/08/2015 |
| Microplastics | D6.1 | 02/08/2015 |
| Heavy metals | D7.1 | 03/08/2015 |
| Underwater noise | D8.1 | 14/07/2014 |

**Table 2. Summary if sensor specifications and characteristics according to their developers (from WP9; updated May 2016)**

| Sensor | Name | Piro and piezo resistive polymeric temperature sensor | Piro and piezo resistive polymeric pressure sensor | SPE electrode nanosensors for resistivity for pH and pCO2 measurements | Eutrophication sensor system | Microplastics | Electrochemical sensors for the detection of heavy metals | Underwater noise buoy | Underwater noise sensor |
|---|---|---|---|---|---|---|---|---|---|
| | **Measured parameters** | Temperature | Water pressure | pH ($pCO_2$) | Concentrations of NO2, NO3, PO4 and NH4 ions in sea water | suspended plastic particles (Polyethiylene, Polystyrene, Polypropylene or Polyamida in the range of 0.5–5 mm | Concentration of Cu, Cd, Pb, Hg and Zn compounds in sea water | Acoustic pressure time series, from 5/100 Hz up to 12 kHz | Noise up to 10kHz, with specific data analysis on the 1/3rd octave bands centred respectively at 63Hz and 125Hz |

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| | **Main characteristics** | Bi-layer film with a sensing area around 2x3 $mm^2$ and 10–30 µm (including temperature sensing layer: 0.5 to 1 µm) | Bi-layer film with a sensing area around 8x2 $mm^2$ and 10–30µm thick, placed over the membrane affected by pressure changes. Temperature compensated by Weanstone bridge. | SPE sensor electrodes based on G/PANI and MWCNT/PANI nanocomposite | Pump+microfluidic path+microcolorimeter | An optical transducer including imaging acquisition and excitation sources (UV light) | Electrochemical sensors based on a Carbon-bismuth materials | Autonomic Hydroacoustic | Autonomic Hydroacoustic |
| **Sensor technical characteristics** | **basics** | Resolution: 0.001°C. Effective Range: -2°C to 32°C : | Resolution: 0.05 KP Effective Range: 0 to 100 KP | Water samples (few mL) must be transported to the electrode by some fluidic system | Sample ~ 1 ml. Limits of detection (0.03µM Nitrite, 1.0µM Nitrate, 0.1µM Phosphate) | An optical transducer and a control board including processor for data acquisition, processing and conversion to transmission format. | Filtered sea water is delivered to the sensor, driven by a Potentiostat, through a microfluidic system. Sample ~ 1 ml | Buoy. up to 4 hydrophones. Looking up echo sounder - 119 kHz, compass and inclinometer | Hydrophones Neptune Sonar D/70/H and data processor. |
| | **operational depth** | surface (0-10 m) | surface (0-10 m) | Pumped surface or water samples | Surface (0-3 m) or water samples | Pumped surface or water samples | Pumped surface or water samples | , deploying depth up 100 m, | Sensor electronics 0-5 m. Hydrophone 0 - 50 m. |
| | **power requirements** | Sensor < 5µW. Sensor+adapter < 175 mW | Sensor < 5µW. Sensor+adapter < 175 mW | Voltage =5V; Current 100 mA | Not yet defined | Not yet defined | Potentiostat + pumps for microfluidic < 2W | | 24v 600mA peak current at start up |
| | **basic output** | analog | analog | digital | digital | digital | digital | digital | digital |

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| | **maintenance** | No | Periodic fouling control | Periodic reconditioning of the electrodes | Targeted maintenance interval is 1 month: storage capacity of reagent, calibrant and waste storage containers will be sufficient for this period and battery lifetime without energy harvesting. | | The sensors do not need maintenance since are single use and an array of them will be available for the different measurements. The fluidic system might need maintenance against fouling. | autonomy up to 1 month | Replace / download Solid State Drive. Periodic cleaning of hydrophone. Also to be dictated by power consumption |
| **Operation** | **Installation methodology and difficulties** | Sensor in its housing +adapter is small (<15 cm) and light (<200 g). | Sensor in its housing +adapter is small (<15 cm) and light (<200 g). | Depending on the platform and the deployment scenario (depth, sea conditions, accessibility etc.). Technical advice and support on mountings is expected from other partners experience in marine deployments. | Depending on the platform and the deployment scenario (depth, sea conditions, accessibility etc.). Technical advice and support on mountings is expected from other partners experience in marine deployments. | Installation on vessels' laboratory. Water samples will flow through a transparent channel to the optical sensor. Water samples obtained by the specific Idronaut's water sampler or from surface water pump. | Depending on the platform and the deployment scenario (depth, sea conditions, accessibility etc.). Technical advice and support on mountings is expected from other partners experience in marine deployments. | Deploying from ship crane with the suspension arm > 6 m, lifting capacity >5000 N. Weight ~160 kg, | To be deployed / installed using a low noise method e.g. quiet moorings, movement through the water limited to 4knots (maximum) |
| | **Environmental conditions** | Env. Range: -50°C to 80°C. | Env. Range: -50°C to 80°C. | laboratory conditions | Applicable temperature range of the sensors not yet assessed | laboratory conditions | laboratory conditions | Problems with fishing out of the buoy when sea state > 4 B | Problems with fishing out of the buoy when sea state > 4 B |

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| | **Sensor operability, optimization, specificities.** | Data can be stored in USB memory or transmitted by telemetry. | Data can be stored in USB memory or transmitted by telemetry. | Resistivity Changes due to the variation of pH of the water and pCO2 values. Current vs. voltage values are read. Only the peaks position is needed for the measurement | Analytical specifications of the sensors are yet to be determined. | Spectral imaging and FT-NIR require important processing capabilities. A dedicated control board is required. Memory and data formatting can be included in this board. Also an interface with the instrument to allow integration with the rest of the sensors for data transmission. | Raw measurement consists of a time series of Current Intensity and Voltage. | | 1/3 octave bands 63Hz and 125Hz will be summarised for data transmission to shore. |
| | **Special needs?** | Temperature sensing element need some protection (housing) that is under development | Pressure sensing element needs some protection (housing) that is under development. Electrical connections inside the water should be waterproof. The sensor should be fixed to avoid vibrations due to waves. | Reservoirs of distilled water and of two buffer solutions may be needed for periodic reconditioning of the electrodes | Additional needs may be identified as the project progresses. | A dedicated electronic board will be developed, system integration should be easily achieved by an agreement on: data format, transmission rates, communication protocols. | Containers for two types of buffer solutions (< 1 L each), for conditioning the sample at the pH needed for the analyses of heavy metals. Eventually 3x20mL containers with standard solutions for each of the 5 heavy metals under study (i.e. 3x5=15 containers of 20 ml). Additional container for residual liquids containing heavy metals. | | Static or slow moving platform with quiet noise signature |

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| | **Platforms where sensor can be deployed (see Table X5.)** | Any | B, C | A, F | A, B, C, D, F | A, B, E. Integration in other platforms (C and D) may present additional difficulties. | A, F | C | B C<br>E maybe |
| **Data acquisition** | **Type of data** | The output can be converted to any digital format. Minimum 16-bit A/D converter should be advisable to produce ASCII data with enough resolution for resistance or converted to high resolution temperature | The output can be converted to any digital format. Minimum 16-bit A/D converter should be advisable to produce ASCII data with enough resolution for resistance or converted to high resolution pressure | . Data collection requires simple processing to obtain calibration curve, that is, peak picking and translation of the peak position to pH through the calibration curve | The primary output will be nutrient concentrations. The raw data will also be transmitted in the form of a series of light intensity readings. Each measurement will also include a temperature reading and date stamp. | Main information: Surface Microplastic concentration in (mg/litre). | Raw measurement output consists of two data columns of Current Intensity and Voltage. Temperature of the sample and time stamp should be included (less than 20 kB). In case of standard addition method each measurement would generate three more of these files. | Size of data packages - depending on the time series usually in one second package noise, also echo profile and position in space (compass+inclinometer) | Most initial data analysis will need to be done within the unit allowing this summary to be provided to the central logger for transmission. This communication platform needs to have an intelligent interface, in the event connection is lost it allows the data packets to recommence from where the link is dropped rather than restarting. |
| | **Manual or Automatic** | Automatic | Automatic | Semiautomatic | Automatic | Semiautomatic | Semiautomatic | Automatic | Automatic |
| | **Sampling Frequency** | Any frequency from 1/second to 1/day | Any frequency from 1/second to 1/day | Hourly. Min 30 min. Typical measurement time is 5to 8 min. After 5 min stabilization | Hourly | Every few minutes | Every few hours | 4*30 KSamples/sec. | 25kHz to 50kHz |

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| | **Limitations on data volume collected** | No | No | No | Will be determined by the selected mode of storage for SD cards. Due to the small size of data generated this is not expected to represent a limitation. | No special limitations are foreseen in this topic. | No limitations | Data must be summarized every 1-3 sec. depending on channel capacity | Short packets of data or summary data are all that can be sensibly transmitted. |
| **Data transfer and storage** | **Local data storage?** | Raw data that would be stored as resistance vs. time | Raw data that would be stored as resistance vs. time | Raw data should be stored in the form of resistivity changes due to the different pH and pCO2 value of the marine water | Raw data should also be stored as it provides additional information on sensor performance and allows cross-referencing with data stored on board the sensor (e.g. allowing reliability of transmitted data to be validated). | Raw data should be locally stored | Raw data as images should be locally stored | Raw data usually stored on SD cards | Raw sound files and processed sound files, sound pressure and frequency over time. All raw noise data will be saved to SSD locally for shore based analysis. |
| | **Transmission Channels (see Table X11)** | Satellite LEO, Direct radio link or cable, depending on platform and location | Satellite LEO, Direct radio link or cable, depending on the platform used | Satellite, Radio link or mobile depending on location | Any. The deployment location, platform and coverage will determine data transmission mode. Data logging can be utilised in scenarios where none or limited capacity of transmission channels. | Any. The deployment location, platform and coverage will determine the choice of data transmission mode. | Satellite, Radio link or mobile depending on location | Direct radio link. WIFI channels (mobile or satellite) | Cable, Optical Fibre, Direct radio link may be |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Requirements in terms of delivering and managing sensor data** | Deliver sensor information and observations on the web, Allow users to subscribe to sensor alerts and notifications. Allow advanced users to remotely plan sensor tasks (e.g., schedule measurements, etc.) | Deliver sensor information and observations on the web, Allow users to subscribe to sensor alerts and notifications. Allow advanced users to remotely plan sensor tasks (e.g., schedule measurements, etc.) | Deliver sensor information and observations on the web, Allow users to subscribe to sensor alerts and notifications | Deliver sensor information and observations on the web, Allow users to subscribe to sensor alerts and notifications, Allow advanced users to remotely plan sensor tasks (e.g., schedule measurements, etc.), Allow sensors to be discovered through a search interface | Deliver sensor information and observations on the web, Allow advanced users to remotely plan sensor tasks (e.g., schedule measurements, etc.) , Allow sensors to be discovered through a search interface | Deliver sensor information and observations on the web, Allow users to subscribe to sensor alerts and notifications | Deliver sensor information and observations on the web, Allow users to subscribe to sensor alerts and notifications. Allow advanced users to remotely plan sensor tasks (e.g., schedule measurements, etc.) | Summary data in real time, on a programmed duty cycle, backed up by onboard storage |
| | **Post process required?** | If the calibration of R(T) is not included in the acquisition package. GPS information should be included if it is installed in a moving platform | If the calibration of R(T) is not included in the acquisition package. | If raw data is transmitted but typically, data transferred would be converted to physical units before transfer. | Raw data of light intensity will be acquired and transmitted. They will need to be ultimately converted to nutrient concentrations. The final data to be stored and displayed, plus Time stamp and GPS position data. The data management system should also allow for additional features such as: Event detection and classification (identification of false positives/negatives), and data smoothing (for display purposes) | Sensor data will be processed in the dedicated electronic board before sending them. Additional processing might be needed to join sensor data with other inputs like: GPS coordinates, time stamp, water temperature, etc. | Yes, the raw data is an intensity vs. voltage and a final processing (of eventually several of these datasets if standard addition method is used) will be needed before obtaining the heavy metal concentrations in water. | Data must be processed. Final parameters are: Noise spectrum level, statistics of momentary values acoustic pressure of the noise | Processed sound files, sound pressure and frequency over time |

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**Table 3. List of properties of measured parameters, methodology used or sensor characteristics relevant for testing**

| Acronym | Characteristic | related to | Details |
|---|---|---|---|
| **SV** | Single value | Parameter | observation can be expressed as CV |
| **CV** | Complex value | | observation can be expressed as SV |
| **CD** | Continuous | | property is continuously distributed in water |
| **DD** | Discrete | | property is discretely distributed in water |
| **PD** | Point | | property can be associated to a single point at a time |
| **ED** | Extended | | property can be associated to an extended volume at a time |
| **AM** | Automatic | Method | Analysis is fully automatic |
| **SM** | Semiautomatic | | Analysis requires periodic human intervention |
| **MM** | Manual | | Analysis requires human intervention |
| **CS** | Continuous sampling | | Delivered data can be continuous in time |
| **DS** | Discrete sampling | | Delivered data is always discrete in time |
| **LD** | Low data | | Information depends on few data |
| **HD** | High data | | Information depends on many data |
| **PP** | Pre process | | Pre process is always required before sending data |
| **SS** | Small | Sensor | Sensor and installation are small |
| **LS** | Large | | Sensor and installation are large |
| **AR** | Auxiliary | | Sensor requires auxiliary material (reagents, standards, etc) |
| **RS** | Replacement | | Sensor is disposable and has to be replaced after some samples |

**Table 4. Items of Table 3 related to each one of the sensors**

| **Acronym** | **Temperature** | **Pressure** | **pH** | **Nutrients** | **Microplasitcs** | **Heavy Metals** | **Underwater Noise** |
|---|---|---|---|---|---|---|---|
| **SV/CV** | SV | SV | SV | SV | SV | SV | CV |
| **CD/DD** | CD | CD | CD | CD | DD | CD | CD |
| **PD/ED** | PD | PD | PD | PD | PD | PD | ED |
| **AM/SM/MM** | AM | AM | MM | SM | SM | MM | AM |
| **CS/DS** | CS | CS | DS | DS | DS | DS | CS |
| **LD/HD** | LD | LD | LD | LD | HD | LD | HD |
| **PP** | *N* | *N* | *N* | *N* | *Y* | *N* | *Y* |
| **SS/LS** | SS | SS | SS | SS | LS | SS | LS |
| **AR** | *N* | *N* | *Y* | *Y* | *N* | *Y* | *N* |
| **RS** | *N* | *N* | *Y* | *Y* | *N* | *Y* | *N* |

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**Table 5. Platforms for sensor testing**

| Category | Description | Sensors for testing | Reference | Data transmission |
|---|---|---|---|---|
| **A** | Research vessels | All | All | Satellite; Mobile |
| **B** | Fixed platforms | All | Only autonomous. Possible sampling | Cable, Fixed radio links |
| **C** | Buoys and moorings | Temperature, Pressure, Nutrients, Heavy metals, Microplastics | Only autonomous | Fixed radio links |
| **D** | Ocean racing yachts | Temperature, Nutrients, Microplastics | Only autonomous | Satellite |
| **E** | Drifting buoys | Temperature | CTD | Satellite |
| **F** | Fishing vessels | Temperature, Pressure, pH, Nutrients, Heavy metals, Micrpolastics | Autonomous and limited capacity for analytical processes. Possible sampling | Satellite, Mobile phone, fixed radio links |

**Table 6. Typical sensors, sampling method and type of analysis to be used as reference for each parameter. Note: "Standards" means that analytical techniques or instruments used for analyses require standardisation**

| Parameter | ref. sensor | standards | Auto/manual | sampling | analysis | deliverable |
|---|---|---|---|---|---|---|
| Temperature | Pt probe | NA | A/M | NA | NA | D4.1 |
| | CTD calibrated | | A | | | |
| pH | Ph-meter | Y | A/M | water | Chemical | D4.2 |
| Nutrients | Colorimeter | Y | A/M | water | Chemical | D5.1 |
| Microplastics | No | NA | M | Specific sampler Net/Filter | Image processing | D6.2 |
| Heavy Metals | Potentiostat | Y | M | filtered water | Chemical | D7.1 |
| Noise | Hydrophone chain | NA | A | NA | NA | D8.3 |

**Table 7. Communication channel for testing according to the platform type (see Table X5) and instrument power**

| Platform | Instrument Power | coastal | remote |
|---|---|---|---|
| **A** | Line | mobile/ Fixed Radio link | sat_GEO |
| | Battery | sat_ LEO | sat_ LEO |
| **B** | Any | Optical Fibre | Optical Fibre |
| **C** | Battery | Fixed Radio link | sat_ LEO |
| **D** | Line | N/A | sat_GEO |
| | Battery | N/A | sat_ LEO |
| **E** | Battery | N/A | sat_ LEO |
| **F** | Line | mobile/ Fixed Radio link | sat_GEO |
| | Battery | sat_ LEO | sat_ LEO |

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**Table 8. Stressors under which sensors can be tested. Note that "Yes" means that sensor should be tested under the stressor**

| **Stressors** | **sea state and wind** | | | **Temperature** | | **long term effects** | |
|---|---|---|---|---|---|---|---|
| **Sensors** | calm | moderate (10-20 kn) | rough (>20 kn) | Low | High | corrosion | fouling |
| **Temperature** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Pressure** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **pH** | Yes | In lab | In lab | N/A | N/A | Yes | Yes |
| **Nutrients** | Yes | In lab | In lab | N/A | N/A | Yes | Yes |
| **Microplastics analyzer** | Yes | Yes | Yes | Yes | N/A | Yes | Yes |
| **Microplastics sampler** | Yes | NO | NO | Yes | Yes | N/A | N/A |
| **Heavy metals** | Yes | In lab | In lab | N/A | N/A | Yes | Yes |
| **Underwater noise** | Yes | Yes | NO | Yes | Yes | Yes | Yes |

**Table 9. Some testing locations for sensors and stressors**

| **Location** | **Platform** | **Region** | **Stressors** | **Relevance** | **Monitored** | **Transmission** |
|---|---|---|---|---|---|---|
| Barcelona coastal station | **C** | W. Mediterranean | C,F,HT | T,P,pH,N,M,HM,U | T,N | FxR, LEO |
| OBSEA Vilanova | **B** | W. Mediterranean | C,F,HT | T,P,pH,N,HM,U | T,P,U | Optical |
| Gdańsk bay | **B** | Baltic | SS,F,LT | T,P,pH,N,HM,U | T,N,U | Cable |
| Oristano bay | **B,C** | Tyrrhenian | C,F,HT | T,P,pH,N,M,HM | T,P,pH,N,HM | FxR, LEO, Cable |
| Svalbard Ny Alesund | **A,C** | Arctic | SS,LT | T,P,pH,N,HM | | FxR, LEO |
| Gulf of Cadiz coast | **A,F** | NE Atlantic | SS,F | T,N,HM | sporadic | FxR, mobile |
| Southern Ocean | **D,E** | Open sea | SS,LT,C.F | T | remote sensing | LEO |
| Gulf of Guinea coast | **A,E,F** | E Atlantic | SS,F,HT | T,N,M,HM | none | FxR, LEO |
| Rio de la Plata estuary | **A,F** | SW Atlantic | F | T,N,M,HM,U | | FxR, LEO |
| Bay of Bengal | **A,E,F** | Indian | F,HT | T,N,M,HM | none | LEO |
| Legend | | LT: Low Temp | SS: sea state | T: Temperature | HM: Heavy Metals | FxR: Fixed Radio link |
| | | HT: High Temp. | F: Fouling | P: Pressure | M: microplasitcs | |
| | | C: corrosion | | N: Nutrients | U: Und. noise | |

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**Table 10. General items to be certified from testing at sea, methods and target sensor characteristics**

| Item | Method | Sensor |
|---|---|---|
| accuracy (units). | Data Validation | All |
| autonomy (time). | Field Testing | autonomous |
| drifts (units). | Data validation | All |
| data telemetry (conditions) | Operability Testing | All |
| depth (pressure) range (m) | Operability Testing | suitable |
| corrosion damages (time/temperature) | Testing vulnerabilities | All |
| fouling drifts (time/temperature/depth) | Testing vulnerabilities | All |
| light distortion/influence on measurements | Testing vulnerabilities | suitable |
| long term drifts (time) | Data validation | autonomous |
| Sea state conditions (wave/swell) | Testing vulnerabilities | suitable |
| temperature range (°C) | Testing vulnerabilities | All |
| wind range (m/s) | Testing vulnerabilities | suitable |

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**Table 11. Summary of communication channels and their characteristics**

| Transmission Channel | Initial Cost | Recurring costs | Distance | Power | Platform | Capacity | Advantages | Disadvantages |
|---|---|---|---|---|---|---|---|---|
| **Undersea optical fibre** | Very high | Maintenance / Insurance | No limit | irrelevant | B,C | The highest (10 Gbps) | Highest capacity | Highest installation cost (10000 €/km) and maintenance |
| **Cable** | Medium | Maintenance | No limit | irrelevant | B,C | Very high | Very high capacity | installation and maintenance costs |
| **Acoustic** | High | Maintenance/ Insurance | 2-3 km | high | none | Low (up to 2 Kbps) | for moving underwater sensors | costs, power requirements |
| **Direct radio link** | Low | Maintenance | <30 km (more if receiver is elevated) | low | C,F | High (50 Mbps) | Low cost equipment, high capacity, high reliability | Requires LoS. Short distances |
| **Troposcatter** | Medium | Maintenance | < 250 km | very high | none | Medium (up to 22 Mbps) | High capacity, high reliability, no delay, IP based system, no recurring monthly costs | initial costs, power requirements |
| **Mobile GSM: 2G,3G,4G** | Low | Monthly. based on capacity and total monthly bytes | Short. Dependent of operator node network availability | low | A,C,F | Medium (up to 20 Mbps) | Low cost equipment, high capacity, high reliability, network implemented in land | Many different communications protocols, continuously evolving, only nearshore coverage |
| **Satellite link GEO** | Low | Monthly. based on capacity and total monthly bytes | irrelevant | very high | none | Low: 256 bps to 8 Mbps | Low equipment cost (for very low capacity <512 bps) | delays, power requirements |
| **Satellite link LEO** | Low | Monthly. based on capacity and total monthly bytes | irrelevant | low | A,C,D,E,F | Low: 256 bps to 8 Mbps | Low equipment cost (for low capacity <7.2 Kbps ) | recurring costs |

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**Table 12. Comparison between Globalstar and Iridium constellations for data communication. ARGOS is included for reference**

| Constellation | | Globalstar | Iridium | ARGOS |
|---|---|---|---|---|
| Number of satellites | | 48 | 66 | 8 |
| Maximum Capacity (Kbps) | | 7 | 2 | 3 |
| Uni/Bi directional | | B | B | U |
| Coverage | | Partial (Fig. Y2) | Total | Total |
| Power required for short burst | | .5 W | 1 W | 1 W |
| Expected delays | | Off coverage | No | Yes |
| Terminal cost (€) | | 100 | 200 | 50 |
| Recurring costs (€/month) | Short burst and <30Kb/month | 10 | 20 | 250 |
| | Max capacity | <150 | <265 | 250 |

## 6. FIGURES

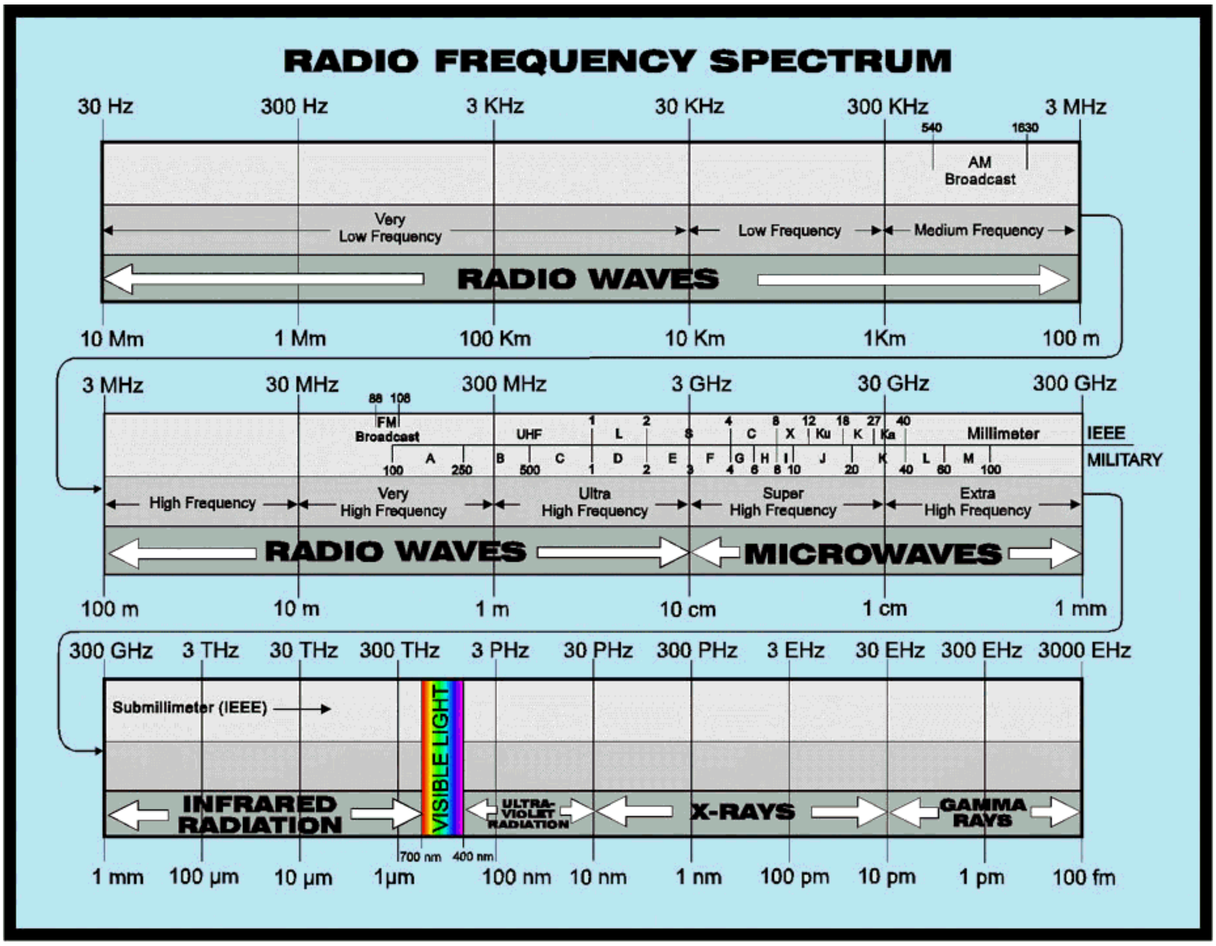


**Figure 1. Complete electromagnetic wave spectrum (On top: frequency, below: wavelength)**

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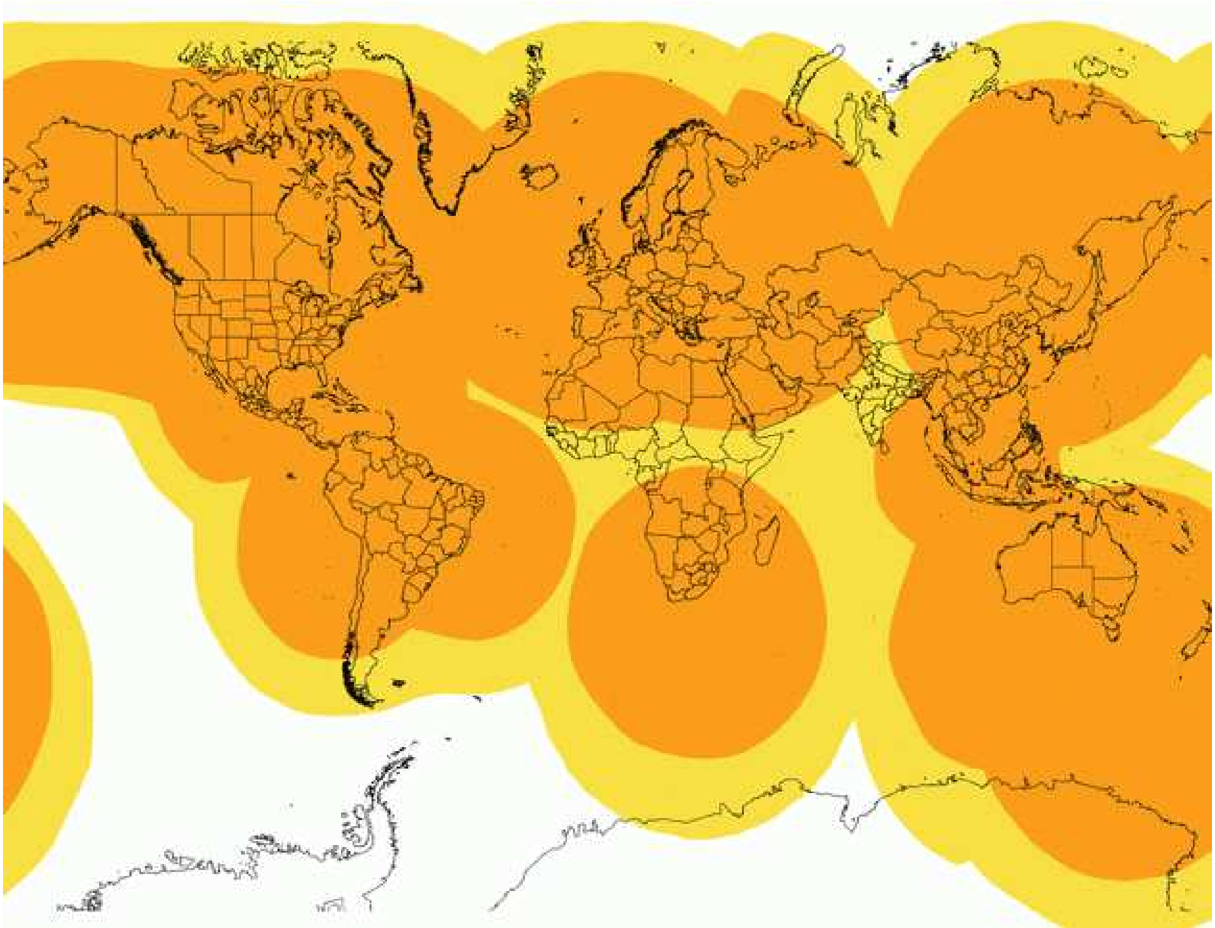

**Figure 2. Globalstar full coverage (Orange areas). 96% of probability of successfully sending a single message within 20 minutes period (Yellow areas)**

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# A. ANNEX 1: Extract of the temperature testing onboard the S/Y OCEANIA (June 2016)

## *A.1 Set-up the system in the ship's laboratory*

Since temperature sensor at this time was not in a proper housing, being quite delicate, it was decided to put it into a 500 ml glass bottle (Fig.A1a). Three holes on the lid allowed for water input and output, and sensor cable to the electronics. Input water was connected to the source through a water distributor (Gardena) allowing for 4 connections (Fig. A1b). The other three connexions were to serve the microplastic sensor also in testing (see the corresponding report), a fluorometer required for IOPAN experiments and the remainder was used as overflow to control the rate through the used outputs (Fig. A2).

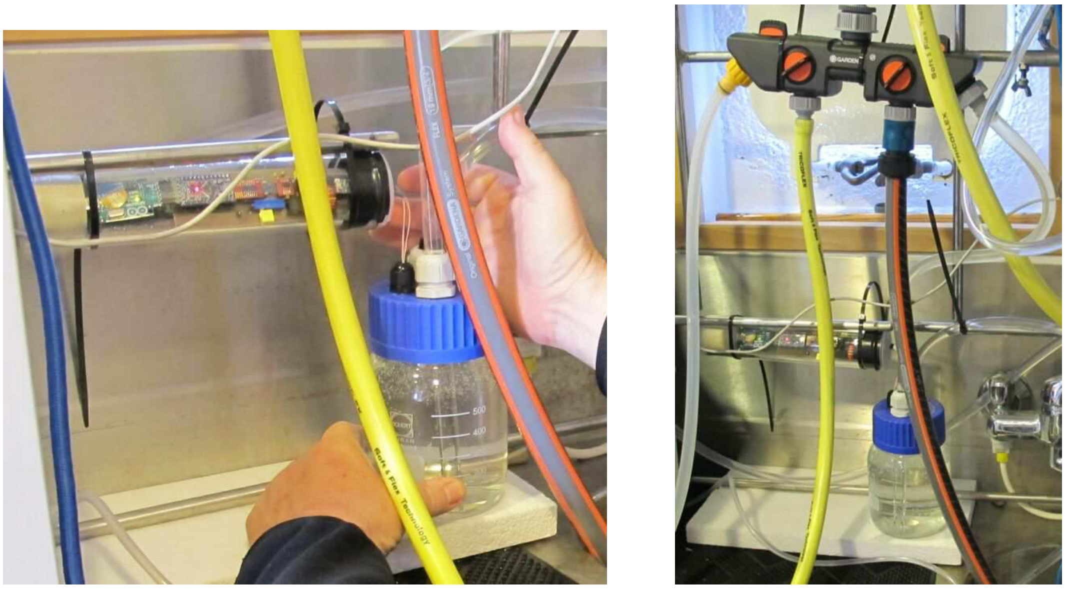

**Fig.A1. New sensor installation at the Oceania laboratory**

**Fig. A2 Instruments using surface pumped water underway at the Oceania wet laboratory**

Flow rate was maintained between 1.5 to 2.5 L/min. It was enough to ensure a good water renewal within de glass bottle and not so high to produce excess turbulence that might affect the sensor.

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The sensor was connected to an adapted board, including an A/D converter and a microprocessor to output in ASCII through a USB connector. The Output was connected to a PC and stored through capturing an hyperterminal (Table A1) application to a file. Files were closed every 2 to 8 hours and data was continuously displayed as to check the sensor behaviour.

**Table A1. Partial reproduction of the sequences sent via hyperterminal: line_number; time (seconds); sensor_output; reference voltage**

| |
|---|
| 12498;131084;1917343;2001328 |
| 12499;131094;1916343;2001312 |
| 12500;131105;1920171;2001328 |
| 12501;131115;1925375;2001312 |

## A.2 *Data collection underway along the vessel's track*

Part of the water pumped was diverted to the ship's deck where a SBE-911 CTD was analysing temperature, conductivity and other variables required within the frame of IOPAN experiments (Fig. A3). CTD data was recorded at 1s rate and geo-referenced through the GPS system of the vessel. Other variables such as meteorological and navigation data were also recorded underway.

**Fig. A3. CTD on the Oceania deck measuring surface pumped water underway**

All computers gathering information were synchronised with the GPS at GMT, as to have a unique time reference for all the data.

All the system was ready before starting the cruise at 22:00, 13 June 2016 in the Gdańsk harbour.

**1. Data from sensor**

Sampling started using the sensor#1, however a first look at the output revealed strong output noise. A first verification of this output revealed a failure on the sensor that gave an useless information (Table A2). It was probably water leaking inside the brass cover, as it already happened with sensor#2 during the previous laboratory tests. Therefore sensor#1 was disconnected and replaced be sensor#3.

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**Table A2. Sequence of data captured from sensor #1 starting the cruise.**

| |
|---|
| 41;409;759515;2001328 |
| 42;419;850390;2001312 |
| 43;430;693062;2001328 |
| 44;440;833843;2001312 |
| 45;451;555906;2001312 |
| 46;461;513734;2001328 |
| 47;472;499734;2001312 |
| 48;482;474171;2001312 |
| 49;493;440562;2001312 |
| 50;503;428515;2001312 |
| 51;513;536687;2001312 |
| 52;524;481906;2001328 |
| 53;534;383312;2001328 |
| 54;545;372718;2001328 |

After the connexion, sensor#3 did not produce any significant noise so that it was decided to run all the testing with this sensor while working. Unfortunately the analog output of this sensor was out of range for low temperatures in laboratory testing so that, it was assumed that the northernmost part of the transit measures will be out of range, since temperatures beyond a certain latitude were expected to be below 10°C. Data provided by the sensor was reasonably stable and, indeed, beyond ~65°N most of the data was out of range as foreseen (see Fig. A4)

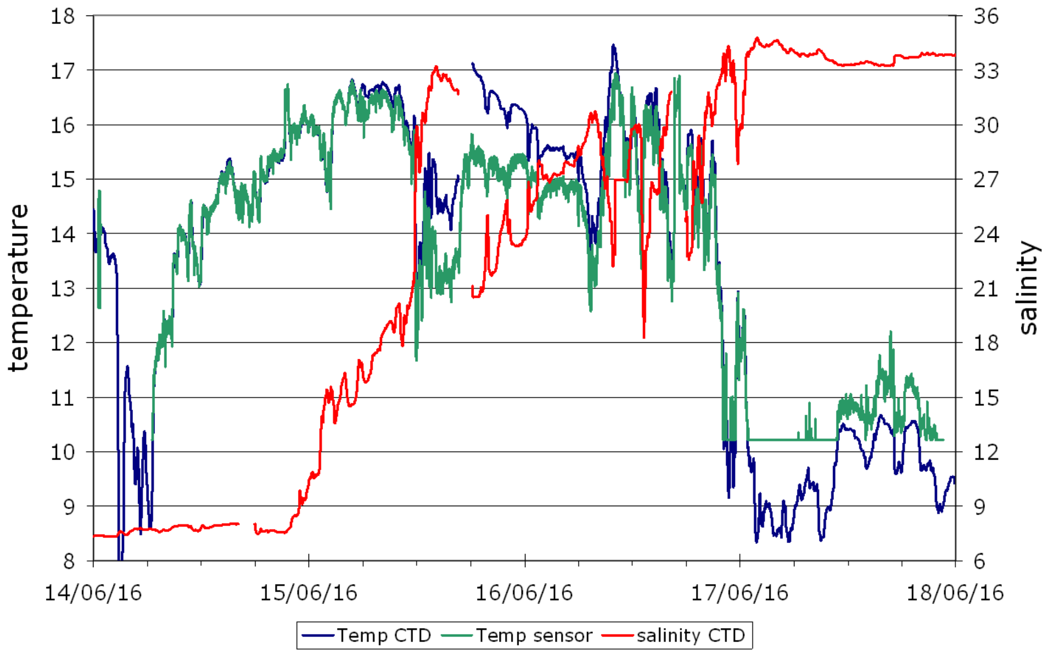


**Figure A4. Time-series of temperature from CTD and new sensor, and salinity from CTD underway the Oceania course**

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**2. Data from CTD**

No problem was found with CTD data. CTD has been calibrated before the cruise and only few interruptions for maintenance were cutting the sequence underway.

## *A.3 Data comparison and adjusting*

Since temperature was linearly dependent on the sensor conductivity, an adjustment was performed to convert the reciprocal voltage to temperature, assuming a fixed current of 10µA, by comparing tipping points of the records such as maxima and minima. A first adjustment during the second day of sampling using 8 points (Fig. A5) within the temperature interval of 12 to 17°C in the Baltic sea. Linear adjustment was very good (r= 0.9990) and standard deviation of the residuals (0.0686°C) gave a reasonably good accuracy.

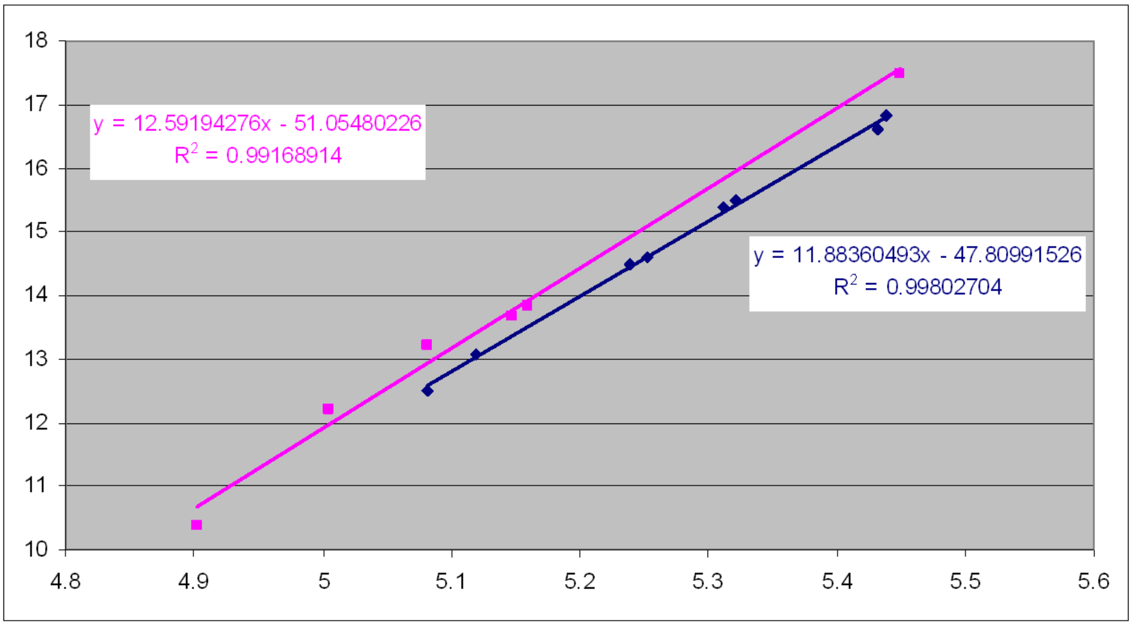


**Fig. A5. Linear adjustment of sensor output converted to conductivity (µS) and CTD temperature. Blue dots (right) correspond to the first period (roughly before noon 15 June) and pink dots (left) to the second period (see fig. A4)**

However after crossing the Danish straits, a significant deviation was found between sensor converted data and the CTD. A new series of 6 tipping points were used to find a new relationship giving a significant drift with respect to the previous one (ΔT ~ 0.5°C) and lower accuracy from residuals SD (0.1339°C).

This behaviour was quite surprising. No evidence of what might be the cause of the drift and lower accuracy. The only environmental condition that significantly changed was salinity, from less than 10 (Baltic) to more than 30 (North Sea). However it is hard to assume that a well sealed (otherwise it would not be working) sensor could be influenced by a change in water conductivity, even though it was a quite large shift. Any other conditions that could come from changes in on deck conditions for the CTD but neither environmental temperature nor sun exposition (very scarce all the time) seem to be significant over the large flow rate (>10 L/min). Of course, laboratory conditions on the ship were almost constant all the time.

On the other hand no changes in sea conditions were found (low wind and waves) before entering in a storm later, that apparently did not affect the sensor activity.

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## *A.4 Results*

Figure A4 shows a time series of CTD temperature and salinity, and sensor data converted to temperature using the first two days adjustment. Note that the sequence is almost coincident at the beginning and shifted after crossing the Danish straits as evidenced by the salinity record.

It can also be noted that at the end of the time series, sensor readings are out of scale but they are recovering at points where temperature raised above the threshold but showing a different shift.

The whole sequence has then three parts:

1. Mainly within the Baltic sea with high accuracy and very good adjustment.

2. After crossing the Danish straits with less accuracy and a negative shift (Sensor < CTD)

3. At the end of the series when temperature is generally below the sensor threshold showing a positive shift where sensor temperatures are slightly higher than CTD.

## *A.5 Final test after cruise*

The above results on the sensor#3 behaviour suggested that it might be suffering a time-dependent drift or may be affected by other environmental conditions such as salinity. In view of that a complete laboratory test using sea water is planned after the cruise. The idea was to use the testing system already used in the first laboratory tests (last year)

Unfortunately when testing in the laboratory was ready and sensor connected, a high noise appeared in the sensor output (Fig. A6). Therefore no test after the cruise could be done and the causes of the observed drift will remain unclear

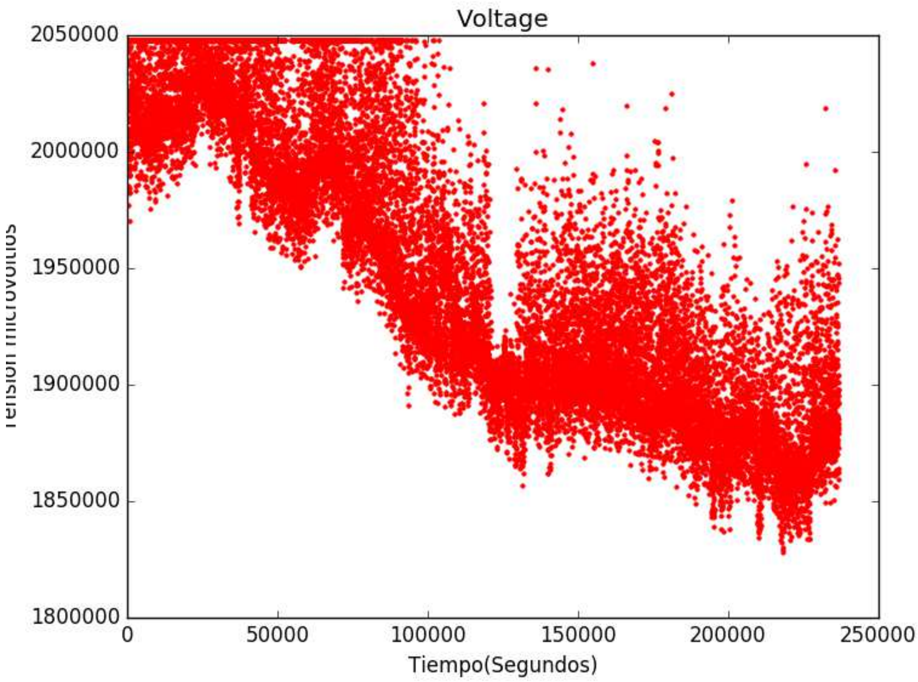


**Fig. A6. Time series of sensor output (µV) in an attempt to reproduce a progressive temperature increase in laboratory conditions after the cruise.**

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## A.6 Conclusions

This is a very first test in real sea conditions of the new pyro- and piezo-resistive polymeric temperature sensor developed within the COMMON SENSE Project. Globally this first test can be assumed as very useful to show the pros and cons of the sensor behaviour, test the electronics and have an idea of what has to be done to integrate the sensor in any other device. Unfortunately a final test has not been possible to understand the observed changes in response.

The following points are intended to summarize of this experience:

1. Sensor development:

   All the process to prepare the sensor has to be clearly improved. Especially contacts, housing and sealing against water leaking.

   All the ensemble is clearly too fragile against stresses on connexions and cables.

   Sensor resistance ranges should be always kept between 10000 and 30000 Ω for the typical seawater temperatures (-2 to 32°C)

2. PCB conditioner was working correctly but if modified for 5V instead of 12V DC power supply, consumption must likely be reduced.

3. A/D and processor. This is supposed to be developed within the SSU. All the present experience has been done using a board adapted from another use. It has been working properly but it is not the one developed within the COMMON SENSE consortium.

4. The whole system has shown good linear response, quite good accuracy but some uncontrolled shifts had been observed whose origin must be carefully studied in the laboratory.

Next filed testing step will be to fix the sensor in a buoy and leave it for a while. To do this new step all the previous steps must be satisfactory solved.

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