D1.1
EMERGING TECHNOLOGIES, EMERGING MARKETS: FOSTERING THE INNOVATION POTENTIAL OF RESEARCH INFRASTRUCTURES

WORK PACKAGE 1 – NEW SENSOR TECHNOLOGIES: INNOVATION AND SERVICES

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Abstract

The aim of WP1-task 1.1, is to identify and analyse emerging environmental observations technologies (sensors and platforms) that could be useful to, and benefit from, Research infrastructures (RIs) to realize and achieve their market potential. The task also aims to explore technical challenges, market barriers and ongoing initiatives related to these technologies. The deliverable D1.1 is tailored to be a source of inspiration for Small and Medium Enterprises (SMEs), while investigating new business opportunities, as well as for the EU bodies, pointing them the specific areas requiring additional attention and financing.

Environmental observations performed by RIs are dedicated to answering the grand challenges (ENVRI+ Theme 4). This is a tremendous endeavour dealing with hundreds of types of measurements by means of numerous sensors, installed on numerous types of platforms and performing measurements in all environmental domains. D1.1 presents technological advances implemented by the RIs, for observing four environmental domains, i.e. the atmospheric (ICOS, IAGOS, SIOS, ACTRIS), marine (EURO-ARGO, JERICO), ecosystem / biosphere (ANAEE) and solid earth (EPOS) domains. For each of these domains, a limited number of selected variables and parameters, crucial for describing a given environmental system are identified. The deliverable reviews emerging technologies along with existing ones for the measurements of key-parameters, analyses their strength and weakness, and identifies the main providers. Technologies described in this document, represent those that are mostly valued by scientists, and then that are the most wanted or expected to become available on the market in the near future (emerging technologies).

For each domain, a preliminary market description is provided, where existing and potential regulatory framework that could influence the production and/or market penetration of sensors is described, together with countries/communities that could be interested in developing specific sensors and technologies.

Along with sensors, observing platforms represent promising technological sector that rapidly develops. The document presents recent advances in this field, with focus on the emerging use of drones for observations of atmosphere, biosphere and marine environment. It is supplemented by an assessment of advances on energy supply for sensors and platforms and the subsequent emerging opportunity for deploying sensors in hardly accessible regions.

The role of environmental research infrastructures in bringing observing technologies to the market is also discussed, with a focus on how RIs can support and facilitate public-private partnerships engaging scientists, companies and governmental bodies in promoting the development of technologies and bring value to all parties. New business opportunities based on the interactions of RIs with other parties are provided.

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Terminology

A complete project terminology is included as an Appendix 2.

Project summary

ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It is driven by three overarching goals: 1) promoting cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment for an increasing number of users outside the RIs.

ENVRIplus aligns its activities to a core strategic plan where sharing multi-disciplinary expertise will be most effective. The project aims to improve Earth observation monitoring systems and strategies, including actions to improve harmonization and innovation, and generate common solutions to many shared information technology and data related challenges. It also seeks to harmonize policies for access and provide strategies for knowledge transfer amongst RIs.

ENVRIplus develops guidelines to enhance trans-disciplinary use of data and data-products supported by applied use-cases involving RIs from different domains. The project coordinates actions to improve communication and cooperation, addressing Environmental RIs at all levels, from management to end-users, implementing RI-staff exchange programs, generating material for RI personnel, and proposing common strategic developments and actions for enhancing services to users and evaluating the socio-economic impacts.

ENVRIplus is expected to facilitate structuration and improve quality of services offered both within single RIs and at the pan-RI level. It promotes efficient and multi-disciplinary research offering new opportunities to users, new tools to RI managers and new communication strategies for environmental RI communities. The resulting solutions, services and other project outcomes are made available to all environmental RI initiatives, thus contributing to the development of a coherent European RI ecosystem.

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1 Introduction

Societies are facing a number of environmental grand challenges (ENVRIplus WP 12) interlinking the four domains covered by ENVRIplus. The data provided by RIs through environmental observation is crucial in tackling these challenges. The present research supports this environmental monitoring role by facilitating the supply of novel measurement techniques, able to reinforce the role and impact of RIs.

1.1 Grand challenges

Climate change is a global issue caused by anthropogenic emissions of climate forcers, especially long lived greenhouse gases (GHG). Climate positive feedbacks take place in remote, vulnerable regional ecosystems (e.g. permafrost, Kuhry et al. 2013) mediated by GHGs are a major threat to be investigated and monitored over the long term. Air quality is another biggest issue. Human death associated to air pollution remain at significantly high levels. Ubiquitous aerosols result in complex effects on climate and in adverse health impacts. Further increase of temperatures cause the threat that Amazonian or Siberian forests become more vulnerable to fires. Changes in the environment include changes in the biosphere and, thus, the agriculture and food production (Parry et al. 2004). Due to droughts, most of the farmlands may turn into deserts, this would in turn challenge food security. Contrary to general belief, the agricultural activities will not be expanded to the northern regions in these conditions, because they will be limited with the poor land quality. Meat production, considered as one of the main sources of GHG, does not help to stabilize the situation, as it takes many plant-based nutrients to produce animal-based food. Monitoring environmental parameters of the oceans is another task of great importance. Ocean systems stay in close relation to the other domains and are heavily influenced by any changes of environmental parameters. Thus, rise of the average temperatures will shift the habitual areas of numerous fish species and may influence the procreation of others. Large concentrations of CO_2 in the atmosphere above sea waters will decrease the solubility of oxygen in the water preventing sea animals from breathing. At the same time, dissolved CO_2 can cause acidification of the water, preventing corals and other sea inhabitants from binding carbon and building shell structures.

1.2 Position of this work in the current landscape

Monitoring environmental parameters and climate change is a complex task which answers grand challenges. It is of crucial importance (Bell and Joseph 2018) for all countries and societies. Development of technologies for such monitoring is in huge demand and driven by numerous factors (fig.1). Among them are demand for the high quality of measurements and development of new types of measurements, reduction of measurements costs, necessity to control the pollution and avoiding the legislative responsibility for the contamination of the environment. Besides, there is a large societal demand based on the ongoing decrease of air, soil and water quality. Environmental monitoring is a complicated activity, because technical requirements for the innovative measurement platforms, systems and sensors can vary significantly across regions and domains. Such variations certainly create unwanted difficulties for the technology producers, especially small and medium enterprises (SMEs), due to their generally limited resources. European businesses are limited in their development in this field due to the inability to overcome the technological differences, to overview the possible paths for development of corresponding markets and to establish the contacts in-between research communities, technology producers and other supporting businesses. This deliverable of ENVRIplus[1] project serves to overpass mentioned difficulties of environmental measurements in Europe. It is aimed to help SMEs, scientific communities and other interested partners to establish fruitful, beneficial collaborations and to understand the possible vectors of development of European environmental measurements and monitoring.

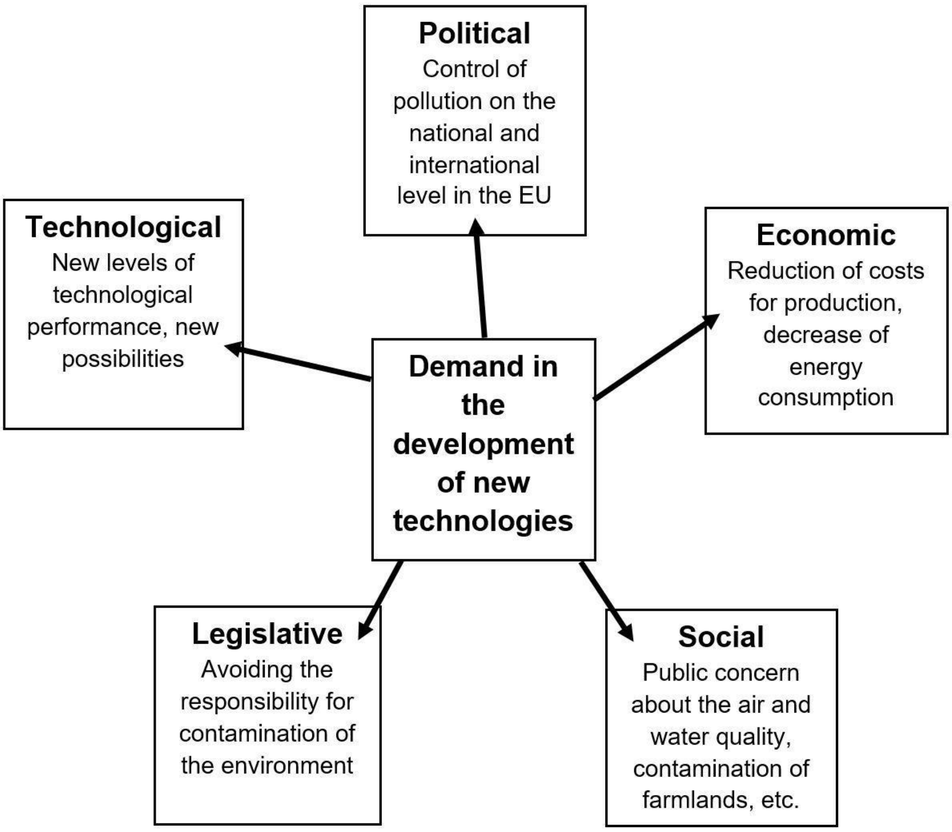

FIGURE 1 FACTORS INFLUENCING THE DEVELOPMENT OF TECHNOLOGY

1.3 Approach of this work: methodology

The aim of ENVRIplus Deliverable 1.1 was to analyze and identify useful technologies (sensors and platform-related) for environmental observations and services with high potential of

[1]http://www. ENVRIplus.eu/

turning into profitable businesses with the help of Research infrastructures (RIs). The task also aimed to explore the challenges and barriers (technical and market) and initial initiatives in the area. The resulting Deliverable 1.1 shall act as a guideline for the SMEs, inspiring future development and production decisions, as well as for the EU and national decision makers and funding organizations, highlighting specific emerging areas.

The work on Deliverable 1.1 has started from the "white board" exercise in Prague (2015), where participants (all experts from RIs) have first time identified the measurement variables, critical for RIs, corresponding sensors, capable of measuring this variables and SMEs which could produce such sensors. This work has continued at ENVRI weeks until 2017, when the face-to-face meeting between RIs and SMEs was organized in Grenoble in the frame of the 1st EU Environmental Research Infrastructures–Industry Joint Innovation Partnering Forum. The participants (SMEs and RIs members) shared their vision on development of environmental sensors and data communication systems and defined their possible applications.

The deliverable itself has been outlined at a meeting of Theme, workpackage and task leaders (Ifremer and CEA), in Brest (October 2017), where they discussed the possible structure of the deliverable and its content, main measurement parameters to focus upon and the best ways to show inter-connections between RIs.

Further on, the structure of current deliverable was proposed and discussed at the ENVRIplus meeting in Malaga, Spain, during November 2017. Participants from various RIs agreed on "domain" structure of the document, meaning that the important environmental parameters and technologies for their measurements were sorted by four domains (Atmosphere, Biosphere, Hydrosphere and Solid Earth). In addition, participants decided to add the "market" section to the document, where economy-related questions could have been discussed, such as RIs being innovative partners and contributors to the new technologies, promotion of businesses and market demands. This chapter was meant to provide the relation to the ENVRIplus WP18, "Liaison to users: industry, innovation economics" and identify existing and new user communities interested in application of novel environmental technologies. The timelines for the deliverable preparation and submission were discussed too.

After ENVRIplus meeting in Malaga, the task leader, CEA, presented its vision of the document by practical example, referring to the emerging technologies, relevant for measurements of GHG. This section was chosen by CEA as participant to ENVRIplus on behalf of ICOS. With this piece of work, authors have approached numerous instrumentation experts to know their opinion about existing and emerging technologies for environmental measurements with high potential. Among these experts were the specialists from atmospheric (ICOS, IAGOS, SIOS, ACTRIS) marine (EURO-ARGO, JERICO), ecosystem / biosphere (ANAEE) and solid earth (EPOS) domains. Participants were offered to follow the structure of the document proposed by the task leader and to write similarly about the technologies of interest for their RIs. Besides that, the discussions have touched the important points of availability of new platforms for sensors installations, power supplies for the sensors and international market development of environmental monitoring instrumentation.

During the ENVRIplus meeting in Zandvoort, Netherlands during May 2018, the task leader presented the resulting work to the participants and requested final comments. After the deliverable was commented upon, the document had been modified accordingly and submitted to the internal and external reviewers prior to the submission to the ENVRIplus head office.

1.4 Structure of this document

The document aims at easing the reader's walk through the presented information.

Chapter one, introduction, shows the background and explains the necessity of this document. It describes grand environmental challenges and consequent necessity in advanced environmental measurements and technologies. It positions the work in the current landscape, explains methodology of work and structure of the document.

Chapter two deals with the technologies for atmospheric measurements, such as measurements of GHG and Aerosols parameters. This chapter analyses the strengths and weaknesses of the technologies, and identifies main providers. Described technologies represent those that are mostly valued by scientists and that are the most wanted or expected to become available on the market in the nearest future. Similar structure is accepted for the chapters three, four and five, corresponding to the measurements of land biosphere, marine, and solid earth parameters.

Each of the **chapters two-five** is complemented with the section of market overview, where authors talk about main market trends influencing the development of corresponding sensors and main driving forces for such development.

Chapter six describes the on-going development of the new platforms for environmental measurements. Among those are unmanned autonomous vehicles for atmospheric, biosphere and marine measurements as well as wireless sensor networks.

Chapter seven is specifically dedicated to the issue of energy supply, which is a critical issue for the measurements performed in the remote, hard-accessible areas. It describes various means of energy supply, such as solar panels, wind and water turbines, fuel cells and others.

Chapter eight discusses the place of research infrastructures on the technological market. This chapter demonstrates the connections of research infrastructures with the other market players, such as individual researchers, SMEs, large companies and grant holders. It addresses traditional and innovative business models and societies interested in development of new sensors. Chapter nine gives an overview to the meeting of ENVRIplus participants with the industrial producers of environmental sensors in Grenoble (18-19 May 2017) in order to underline the strong dedication of environmental RIs to the establishment of strong relations with the market players.

Finally, **chapter ten** provides the final conclusions. It summarizes the trends of technology and market developments, the possible applications of sensor technologies.

It also refers to the **Annex 1** table, where authors show the possibilities of cross-utilisation of sensors by various research infrastructures, thus underlining similarities of RIs in the field of technologies.

2 Measurement of atmospheric parameters

2.1 Measurements of Greenhouse gases (GHG).

2.1.1 Why measuring GHG is important.

Climate change is mainly caused by accumulation of large excesses of greenhouse gases (GHG) in the atmosphere, mainly CO_2 and CH_4, but also N_2O, SF_6 and some others [2] (Table 1). Thus, GHG measurements are needed to understand the drivers of climate change and to help mitigating adverse climate change.

TABLE 1 EXAMPLES OF GREENHOUSE GASES AND THEIR ANTHROPOGENIC SOURCES

Source	Electricity and heat production through burning of fossil fuel	Wastewater handling	Road transportation	Agricultural Activity (soils)	Refrigeration and climate equipment	Enteric Fermentation	Aviation
Gas	CO_2	CH_4, N_2O	CO_2, N_2O	N_2O	HFC	CH_4	CO_2, , N_2O, H_2O

Thus, along with the development of societal need for climate action, scientific communities and industrial companies need to take significant efforts to ensure proper measurements and quantifications of GHG fluxes. Current environmental legislation in most-economically developed countries prescribe large emitters to submit an annual emissions report. The data about the emissions can be collected following two main paths. The companies may (1) estimate the emissions based on inventories (typically exemplified by UNFCC reporting and constitutes the basis of INDC in the frame of the Paris agreement), or (2) perform GHG concentration monitoring by means of instruments or sensors combined with inverse modelling to retrieve GHG fluxes (now admitted in the discussion as per UNFCCC

[2]http://www.ipcc.ch/report/ar5/wg1/

methodology[3]. Inventory approaches are widely used nowadays, because they are relatively cheap and do not require complicated installations or service. On the other hand, direct measurements of produced GHG concentration by means of special sensors are highly precise but the finally retrieved GHG fluxes values may have a high uncertainty due to inverse modelling. Assuming that environmental regulations in the EU and worldwide are getting stricter, one can see the instrumental measurements of GHG as the target that GHG producers shall aim. In truth, producers of GHG shall be genuinely interested in accurate measurements of GHG, because it will help them to cope with the strict environmental legislation in the future, reduce operating costs, fuel consumption and waste production, etc.

2.1.2 Existing common techniques

2.1.2.1 *Overview*

There is a number of techniques dedicated to the measurements of GHG concentrations in the atmosphere as well as to measurements of various gaz phase components. Among the most used techniques are:

- Optical techniques for concentration measurements: Fourier transform infrared spectroscopy, UV-DOAS, IR camera, solar occultation flux. Laser measurements based techniques: tunable diode laser, cavity ring down spectroscopy, LIDAR (DIAL)
- Non-optical techniques for concentration measurements: gas chromatography, mass spectrometry, photo-acoustical measurements, electro-chemical measurements
- Experimental approaches of analysis: radial plume mapping, tracer correlation, background Lagrangian stochastic,

2.1.2.2 *Fourier Transform Infrared Spectroscopy (FTIR)*

FTIR is a broadband optical spectroscopy method, capable of performing real time monitoring of GHG (Schütze et al. 2013; Hase et al. 2015) and volatile organic substances in the air (Christian et al. 2004). FTIR uses characteristic spectral features of individual compounds for the detection and, thus, can detect numerous substances even in highly polluted zones. It can detect and identify the vibrational frequencies of all molecules, capable of absorption of IR energy (Bacsik et al. 2007). FTIR systems are normally represented with two types of systems, namely extractive cell and open-path. For extractive FTIR measurements, the beam is passed through the cell, located in the instrument and containing gas sample of interest. Sample cell path lengths can range from 10 cm to 150 m folded-path cells.

Open path FTIR spectrometers are not equipped with an internal measurement cell. Indeed, the measurement is done along an external optical path. Thus, the path length pay vary from several meters to several hundred meters. Open path FTIR devices are represented by monostatic or bistatic configurations. In monostatic configuration, emitter of light and its

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[3] http://unfccc.int/resource/docs/2017/sbsta/eng/l21.pdf

detector are located in one compartment, while external light reflectors are used to reverse the light beam from the lights source to the detector. This configuration is beneficial, since both emitter and receiver of light can be connected to the same power source. In bistatic configuration, light emitter and light detector are in different locations. The typical bistatic configuration uses the sun as the light source (e.g. FTIR spectrometer used in the TCCON project) and by measuring thus the direct solar spectra, measures the mean concentration of GHG and other compounds in the total atmospheric column.

TABLE 2 STRENGTHS AND LIMITATIONS OF FTIR

Strengths	Limitations
Large number of IR active components	Interference of gaseous H_2O, interference of CO and CO_2, cannot detect Cl_2, O_2, N_2, weak IR absorption for many inorganic molecules
Compounds can be analysed simultaneously	Limited wavelength range of IR beam
Easy portable	Set up requires 5-8 hours and 2 people
Relatively low instrument cost	Requires highly skilled professionals for field deployment and data collection

FTIR producing companies are listed in table 3

TABLE 3 PRODUCERS OF DEVICES FOR FTIR

Company	website
Imacc	https://www.imacc-instruments.com/
Opsis	http://www.opsis.se/
MIDAC Corporation	http://www.midac.com/
ABB	http://new.abb.com/
Cerex	http://cerexms.com/
Bruker	https://www.bruker.com/
Kassay	http://www.kassay.com/

2.1.2.3 *Ultraviolet Differential Optical Absorption Spectroscopy (UV-DOAS)*

The UV-DOAS is an optical remote sensing technology (Leytem et al. 2009), determining concentrations of gaseous species of interest through measuring the absorption of UV light by chemical compounds in the gas phase and calculating their concentration through Beer-Lambert law (Volkamera et al. 1998). Open path UV-DOAS instrument can be deployed in several modes, namely monostatic, bistatic and passive (EPA Handbook: Optical Remote

Sensing for Measurement and Monitoring of Emissions flux, 2011). Constructions of monostatic and bistatic configurations is similar to those of FTIR, described above. Passive configuration uses the ambient light to measure the concentrations of pollutants and does not require a transmitter in its construction. Such configuration is especially suitable for the installation on the balloon stations to measure the concentrations of the pollutants in the atmosphere.

TABLE 4 STRENGTHS AND LIMITATION OF UV-DOAS

Strengths	Limitations
Many compounds can be detected in low ppb range	A number of species do not have suitable UV-visible absorption structures (invisible for UV-DOAS)
Broad spectrum instruments can monitor up to three criteria pollutants and trace species	Difficulties in aligning the optics at the long path
Continuous remote monitoring and data collection, near real time data	Affected by poor visibility conditions
Long measurement path length	Fixed observation are, on the line of the beam
Portable	No point wise measurements, or resolved along-path concentrations
Relatively low cost of the instrument, low cost of long term deployment.	-

UV-DOAS producing companies are listed in table 5

TABLE 5 PRODUCERS OF DEVICES FOR UV-DOAS

Company	website
Opsis	http://opsis.se/
Cerex	http://cerexms.com/
ETG Risorse e Technologia	http://www.etgrisorse.com/en/
Enviro Technology Services	http://www.et.co.uk/
Environnement S.A.	http://www.environnement-sa.com/
Argos Scientific	http://www.argos-sci.com/

2.1.2.4 *Tunable Diode Laser Absorption Spectroscopy (TDLAS)*

TDLAS is a family of techniques based on the generation of light beam, characterized with the narrow wavelength and small cross-section area (Laser) (Pattey et al. 2006). This Laser beam is passed through the sample of gas, and detectors determine gas concentration by measuring the amount of absorbed light (Lackner 2007). Measured absorption spectra is matched with the ambient conditions, such as temperature and pressure and, at known effective path length, is used to determine the concentration of the gas. Developed over 30 years ago, near-infrared NIR-TDLAS is a technology with the high technology readiness level, commercially successful at multiple markets. During last years the TDLAS technology was improving, mainly due to the development of new laser sources, such as semiconductor quantum cascade lasers (QCLs) and inter-band cascade lasers (ICLs) (Sonnenfroh et al. 2004, Frish, 2014). These are midinfrared laser sources (Mid-IR) suitable for measurements in the molecular fingerprint spectral region, where absorption line strengths are much stronger than in the NIR region. Because of that, MWIR can be used for detection of complex molecules, difficult to detect with NIR TDLAS. The further efforts are taken to reduce MWIR sensor noise and energy consumption by use of uncooled pulsed or low-power laser sources and small area uncooled detectors. Further reduction of MWIR laser cost by high-volume production, will make MWIR TDLAS sensors commercially attractive and widely used.

TABLE 6 STRENGTHS AND LIMITATION OF TDLAS

Strengths	Limitations
High compound specificity due to the narrowness of laser wavelength and possibility of additional tuning	Detects components only within limited laser wavelength range
Easy to calibrate, rapid response, low noise levels	Only compounds absorbing within near- and mid- IR range can be detected
Low equipment cost, minimal consumables needed for operation	Only possible to apply in clean, non-dusty environments.
Remote long-term monitoring and near real time data	
Easy to transport and deploy, relatively light weight of devices	
Capable to measure concentrations from 1 ppb to 1000 ppm on path lengths up to 1 km	

Producing companies of TDL are presented in table 7.

TABLE 7 PRODUCERS OF DEVICES FOR TDLAS

Company	website
Opsis	http://opsis.se/
Aerodyne	http://www.aerodyne.com/
AP2E	https://www.ap2e.com/
Los Gatos Research	http://www.lgrinc.com/

2.1.2.5 *Non Dispersive Infra-Red sensor (NDIR)*

NDIR is a technique that has a long track record in this community. In NDIR, an infrared lamp shines the light through a tube filled with sample of air. Gas molecules in the experimental tube absorb the light of the wavelength matching with the size of gas molecules according to Beer-Lambert Law. The detector measures the attenuation of the wavelengths in order to determine the gas concentration. The detector is equipped with the optical filter that removes all light wavelengths, except the wavelengths that are absorbed by the gas of interest (Hummelga et al. 2015).

TABLE 8 STRENGTH AND LIMITATIONS OF NDIR

Strengths	Limitations
Low cost of purchase and running	Detection range and sensitivity for different gases varies within very large range
Stable long term operation and small calibration efforts, stable even after long term storage	Measurements depend strongly on the ambient conditions, such as temperature and atmospheric pressure due to variability in gas density
	Water vapours interfere with the measurements

Producers of NDIR sensors are presented in table 13

TABLE 9 COMPANIES PRODUCING NDIR

Company	website
Alphasense	http://www.alphasense.com/
Dynament	http://www.dynament.com/
Edinburgh Sensors	https://edinburghsensors.com/

Sensors	http://www.sensors-inc.com/
Heimann Sensor GmbH	http://www.heimannsensor.com/
Li-Cor Environmental	https://www.licor.com/
Senseair	https://senseair.com/

2.1.2.6 *Cavity ring down spectroscopy (CRDS)*

CRDS is a technique that is a part of TDLAS family. Contrary to traditional adsorption techniques measuring the absolute change in light intensity after passing the light beam through the certain volume of sample, CRDS technique is based on the measurements of light intensity decay rate, exiting from a high-finesse optical cavity (Berden et al. 2010). By using cavity resonance to reach the light intensity threshold before switching the laser off and measuring the time of light decay. CRDS technique are less sensitive to variations in laser source intensity. In addition, CRDS techniques reveal excellent sensitivity since the reflectivity of the closed optical cavity yields much longer effective sample path length (up to several km).

TABLE 10 STRENGTHS AND LIMITATION OF CRDS

Strengths	Weaknesses
Great sensitivity due to much longer effective path lengths, not influenced by variations in light source intensity.	High reflectivity mirrors are only able to reflect the small wavelength range, what hardens detection of multiple species.
Little/ no sample preparation required	sensitive to vibration as the mirrors must be well aligned to get the cavity resonance

Producing companies of CRDS and its components are presented in the table 9

TABLE 11 PRODUCERS OF DEVICES FOR CRDS

Company	website
Picarro	http://www.picarro.com/
Tiger Opticsm LLC	http://www.tigeroptics.com/

2.1.2.7 *Light Detection and Ranging/ Discovery and Launch (LIDAR/ DIAL)*

LIDAR is the method of remote atmospheric sensing based on the measuring the distance to the target by illuminating the target with the pulsing laser light and measuring the reflected light impulses. LIDAR does not require the establishment of line of sight or installation of retro-reflectors. DIAL is a special application of LIDAR, proposed to locate and measure the concentrations of pollutants in the atmosphere (Browell et al. 1998). The device sends the pulsing laser beam, alternating between two wavelengths, to the region of interest in the atmosphere. Upon reaching the region of measurements, the light of one wavelength is adsorbed by the compound of interest or scattered at reduced intensity, while the light of another wavelength is scattered elastically. This scattered light is collected by receiving optics, analysed and used to determine the concentration and location of the pollutant. The light of the wavelength, scattered at reduced intensity, is used to determine the concentration of substance of interest, while the light scattered elastically is used to measure background light scattering. Location of pollutant can be measured based on the delay of backscattered light to the detector. Raman LIDAR technique is seen as potentially interesting for CO_2 measurements. A prototype has been developed in China and is capable to measure CO_2 atmospheric concentrations, with night-time measurement limitations (Zhao et al. 2008).

TABLE 12 STRENGTHS AND LIMITATIONS OF LIDAR/DIAL

Strengths	Limitations
The concentration data is presented as a function of distance along the path of laser beam	Absorption characteristics of substances are dependent on ambient conditions, such as temperature and pressure, thus additional calibration according to the weather conditions might be needed
Easily portable, provides better overview of the atmospheric region when measurements performed from several locations	High cost of the system
Fast measurements (up to 15 minutes) over long distances (up to 3000 m)	Beam path might be limited by the landscape
Can be mounted on the airborne platforms	There must be sufficient backscattering in the atmosphere for the device to work correctly
Can measure the concentrations and state of multiple species	Species with unique absorption bands are measurable. Species with the common absorption bands cannot be distinguished

Provides real time data

Producers of LIDAR systems are listed in table 11

TABLE 13 PRODUCERS OF DEVICES FOR LIDAR

Company	website
National Physical Laboratory	http://www.npl.co.uk/
Spectrasyne	http://www.spectrasyne.ltd.uk/
ITT	http://www.itt.com/
LASEN	http://www.lasen.com/
GreenValley International	http://greenvalleyintl.com/

2.1.3 Emerging techniques for GHG measurements

2.1.3.1 *Overview*

Development of technologies for GHG measurements is a constant process ongoing in several directions. Significant efforts are dedicated to the development of technologies based on the new physical principles and improving the existing technologies, making them more suitable for the analysis of GHG. Large work is made to improve the detection limits and limits of quantification of existing techniques, making them capable of in-situ and real-time analysis of GHG, working in environmental "dirty" conditions and at wide range of environmental conditions. Below we provide a short summary of techniques, which, we believe, deserve special attention, as well as those that have a large potential for further improvements and developments for the purpose of GHG measurements.

2.1.3.2 *Laser Dispersion Spectroscopy (LDS)*

Traditional spectroscopy techniques detect light intensity to determine the concentration of gas. In contrast, LDS (Daghestani et al 2014) uses the phase of light for these purposes. This makes the LDS technique highly insensitive to the intensity fluctuations. Thus, LDS technique can perform precise real time measurements of trace gas molecules in "dirty" environments, where intensity fluctuations may result from soot, fog or other interceptors of the optical path. LDS technique can detect the contaminants in broad range (ppb to percentage level), since the dispersion approach shows linear response over a broad concentration range.

TABLE 14 STRENGTHS AND LIMITATIONS OF LDS

Strengths	Limitations
High sensitivity	Detects one compound per one laser, fewer measurable compounds, limited sensitivity

High selectivity	Only compounds absorbing within near- and mid- IR range can be detected
Suitable for demanding environments	-
Real time measurements	-
Broad range of concentrations	-

Companies, producing of LDS are listed in table 15

TABLE 15 PRODUCERS OF DEVICES FOR LDS

Company	website
MIRICO	http://mirico.co.uk/

2.1.3.3 *Laser Photoacoustic Spectroscopy (LPAS)*

Photoacoustic Spectroscopy is a technique, based on the measurements of the acoustic effects, emerging during absorption of light by the analysed matter (gas). Upon radiation of gas by light, the temperature of gas increases, leading to a periodic expansion and contraction of gas volume, synchronous with the modulation frequency of radiation. This generates a pressure wave (sound) that can be detected by the microphone (Dumitras et al. 2007). Intensity of generated sound is proportional to the light intensity, and that is why laser light sources are widely applied in this technique. Even though the technique was applied for atmospheric measurements more than 30 years ago (Meyer, Sigrist 1990), the technology is significantly advancing due to the development of new laser sources (Gondal et al. 2012; Wang and Wang 2016) and other parts of experimental set-ups, such as resonators (Tavakoli et al. 2010).

TABLE 16 STRENGTHS AND LIMITATIONS OF LPAS

Strengths	Limitations
High sensitivity (ppb)	Strict requirements for laser source (power, tuning range, band width,)
Selective excitation of several species	sound detecting system is sensitive to the environmental noise
Easy to detect large molecules	Hard to detect small molecules
Due to photo-thermal mechanism, LPAS is useful for transparent samples where the light absorption is small	

Producers of LPAS technique are listed in table 17

TABLE 17 PRODUCERS OF DEVICES FOR LPAS

Company	website
GASERA	http://www.gasera.fi/
LumaSense TECHNOLOGIES	https://www.lumasenseinc.com/
California Analytical Instruments, Inc.	http://www.gasanalysers.com/
MirSense	http://mirsense.com/
AEROVIA	https://aerovia.fr/

2.1.4 Development of GHG sensors market

2.1.4.1 *Overview*

There is crucial need in the development of technologies and sensors to monitor GHG emissions in the Earth's atmosphere and especially to monitor industrial GHG fluxes in Europe and worldwide. To fulfil this need, a number of RIs such as ICOS or IAGOS, were established to provide the access to the GHG measurement facilities to all interested communities. Besides that, a large number of companies are providing services and dealing with production of sensors and technologies for GHG measurements. It is expected that co-emergence of denser networks and national/international legal frameworks will expand market opportunities in this field. Below we describe the main international events and legislation acts that will strongly influence the development of GHG sensor market. We also provide an estimate of the GHG sensors market, the numbers being found in the open sources.

2.1.4.2 *Development of normative documents related to climate change*

1. The well-known Kyoto protocol[4], adopted on 11 December 1997 and entered in force on 16 February 2005 set the internationally binding GHG emission reduction targets.

2. In 2007 - 2009, important international conferences in Bali[5] (2007) and in Copenhagen[6] (2009) gave a strong value to the independent information that allows monitoring and verification of GHG emissions with the purpose of their reduction in the future. As a result, at Copenhagen conference (2009), national emission reduction targets were agreed upon by the economically developed countries.

[4]http://unfccc.int/kyoto_protocol/items/2830.php

[5]http://unfccc.int/meetings/bali_dec_2007/meeting/6319.php
[6]http://unfccc.int/meetings/copenhagen_dec_2009/meeting/6295.php

3. In 2010, at climate change conference in Cancun[7], Mexico, developed countries agreed to strengthen the GHG emissions reporting frequency and to develop low-carbon national plans and strategies. Developing countries were also encouraged to develop such plans and strategies.

4. In 2010 in France, the project of decree for GHG emission reporting[8] provided a national legal framework to monitor the emissions from large communities and industrial settings. This opened the market for simple and relatively cheap sensors for GHG detection around industrial sites and landfills.

6. In 2012 in Doha[9] Kyoto protocol was extended until 2020.

7. In 2016, Paris agreement on climate change was developed, announcing one of the main aims to make finance flow consistent towards lowering greenhouse gas emissions and climate-resilient development. Later in 2016, both USA and China joined Paris agreement for climate change, the declaration was meant to push other countries to formally join the agreement. As of October 2017, 195 UNFCCC members have signed the Paris agreement and 169 have become part of it.[10]

8. In November 2017 UN FCCC subsidiary body for scientific and technological advice noted[11] the increasing capability to systematically monitor GHG concentrations and emissions, through *in situ* as well as satellite observations and its relevance in support of the Paris Agreement.

Despite the difficulties that world countries face in negotiations of international agreements for GHG flux reductions, there is a clear progress in development of legislative documents covering this issue. Thus, all EU countries are required to monitor their emissions under the EU's greenhouse gas monitoring mechanism, which sets the EU's own internal reporting rules based on international agreements. The reporting covers the emissions of seven GHG from land use, forestry, industrial and energy processes, etc., projections, policies and measures to cut GHG emissions, national measures to adapt to climate change, low carbon strategies, financial and technical support for developing countries as well as national governments' use of revenues from the accounting of allowances in the EU emissions trading systems. In future, EU plans to cut emissions by 40% by 2030 on 1990 level while the US plans the cut of 28% by 2025 compared to 2205. Other large countries are expected to join these plans too. Up-rising concern of society about the atmosphere pollution will increase the amount of private sector

[7]http://unfccc.int/meetings/cancun_nov_2010/meeting/6266.php
[8]https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434
[9]http://unfccc.int/meetings/doha_nov_2012/meeting/6815.php
[10]http://unfccc.int/paris_agreement/items/9485.php
[11] http://unfccc.int/resource/docs/2017/sbsta/eng/l21.pdf

and R&D projects dedicated to the measurements of GHG gases in the atmosphere. In summary, the combination of private national and international requests will broaden the technological market of sensors for GHG monitoring.

2.1.4.3 ***Market overview by the leading players***

In 2010, Chemical and Engineering news (Reisch 2010) asked the representatives of largest producers of GHG sensors about their vision of the market in the future and its size. The representatives of Fischer Scientific estimated the global market as 700 million USD; the estimate included the monitors of acid rain precursors and other pollutants such as lead, ozone and GHG. They said that the sales of GHG monitors could increase greatly if they were added to the governmental networks of ambient air quality monitoring stations. They added that measurements of GHG had only a small share of the market, but they expected the increase in the sales due to the changing legislations around the world. Li-COR Biosciences confirmed that they expected the tangential expansion of industrial markets. The company was strongly counting on their governmental and scientific customers, planning to sell several thousand high precision GHG monitors per year. Representatives of Shimadzu Scientific instruments agreed that academic customers were their main customers, but they also started the work to adapt their products for the industrial applications. Oppositely, Agilent technologies reported that their key customers were industrial players. They have developed their gas chromatograph for easy GHG analysis. Some other companies focused on the infrared absorption GHG measurements. For example, representatives of Picarro said that they were experiencing strong growth, selling their cavity-ring-down technologies to 47 countries around the world. Another instrument maker Los Gatos sold several hundred instruments to measure the CO_2 and methane emissions. Los Gatos owns its own CRDS technology. They worked with several large partners like General Electric to deploy their instruments at several industrial facilities. Additional contender, Tiger Optics, claimed to sell over 800 instruments for monitoring industrial gas quality.

2.2 Measurement of atmospheric aerosols

2.2.1 Why measurement of atmospheric aerosols is important

Aerosols are represented by small particles suspended in the atmosphere. If these particles are large and their concentration is sufficiently high we can notice their presence as they scatter light, reduce visibility and cause the redden sunrises and sunsets. There are three known types of aerosols. The first is the volcanic aerosol, which forms after major volcanic eruptions. This type of aerosol is formed by Sulphur dioxide gas, converted to droplets of sulphuric acid in the stratosphere sometime after eruption. Once formed, these aerosols can remain in the atmosphere for about two years. Second type of aerosols is desert dust. Particles of these aerosols are composed of minerals and thus readily absorb and scatter sun radiation. They can be transported over large distances and are believed to be responsible for the formation of storm clouds. Finally, human made sulphate-based aerosols come in the form of smoke originating from burning fossil fuels. The concentration of these aerosols is highest in the northern hemisphere, where the industrial activity is the highest.

It is well known that global climate change is highly dependent on the complex interactions between solar radiation and atmospheric particles, however the magnitude of this interaction as well as its effects are poorly understood. For example, scientists still argue whether aerosols are promoting mostly global warming or global cooling[12].Numerous models were developed for better understanding of interactions of aerosol particles with solar and terrestrial radiation, formation of droplets and ice-crystals initiated by interactions of aerosol particles with atmospheric gaseous H_2O. Many of models and simulations contradict each other, because the parameters of aerosols and their particles are presented incorrectly. This wrong understanding of aerosol properties is a direct consequence of lack of direct measurements and detailed characterization of all aerosol properties. Instrumentation for measurements of aerosol properties can be divided accordingly to the specific characteristics of aerosols they are designed to measure.

- Total number and mass concentration of particles
- Optical properties of aerosol
- Chemical composition of the particles
- Size distribution of particles

2.2.2 Aerosol common measurement techniques

2.2.2.1 *Aerosol number concentrations*

2.2.2.1.1 Condensation particle counters (CPC)

Condensation particle counters are normally used to measure the total particle concentrations in aerosol (Kesten et al. 1991). In the continuous flow diffusion CPC, ambient aerosol enters in the device chamber through the inlet and is exposed to a supersaturated vapour of a working fluid. This exposure results in the rapid growth of particles, which after that are exposed to the light of laser. Scattered light of laser is detected by photodiode and the individual particles are counted. Based on the amount of calculated particles and known flow of gas through the system, one can calculate the total number concentration in the aerosol.

Advantages of CPC technique are presented in the table 18.

TABLE 18 STRENGTHS AND LIMITATION OF CPC

Strengths	Limitations

[12]https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WGIAR5_SPM_brochure_en.pdf

Can count particles with size down to 2 nm	Don’t provide information on size of the particles
Very fast response (1 sec or less)	Can’t be deployed outside aircraft
Can operate with water as condensation fluid	Need condensation fluid refill

Producers of CPC are presented in table 19

TABLE 19 COMPANIES PRODUCING CPC

Producer name	Website
TSI	www.tsi.com
Kanomax	www.kanomax-usa.com
Beckman Coulter	bc-particle.com

2.2.2.1.2 Passive Cavity Aerosol Spectroscopy Probe (PCASP)

PCASP is one of the few techniques dedicated to the measurements of particle number concentrations as a function of size in situ, while being mounted on the exterior of the aircraft (Jonsson et al. 1995). The instrument measures the intensity of light scattered from the individual particles within the aerosol, which pass through a focused laser beam. PCASP collect side scattered light, the collected light being proportional to the to the particle size. Particle number concentration is derived from measured particle size, knowing the particle refractive index, shape and wavelength of the incident light.

Advantages of PCASP are presented in table 20.

TABLE 20 STRENGTHS AND LIMITATIONS OF PCASP

Strengths	Limitations
Can be deployed outside aircraft	Can detect only particles with diameter > 100 nm
Rapid measurements	

Producers of PCASP are presented in table 21.

TABLE 21 PRODUCERS OF DEVICES FOR PCASP

Producer name	Website
Droplet Measurement Technologies	dropletmeasurement.com

2.2.2.2 *Aerosol optical properties*

2.2.2.2.1 Photoacoustic Absorption Spectroscopy (PAS)/Photoacoustic Extinctiometer (PAX)

Photoacoustic absorption spectroscopy is the technique that determines the absorption coefficient, through the measurement of sound, produced on radiation of aerosol particles by laser light (Lack et al. 2006). Part of incoming laser intensity is scattered or transmitted, while the remaining fraction is absorbed by either by light absorbing particles or surrounding gas, Absorbed radiation generated particle heating and increase in pressure, detected by sensitive microphone. Photoacoustic spectrometers have fast response time and are well fitted for airborne applications. A similar technique is used by photoacoustic extinctiometers to measure also scattering coefficient.

TABLE 22 STRENGTHS AND LIMITATIONS OF PAS/PAX

Strengths	Limitations
Better response time compared to filter instruments	Calibration required
Can be deployed outside aircraft	Problems have been noticed in very noisy environments (laboratory)
No filter/loading corrections are needed	
PAX can measure scattering and absorption at the same time	

Producers of PAS are presented in table 23.

TABLE 23 PRODUCERS OF DEVICES FOR PAS

Producer name	Web-site
Droplet Measurement Technology	http://dropletmeasurement.com

2.2.2.2.2 Absorption photometers/aethalometer

Absorption photometers (or aethalometers) are devices that determine the light absorption coefficient of aerosols through the measurement of transmissivity of a filter that is gradually loaded with particles (Arnot et al. 2005). They usually employ light sources at several wavelengths from the UV to near IR. Most of the available commercial instruments use systems for automatic change of the filter when transmissivity is below a critical level, while some of them measure also the backscattered light in order to compensate the final measurement for this effect. Some instruments provide directly the value of the equivalent black carbon (in gram per cubic meter) that would produce this absorption, through the assumption of a specific absorption coefficient per unit mass.

TABLE 24 STRENGTHS AND LIMITATIONS OF ABSORPTION PHOTOMETERS/AETHALOMETERS

Strengths	Limitations
No calibration required as the measurement is relative to a blank filter	The conversion to equivalent black carbon concentration depends critically from the assumed specific absorption coefficient
Multiple wavelength	High flux volumes or long integration times are required to measure low concentrations
	Need filter change
	Corrections are required to take into account the filter/loading effects

Producers are presented in table 25.

TABLE 25 COMPANIES PRODUCING ABSORPTION PHOTOMETERS/AETHALOMETERS

Producer name	Web-site
Magee Scientific	www.mageesci.com/
AethLabs	www.aethlabs.com
ThermoFisher Scientific	www.thermofisher.com

2.2.2.2.3 Nephelometers

Nephelometers are instrument devoted to the measurement of the scattering coefficient of the aerosol particles (Heintzenberg and Charlson 1996). They usually work following the so-called inverse method, that is, they measure the light scattered the particles in a specific direction and that was emitted by a (hemi)-spherical source. It is inverse in the sense that the scattering coefficient refers to the light scattered in any direction and coming from a very narrow one. They can operate at one or more wavelengths, from UV to near IR. They need periodic calibration with standard gas, such as CO_2.

TABLE 26 STRENGTHS AND LIMITATIONS OF NEPHELOMETERS

Strengths	Limitations
Don't need filters or other supports	Need periodic calibration
Multiple wavelength	
Very high temporal response	

Producers are presented in table 27.

TABLE 27 COMPANIES PRODUCING NEPHELOMETERS

Producer name	Web-site
Ecotech Research	www.ecotech-research.com
Air Photon	www.airphoton.com
Radiance Research (discontinued)	
TSI (discontinued)	

2.2.2.2.4 LIDARs

Atmospheric LIDAR is a class of instruments that uses laser light to study atmospheric properties from the ground up to the top of the atmosphere (Kavaya and Menzies 1985). Such instruments have been used to study, among other, atmospheric gases, aerosols, clouds, and temperature. The transmission unit consists of a laser source, followed by a series of mirrors, and a beam expander, which sends the collimated light beam vertically up to the open atmosphere. Part of the transmitted radiation is scattered by atmospheric components (i.e., gases, molecules, aerosols, clouds) backward to the LIDAR, where a telescope collects it. The backscattered light is driven to an optical analyser where the optical signal is first spectrally separated, amplified and transformed to an electrical signal. Finally, the signal is digitized and stored in a computer unit. While knowing the aerosol properties (forward problem) and predicting the LIDAR signal is a straightforward calculation, the inverse process is mathematically ill-posed (i.e., non-unique and incomplete solution space), showing a strong sensitivity on input uncertainties.

TABLE 28 STRENGTHS AND LIMITATIONS OF LIDARS

Strengths	Limitations
Provide vertical distribution of aerosol	Inversion is strongly sensitive on input uncertainties
Can provide the shape (degree of sphericity) of the particles	Need integration with independent source of information
Multiple wavelength	Works better during night (no sunlight interference)

Producers are presented in table 29.

TABLE 29 COMPANIES PRODUCING LIDARS

Producer name	Web-site
Leosphere	www.leosphere.com
Ala Systems	www.alasystems.it

2.2.2.3 *Aerosol chemical properties*

2.2.2.3.1 Time of Flight Aerosol Mass Spectrometer (TOF-AMS)

TOF-AMS is used to study the chemical and physical nature of aerosol particles online and is constructed as a combination of AMS vacuum system, particle focusing, sizing and evaporation/ ionization components with a compact orthogonal acceleration reflection time-of-flight spectrometer (De Carlo et al. 2006). Aerosol particles in the size range of 0.04 to 1.0 micrometres are sampled into a high vacuum system where they are focused into a narrow beam. This beam is then directed via ionization quadrupole mass spectrometry. Particle aerodynamic diameter is determined from particle time of flight (velocity) measurements using a beam chopping technique.

TABLE 30 STRENGTHS AND LIMITATIONS OF TOF-AMS

Strengths	Limitations
Online chemical and physical nature of aerosol particles	Complexity
particle aerodynamic diameter and aerosol composition in a single measurement	High cost
Quantitative particle analysis possible	
direct sampling of aerosol	
Fast measurements (1-10 sec) of particle size distributions and non-refractory chemical composition	

Producers of TOF-AMS are presented in table 31.

TABLE 31 PRODUCERS OF DEVICES FOR TOF-AMS

Producer name	Website
Aerodyne Research	http://www.aerodyne.com/

2.2.2.4 *Aerosol size distribution*

2.2.2.4.1 Optical Particle Counters (OPC)

A high intensity light source is used to illuminate the particle as it passes through the detection chamber. The particle passes through the light source (typically a laser or halogen light) and the redirected light is detected by a photodetector. The amplitude of the light scattered is measured and the particle is counted and tabulated into standardized counting bins, after assumption of the refractive index of the particles (Snider and Petters 2008)

TABLE 32 STRENGTHS AND LIMITATIONS OF OPTICAL PARTICLE COUNTERS

Strengths	Limitations
Can be miniaturized	The binning of the particles depends on the assumed refractive index and on the shape of the particles
Fast response	Unable to detect particles smaller than 50-100 nm

Producers are presented in table 33.

TABLE 33 COMPANIES PRODUCING OPTICAL PARTICLE COUNTERS

Producer name	Web-site
FAI Instruments	www.fai-instruments.com
TSI	www.tsi.com
GRIMM Aerosol Technik Ainring GmbH & Co.KG	www.grimm-aerosol.com
Lighthouse Worldwide Solutions	https://www.golighthouse.com/en

2.2.2.4.2 Differential Mobility Particle Sizer (DMPS)

Differential mobility particle sizing is an alternative to the optical sizing technique for measurement of submicron aerosol size distributions (Wiedensohler et al. 2012). Differential mobility techniques are able to measure much smaller particles, down to 2.5nm and are not sensitive to differences in refractive index, but are not able to achieve the same temporal resolution as optical instruments, and are also sensitive to variations in particle shape. The Differential Mobility Particle Sizer (DMPS) couples a differential mobility analyser, which classifies charged particles according to their mobility in an electric field, and a condensation particle counter (CPC) to count particles of a specific mobility. Other instruments using variations on this technique include the SMPS and HTDMA.

TABLE 34 STRENGTHS AND LIMITATIONS OF DIFFERENTIAL MOBILITY PARTICLE SIZER

Strengths	Limitations
Can measure particles down to 2.5 nm	For non-spherical particles mobility diameter is a function of particle shape and orientation

Can operate with water as condensation fluid	Need condensation fluid refill

Producers are presented in table 35.

TABLE 35 PRODUCERS OF DEVICES FOR DMPS

Producer name	Web-site
TSI	www.tsi.com
Particle Measuring Systems	www.pmeasuring.com

2.2.2.4.3 Aerodynamic Particle Sizer

The aerodynamic particle sizer uses the principle of inertia to size particles (Wang and John 1987). In this instrument the particle and sheath flow are constricted through a nozzle, accelerating the airflow. Particles within the airflow are also accelerated, but by different amounts depending on particle surface area and mass, thus particles exiting the jet have a velocity related to their aerodynamic diameter. Aerodynamic diameter is defined assuming spherical particles and unity density. The APS measures particle velocity by passing the particles through two laser beams separated by about 200 microns. A particle passing through both beams produces two pulses of scattered light, the time delay between the pulses being related to the velocity and hence aerodynamic diameter of the particle.

TABLE 36 STRENGTHS AND LIMITATIONS OF AERODYNAMIC PARTICLE SIZER

Strengths	Limitations
Can operate at very high rate (10 Hz)	For non-spherical particles mobility diameter is a function of particle shape and orientation
Don't need any refill or filter change	

Producers are presented in table 37.

TABLE 37 COMPANIES PRODUCING AERODYNAMIC PARTICLE SIZER

Producer name	Web-site
TSI	www.tsi.com
Particle Measuring Systems	www.pmeasuring.com

2.2.3 Emerging technologies for aerosol properties measurements

2.2.3.1 *New approach for ice nucleation detection*

Budke at al 2008 described a novel device for ice nucleation measurements based on the following principles. Turbulent mixing of cold dry air with warm humid air is performed in the Fast Ice Nucleus Chamber. Resulting ice particles with the size over 4 µm formed during 10 s of experimental time are separated from the droplets based on their individual circular depolarization properties and counted by an optical detector. Biological fraction is measured by special fluorescence channel.

TABLE 38 STRENGTHS AND LIMITATIONS OF ICE NUCLEATION DETECTION

Strengths	Limitations
Active monitoring of RH and T in the ice activation region	Complex depolarization
High sample flow	Frost point measurements
Good counting statistics at low IN concentrations	
Good possibility to vary the experimental conditions through changing the gases flow rates	

2.2.3.2 *Measurements of particle morphology*

Aerosol Particle Spectrometer with Depolarization (APSD) measures light scattered at two angles from individual particles and the extent at which these particles rotate the incident plane of polarization when they pass through a focused laser beam. The amount of scattered light is used to determine the particle size using Mie theory, while the direction of scattered light is used to determine the deviation of particles shape from sphere.

TABLE 39 STRENGTHS AND LIMITATIONS OF APSD

Strengths	Limitations
Can measure particles in cloud-free air and in the residuals of clouds, determining source of cloud nuclei	Not found

2.2.4 Development of market of aerosols measurements

Aerosols impair visibility, affect ecosystem processes and can deposit onto surfaces, damaging materials. They also make an impact on climate change: most particles are reflective and lead to net cooling, while some, especially black carbon particles, absorb energy and promote global warming. Breathing particulate matter/ aerosols can cause coughing, difficulties in breathing, irregular heartbeat, nonfatal heart attacks, aggravated asthma, and decreased lung functioning and general irritation of airways. It can be a reason of premature death of people with heart or lung disease, as well as general decrease of life quality of exposed population.

This is causing increased demand for the medical services and care, meaning additional healthcare expenses for the governments and local authorities.

Keeping in mind the above mentioned problems, local and state authorities would be the first in the list of parties, interested in monitoring and preventing air pollution with aerosols, both those, appearing due to the natural reasons, for example sandstorms, or forest fires and due the anthropogenic activity. State authorities would also be interested in development the legislation that would oblige large industrial and energy providers to monitor their fluxes of aerosols and analyse their composition. Thus, we believe that the main markets for the aerosol measurement devices will be:

- The countries of Middle East and North Africa (due to the large desert areas and exposure to sand storms)
- Developing countries, producing electricity mostly by burning of fossil fuels (mainly coal)
- Countries, which are in the state of rapid development of infrastructure.

Increased concern of people about their health will increase the amount of private and state-funded research projects, dedicated to the investigations of aerosols, especially in the urban areas. Thus, we also expect universities and private companies to become strong consumers of sensors for aerosol measurement.

Measurement responses of modern devices for aerosol measurements depend largely on aerosol properties including particle shape, composition and density. These parameters may vary significantly depending on the type of aerosol, often remain unknown and bring significant uncertainties to the measurements. Thus, we think that more effort needs to be taken to improve measurement accuracies for realistic atmospheric samples. The measurement of organic species in atmospheric particles requires additional development. Atmospheric aerosols normally include dozens of organic compounds, and only a small fraction (~10%) of these can be detected and identified by modern analytical methodologies. Total particulate organic carbon mass concentration measurements is another challenge due to the difficulties in determination of evaporative losses during sampling, adsorption of gas-phase organic compounds onto sampling substrates and the unknown relations between carbon mass and mass of the particulate organics. The development of improved methodologies for such measurements should be a high priority for the future. The new models of mass spectrometers capable of measuring the composition of individual particles have recently been developed. These instruments have to be improved to provide quantitative information on species mass concentrations, and more work is needed to perform routine interpretation of large datasets generated during field sampling.

3 Measurements of land biosphere parameters

3.1 Why measurements of land biosphere parameters are important

Population of our planet is the large consumer of various products, originating from biosphere. This refers mainly to agriculture and forest products. Before the consumption, the products pass several stages, such as production, packaging and delivery, with GHG being released at all steps. One of the largest source of GHG, such as methane and nitrous oxide is farming. Methane is produced mainly by livestock during the digestion due to the enteric fermentation, while nitrous oxide is as indirect product of organic and mineral fertilizers. Within the EU, agriculture was responsible for 10% of total GHG emissions in 2012. This number appears to be a good achievement, since the GHG emissions were reduced by 24% during time period 1990-2012 through decrease of livestock number and wise management of fertilizers. (EEA, 2015). Even though the trends of agriculture GHG emissions in Europe are promising, the world's agriculture showed opposite trends: From 2001 to 2011, the global GHG emissions originating from crop and livestock production grew 14% mainly due to the rapid growth of agricultural activity in the developing countries. At the same time, emission of GHG from animal production grew 11% and accounted for nearly 40% of agricultural GHG output in 2011. Due to the constant growth of world's population and non-rational use of natural resources and produced food, reduction of agriculture-sourced GHG appears to be quite a challenging task. To fulfil this task, agricultural sector needs to invent and integrate better, more precise innovative techniques, sensors and platforms for measurements and capture of GHG. In addition to the technological measures that has to be taken, attention has to be paid to the culture of consumption. Society has to contribute to the global cut of agriculture-derived GHG emissions by consumption of food products with the smaller global carbon footprint (less meat and dairy products)[13].

Vegetation is the main storage of atmospheric carbon on land and one of the main actor of its cycling from the atmosphere back to the ground. Plant photosynthesis does not only sequester CO_2 from the atmosphere but also emit water vapour as evapotranspiration, a critical process for the global energy balance that modulates the transmission of radiative and thermal energy between surface, atmosphere and space. Different plant covers can affect the amount of absorbed and reflected radiation (and therefore the sensible and latent heat fluxes) also due to their optical properties. Plants with an overall paler shade of green will have a higher albedo, reflecting more incoming radiation and, therefore, contributing to cool the surface (i.e.: contrasting climate change). Many plants can also emit small organic volatile compounds (VOCs) that can interact with photochemistry and generate secondary aerosols.

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[13]ec.europa.eu/eurostat/statistics - explained/index.php/Agricultural_ production_-_crops

The latter can again contribute to the radiative balance, by influencing absorbed and reflected radiation (Guenther et al. 1995). Vegetation also harbours a host of microorganisms living on their leaves that can also be aerosolized and could act both as cloud condensation and as ice nuclei furthermore affecting local precipitation patterns. In addition, biosphere ecosystems can also exchange and emit in the atmosphere other greenhouse gases, in particular CH_4 and N_2O. A modification of the vegetation status (i.e.: respiration) and geographical extension could yield to significant climatic impacts. For example, Crucifix et al. (2005) found that removal of vegetation decreased both precipitation, evapotranspiration and moisture convergence in central and northern Amazonia. Northeast Brazil would similarly see a decrease in precipitation in case of vegetation removal (Oyama and Nobre 2004). CO_2 is the most important greenhouse gas, and from a biosphere perspective it is more important to assess its exchange between the vegetation and the atmosphere ("flux") rather than the absolute concentration (i.e.: understanding how much the vegetated surface is a sink or rather a source for a given greenhouse gas). For this reasons the instruments and techniques used for biosphere measurements differ from the atmospheric ones, and have stricter requirements in terms of time response and more relaxed requirements in terms of absolute accuracy. In biosphere sciences, the main method employed to measure exchange of greenhouse gases species from/to the vegetation to/from the atmosphere is the eddy covariance technique. This is also because exchange of CO_2 and H_2O is related to plant metabolism and can be used to track primary production and plant growth.

Furthermore, plant leaves harbour microorganisms that can potentially serve as cloud condensation and/or ice nuclei (Möhler et al. 2007) and can therefore potentially affect cloud formation, precipitation and climate (Amato et al. 2007; Morris et al. 2004) since they are more efficient than their inorganic counterparts (Morris et al. 2004). This latter effect of biosphere on climate is still investigated and is mainly hindered by lack of knowledge of emitted microorganisms from the plant canopy, since techniques such as eddy-covariance cannot be applied to microorganisms' flux.

For agricultural practices, the main concern is not carbon storage but how climate change affects yield and water usage. To this end, measurements are focused on identifying stresses affecting the vegetation in order to minimize losses. Generally such measurements are done via spectral imaging in which either a proximal (handheld or similar) or a remote (such as a satellite or an airborne carried instrument) sensor takes multiple snapshots of the vegetated area in various spectral regions and specific wavelengths. Vegetated surfaces have different reflective (in the short-wave spectral domain) and emissive (in the long-wave spectral domain) properties in different wavelengths depending also on the stresses affecting them and therefore this kind of sensing can identify and quantify vegetation status. Total amount of biomass, which is related to the total globally sequestered CO_2, can be characterized both in managed and natural contexts (e.g.: crops, forests, pastures, grasslands) in order to correlate yield, carbon sequestration and land-use change over time. Quantification of biomass may be performed through airborne laser scanning technology.

3.2 Common measurement techniques for Land Biosphere parameters

3.2.1 Eddy covariance technique

This technique is employed to measure exchanges between the surface (i.e.: ecosystem, including vegetation and soil) and the atmosphere.

FIGURE 2 EDDY-COVARIANCE TECHNIQUE ON-SITE

It can be used, for example, to measure how much a given surface is either a sink or a source for a greenhouse gas such as CO_2 or any other species that can be sampled with a sufficiently fast time response. The technique is based on fast (10 Hz or more) measurements of both three dimensional wind velocity (atmospheric turbulence, usually done through an ultrasonic anemometer) and atmospheric concentration of the chemical species of interests (generally CO_2, CH_4 and N_2O in addition to energy). These two measurements can be related together following a specific mathematical approach to yield a flux with a high temporal resolution and integrated at ecosystem scale (1 km^2).

TABLE 40 STRENGTHS AND LIMITATIONS OF EDDY COVARIANCE TECHNIQUE

Strengths	Limitations
Can measure how much a biospheric component (forest, grassland, …) is either a source or sink for greenhouse gas (CO2, CH4, N2O, H2O) or other species, or energy	Requires specific conditions to work properly (horizontal homogeneity, absence of strong orography, specific atmospheric conditions)
Can measure net primary productivity (NPP), and infer gross primary productivity (GPP) and ecosystem respiration (ER)	Requires fast response sensors and high flow sampling lines

It is not disturbing the ecosystem and integrates measurements over large areas, allowing a good link with satellite measurements	It is complex to apply and relatively expensive

TABLE 41 PRODUCERS OF DEVICES BASED ON EDDY COVARIANCE TECHNIQUE

Producer Name	Website
LI-COR (gas analysers, full eddy-covariance systems through link to other companies)	https://www.licor.com/env/
Campbell (ultrasonic anemometers,IRGAs)	https://www.campbellsci.com/
Metek (ultrasonic anemometers)	http://metek.de/
Gill (ultrasonic anemometers)	http://gillinstruments.com/
PICARRO (gas analysers)	https://www.picarro.com/
Los Gatos Research	http://www.lgrinc.com/

3.2.2 Spectral imaging

Special cameras investigating wavelengths different from (or in addition to) the visible ones can give much more information about vegetation status. They are tools of great importance especially in precision agriculture since they allow investigating if there are specific areas where the plants are stressed due, for example, lack of water or the presence of pathogens. These tools work on the principle that plants are living breathing organisms therefore having different temperatures and spectral characteristics from the non-living background. This happens because they absorb light in specific wavelengths (the photosynthetic active radiation window, between 400 and 700 nanometres) and reflect it in various spectral regions (especially in the near infrared above 780 nanometres) according to biophysical properties of the vegetation. Stresses alters such plant responses and are therefore detectable with thermal (in the long-wave spectral domain) and multispectral (in the short-wave spectral domain) imaging, allowing a precise identification of critical situations where it is possible to intervene to improve agricultural practices.

TABLE 42 STRENGTHS AND LIMITATIONS OF SPECTRAL IMAGING

Strengths	Limitations
Can detect plant stresses and improve agricultural activities	Not easily generalizable, each situation requires a dedicated campaign and therefore a certain scientific and economic effort.

Better agricultural activities translate into greater yield and less environmental impacts

TABLE 43 PRODUCERS OF DEVICES FOR SPECTRAL IMAGING

Producer Name	Website
FLIR	http://www.flir.it/home/
TETRACAM	http://www.tetracam.com/
Ocean Optics	https://oceanoptics.com/
HEADWALL Photonics	http://www.headwallphotonics.com/
SPECIM	http://www.specim.fi/
ITRES Research	http://www.itres.com/

3.2.2.1 *Proton-transfer-reaction mass spectrometry (PTR-MS)*

PTR-MS is a technique that uses hydronium ions to transfer protons to any ambient volatile organic compound. VOCs have a higher affinity to hydrogen ions (the protons) compared to water or air and are therefore proton transfer happens only on substances of interest. Charged VOCs are then passed through the mass-spectrometer phase of the technique which allows their identification and quantification on the basis of each VOC spectral peaks.

The technique has been recently enhanced by coupling the proton transfer reaction to a time of flight mass spectrometer (PTR-TOF-MS). This yields a higher resolving power and better duty cycle. All ions are detected at once without having to cycle on different mass-to-charge ratios for detection as it happens in the PTR-MS.

TABLE 44 STRENGTHS AND LIMITATIONS OF PTR-MS

Strengths	Limitations
Real-time	Cannot detect substances with proton affinity lower than H2O
No sample preparation required	After 10 ppmv of VOCs the concentration response is not linear anymore. Samples can be diluted to overcome this limitation.
Can detect very low concentrations	

TABLE 45 PRODUCERS OF DEVICES FOR PTR-MS

Producer Name	Website

IONICON	http://www.ionicon.com/information/technology/ptr-ms

3.3 Emerging Technologies: Fluorescence

3.3.1 Fluorescence Measurement of Photosynthesis

Photosynthesis is the key mechanism with which biosphere fixates ("absorbs") CO_2 from the atmosphere. Any change in gross photosynthesis will be reflected on the whole carbon cycle and, therefore, photosynthesis prediction is becoming a priority effort. Photosynthetic rates can also give information about plant growth and ecosystem productivity and therefore feedback mechanisms between vegetation, atmosphere and climate. Photosynthesis measurements are already commercially available for single leaves or very small canopies. It employs mainly two methods of measurements: either measuring on a small scale the CO2 exchange with the atmosphere (mainly produced by LICOR), either measuring the fluorescence emitted by the vegetation in specific wavelength due to the molecular mechanisms involved in the photosynthetic and energy dissipation processes (mainly produced by Walz). The latter method uses LED pulsating a certain frequencies followed by a spectral readout from the plant. This system is manageable at leaf scale, but its active principle (based on an excitation-response mechanism) is not applicable far from the plant canopy. Recently, though, a new ESA mission will launch a satellite, FLEX, in 2022 that will be able to use passive method for quantifying plant fluorescence (e.g SIF, Solar Induced Fluorescence).

Plant photosynthesis will therefore enter a whole new scenario in which remote sensing will start playing an important role. The technology employed by such new observation satellite is actually being developed as aircraft payload by the Forschnungszentrum Jülich and the Specim Company, and will be commercially available for ground or aircraft-based biosphere measurements.

TABLE 46 STRENGTHS AND LIMITATIONS OF FLUORESCENCE MEASUREMENT OF PHOTOSYNTHESIS

Strengths	Limitations
Passive sensor allowing to survey in real time photosynthesis of large vegetated surface	Still in development and costly
	Data retrieval non-straightforward

TABLE 47 PRODUCERS OF DEVICES FOR FLUORESCENCE MEASUREMENT OF PHOTOSYNTHESIS

Producer Name	Website
Walz (leaf photosynthesis)	http://www.walz.com/
SPECIM (SIF passive sensors)	http://www.specim.fi/

3.3.2 Fluorescence Measurements of Microorganisms

Land Biosphere measurements of microorganisms emitted from the plant canopy generally using a combination of meteorological measurements (such as radiation, wind speed and temperature, either as single-point measurement or profiles) and quantitative microbiological techniques (for more information see Despres et al., 2012 and Carotenuto et al., 2017).

In the past years, though, a new technology is emerging that would be able to quantify microorganisms in real time. This is done through special aerosol samplers that not only determine physical characteristics of aerosols (such as size and asymmetry) but also response in fluorescence wavelengths related to organic molecules (such as NADH and the amino-acid tryptophan). Each aerosol particle is quickly illuminated ("flashed") by exciting emitters and appropriate detectors collect the fluorescence response. The combination of such information allows discriminating between inorganic aerosols, bacteria, fungi, etc. measuring the organic fraction that can potentially rise up in the atmosphere and act as biological ice or cloud condensation nuclei.

TABLE 48 STRENGTHS AND LIMITATIONS OF FLUORESCENCE MEASUREMENTS OF MICROORGANISMS

Strengths	Limitations
Real time sensor	High cost
Allow discrimination between different types of biological aerosols	Potential interferences on the signals
Portable	

TABLE 49 STRENGTHS AND LIMITATIONS OF FLUORESCENCE MEASUREMENTS OF MICROORGANISMS

Producer Name	Website
Droplet Measurement Technologies	http://www.dropletmeasurement.com/
FLIR	http://www.flir.it/home/

3.4 Market overview

Agriculture is one of the sectors with largest environmental impact, which is expected to grow even further. The demand for the food is expected to grow 70% during next decades. Providing the food resources is the key to the international social stability, reducing the amounts of produced food is not the optimal solution. Thus the regulatory measures have to be taken to make agricultural sector produce larger amounts of food with less harm to the environment. There are a number of policies and strategies influencing the development of agricultural sector from the point of view of GHG emissions. First of all these are the globally binding agreements such as Kyoto protocol and Paris agreement, which led to the introduction of systems for Emissions quotes trading in the EU, but also such long term strategies as the EU low carbon roadmap, climate and energy policy. Policies and strategies help to undertake climate mitigation activities in the agricultural sector in the short term. For example, Nitrates Directive determines the amount of nitrogen that could be applied to the agricultural soils, while the National Emissions Ceiling Directive (Directive 2001/81/EC), establishes the limit values for ammonia, precursor to N_2O. (Allen and Maréchal 2017) Agriculture GHG emissions: determining the potential contribution to the Effort Sharing Regulation. Report prepared for Transport and Environment. Institute for European Environmental Policy, London).

In 2016, European Commission presented the winter package of proposals for clean energy transition in Europe. This package includes a number of updates to the existing regulations, among them are revisions to the Renewable Energy Directive and setting of proposed Governance Regulation (COM 2016 759 final/2). Article 14 of this Regulation requires EU member states to prepare and report the European Commission their long-term emission strategies for the next 50 year period perspective to contribute to the reduction and removals of emissions in the EU. Such strategy shall include the plans for the reductions and removals of emissions in several individual sectors, including agriculture and forestry.

The main policy that directly influences the development of agricultural sector is the common agricultural policy (CAP) of European Union. It was established in 1962 and nowadays includes three core objectives: Viable food production, sustainable management of natural resources and climate action and, finally, balanced territorial development.

Agricultural production requires certain amounts of soil, water, sunlight and heat to develop. Availability of these factors have a great influence on the length of growing season, flowering and harvest dates for crops. Assuming that the climate change characterized by the general increase of temperature will continue, the northern countries will be able to enlarge their agricultural sector and cultivate more crops, while southern counties will suffer from extreme heat and will either shift the production to the colder seasons or reduce the total production. Main markets for the sensors are:

Developing countries, with large population: China, India, Brazil developing countries of Africa. Huge population of these countries requires large amounts of food. For example, China is a world leader in production of pork, sheep, goat and duck meat, while India is the biggest producer of dairy products. Due to the steep economic growth and increasing demand for better life quality by large population, these countries can be considered as large markets for sensors for GHG measurements in the short and medium-period perspective.

Developing countries with large agricultural potential and large producers of fertilizers: Russia, Ukraine, Belarus, Kazakhstan. These countries have the largest potential of agriculture development, due to the availability of large territories and good soil quality. For example, in

2017 Russia showed large increase in crops production and export. In addition, these countries are large producers and consumers of various fertilizers. Current demand for the sensors for GHG measurements in these countries is doubtful, because the environmental regulation are not very strict. However, they can become large markets for the GHG measurement sensors in the medium and long-term perspective.

Northern countries with the potential to develop agriculture due to the global warming: Canada, Sweden, Finland, Russia. Due to the increase of average year temperatures, these countries have a great potential to grow the agriculture sector, since new territories will be available for the crop and animal production.

Developed countries, traditionally strong in agriculture, interested in further reduction of GHG emissions: USA, France, Germany, (EU) etc. These traditional players of agricultural market sector are interested in more efficient production of agricultural goods and precise monitoring of resulting emissions due to the very strict environmental regulations. These countries represent today's largest market for the distribution of sensors for measurements of agriculture produced GHG.

4 Measurement of Ocean parameters

4.1 Why measurements of ocean parameters are important

Global Ocean is a sensitive system, closely interacting with all domains of planet Earth and, thus, serving as an indicator of global processes. Mankind interest has been focused on land and it took a long time before the importance of the ocean investigations for most of the natural sciences disciplines was acknowledged. Nowadays, there are plenty of paradigms based on certain observations. Thus Blue Planet paradigm is based on satellite observations (remote sensing), the "Hidden Planet" is based on seafloor research (deep sea observatory oriented - "Illuminating the Hidden Planet: The Future of Seafloor Observatory Science"[14]), the Source to sink vision of the coastal processes either considers dilution of pollutants or hydrology and sediment transport, the eco-systemic approach of marine life deals with the tremendous marine biodiversity, the Energy buffer vision addresses the global circulation/vorticity and thermodynamic coupling with atmosphere, the Fluid interface to continental plate focuses on active boundaries or continental margin seeping processes and Blue Growth Economy aims at developing sustainable industries.

The marine environment research infrastructure approach brings together several scientific questions from several disciplines with an objective of providing long-term in-situ data. The measurements of marine variables can last from hours to several decades while even longer

[14] http://www.nap.edu/catalog/9920

processes are investigated by cryology (ice cores) or geology (sediment cores). Observations coming mainly from the sea surface and from underwater measurements are by far too scarce. The physical limitations drive the technological challenges: electromagnetic waves and photons hardly propagate through seawater. The imaging and signal transmission under water are generally based on acoustics principles.

The ocean science community bases the strategy of knowledge acquisition on the junction of modelling and in-situ collecting of "Essential Ocean Variables" (EOV). After the 2009 OceanOBS[15] conference, the post-OceanOBS'09 task team prepared the report called "Integrated Framework for Sustained Ocean Observing" (Lindstrom et al 2009). The focus of this report was to:

- Use "Essential Ocean Variables" (EOVs) as the common focus
- Define a system based on requirements
- Overview observations, data and information
- Use "Technology Readiness Levels" (TRL) scale, based on assessment of feasibility, capacity, and impact, for each of the system components
- Incorporate both coastal and open ocean observations

The current document will provide information about technologies measuring mentioned EOV parameters. The report "Marine Board Paper"[16] provides the rationale behind the marine research infrastructures constitution and the priorities in ENVRIplus. The in-situ component of marine observations addresses some EOVs. While studying climate change, the group of scientists has investigated the concentrations of GHG in the ice cores (Lüthi et al. 2008) and concluded, that GHG contributed significantly in global temperature rise and climate change through the entire history. They also showed that GHG concentrations in the atmosphere have been growing rapidly after industrial revolution, proving that human activity is the main contributor to climate change. Climate change influences ocean systems significantly, mainly through changing multiple parameters of seawater, such as water temperature, pH and others. These changes result in numerous negative phenomena, such as coral bleaching, stormy weather, alteration of lifestyle of sea organisms, rising sea level, ocean acidification and decrease of vertical mixing and, most importantly release of GHG.

[15] http://www.oceanobs09.net/proceedings/summary/

[16] http:// www.marineboard.eu/navigating-future-0

4.2 Existing technologies for marine measurements

4.2.1 Acidification of oceans

4.2.1.1 ***Carbonate System (pH, pCO_2, Total Alkalinity, Dissolved Inorganic Carbon)***

Together with dissolved inorganic carbon (DIC), total alkalinity (TA), pH and pCO_2 determines the characteristics of the carbonate system of seawater (Sarmiento and Gruber 2006; Emerson and Hedges 2008). For aquatic in situ measurements of pCO_2 (Atamanchuk et al. 2014), two different detection principles have been used. Infrared method is based on the equilibration of the CO_2 gas dissolved in water, with the inner air-filled compartment of the analyser through a gas permeable membrane. In the analyser, the concentration of CO_2 is measured optically by means of nondispersive infrared absorption spectrometry (HydroC™/CO_2, Kongsberg, and CO_2-Pro™, PSI, www.pro-oceanus.com). Colorimetric method is based on optical detection of the pH induced colour change of the indicator solution, which is equilibrated with ambient seawater pCO_2 through a gas-permeable membrane (Goyet et al. 1992; DeGrandpre 1993; Lefèvre et al. 1993; DeGrandpre et al. 1995). A compact, energy efficient optode pCO_2 sensor designed for oceanographic applications opens the way to a larger number of measurement points in the near future. Possibilities for such measurements are investigated in ENVRIplus task 1.2 for the needs of Research Infrastructures such as EUROARGO and GROOM. PreSens GmbH produces the foils of the optodes while the instrument is designed and built by Aanderaa in Norway. pH sensors for oceanography are based on spectrophotometric principle, many R&D developments are in progress but some sensors are already on the market, Sensorlab (Spain) or FLUIDION (France) companies are some of them. pH sensors can be based as well on IFET principle like the Seabird Seafet product. Precision and accuracy, typical of mentioned technologies are:

- pCO_2: 0.1µatm (surface flux), 1µatm (ocean acidification)
- pH 0.001 (acidification), TA <2µM, DIC <2µM

4.2.2 Release of Greenhouse Gases - Methane

Huge amounts of methane are stored around the world in the sea floor in the form of solid methane hydrates. Rising water temperature will destabilize this storage and methane will get to the atmosphere, destabilizing climate even further (Boulart 2008; Moore 2009).

Dissolved methane measurements rely on the time-consuming collection of discrete water samples followed by gas-chromatography analysis. To date, this approach has proved to be useful for broad interpretation of environmental processes. However, it limits comprehension of environmental processes that are highly variable in space and time. This has led to increased interest in in-situ dissolved methane sensors to augment data from point sampling. To date, a limited number of techniques have been developed to measure methane in seawater. The most commonly used technique is based on the gas-extraction system represented by hydrophobic silicone membrane with high permeability to methane. The known disadvantage of this system is that such membranes influence the performance of the whole sensor in terms of response time and LODs. Recent developments in the field of membrane compound sensors have led to the combined use of hydrophobic gas-permeable membranes with infrared absorption spectrometry. With permeability rates depending on the characteristics of the membrane, dissolved gas molecules in the water diffuse through this layer, which separates the outer water from the inner gas-volume of the sensor. This first step alone does not lead to a sensor being solely sensitive for a certain gas. The usage of a particular infrared wavelength leads to the unambiguous sensitivity of the sensor for the provided analyte while other phenomena associated with infrared spectrometry, such as water vapour cross sensitivity, are also characterized. The used wavelength is matched to a certain vibrational mode of the target molecule. There are two known manufacturers for this membrane sensor type, whose products differ with respect to membrane design, possible analyses (CH_4, CO_2), depth capability and response time.

4.2.2.1 *METS methane sensor*

The METS methane sensor was presented in 1999, as the first sensor for underwater methane monitoring and detection, using a gas-permeable membrane with tin-oxide (SnO_2) semiconductor detection. It is described as being able to detect methane in the concentration range 50 nM–10 µM in its standard version, and up to 2 mM for some versions. It can perform at water depths down to 3500 m and temperatures of 2–40°C. The METS sensor has been widely used for the detection of methane-rich plume signals in the water column overlying cold-seep environments or for long-term monitoring.

4.2.2.2 *HydroC sensor*

HydroC (Konsberg) is the sensor, comparable to the METS sensor except that the detection principle is based on direct IR absorption spectroscopy in the 3.4-µm region. This detection method does not consume methane, what simplifies calibration and reduces measurement errors in flowing fluid. The system can measure concentrations of methane in the range 30 nM–500 µm with a resolution of 3–30 nM. The T90 of the detector is quoted to be 30 s. The HydroC/CH_4 was deployed in 2007 during RV Sonne cruise 190 (27/02/07– 22/03/07) and was able to measure methane plumes (10–50 nM) over the New Zealand continental margin (Contros GmBH, personal communication).

The main limitation of methane sensors operating in the gas phase is the use of gas-extraction membranes, which are sensitive to environmental conditions, what causes deviations in the response times. These problems are exacerbated if the sensor consumes methane, as changes in membrane diffusivity cause changes in calibration of the sensor.

Future avenues in methane sensor development may involve the transfer of techniques and technologies from other fields external to environmental science, which could result in better sensitivity, better selectivity and better response times. Raman spectroscopy, surface-enhanced Raman spectroscopy and mass spectroscopy are under investigation to overcome the membrane limitations.

4.2.3 Measurements of Oxygen levels

Oxygen is a key parameter for biogeochemical cycles and a major player in the carbon system of the ocean (Bopp et al. 2002) as well as the marine nitrogen cycle (Bange et al. 2005). The oxygen concentrations are very sensitive to physical processes as the air-sea fluxes and the interior ocean advection (Karstensen et al. 2008). Consequently, dissolved oxygen is an important parameter for understanding the ocean's role in climate (Joos et al. 2003). Dissolved oxygen (as well as dissolved inorganic nutrients) may be used to trace water masses, to understand mixing processes, and to understand the biogeochemical conditions of their formation regions. Concerning the fate of organic matter in aqueous systems, the role of dissolved oxygen is essential. It influences the degradation of sinking particles and in particular the final extent of degradation (Van Mooy et al. 2002). Oceanic dissolved oxygen concentration is one of the oldest oceanographic parameters observed in the global ocean. Nevertheless, the accuracy of the dissolved oxygen measurements that we can perform today is around 8 µmol/ kg which is far from the current scientific needs (1 µmol kg/1). Dissolved oxygen in seawater is usually determined by using the Winkler's reaction scheme, a chemical titration method used for decades (Winkler 1888). Nowadays, Winkler titration is a standard method used by many marine laboratories. Its main advantage is a good precision and accuracy (± 2 µmol/l). Even when other methods are used, they are usually calibrated against this method (Emerson et al. 2002; Kuss et al., 2006). However, this method cannot be practically used for continuous measurements (ship cruises, autonomous platforms, deep moorings, coastal buoys) as special laboratory equipment is needed. Nowadays, autonomous sensors are based on two techniques: an electrochemical method and an optical method.

4.2.3.1 *Electrochemical sensors (SBE 43)*

The SBE 43, from Seabird Electronics, is an electrochemical sensor based on a Clark polarographic membrane (Clark et al. 1953) used mainly on Seabird shipboard CTD units. The SBE 43 sensor is adapted for autonomous measurements system, in particular for the CTD casts due to its very fast response time (<1s). The initial accuracy is 2% of oxygen saturation while precision is around 1 µmol/kg. Even if this sensor has good specifications, an extensive calibration and maintenance work has to be done prior its installation in order to reduce any electrochemical drift for improving long-term data quality. The chemistry of the sensor electrolyte changes continuously as oxygen is measured, resulting in a slow but continuous loss of sensitivity that produces a predictable drift in the sensor calibration with time. Membrane fouling also contributes to drift by altering the oxygen diffusion rate through the membrane, thus reducing sensitivity.

4.2.3.2 *Optical sensors (optode 3835/4330, RINKO, SBE63)*

Optical sensors operate based on the principle of fluorescence quenching (Tengberg et al. 2006). Nowadays, the Aanderaa optodes 3835 & 4330 are the most used sensors implemented in ARGO floats, gliders and on moorings. Oxygen optodes are based on the oxygen luminescence quenching of a platinum porphyrin complex (fluorescent indicator) that is immobilized in a sensing foil. Optodes show a nonlinear decrease in luminescence decay time with increasing oxygen concentration. The signal can be linearized by means of the Stern–Volmer equation: $[O_2] = (\tau 0/\tau - 1)/Ksv$, where $[O_2]$ is oxygen concentration in µmol/L, τ is luminescence decay time, τ0 is the decay time in the absence of $[O_2]$, and Ksv is the Stern–Volmer constant (Demas et al. 1999). The advantages of the optical sensors are their excellent long-term stability and high precision. They also appear to be accurate provided they have sufficient time to come into equilibrium with the surrounding temperature and oxygen concentration and provided that their temperature response has been carefully calibrated (possibly by individual sensor factory-calibration plus in-situ calibration check/correction based on concomitant Winkler profile).

4.2.3.2.1 The Aanderaa optode sensors 3830-3835

This sensors have a measuring range of 0-500 µM, a resolution of 1 µM and an accuracy of 5 µM as well as an operating depth of up to 6000 m. Due to their small size and power requirements, the first generation of optode sensors (3830/3835) have been also tested on profiling floats (Kortzinger et al. 2005). The first results obtained in 2004 demonstrated that high quality long-term oxygen measurements from ARGO floats are feasible.

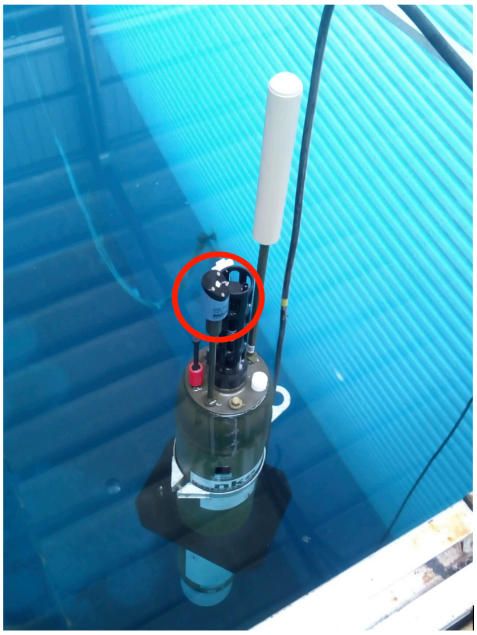

FIGURE 3 THE AANDERAA OPTODE SENSOR ON A PROVOR FLOAT

4.2.3.2.2 The SBE 63 sensor

A new optical DO sensor set for moorings and ARGO floats. The SBE 63 is designed for use in the CTD's pumped flow path. Water does not freely flow through the plumbing between samples, allowing the biocide (TBT ring dissolution) concentration inside the system to maintain high, maximizing bio-fouling protection. The elapsed time between the CTD and associated oxygen measurement is easily quantified, and corrected for in post-processing. The SBE 63 initial accuracy proposed by Seabird is around ±3 µmol/kg and resolution of 0.2 µmol/kg. The response time is lower than 6s. Each SBE 63 is calibrated individually in a temperature-controlled bath.

4.2.3.2.3 The RINKO-III optical oxygen sensor

One of the main disadvantages of recent optical oxygen sensors has been their long response time of several seconds, which does not fit the requirements of an oxygen sensor being used in profiling CTD-systems. The RINKO oxygen sensor is a fast optical oxygen sensor manufactured by JFE Advantech Co., Ltd, Kobe, Japan. The specifications given by the manufacturer are: Accuracy: < +/- 2 %, resolution: 0.4 % and a response time (90 %) of ≤ 1 second.

Optical DO sensors are coming to be considered as an attractive alternative to polarographic sensors because of their insensitivity to stirring and the compactness of the underlying sensing technology. However, these sensors too are sensitive to temperature and pressure, and employ membrane coverings to make them more robust and deal with interference. It is to be expected that this will make them susceptible to many of the same problems affecting their electrochemical counterpart, with the difference that the possible effects on performance are more poorly known, less well characterized, and hence harder to compensate for now. Typical specifications of this sensor are:

•Range 0-350 µM, accuracy 5µM (coastal), 2µM (deep ocean), <0.1µMincubators

4.2.4 Measurements of inorganic nutrients concentrations

It is important to conduct continuous and automatic measurements of nutrients in seawater, such as dissolved inorganic nitrogen and phosphoric and silicic acid ions; however, such continuous measurements are difficult because the data must often be obtained by chemical analysis (Rei Arai et al. 2001; Vuillemin et al. 2009).

In coastal sea areas, wastewater carrying high concentrations of nutrients and organic matter often flows into the seawater, leading to the so-called eutrophication phenomenon. Eutrophication refers to increases in nutrient concentrations that may cause dense phytoplankton growth. In coastal waters, eutrophication causes various environmental problems, such as red tide and anoxic water. The measurements of nutrients such as dissolved inorganic nitrogen (DIN), which comprises nitrate NO_3^-, nitrite NO_2^- and ammonium NH_4^+ ions, and orthophosphoric acid PO_4 and silicic acid ions are very important because they are useful for understanding the specific behaviours of the primary production of phytoplankton. DIN and phosphoric and silicic acid ions are typically analysed in laboratories.

Spectrometry in the ultraviolet (UV) wavelength range is very effective for measuring chemical concentrations of organic substances without any chemical treatment. As nitrate and nitrite ions show particular absorption decays of radiation in the UV wavelength range, spectrometry has been used for many years to monitor nitrates in freshwater, as discussed by Armstrong (1963). However, In the case of seawater, it is difficult to measure the nitrate and nitrite concentrations due to the presence of bromides and dissolved organic matter. Johnson et al. (1986) and Plant et al. (2009) reported significant advances in this task through the application of a high-resolution in situ UV spectrometer (ISUS) for the measurements of nitrate concentrations in depth profiles in oceans.

Contrary to nitrite and nitrate ions, ammonia and phosphorus ions do not absorb light in the UV region and thus cannot be measured with this method. However one cannot neglect these ions since they are essential for the growth of phytoplankton in coastal seas. Flow Injection Analysis (FIA) is an effective technique for continuous measurements of all types of chemical matter. Jaromir et al., whose first paper on the subject appeared in 1975, conceived the FIA concept. Johnson et al. (1986, 1989, 1994) developed an in situ instrument using FIA and used it to measure the nitrate and nitrite ion concentrations at a depth over 2000 m. David et al. (1998, 1999) measured the nitrate, nitrite and ammonia ion concentrations in seawater using FIA with fluorescence detection. This technique provides precise measurements at low concentrations (µM/L). These remarkable results indicate it is possible to determine many types of compounds using FIA: nitrate, nitrite and ammonia ions but also phosphoric acid, silicic acid and iron ions.

Several field analysers based on flow analysis and colorimetry were developed at IFREMER during the 1990s following the first prototypes developed in the United States (Jannasch et al. 1994) and in Japan (Gamo et al., 1994). Alchimist (Le Bris et al., 2000) was the first in situ chemical analyser developed by Ifremer and able to work at a depth of up to 6000 m. It was used for the determination of iron and sulphide in hydrothermal zones (Le Bris et al., 2003; Sarradin et al. 2005), and for the determination of subnanomolar concentrations of iron in coastal waters (Laes et al. 2005). A surface model was tested on a coastal buoy to monitor nitrate concentration in the Iroise sea (Blain et al. 2004) and a first prototype of a fluorimetric analyser for the determination of ammonia in shallow waters was built (Aminot et al. 2001). In parallel, ANAIS (Autonomous Nutrients analyser In Situ) (Vuillemin et al. 1999) was developed to be integrated into a vertical profiler vehicle for nitrate, silicate, and phosphate measurements (Thouron et al. 2003). All these systems are based on flow analysis methods with a pump, detector, and narrow bore manifold tube. The sample is propelled by the pump and mixed in the manifold tube with the reagents in order to form the detectable species. The resulting analyte is then measured using optical (colorimetry or fluorimetry) or electrochemical detectors. A selection valve added to the manifold allows the analysis of standards, needed to perform in situ calibration.

CHEMINI is the new generation of analysers developed by Ifremer to monitor seawater chemical parameters. CHEMINI is a mono-parameter in situ chemical analyser. It has several advantages such as the ability to make simultaneous measurements, the independence of each measurement, increased reliability, the possible use of different detection methods, and the modularity of the system and the possibility of measurement of multiple parameters. The analysers can be set serially on a sampling line and operated by a single controller. Calibration of the analytical methods is performed in-situ. This analyser may be deployed on various carriers such as buoy systems, AUV or ROV, inhabited submersibles or seabed stations to perform long-term monitoring. The deep-sea version of CHEMINI intended for in situ determination of dissolved iron and total sulphide in hydrothermal environments was developed during the EXOCET/D European project (Sarradin et al. 2007). The systems reveals the following characteristics: range of concentrations 0.1 nM - 2 mM, LOD 0.1 nM (open ocean), 0.1 µM (profiling), 1-5 µM coastal / rivers and upwelling.

4.2.5 Salinity/density vs salinity/conductivity

Salinity is the parameter that characterizes global circulation and local exchanges of water masses. It must be known to understand the spatial significance of a measurement and in many cases to correct the raw data of sensors (sound speed, chemical concentration such as nitrate). Marine sciences in general focus and rely on the assessment of “absolute salinity”.

Conductivity is associated with most of the sea measurements including transition zones such as estuaries. It is a proxy to “practical salinity” with two drawbacks when one wants to measure “absolute salinity”. The first drawback is that being an electrical property, conductivity depends on the ion composition of seawater. This issue is partly solved through corrections of empirical values by modeling adjustments, what giving acceptable results in some parts of the global ocean such as Pacific Ocean with a rather fixed bias due to the presence of silicates (non-ionic), but not in coastal and estuarine waters. The second drawback is the calibration of salinometers which requires a reference water (so-called IAPSO/standard water). There are two main techniques for measuring conductivity: induction and electrode cell sensors. The choice of these techniques shall mainly depend on the available resources, deployment capabilities and conditions. Inductive sensors (FSI, Aanderaa) are less accurate while more impervious to fouling and more robust. Glass electrode cell sensors (SeaBird, Idronaut) however, give the best performance from an oceanographic point of view, but are more sensitive to fouling.

The measurements of seawater density does not face the same drawbacks as measurements of conductivity. Density may be measured through refractive index. Such measurement is based on the comparison of the deviation angle of the beam passing through two prisms of different index delimiting a seawater volume. The value of absolute salinity can be directly accessed through these measurements. A sensor called NOSS (nke Marine Electronics Optical Salinity Sensor) has been developed and validated (Le Menn et al. 2011) for the seawater density measurements. It is currently marketed by nke Marine Electronics.

TABLE 50 CORE SPECIFICATIONS FOR MEASURING CONDUCTIVITY

CONDUCTIVITY		
Measurement Range	0 - 7	S/m
Accuracy	0,001	S/m
Sensitivity	0,00005	S/m

4.2.6 Turbidity/Optical Backscattering/Transmissometry

Turbidity is an optical characteristic of seawater, which expresses the amount of light scattered by the material in the water. Thus turbidity of water depends on the amount of suspended solid particles of different sizes and their sedimentation rates. In the ocean these particles can be represented by phytoplankton, micro-zooplankton and suspended sediments such as clay or particulate mineral effluent from hydrothermal vents. The measurement of turbidity and its related variables have several applications. One of them is measuring the abundance of particles in the water column, which can be related to primary productivity and chlorophyll-a levels. Another application is quantification of the particles dominated both by phytoplankton and by clays. In such systems, re-suspension might change the proportion of the constituent particles and indicate changes in the predominance of some processes over the others in controlling environmental conditions over time. Depending on the way the turbidity is measured and other parameters measured together with it, multiple biogeochemical parameters can be estimated including suspended sediment load, particulate organic carbon (POC) concentration, and limited information on particle size.

Three techniques for turbidity measurements, available as commercial systems, are (1) direct beam attenuation, (2) light scattering 90° from the beam path (nephelometer), and (3) optical backscatter at specific wavelengths. A nephelometer emits one or more light beams and measures the intensity of the scattered light from the suspended particles in the fluid. This technique is widely considered as the most direct measurement of turbidity. The units that are commonly used in this optical measuring technique are called NTU (Nephelometric Turbidity Units). Turbidity can be as low as 0,3 NTU for drinking water and as high as 2000 NTU in rivers and lakes. The measuring range in all modern nephelometers is user-selectable but the more the range is increased the less the sensitivity is. Typically for 0 – 50 NTU range the sensitivity goes down to 0,01 NTU, while for 0 – 1000 NTU ranges, 0,12 NTU sensitivity is typical . For the EMSO sites the measurements can vary significantly so the measuring range should be adapted to the site needs.

Optical backscatter technique can operate across a variety of wavelengths while the chosen combinations and measurement implementation determines the final measurement result. For example a single wavelength system measuring at 700 nm can quantify suspended particle concentrations within the sizes of 0,2 to 20 µm. Spikes in this signal can indicate larger particles, and the addition of other wavelengths can also expand particle quantification capability. The data obtained from optical backscattering measurements can also be calibrated to various quantities including POC concentration, using samples that are sufficiently specific. The ratio of chlorophyll-A to optical backscatter can also indicate variations in phytoplankton community. Conveniently, optical backscatter across two wavelengths and chlorophyll-a can be measured in a compact and power efficient triplet fluorescence instrument offered by Wetlabs.

TABLE 51 CORE SPECIFICATIONS FOR MEASURING TURBIDITY AND OPTICAL BACKSCATTER

TURBIDITY and OPTICAL BACKSCATTER (OBS)		
Measurement Range	0 - 150	NTU
Accuracy	0,1	NTU
Sensitivity	0,02	NTU

4.2.7 Currents

Water currents can influence a range of processes and can also be used to translate state variables to flux, such as the transport of particles in time, current speed and direction. The influence of currents on heat flux, nutrient availability, and production in the surface ocean are all fundamental areas of oceanographic research. At the seafloor, the influence of currents on re-suspension, transport of heat and mineral quantities are also important.

The speed and direction of a current can be perfectly measured by means of Acoustic Doppler Current Profilers (ADCP). The measurement is performed using the Doppler Effect from moving particles inside the water column that reflect a precise sound wave emitted from the instrument. The frequency of the sound wave determines the measuring distance, the sensitivity and accuracy of the measurement. Typically an ADCP works at 1200 KHz frequency and has a measuring range of 20 meters, while an ADCP working with a frequency of 300 KHz can measure at the distance of 150 meters. A minimum concentration of suspended particles in the water is necessary to produce detectable acoustic backscatter for the system to work.

Measurements are multipoint meaning that the column of water from the instrument to its furthest measuring point is divided in zones called cells. The measurement of the velocity and direction of suspended particles within these cells constitute a measurement profile of the velocity and direction of currents in the water column. Typically a number of cells ranges from 1 to 128.

For the instrument to work properly, several parameters have to be defined before the measurement start. Usually the user defines a fixed pressure depending on the depth of the instrument, a fixed salinity value (assuming it is uniform for the column of water that is measured). Internal temperature sensor of the instrument helps to determine correct speed of sound in water. The instruments is also equipped with the tilt sensor and compass.

TABLE 52 CORE SPECIFICATIONS FOR MEASURING CURRENTS

CURRENTS		
Velocity Accuracy	1% ±0,5 cm/s	cm/s
Direction Accuracy	±2	Degrees
Velocity Sensitivity	0,1	cm/s
Direction Sensitivity	0,01	Degrees

4.2.8 Fluorescence/Chlorophyll-A

Fluorescence can be tailored to look at a variety of biogeochemical properties, the most well-known of which is chlorophyll-a. Primary productivity can be correlated to chlorophyll-a concentrations, which in turn are correlated to the amount of fluorescence excitations. Primary productivity has fundamental applications including helping to interpret carbon uptake dynamics from the atmosphere into the ocean, quantifying organic carbon production from photosynthesis, and determining of the amounts of organic carbon available to fuel biological activity. Chlorophyll-a data can provide information on local conditions in relation to in situ data, but can also help in calibrations of ocean colour data collected by satellites. More advanced techniques use Fast Repetition Rate fluorometer (FRRf) systems that can also collect information on the physiological condition of phytoplankton and provide an important information on productivity and ecological functioning. The detection of coloured dissolved organic matter (CDOM) can also have specific biogeochemical applications that will not be covered here.

Several companies sell in situ fluorometer systems that come with biofouling protection. There are also FRRF systems that can be fitted to observatories and autonomous systems. In the past five years there have been many long term deployments of fluorimeter systems that have provided useful and sensible data despite potential biofouling or other calibration issues. Like for the most other sensors, pre- and post- deployment in situ calibration measurements is the best way to correct the drift. Moreover, if the intent is to convert the fluorescence values to chlorophyll-A or other specific values, it is advised to collect size fractionated algal pigment samples for calibration purposes. Wet Labs ECO Triplet, or TriOS microFlu, nanoFlu, matrixFlu VIS; TurnerDesigns Cyclops and Chelsea AquaTracka III are examples of widely used systems.

FIGURE 4 TRIOS FLUOROMETERS EQUIPPED WITH IFREMER ANTIFOULING DEVICES

TABLE 53 CORE SPECIFICATIONS FOR MEASURING FLUORESCENCE

FLUORESCENCE / Chlorophyll-A		
Measurement Range	0 - 125	µg/l
Sensitivity	0,02	µg/l

4.2.9 Underwater sound

The ocean is full of sounds. Underwater sound is generated by a variety of natural sources, such as breaking waves, rain, and marine life. It is also generated by a variety of man-made sources, such as ships and sonars. There is an increasing need to measure and report levels of underwater sound in the ocean, partly driven by the need to conform to regulatory requirements with regard to assessment of the environmental impact of anthropogenic noise. Acoustic measurements are required for applications as diverse as acoustical oceanography, sonar performance assessment, geophysical exploration, underwater communications, and offshore engineering. More recently, there has been an increased need to make in situ measurements of underwater noise for the assessment of risks to marine life.

Some sounds are present more or less everywhere in the ocean all the time. The background sound in the ocean is called ambient noise. The primary sources of ambient noise can be categorized by the frequency of the sound. In the frequency range of 20-500 Hz, ambient noise appears primarily due to distant shipping. Even after removing the noise generated by ships close to the receiver, distant ships can be detected. The amount of noise is greater in regions with heavy shipping traffic. In the southern hemisphere, there are fewer ships than in the northern, thus low-frequency ambient noise levels are generally at least 10 dB lower. In the frequency range of 500-100.000 Hz, ambient noise appears mostly due to spray and bubbles coming from breaking waves. These sounds increase with increasing wind speed. At frequencies greater than about 100.000 Hz, the noise generated by the random motion of water molecules, called thermal noise is predominant. This noise sets the ultimate limit to the minimum sound levels that can be measured. Unlike ambient noise discussed above, which is almost always present, some sounds are intermittent or only occur in limited regions of the ocean. There are a large number of intermittent sources of sound in the ocean, including natural physical processes, marine life, and man-made sources.

Devices called hydrophones are widely used to track the underwater sounds. Hydrophones convert sound in water into electrical signals that can be amplified, recorded, played back over loudspeakers, and used to measure the characteristics of the sound. Most hydrophones are made from a piezoelectric material. Under the pressure of a sound wave, the piezoelectric element flexes and produces electrical signals. Some hydrophones, called omnidirectional hydrophones, record sounds from all directions with equal sensitivity. Other hydrophones, called directional hydrophones, have a higher sensitivity to signals from a particular direction. Directional receivers are most often constructed using a number of omnidirectional hydrophones combined in an array. Directional hydrophones are typically used in systems constructed for locating and tracking objects. Hydrophones are specially designed for underwater use. They are normally encased in rubber or polyurethane to provide protection from seawater. They can be mounted in several different ways, such as attached to a boat, towed, or placed in a fixed position underwater.

TABLE 54 CORE SPECIFICATIONS FOR MEASURING PASSIVE ACOUSTICS (GEOLOGY SPECIFIC)

PASSIVE ACOUSTICS (Geology specific)		
Measurement Range	0,1 – 100	Hz
Accuracy	1	V/µPa
Sensitivity	-190	dB (re 1V/µPa)

TABLE 55 CORE SPECIFICATIONS FOR MEASURING PASSIVE ACOUSTICS (OCEAN CIRCULATION SPECIFIC)

PASSIVE ACOUSTICS (Ocean circulation specific)		
Measurement Range	20 – 200.000	Hz
Accuracy	1	V/µPa
Sensitivity	-190	dB (re 1V/µPa)

4.2.10 Imagery of microorganisms and habitat

Capturing underwater images or making an underwater video can be a very useful tool for conducting scientific research as well as a fun hobby. Underwater photography is very useful when scientists need to examine objects on the seafloor over time. For example, scientists may use underwater photography to take photo quadrats to look at the abundance of corals over time at several reef locations. A photo quadrat is a photograph of a particular habitat within a standardized square area, or quadrat. Underwater photos can be used to help to identify species without removing them from the water, especially those that are slow-moving (e.g., nudibranchs) or sessile (e.g., barnacles). Underwater video can be used to observe the behaviour of motile species, such as the interaction between mate pairs in butterfly fish or social behaviour in seals. Video can even be used to examine phenomena such as hydrothermal vents and underwater volcanic eruptions.

Underwater photography and video face many challenges. For example, cameras must be placed in watertight housings. Light attenuation means that red wavelengths of light are absorbed near the surface and light intensity decreases with depth. Light sources are used to add the missing colours back and capture colour markings of species that may be important for identification. Another challenge with taking underwater photo or video is that there are often large particles of sediment and plankton in between the camera and the object of interest. When photographers take photos with a flash, light reflects from these particles and show up as bright dots on the final image. To address this problem, photographers use flashes that are off to the side of the camera, called strobes, so that when a photograph is taken, most of the light reflects back at the strobe and not at the camera objective.

The analysis of underwater imagery imposes a series of unique challenges, which need to be tackled by the IT community in collaboration with biologists and ocean scientists. Among the challenges are image enhancement, scene understanding, classification, detection, segmentation; detection and monitoring of marine life, form tracking, automatic video annotation and summarization, context-aware machine learning and image understanding, image compression.

TABLE 56 CORE SPECIFICATIONS OF EMSO FOR RECORDING HD VIDEO AND STILL IMAGES

High Definition video and Still imaging Specifications		
Resolution	4240×2824	pixels
Minimum video capture speed	7	Frames per second
Sensitivity	Minimum 46%	QE
Sensor type	CCD + CMOS	
Sensor size	1	inches
Output protocol	TCP/IP, USB3	
Sensitivity to IR light	850 -900	Nano metres

4.2.10.1 *The Imaging FlowCytoBot (IFCB) (McLane Research Laboratories)*

IFCB is an in-situ automated submersible imaging flow cytometer that generates high resolution (1380x1034 pixels) images of suspended particles in-flow, in the size range <10 to 150 µm (such as diatoms and dinoflagellates). The instrument continuously samples at a rate of 15 ml seawater per hour, and, depending on the target population, can generate up to 30,000 high resolution images per hour. IFCB uses a combination of flow cytometry and video technology. Laser-induced fluorescence and light scattering from individual particles are measured and used to trigger targeted image acquisition. The optical and image data is then transmitted to the computer in real time, through an Ethernet link. Collected images are continuously monitored and processed externally by the specific automated image classification software. For each imaged particle, approximately 200 different parameters are extracted. Images can be automatically classified to the genus or even species level with demonstrated accuracy comparable to that of human experts (Olson and Sosik 2007).

4.2.10.2 *The FlowCAM (Fluid Imaging Technologies)*

FlowCAM combines selective capabilities of different technologies such as flow cytometry, optical microscopy and fluorescence detection. It can generate high resolution (1280x960 pixels) images of particles in-flow, in the size range 2 µm to 2000 µm (depending on the combination «magnification/flow cell» used for the optical system, i.e. 2X/600µm, 4X/300µm, 10X/100µm or 20X/100µm). The sample introduced in the device is passed by a peristaltic or a syringe pump into a flow cell (or flow chamber) with known dimensions, located in front of a microscope objective, connected to a video camera. «Visual SpreadSheet» is the software provided together with FlowCAM. It is essential for all the major aspects of sample analysis: setup for data acquisition through the context settings, controlling the device, managing files and setting preferences, data acquisition and post-processing of collected data. For each particle, the software provides a set of 26 parameters.

4.2.10.3 *The FastCAM prototype (IFREMER - LDCM)*

This system is based on a high resolution (2 Megapixels) and high speed camera allowing the acquisition of 340 frames per second. It digitizes 10 mL of sample with a 10 times magnification within only 15 min (which is not possible with the first generation of FlowCAM devices). Comparison of grayscale images with those obtained with the first generation of FlowCAM showed that this new system analyses samples much faster and provides high image quality. A LED, driven by a control box emits light pulses of 5 µs duration. Light is injected into a large core diameter (1 mm) optical fiber to homogenize the beam. Upon the exit from the optical fiber, light illuminates the flow cell. A 10X magnification microscope objective associated with a tube lens images the organisms that circulate in the flow cell. The frame grabbing is synchronized with the LED light emission. A pixel of the image corresponds to 0.5 µm. The images are saved on the PC in real time thanks to a fast hard drive. For the image acquisition, a specific software is developed in Visual Basic 12. A second software developed in C language is used for image processing. Thanks to the «Matrox MIL 10» library, nearly 50 parameters are computed based on each image. These parameters then are used to classify images by applying existing classification tools, like «Plankton Identifier» (Delphi and Tanagra environments) or «ZooImage» (R environment).

4.2.10.4 *Underwater Vision Profiler UVP5 (Hydroptic)*

The UVP5 images large plankton (equivalent spherical diameter, ESD >600 µm) (Picheral et al. 2008) usually metazoans but also large unicellular organisms or colonies of those (diatom mats, rhizaria and prokaryotes such as cyanobacteria colonies) (Biard et al. 2016; Guidi et al. 2012). The UVP5 sampling volume varies from 0.5 to 1 L and images are recorded every 5 to 20 cm along vertical profiles, leading to an observed volume of 1 m3 for a 100 m depth profile. Mounted on a CTD rosette frame, the UVP5 starts recording at the depth of a few meters, eventually leading to the underestimation in the quantification of objects just beneath the sea surface. Images produced by the UVP5 are extracted using the ZooProcess software. Image identification is possible for objects larger than 600 µm (total number of objects is approx. 1 million as shown during the Baltic Sea cruise). A computer-assisted method is used to classify all organisms with a Random Forest classification. All images are checked using the Ecotaxa web application[17] by experts to discriminate plankton (including cyanobacteria colonies) from other plankton and detritus. Differences in shapes and grey level assessment are used to distinguish between species.

4.2.10.5 *CytoSense and CytoSub instruments (CytoBuoy)*

Each particle intercepts a laser beam and the generated pulse shapes of optical properties (two scatters, up to three fluorescences) induced by the particle are recorded. Pulse shapes recording allow chains forming cells to be recorded. Increase in laser power and optimization of sheath cleaning enable the resolution of Prochlorococcus. An image-in flow device records pictures of preselected groups of cells, resolving cells at its best above 20 µm but also is capable to collect pictures of 2 µm beads (with low resolution). Particles are recorded above the defined threshold (scatter or fluorescence) and phytoplankton cells are separated from non-photosynthetic particles due to their red autofluorescence properties. The CytoSense sensors can be installed on ships of opportunity and scientific vessels, whereas the submersible version (CytoSub) can be fitted to fixed stations and buoys. They can run samples from a subsampling dedicated system isolating sea water from a continuous flow of pumped sea water. Obtained results are analysed using dedicated software for manual and automatic clustering. For manual clustering, each particle is represented on two dimensional cytograms. Availability of different cytograms makes the manual clustering possible. CytoBuoy Company built its own manual clustering software (CytoClus). However, today, CytoClus does not process images. This is why automated methods of images processing for size calibration, species recognition in micro phytoplankton, and cells counting in colonies are currently under development. These new functionalities will be integrated to the Rclus Tool package (R environment) developed by the LISIC laboratory in collaboration with CNRS LOG (ULCO).

[17] http://ecotaxa.obs-vlfr.fr/

4.3 Specific matters and complications of sea measurements

4.3.1 Hydrosphere vs marine measurements

Seawater is chemically different to inland water. That means that the instrumentation for measurements of sea and inland water parameters are often quite different either in sensing principles or in the range of use. The European experience of implementing the Water Framework Directive nearly two decades ago[18] led to better definition of the tools needed for characterization of "soft water", "transition water" and "coastal water".

The seawater matrix includes ions interacting with dissolved chemical components. Most chemical sensor principles and/or ranges are different in seawater. Thus, most chemical analysers used in rivers have to be either discarded or significantly redesigned for marine application. Only few manufacturers of freshwater instrumentation (physical, chemical or biological parameters) are addressing the market of marine measurements too.

4.3.2 Development of technologies for marine measurements

The technological levels of marine instrumentation R&D actors, both from private or research sectors, allow to envisage the adaptation of advanced sensing techniques to sea surface, underwater and even large depth constraints. This opens oceanography to new perspectives of sensing but with a higher cost. The TRL 7 or 8 of on-shore instruments will provide a technology with a readiness level of TRL 5 or 6 on the marine scale.

4.3.3 Biofouling protection for underwater instrumentation[19]

Oceans environmental monitoring and seafloor exploitation needs in situ sensors and optical devices (cameras, lights) in various locations and on various carriers in order to initiate and to calibrate environmental models or to perform the supervision of underwater industrial processes. To be economically operational, these systems must be equipped with a biofouling protection of sensors and optical devices used in situ. Indeed, biofouling can modify the transducing interfaces of the sensors and cause unacceptable bias on the measurements performed by the in situ monitoring system in less than 15 days. In the same way biofouling can decrease the optical properties of windows and thus alter the lighting and the quality of the images recorded by the cameras.

[18] http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm
[19] https://doi.org/10.1109/OCEANSE.2017.8084636

FIGURE 5 FOULING ON THE SENSORS IS THE MAIN CONSTRAINT FOR IN SITU OCEAN AUTONOMOUS MEASUREMENTS

It is acknowledged that a coastal monitoring system must be able to run without maintenance for 3 months in order for the system to be economically acceptable. For deep-sea observatories, actual maintenance interval for the Canadian Venus system is 6 months. ESONET, the European network of excellence for deep-sea observatories defines maintenance interval recommendation from 12 up to 36 months.

Protection strategies adopted by oceanographic sensors manufacturers rely on two methods. One method is classified as active and is generally based on wipers. This technique has a significant weakness, as after one month in seawater the material used for the wiper is getting ineffective due to its deterioration. Moreover, the design of the sensor-transducing interface must be adapted to allow the wiper to work properly, which is sometimes impossible. In another, passive method, the surfaces that need to be protected are covered with copper. This technique works quite well when a closed cell can be arranged around the protected area. However, in some investigations, such as dissolved oxygen monitoring, copper ions can disrupt the measurement process and cause bias on the performed measurements. Recently, the Canadian company AML has proposed a UV irradiation biofouling protection scheme for sensors. The system, called UV•Xchange, is based on UV Bulbs that irradiate the area to be protected. In some situations, where energy is not too much of a concern, this solution seems to be a good choice.

Another way to prevent biofouling of in situ oceanographic monitoring systems, is based on seawater electrolysis performed in order to produce hypochlorous acid. This method has been successfully applied in various marine monitoring applications for autonomous and transportable systems like nke Marine Electronics Smatch multiparameter probes, or seafloor observatories like Momar, Venus, Neptune, or Ifremer Tempo module where the sensors are directly immersed in seawater without any proxies like pumping devices. For optical sensors, electrolysis principle can be applied on a “transparent” conductive coating of the optical window. This robust transparent conductive layer is polarized in order to generate a very low quantity of hypochlorous acid on the entire surface of the optical port. This technic offers a high level of robustness (no moving parts), a high level of protection efficiency (the whole optical window is protected) and consumes very low energy. Polarization can be turned on and off in order to control the generation of biocide. This specific biofouling protection technique can be coupled to an ALVIM Srl biofilm sensor in order to apply the active biofouling protection only when fouling pressure is indeed sensed by the biofilm sensor. This allows optimization of sensor functioning in terms of biocide production and energy consumption.

4.3.4 Platform/instrument/sensor

Platform innovation is one of the drivers of increasing capabilities of marine systems. It is a structuring point for the constitution of several RIs (EUROARGO - profiling floats, GROOM - gliders, EMSO - sea floor +water column fixed point observatories, EuroFLEETS - oceanographic vessels). Each RI needs to mobilize the providers to cope with its own specifications and at the same time to benefit from inter RI cooperation. In this respect, manufacturers of sensors have to adapt to niche markets with high commercial/manufacturing cost ratio. That is why there is a market tendency for the instruments to include several sensors (multiprobe instruments since the 90s, EMSO Generic Instrumentation Module in 2017 EGIM).

FIGURE 6 MULTIPARAMETER SYSTEM FOR SEA MEASUREMENTS.

AUVs and Gliders (marine drones) use the aircraft concept of “pay load” to offer an interface to any sensor of the client. Research Infrastructures need a careful metrology approach (WP2 ENVRIPLUS) and an easy plug and play sensor interface policy (see WP1 Task 4 in ENVRIPLUS) to deal with this industrial structuration.

4.4 Marine technologies of the future

4.4.1 Optics

Throughout the world, a significant number of research institutions and commercial entities are engaged in the research, development and manufacturing of optical instrumentation for oceanographic research and observations. Two broad trends encompass many of the advances seen in today's technologies. First, many instruments have emerged from studies of traditional "optical oceanography", and provide measurements or products such as determination of ocean colour, scattering, absorption, attenuation, and particle concentrations. More advanced approaches are currently developed on these fundamental observations to provide data about biological and chemical oceanographic related parameters such as nutrient concentrations, standing stock, productivity, particle size and composition, and taxonomic identification of organisms. (Moore 2009).

Scientists and technologists are now engaged in developments of inversion methods to obtain biogeochemical and physical products from ocean optical measurements. The devices for the measurements, are represented by spectral radiometers (radiance and irradiance), spectral backscattering, spectral absorption, and spectral beam attenuation meters. The diversity of products demonstrates the real potential of optical measurements in water. Absorption meters determine nitrate concentration and identify harmful algal bloom species. Spectral fluorometers yield valuable information on phytoplankton species identification and dissolved organic chemistry. Devices that characterize the Volume Scattering Function are used to determine particle size distribution and classification. Excitation – relaxation fluorometers provide biological productivity parameters. Advances in core photonics and materials sciences as well as embedded computing make a new realm of options available in applying optical techniques for identification of materials in the ocean. In-water flow cytometers are now capable of conducting automated and continuous sampling for the long periods (up to months) to identify concentrations of multiple phytoplankton and zooplankton species. Complex spectral excitation-emission and time-resolved fluorescence are getting better in identifying volatile hydrocarbons. Laser Raman spectroscopy, and laser- induced breakdown spectroscopy (LIBS) strive to identify the molecular and elemental composition of solids, liquids and gases in situ. Membranes and analysers coupled with optical sensors can provide information on pH, nutrients, dissolved gases, and metal concentrations. All these tools will result in significant advances in observing ocean chemistry, biology, and geology.

Optical techniques have also demonstrated the ability to determine physical parameters such as temperature, density, and turbulence, and to measure directly the absorption of solar photons that contribute to the local heating of the ocean and the development of thermal structure and dynamics. While it is unlikely that all these efforts will result in commercially viable technologies, they collectively manifest as a significant crosscutting driver in modern observational ocean sciences.

For those sensors that are already commercialized there are still significant issues in integrating them into the current ocean monitoring infrastructure. For turbidity sensors and single channel fluorometers, this is a relatively straightforward process. However, as the sensors become more complex so does the problem of integration. Beyond the basic challenges of coupling sensors into platforms and systems, there are other issues, such as production of data products appropriate for models, examination with other sampling methods and tools, and development of general usage protocols and expectations for accuracy, stability and other qualities that make a sensor widely useful.

The new generation optical sensors are now beginning to address the wide diversity of properties involved in understanding ecosystems. Spectrophotometry coupled with reaction chemistry and semi- permeable membranes, along with direct absorption processes have now allowed a direct observational link among biology, physics and chemistry.

With optical techniques, one has the potential to estimate everything from temperature (Hickman, 1991; Fry, 2002) to salinity to dissolved gases concentrations and a long list of other constituents in water. In addition, optical methods are optimal in all cases. In general, sensors based on optical techniques are becoming increasingly significant in ocean monitoring and research, and their further development is highly needed within a growing base of applications.

4.4.2 Acoustics

4.4.2.1 *Passive acoustics*

Listening to underwater sound has been restricted to military usage during a long time. The overall ocean coverage endeavoured by the CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organization –www.ctbto.org) is now implemented and the data is open after a given delay. This opens the way to cooperation with Research Infrastructures such as EMSO ERIC. Sensor technologies are now quite similar between research and security fields.

Noise pollution in particular has become a subject of interest, in relation to not only high intensity anthropogenic sounds (naval sonar, pile driving, seismic reflection, etc.) that can cause direct harm to ocean species, but also with respect to the continuous sounds produced by e.g. shipping traffic or drilling platforms that can mask biological signals. Due to an increase in these activities over the last century, the ambient sound levels especially at low frequencies have been slowly increasing, raising environmental concerns. Marine mammals and many fish species depend on sound signals, and masking can reduce their exploration or communication range prompting behavioural changes or driving animals away from their habitat. Of special interest is the European Marine Strategy Framework Directive - Good Environmental Status[20]

[20] http://ec.europa.eu/environment/marine/pdf/MSFD_reportTSG_Noise.pdf

that requires the monitoring of anthropogenic noise. There are around 125 known species of marine mammals in the world, comprising 84 cetacean species (whales, dolphins and porpoises), 33 species of Pinnipeds (seals and sea lions), five Sirenians (Manatees, Dugongs and Sea Cow), plus otters and polar bears (three species). These species produce a diverse array of sounds, ranging from the low frequency (10 – 15 Hz, approx. 15s duration) moans of blue whales to ultrasonic (130 kHz, approx. 100 µs duration) echolocations clicks of porpoises and some dolphin species. Between these extreme cases, cetacean calls can be found in all parts of the spectrum. Some species, such as the harbour porpoise and most beaked whales, appear to produce highly stereotyped clicks with little variation between individuals, other species, such as blue whales have stereotyped but region specific calls, with different populations and sub species producing different call types. Other species produce highly variable call types and demonstrate strong evidence of social learning, changing the calls they make over periods of months and years. The classic example of this behaviour is humpback whales, which exchange and learn different songs during their annual migratory cycles. It should also be noted that several species have not yet been recorded and for some species, recordings come from a small number of individuals and may not be representative of the species as a whole. It is not uncommon to hear sounds during surveys which are clearly marine mammal like, but cannot be assigned to any species.

The energy constraint and the volume of data are limitations for long time monitoring. These limitations are addressed by implementing duty cycles, data compression and tentative in-situ data treatment. The Research Infrastructures such as JERICO, GROOM and EMSO are leading actors in implementing new generations of hydrophones and hydrophone interfaces to monitor both noise and marine mammal sounds.

TABLE 57 PROPOSED HYDROPHONE REQUIREMENTS FOR NOISE AND BIOACOUSTICS IN THE OPEN-OCEAN – FOR FIXO3/EMSO – ERIC DELORY – PLOCAN

Resolution	Dynamic Range (DR)	Directivity	Accuracy	Sampling frequency	Special requirements	Other1	Other2
16 to 24 bits, with different gains to fit DR	<SS0; 50 to 180dB re 1µPa	Omni-Directional	+/-3dB	100kSps	Embedded noise and bioacoustics statistics	Store on detection, Solid-state storage	Low power for stand-alone systems *ESONET Label

4.4.2.2 ***Active acoustics***

4.4.2.2.1 Fish abundance and biodiversity

The management of fish stocks is a key parameter of GEO (Global Environmental Outlook). Avoiding extinction of large stocks is not sufficient aim today and the research infrastructure mission is to study and implement criteria for the ecosystemic operation of fisheries. Scientific fishing with oceanographic vessels is used as the basis for the stock estimation and establishment of fish and zoo-plancton abundance time series. The techniques are now less and less intrusive and based on echosounding from acoustic sounders on the ship hulls. Fixed-point observatories are now able to carry such echosounders. Data is treated with the help of echointegration algorithms limiting the dataflow of this acoustic imagery.

4.4.2.2.2 Bubbles and fluid flares and seeps

Fluid seeps are a major unknown of the interaction between earth crust and oceans. The order of magnitude of the fluxes is still a matter of research. While the mapping of the seepage areas from the seabed is devoted to oceanographic vessels, innovative imagery sensors are under test to investigate the variation in time of those fluid escapes.

4.4.2.2.3 Current meters

Ocean current direction and velocity are Essential Ocean Variables. They are often measured in the vicinity of other sensors to understand their variations but the need is too measure along large ranges thanks to Acoustic Doppler Current Profilers (ADCP). ADCPs are now a mature technology but adaptations to long term observatories is a major issue.

4.4.2.2.4 Industrial aspects

Some civil sector institutes (Bergen University, Scripps, Woods Hole, Ifremer) interact closely with the industry of acoustic measurements in order to guide the development of innovative technologies, access the new improved software products and help to formulate the needs of research community. Similarly to this approach, recent projects such as NeXOS, ESONET and FixO3 showed the way to influence the development of new marine technologies through European Research Infrastructure communities.

4.4.3 Electrochemical measurements / ISFETs

The use of micro sensors for in situ monitoring of environmental parameters is gaining interest due to their advantages over conventional sensors. (Jimenez-Jorquera et al 2010; Denuault 2009) A few common electrochemical techniques successfully operate outside the labs and have acquired such an importance that several key environmental parameters would be hard to measure differently. In aquatic systems oxidation-reduction potentials (ORP) and pH are measured by potentiometry (measurement of a potential), dissolved oxygen (DO) is measured by amperometry (measurement of a current), trace metals and speciation are measured by voltammetry (measurement of currents over a range of potentials) while conductivity and therefore salinity are measured by impedimetry (measurement of an electrical impedance). Over the last twenty five years voltammetry has been successfully used with microelectrodes to determine the concentration and speciation of some redox species in situ (Luther et al., 1999). Microelectrodes have also been employed as amperometric sensors to control mass transport and alleviate the need for membranes (Prien et al., 2001, 2005; Sosna et al., 2007, 2008).

Microsensors based on semiconductor technology offer additional advantages such as small size, robustness, low output impedance and rapid response. These characteristics allow integration of circuitry and multiple sensors in the same substrate and accordingly they can be implemented in compact probes for particular applications e.g., in situ monitoring and/or on-line measurements. In the field of micro sensors for environmental applications, Ion Selective Field Effect Transistors (ISFETs) is of special interest. They are particularly helpful for measuring pH and various ions in small volumes and they can be integrated in compact flow cells for continuous measurements. The application of ISFET based sensors in different areas of analytical chemistry has advanced new technological developments and the implementation of sensors in more automated systems. The main example is their application in continuous flow systems such as Flow Injection Analysis (FIA) and Sequential Injection Analysis (SIA) with their key features such as miniaturization of the flow cell, resulting low reagent consumption and fast analysis throughput.

Application of ISFET-based sensors to ocean monitoring, where miniaturization is not critical (sample is almost unlimited) appears to be of limited interest as a first option. However, there are very challenging analytical applications in this field. For example multiparameter detection probes, integrating various sensors on demand for in situ measurements are highly required for marine water monitoring. It is in this context where ISFETs offer a high added value due to their small size, robustness and low power consumption. Besides, ISFETs are ideal for integration in (semi)automated flow systems (i.e., FIA, SIA) or in miniaturized analytical systems (i.e., µTAS, LoC) providing high throughput analysis, low reagent consumption and automatic sampling conditioning and calibration. Such benefits would be absolutely unachievable when working with conventional electrodes. Sensors employing ISFETs consume low power, have rapid response times, and do not require moving parts. ISFETs technology is capable of long-term deployments with little drift only (Gray et al. 2011; Hofmann et al. 2011). One commercial product based on such technology is the SEA-BIRD Scientific SeaFET™ Ocean pH sensor that is an ion selective field effect transistor (ISFET) type sensor for accurate long-term pH measurements in salty water.

4.4.4 Wet chemistry vs. compact sensors

It is possible to transfer some of the reference analytical methods used in the lab to automated in-situ analysers. It requires certain efforts to adapt the laboratory-based method, electronics, mechanical integration and optics for the marine-based measurements. The main drawback in case of utilization of chemical reagents underwater or on buoys comes from the need to avoid their release in the natural environment. Flow injection analysis FIA is widely used for the automation of wet chemical techniques for the analysis of, e.g., nutrients, iron, manganese, sulphur-compounds, and carbonate system (pH, CO2, DIC, alkalinity). The seawater sample is pumped and mixed with specific reagents and the reaction product is analysed by colorimetry, fluorescence, chemiluminescence or electrochemistry. Some instruments can also perform in situ preconcentration of analytes as well as automatic calibration.

4.4.4.1 ***Industrial aspects***

FIA or similar flow techniques (Segmented Flux Analysers - SFA, Reverse Flow Analysis - RFIA) are used on boards of research vessels in the laboratory instruments from companies such as Technicon, SEAL Analytical, Bran Luebbe. Companies such as AMS Alliance and Systea propose rugged version of instruments for nutrients measurements. Systea shallow water immersed version called WIZ performs nitrate and nitrite analysis. Few institutes such as Ifremer in France and MBARI in California are able to perform wet chemistry analysis for many analytes down to 4000 m water depth or more. In shallow water, in-situ measurement of silicate and ammonia has been performed by prototypes. Some companies market dedicated instruments are using flow injection for the measurements of one specific parameter. The pCO_2 measurements of nke Marine Electronics Carioca buoy or of SUNBURST Sensors SAMI are performed by flow analysis including gas equilibrium. Some of the promising automated carbonate system measurements on board ferry-boxes are also using flow analysis. Lab on a chip (LOC) technologies are available in research labs for the analysis of nutrients, carbonate system compounds, and trace metals. Current developments include applications for organic speciation, measurements of nucleic acids (RNA, DNA, including in situ PCR), ATP, and microflow-cytometry (microbial abundance, biomass) to characterize particles. The market product based on these techniques is not available yet. More compact sensors based on optical or electrochemical properties are currently under development. The first of them to be widely used is the oxygen optode by Aanderaa. The story of its development and the heavy work of validation in all ocean conditions were presented during the ENVRIplus Grenoble meeting in 2017. The nitrate direct measuring by optical method in the sea is now validated for SUNA V2. Other sensors are expected to reach TRL=7 for pH, pCO_2 and silicate measurements.

4.4.5 Spectrometry in-situ

4.4.5.1 ***Raman spectrometry (RS)***

RS is an optical technique that identifies and quantifies molecules based on specific vibrational spectra that are emitted upon excitation with lasers. So far, only very few in situ Raman spectrometers for deep sea applications have been developed. RS can be used for identification of gases, solids and solutes including methane, minerals, hydrates, dissolved hydrocarbons, sulphates etc. Surface Enhanced Raman Scattering (SERS) provides high sensitivity also for dissolved compounds and may resolve concentrations in the ppb range.

The world leading company in Raman spectrometry, Horiba Jobin Yvon, works with Ifremer towards defining industrial versions of deep sea Ifremer prototypes.

4.4.5.2 ***Mass spectrometry***

For in situ Mass Spectrometry measurements, the analyte passes from the seawater through a membrane to the evacuated instrument body. A limitation is that water molecules can also cross the membrane, which affects the quality of the vacuum and the sensitivity of the analysis. Compounds that are typically analysed include methane and other small organic compounds, sulphide, carbon dioxide, helium, nitrogen, argon, and oxygen. In-situ Mass Spectrometers are not available on the market. Several prototypes have been produced for deep sea use by US research institutes and SME partners.

4.5 Market overview

Marine sensors are widely used for the broad range of activities such as mapping the seafloor, underwater communications, locating underwater objects or observing underwater animals and plants. These activities can be carried out by government, industries or scientific research community and serve for legal, R&D, or monitoring applications across market segments. Sensor requirements are mainly defined by the purpose of their application. In that sense, industrial applications require sensors with increased robustness, R&D applications require improved accuracy and stability, while legal applications would determine prices of sensors.

Due to the constant new developments of sensors and creation of new markets, the entire market of marine sensors is far from reaching the balance point and characterized with the significant potential of growth, increase of revenues and flexibility of business models. European sensors and instrumentation industry is, probably, the strongest sensor industry in the world, thanks to the reach traditions of environmental protection and strong environmental legislation in Europe. However, European sensors providers struggle to enter North American market due to its strong innovation potential, while same difficulties are expected in Asian and South-American regions due to the lower prices of sensors there.

As in other domains, there are four stakeholder groups, determining the characteristics of sensors. These are sensor manufacturers, developers, service providers and end users. The role of these groups in determination of sensors characteristics will of course depend on their interaction and cooperation, which in turn will be determined by market segment maturity, purpose of activity, size of subsequent market and other special conditions, determined by local national markets (Gille et. al 2014).

4.5.1 Countries Interested in the sensors for sea measurements, export and import

The numbers of world's exports of navigational and survey instruments for marine applications reflect the strong potential of the market. Thus from 2001 to 2011 the exports grew from 7.5$ billion to 16$ billion. Out of these 16$ billion, 10$ billion were accounted for surveying, hydrographic, oceanographic, hydrological, meteorological or geophysical instruments, while other 5.8$ were accounted for navigational instruments. In 2011, the export of USA represented 26.4% of total world's exports of surveying instruments, followed by the UK (13.4%), France (9.5%), Germany (8.3%) and China (6.3%). Among the top 20 exporters, Germany, China and Canada increased their shear in the world's market by 6%, 3% and 3% respectively, while USA and the UK lost their shares 10% and 7% respectively.

As for the imports, USA was also the largest importer of navigational and survey instruments, accounting for 17.4% of the world import in 2011. USA export was followed by the UK (10.8%), Germany (7.0%) m Canada (6.7%) and China (6.6%). Among the top 20 importers, markets of China and Singapore had expanded the most by 2011. There shares in world import increased by 2.2% and 1.4% respectively. At the same time market, shares of the UK and France decreased by 4.6% and 1.3% respectively by 2011.

Even though the above-mentioned figures demonstrate the predominance of western countries on the market of marine sensors, there are several emerging markets showing tremendous growth during last years. Thus, in 2011, Colombia showed and explosive import growth of 452%, followed by Indonesia (279%), Russia (245%) and Brazil (158%). Brazil is expected to become a strong importer of underwater acoustic technologies due to the rapid development of offshore oil industry. (Lee et al. 2012).

4.5.2 Countries seen as growing markets for the marine sensors

Needless to say that all countries shall be interested in monitoring the environmental conditions and climate change in the marine domain, because all countries will be influenced by the changes happening with the oceans. However, we would like to point several groups of countries, which, as we believe, will become rapidly growing markets for the marine sensors due to their geographical location and traditional sources of income.

Northern countries: Norway, Sweden, Denmark, Canada, USA, Russia. In these northern countries with the large coastal area, rise of sea temperature will cause changes in availability of sea resources and bursts of GHG from seafloor. In addition, many sea regions are getting free of ice, which makes possible for the northern countries to explore underwater resources and establish new navigation routes.

Countries traditionally relying on sea resources, coastal and island states: Norway, Iceland, Japan, developing island states. Change of seawater parameters in these countries will strike their economies and decrease the quality of life for large groups of population.

Countries, whose wellbeing largely depends on the sea level: Netherlands, island/archipelago countries, Indonesia, Singapore. Rising of sea level will cause flooding of entire territories of these countries or their significant parts and will make the population to relocate or to move to different countries. In addition, these countries need to monitor the natural disasters, such as tsunami that are often happening in the region and expected to happen even more due to the climate change.

4.5.3 Recent events, conferences, documents, which promote development of technology for marine domain

At World level, the Blue economy concept is supported by company leaders for instance through the World Ocean Council. The WOC also works on ensuring that Corporate Ocean Responsibility is at the core of new business models developed by the maritime industry and fostering the financial support of private and public investors to ocean sustainability projects. Through its network, it aims at creating fruitful collaboration between the maritime industry and investors. Such institutions are at the forefront of low-carbon investments in innovation and technologies to mitigate and adapt to climate change consequences.

A very efficient tool for the European community of ocean and coastal instrumentation and intervention is the Oceanology International (OI) Conference and Show in London taking place every even year in March. A mirror conference is organized in the Far East on odd years. OI is the opportunity to present the products on the market and innovative developments. Marine Domain RIs are very active and organize sessions on relations with industry, market, standardization issues.

5 Solid earth measurements

5.1 Why measurements of Solid Earth parameters are important

Measurements in the solid Earth sciences concern everything related to the composition, structure and dynamics of the interior of our planet, from the shallow subsurface to the deep interior. Scientific goals behind these measurements range from the general quest to understand how our planet works (e.g. planet formation, geo-dynamo) through a better grasp of geo-hazards (volcanoes, earthquakes) and geo-resources (mineral, ore, and carbon deposits) to the modeling and monitoring of human interaction with the subsurface (resource exploitation, energy production, carbon capture & storage, waste repositories). Solid Earth research covers a wide variety of specialized disciplines (Geology, Seismology, Volcanology, Geomagnetism, Geodesy, Geodynamics) as well as multi-disciplinary application fields (monitoring tectonically active structures or anthropogenic hazards, geo-energy research, analytical laboratories, numerical modelling). Relevant measurements in Solid Earth sciences cover standard and non-standard laboratory analysis (chemistry, spectroscopy, imaging from gamma rays to infrared, specialized material properties and behaviour studies), ground motion and deformation on all scales (temporal and spatial), electromagnetic field properties, and atmospheric composition.

While in the past the various disciplines often remained within their own “bubble” of measurement data and physical parameters, in particular the challenges to better understand geo-hazard and geo-resource issues, with their direct impact on society, require more and more cross- and multidisciplinary data generation and processing, together will all the modern data handling and curation issues.

5.2 Existing technologies

The range of technologies employed in solid Earth matches the width of the domains, diversity of measurements and parameters. A lot of laboratory based measurements rely on standard instrumentation where the development drive comes mainly from other, economically much more relevant disciplines (material sciences, biomedical, etc.), and specialized instrumentation is often custom built in collaboration between academic researchers and expert companies, often with close established ties to particular research groups, or directly by specialized workshops attached to the academic institutions. Rather randomly selected examples are e.g. the BRAVA rock deformation apparatus (Colettini et al. 2014), or the SHIVA sample shearing apparatus (Di Toro et al. 2010) developed by Italian research groups. Depending on purchasing regulations, public tenders following WTO regulations may also be opened, based on specific instrumentation design requirements, in principle offering any potential provider the chance to bid. One recent example is the call for the development of an integrated rock testing system 'LabQuake' published by ETH Zürich[21].

In other fields (e.g. seismological or geodetic instrumentation), measurement technology and instrumentation development is mainly driven by big industry (resource exploration, surveying, construction) or even the military sector. Thus high sensitivity seismic recording instrumentation development was mainly pushed in the 1950s to 1970s by nuclear explosion monitoring needs, while implementation and installation of satellite-based positioning systems (such as GPS) was funded by military to cover their precision navigation needs. For academic use, specific adaptations may then be required, sometimes leading to niche markets with a small number of specialized companies (usually SMEs, but sometimes merged into larger industrial companies or holdings). Important companies in seismological instrumentation in Europe are e.g. Streckeisen of Switzerland (no web presence, sales through Kinemetrics), Guralp[22] and EarthData[23] of the UK, or Lennartz of Germany[24], while global market leaders are located in the U.S. and Canada (Kinemetrics[25], Nanometrics[26], RefTek[27]). For geodetic (GNSS) instruments the main providers globally are Leica[28] and Trimble[29]. UNAVCO maintains a website listing GNSS receivers and their providers in use by them[30].

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[21] www.simap.ch, project ID 167804, published 02-Mar-2018
[22] www.guralp.com
[23] www.earthdata.co.uk
[24] www.lennartz-electronic.de
[25] www.kinemetrics.com
[26] www.nanometrics.com
[27] www.reftek.com
[28] leica-geosystems.com
[29] geospatial.trimble.com
[30] http://kb.unavco.org/kb/article/unavco-resources-gnss-receivers-434.html

Cefalo et al. (2018) present a selection of papers from a 2016 workshop on New Advanced GNSS and 3D Spatial Techniques - Applications to Civil and Environmental Engineering, Geophysics, Architecture, Archaeology and Cultural Heritage[31] that comprehensively describe current scientific and corresponding instrumentation challenges in the field.

Probably the largest markets (in terms of economic volume) in solid Earth sciences are seismological and geodetic (GNSS) instrumentation (including not only sensors but also data loggers / digitizers), where the academic sector and the relevant governmental agencies create a demand of hundreds to (tens of) thousands units of instruments.

Ancillary equipment, e.g. power supply systems or communication devices, is as necessary in solid Earth sciences as in other sectors covered in this document, and the issues mentioned there all apply.

5.3 Emerging technologies

One kind of new technology development is driven by new scientific insights (or ideas) that lead to a desire to measure new physical parameters, or established parameters under new conditions. This is e.g. the case for laboratory instruments allowing higher/ lower temperature, pressure, electromagnetic fields, or better precision control of applied and measured conditions. The economic impact of such developments is usually rather limited, as instrumentation is produced in prototypes or very small numbers of units, even though a single instrument may cost up to a (few) millions Eur.

Economically more interesting, in particular for SMEs, may be scientific developments that require larger number of instruments, corresponding data acquisition and transmission technology. In solid Earth sciences today, relevant fields would be (incomplete list):

- Large-N seismological studies, where hundreds to thousands of low- to mid-performance instruments (nodal sensors or nodes) are used in dense deployments (potentially expandable to geodetic / GNSS and perhaps even electromagnetic measurements);
- The emergence of 'rotational seismology' instruments that allow high-precision and -resolution measurements of ground rotations in all 3 dimensions, basically leading to a new family of seismological sensors (various developments under way, first commercial products e.g. from iXblue (France), www.blueseis.com);
- The increasing potential of instruments for the oceanic applications, both with stationary observatories and roaming instruments (floats, gliders), mainly focusing on seismo-acoustic measurements. Recent flagship projects worth mentioning here are the free-floating Mermaids[32] (commercially produced by Osean[33] France),) or the

[31]https://gnss.dia.units.it
32https://www.geoazur.fr/GLOBALSEIS/Mermaid.html
33http://www.osean.fr/pdf/osean_oceanographic_profiler_V1.pdf

ocean bottom observatory developed by Scripps, UCSD (USA) that combines an ocean bottom unit with a wave glider (Berger et al. 2016).

All these new developments are driven by the scientific need to gather data either at more dense spacing or to provide measurements in previously not covered geographic areas or to measure previously unattainable quantities (respectively measure those quantities at higher resolution or with higher accuracy).

Of particular importance for at least some of these fields are developments in optical and opto-mechanical measurement systems (e.g. fiber-optic gyros, opto-mechanical strain- and seismometers) that allow the development of instruments with particular low energy consumption, high temperature tolerance, or provide long signal transmission capabilities.

5.4 Market overview

Comprehensive market overviews / assessments that cover the whole or even relevant parts of the Solid Earth sciences instrumentation do not exist. While on the governmental agency side, certainly the instrumentation density is higher in richer countries and in those that have a higher exposure to geo-hazards (volcanoes, earthquakes), active research groups in all Solid Earth sectors exist in all countries in Europe. The funding available for investments in instrumentation is, however, highly variable and depends both on the overall funding for geosciences (or geo-monitoring) in a specific country as well as on specific projects and initiatives, e.g. to promote further understanding and development of geo-energy, or to implement specific geo-hazard monitoring infrastructures.

With respect to recent or expected legislation, the monitoring of anthropogenic hazards, i.e. the potential hazardous impact of subsurface industrial infrastructures (deep geothermal energy, CO_2 storage, fracking-based exploration, or nuclear waste repositories) may have a significant potential to generate new instrumentation requirements and associated funding, but it is too early to put any confidence or even number to that.

6 New platforms for environmental measurements. Unmanned aircraft and vehicles (UAVs), Autonomous underwater and surface vehicles (AUV, ASV) and wireless sensor networks (WSNs)

6.1 Overview

Large scale monitoring of climate change in four domains (atmosphere, biosphere, sea and solid earth) appears to be a non-trivial task that requires platforms which can carry a large number of various sensors, perform observations in remote areas during long periods of time, provide necessary computational resources for data gathering and management and to be relatively independent of access to energy. Currently, wireless sensor networks (WSNs) and

Unmanned Aerial Vehicles (UAVs) correspond well to these requirements and, thus, represent the best alternative to monitor different parameters of climate change.

6.2 Systems for atmospheric measurements

Recent technological improvements in gas sensors, electronics, communication and power supply technologies made possible the development of WSNs and UAVs equipped with gas sensing systems. WSNs are essential to monitor large areas, such as cities, roads and forests. Their ability to communicate via nodes or multihop networks can be used to map and track the gas plumes to identify its source. Currently they are widely used in commercial applications[34] to monitor GHG emissions from anthropogenic sources, such as CO_2 (Stocker et al. 2014), NO_2 (Cape et al. 2004) and CH_4 (Sihota et al. 2013). Suggestions has been made to monitor other gases such as NH_3 and N_2O resulting from fertilizer use (Jung et al., 2008; Ruiz-Garcia et al., 2009). The most popular gas sensing technology used in WSNs for the environmental monitoring is based upon metal oxide resistive sensors. Such sensors have developed quite rapidly together with the development of nanotechnologies, which allow manufacturing of smaller, more sensitive sensors (Comini 2013), performing in the quantum regime.

UAVs play an important role in gas sensing, especially in the remote areas or areas with limited accessibility. For example, drones are widely used to perform measurements of volcanic gases. Thus, McGonigle et al. (2008) carried out measurements of volcanic gases at la Fossa volcano crater in Italy. They used the UAV helicopter capable of 12 minutes flight time and equipped with the ultraviolet and infrared spectrometers for SO_2 and CO_2 measurements. Khan et al. 2012 developed a greenhouse gas analyser for the installation on the helicopter UAV, using a vertical cavity surface emitting laser (VCSEL) for these purposes. Watai et al. (2005) mounted NDIR sensing system on UAV to monitor atmospheric CO_2. Authors designed economic and accurate gas sensor and performed several flight tests with the payload of 3.5 kg and operation time of no longer than 1 hour. While WSNs are usually equipped with MOX sensors as was discussed above, UAV mostly apply optical sensing devices. Malaver, Motta et al. (2015) performed analysis of applications of both MOX and optical devices to integrate both sensing technologies at both platforms and reduce the costs. The table presented in this study is shown below.

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[34]http://www.figaro.co.jp/en/product/entry/tgs2444.html

TABLE 58 ADVANTAGES AND DISADVANTAGES OF MOX AND OPTICAL SENSORS FOR GHG MEASUREMENTS ACCORDING TO MALAVER, MOTTA ET AL. (2015)

Category	MOX sensors		Optical Sensing Techniques	
	Advantages	Disadvantages	Advantages	Disadvantages
Aerial missions	Low energy consumption and light weight	Slow sensor response hinder aerial applications	Tested and proved	Energy consumption and weight may limit flight endurance
Ground missions	Tested and proved	Cross reference to different gases and sensitive to humidity	High sampling frequency, high specificity to target gas	No data/sensor is too expensive to be left unattended
Continuous release mission	Low energy consumption and light weight, covers wide range of gasses	No data	High sampling frequency, high specificity to target gas	Energy consumption and weight may limit flight endurance
Instantaneous release	Low energy consumption and light weight, covers wide range of gasses	Low sensor response time	High sampling frequency, high specificity to target gas	Energy consumption and weight may limit flight endurance
Computational resources	Few output variables. Some variables remain over large range of gases	No data	No data	The number of output variables to measure depends on the optical technique and target gas
Resolution	Regular resistive sensors achieve ppm gases	Few sensors achieve ppb resolution	Several techniques achieve ppm and ppb resolution	No data
Cost position in market cost	Low	None	Low for NDIR modules	Medium too high for complex systems

UAVs or drones are relatively new measurement platforms that have been used in most of the countries with strong climate research programs. Their great advantage is that they can be used in the conditions where presence of human is not desirable or not possible. These platforms are represented by the machines of diverse constructions and capabilities. Based on the ability to perform the measurements, UAV can be divided into following groups:

- LALE (Long Altitude Long Endurance)
- MALE (Medium Altitude Long Endurance)
- HALE (High Altitude Long Endurance)
- LAME (Low Altitude Medium Endurance)

The weight of drones can vary from 500 g to nearly 15 tons, while the time of autonomous activity varies from several minutes to several days. The price of drones may vary from several hundred euro (dollars) to several millions in case large autonomous machines are utilized. Integration of instrumentation on this platform also appears as non-trivial task, because the instruments shall be light and well balanced on the platform. They also shall have the possibility for wireless communication (GPS, IRIDIUM, GLONASS) and data transfer. Environmental parameters that can be measured by means of UAVs include temperature, pressure, humidity and wind parameters. Drones can also be equipped with visible and IR cameras, laser altimetry and multispectral imagery. In the future, various gas and aerosol analysers will be developed for the installation on this platform. The potential of drones includes measurements in remote locations, routine long-term measurements, measurement campaigns and validation of information obtained from satellites.

Most of UAV systems find their application in the projects of the economically developed countries. However, these countries are not responsible for global pollution in the same extent as many developing countries, where people lack to take care of the environment due to the constant fight for their wellbeing. In these countries, the health of population is often under strike due to decreasing quality of water and air resources. Cost-effective drones can be used in these countries to sample and monitor water quality, composition of atmosphere and climate patterns.

TABLE 59 STRENGTHS AND LIMITATIONS OF UAVS

Strengths	Limitations
Eco-friendly if battery powered	Special person required for navigation
Silent, not disturbing nature	Special person required for the interpretation of the results
Cheap versions available	Agreed air path is required
Can fly in remote areas	Unmanned technology is taken as a threat
Can collect results on routine basis for a long time	Can be hacked

6.3 Systems for biosphere measurements

Most of the drones employed in biosphere sciences are similar to the UAVs used in atmospheric applications. Generally rotary drones (e.g.: hexacopters, octocopters, etcetera) are used, since they have a high stability and are able to stay fixed at certain positions and altitudes in order to perform measurements. Payloads that are used in biosphere drone measurements are generally related to the assessment of vegetation status (i.e.: stresses and inhomogeneities) or the amount of total biomass. For the first assessment a combination of thermal, RGB and hyperspectral cameras are used; while for the latter techniques such as Light Detection and Ranging (LIDAR) are used.

Developments have taken place in the framework of the Ocean of Tomorrow with the design, development and testing of passive acoustics to monitor bioacoustic sources (whales and dolphins), also addressing noise measurement that could affect a number of aquatic mammals in coastal areas or along intense-shipping routes. An example is the design and development of new hydrophones with embedded processing, based on community software and made available open-source, in order to adapt needs as they come and take new requirements as a function of geography and known populations in given areas (Delory et al. 2017). These sensors were integrated on commercial gliders and profilers, as reported by Memè et al. (2017). Technology Readiness remains at a level where more tests are needed in operational conditions in order to validate species or groups of species identification, increase reliability such as via reduction of false positives and sensitivity to noise artefacts.

6.4 Systems for aquatic measurements

Underwater Unmanned Autonomous Vehicles (gliders and other UAVs) are commonly used by oceanographers for research and monitoring of the physical and biogeochemical characteristics of the first 1000m of the ocean. The recently created GOOS program called “OceanGliders” (current web domain is http://www.ego-network.org) is gathering the major part of the worldwide gliders fleet and focuses its activity on the sustainable measurements of five Essential Ocean Variables (EOVs): temperature, salinity, chlorophyll a, oxygen and Coloured Dissolved Organic Matter (CDOM). Unless only these parameters are part of the network, many other sensors have been developed, integrated, tested and operationally deployed on AUVs such as passive acoustics, ADCP (current sensor), turbulence, hydrocarbonic sensor, nutrients, pH etc. Currently these sensors are not integrated in the network mainly for harmonized data management reasons but also because the technology is sporadically used by the community. The increasing capacities of gliders (depth, endurance and payload) and the relatively low cost of the technology, make it a very interesting tool for marine and maritime industries. Ocean gliders naturally complement existing elements of the GOOS with their utility on the continental slopes, ability to complete repeat surveys and resolve mesoscale oceanographic features such as fronts.

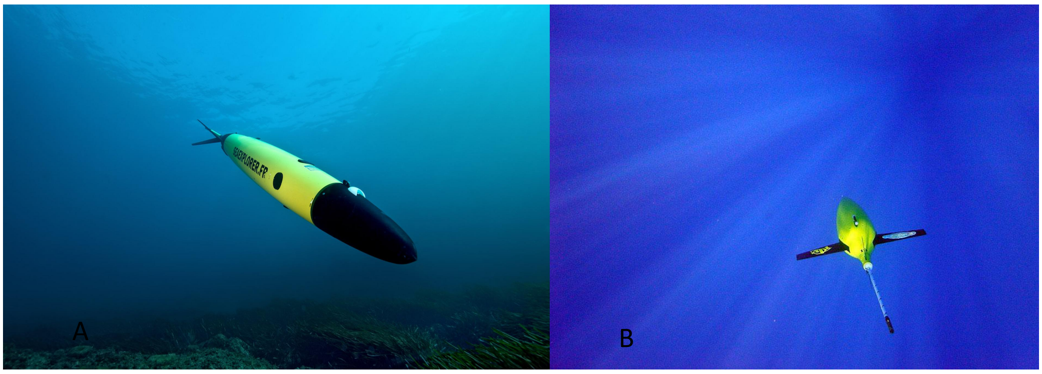

FIGURE 7 DRONES FOR UNDERWATER MEASUREMENTS: (A) SEA EXPLORER, (B) SEAGLIDER

The European Glider Network is composed of about 100 platforms that are deployed in the Atlantic, Mediterranean Sea and Baltic Sea. It is important to precise that some of the European gliders are also deployed in non-European region for specific research purposes. The European Glider Network will certainly keep growing as many “new” laboratories are currently purchasing platforms (Ireland and Sweden for example).

It is also noticeable that if the current average capacity of ocean gliders is 1000m depth, new feature able to dive to 6000m depth are now available on the market and will soon complement the glider fleet in Europe.

6.5 Issue of energy supply for UAVs

Gliders are powered by three different types of technology: non rechargeable alkaline batteries, non-rechargeable lithium batteries, and rechargeable lithium batteries. The choice of the technology is determined by its cost but also by the use of the platform, whether it is for long deployment (more than a month) or more frequent deployment (rechargeable battery do not last more than a month or two, depending on the payload). If rechargeable technology could increase glider endurance at sea in the future, we can certainly expect this technology to be more popular as it is practical and cheaper on the longer term. In any case, the next cutting-edge glider technology in terms of energy will probably be related to the development of the thermal glider that uses the thermal gradient between surface water and deep water to provide energy to the platform.

6.6 Wireless sensor networks

Since already a number of years, the advances of wireless communication technology (both bandwidth increase and power consumption decrease) has allowed the development of sensor packages with wireless communication interfaces that can then be deployed as wireless sensor networks (WSN). In addition, the possibilities of 'automatic' routing configuration via self-organizing wireless mesh networks (WMN), allows for particularly easy (and fast) field installations. For example, Picozzi et al. (2010) describe a WMN targeted towards smaller scale deployments in seismology, investigating local subsurface properties (site effects), and Pereira et al. (2014) use a WSN for monitoring seismic activities and volcanoes. WSNs are particularly useful to support the 'dirt-(to DMS-) to desktop' (D^3) rapid production of research-ready datasets, and are expected to play a major role in any future large-N instrument pools (and field experiments).

6.7 Use of single-board computers as multi-purpose instrument platforms

Another technological development over the last decade that has a growing impact on instrumentation development in the environmental and Earth sciences is the availability of lightweight, robust, low-power computers (often in single-board designs) that nevertheless offer enough processing and storage capacity to be usefully integrated in scientific grade instrumentation. One example is the DataCube, an extremely low power and lightweight seismic recording system developed at GFZ Potsdam and now industrially produced by Omnirecs[35]. Another example already in use is the RaspberryPi platform, e.g. in the RaspberryShake seismometer system developed by OSOP[36]. Ibrahim et al. (2015) describe the development of a standardized multi-parameter environmental monitoring device on the RaspberryPi platform that combines environmental parameter measurements like temperature, humidity and CO even with the capacity to add a seismic sensor. The standardization of instrumentation interfaces together with the increasing capabilities of these computational platforms offers the potential for the development of highly versatile and modular instrumentation that can serve a large variety of environmental and Earth science instrumentation and measurement challenges.

7 Energy supply: a transversal issue for all scientific measurements

7.1 Sensors challenges

Scientific measurements are sometimes performed in extreme environments: Polar Regions, bottom of oceans and high atmosphere. Consequently, all equipment (sensors, energy supply units, telecommunications, etc.) need to face very hard environmental conditions. Thus, they have to be constructed in resistant and sustainable manner.

As far as it is known from the ENVRI+ network, the energy systems need to be able to:

[35] www.omnirecs.de
[36] www.raspberryshake.org

- Face very low temperatures. Energy systems need to be able to operate not only to the “classical” testing temperatures of -20°C, but also at the temperatures below -50°C, often measured in the polar regions.
- Face humidity and dust. Most of RIs (Research Infrastructures) are constructed according to “IP6.3” standard, where IP means “International Protection Marking”. In the same code, the first number reveals the capacity to face dust, while the second means the level of protection against water.
- Have a high operating rate without regular maintenance (or any tank refuel).
- To be as light as possible. All devices for isolated scientific stations are designed to be portable as humans usually carry them.
- To be mechanically strong. Equipment has to face very strong winds, or high salinity environment that readily leads to corrosion.

For all known sensors (working in all known domains), an autonomous energy supply is a critical issue. The main remaining problem for the energy supply is that some of the measurement sites are very isolated, while only one mission per year (or even less frequent) is organized to maintain the equipment and energy supply units. That once again proves that power supplies systems have to be sustainable and robust, while all scientific or telecommunication mechanisms need to consume as low energy as possible to ensure longer functionality of the set-up.

7.2 Modern technological solutions

As known from the ENVRIplus community, technologies for the energy supply are represented by solar cells (63%), wind and hydroturbines (4% each) and other solutions (29%). Thus, solar panels is by far the most used technology, used to provide energy for isolated sites. Figure 8 shows the diagram of usage of various power supply solutions for isolated scientific stations within ENVRIplus network.

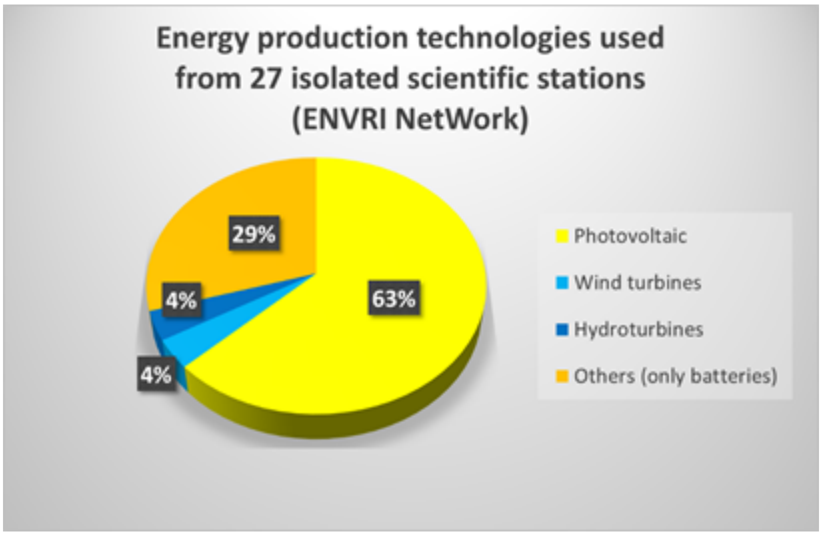

FIGURE 8 POWER SUPPLY SYSTEMS. ENVRIPLUS WP 3.1 "ENERGY REPORT", 2017

7.2.1 Solar panels

Typical solar panel will be have specifications as mentioned below:

- Silicon crystal technology.
- Output power will range from 50W to 100W per solar panel in average, in order to minimize the risks for transportation and facing the wind.
- The construction shall have strong mechanic shape.
- The construction shall be linked with MPPT (Most Power Point Tracking) or PWM (Pulse Width Modulation) solar charge controllers.

Both MPPT and PWM are the technologies which optimize the current needed for the charging of battery. The price difference between PWM technology ("the old one") and MPPT one ("the newer one") is so small that MPPT shall definitely be the one preferred. Such preference shall be given to MPPT at any sites except for the very isolated ones (such as Polar sites) where Zener diodes are used to minimize energy consumption of the regulating parts.

7.2.2 Wind turbines

Very few examples of small wind turbines have been found through the ENVRI RIs community. Most of them demonstrated the power output ranging from 50 W to 400 W (nominal output that is different from on-site output).

From the mechanical point of view, wind turbines are way weaker than solar panels, when facing extreme conditions. Their bearings and joints shall be a subject to very strong, not regular and sometimes turbulent winds and very cold temperatures which likely lead to early wear and malfunction. Thus, turbines cannot be named as the fully suitable technology for the remote sites. Still, for the territories with very low sun irradiance, turbines can represent a very interesting solution that is worth further developments and improvements. The main improvement of turbines technology shall be made to find the most efficient ratio between used space, weight of turbine and produced power.

7.2.3 Hydro turbines

Only one hydro-turbine, used in the deep Amazonian forest, was registered in the ENVRI community. This was a 10 kW "Pelleton" hydro-turbine. This hydro-turbine can be characterized as rather large compared to previously described wind turbines or solar panels. A special technical building would be required to install this turbine and operate it. Thus, this turbine cannot be named as fully portable solution for power supply.

7.2.4 Fuel cells

Fuel cells represent another technological solution that is widely used, however less abundant than solar cells and turbines. Among the most popular fuel cells one can name those of EFOY (manufacturer), running on methanol. Due to production of CO_2 and H_20 vapours during production of energy, this technology is not a good solution for cold conditions (under 0°C). To ensure the possibility of utilization of these fuel cells in the cold conditions, EFOY provide thermally insulated boxes for their fuel cells, which (according to manufacturer) can make them run down to -40°C (not tested yet). The technology of such fuel cells is still very expensive. Obvious limitations apply due to the fact that methanol is highly poisonous substance and shall be transported/manipulated with many restrictions.

7.2.5 Batteries

Lead acid batteries, VRLA (Valve Regulated Lead Acid), with gel or AGM are, by far, the most used ones through the ENVRI RI community. They are especially widely used for terrestrial measurements. Figure 9 shows the distribution (%) among battery technologies used for the measurements at 27 scientific stations within ENVRI network. As can be seen, 69% are taken by the lead batteries and 23% by lithium batteries, while alkaline and other technologies represent 4% each.

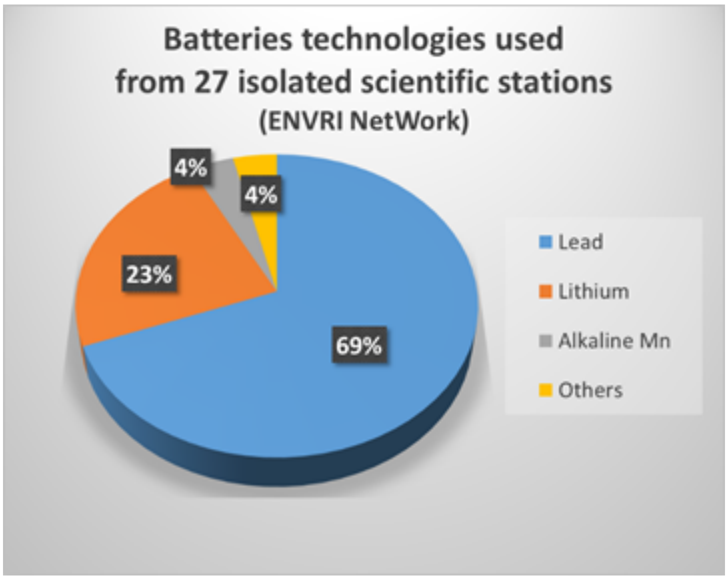

FIGURE 9 POWER STORAGE SYSTEMS. ENVRI+ WP3.1 "ENERGY REPORT", 2017

The biggest challenges of the batteries are that they need to face and run under very low temperatures, down to -20°C, and sometimes down to -40° to 50°C and be as light as possible. The weight of batteries is especially important when one considers their installation on drones. Light weight of the batteries allows larger amount of scientific equipment to be installed and, thus, is more desirable. Lithium batteries are currently the ones with the highest energy-to-weight ratio. That is why they are widely used for the environmental measurements within oceanic domain, and for the installation on drones. In the table 60 we summarize the companies providing technologies for the power supply and specify the type/ model of technology.

TABLE 60 COMPANIES PRODUCING TECHNOLOGICAL SOLUTIONS

Technology	Manufacturer	Specification/ model	Comments
Solar panels	Kyocera	Any, Mono or poly crystalline from 10 to 100 W (typically)	The market of solar panels is a new and very dynamic market, where new companies appear and disappear every day.
	Victron	Any, Mono or poly crystalline from 10 to 100 W (typically)	
	PhotoWatt (not exist anymore)	Any, Mono or poly crystalline from 10 to 100 W (typically)	
	SolarWorld (not exist anymore)	Any, Mono or poly crystalline from 10 to 100 W (typically)	
Wind turbines	Primus	Primus AIR 30	
		Primus AIR 40	
	FORGEN	Forgen Ventus 70	
		Forgen Antarctic	
	Wind-Kinetic	Polar	
Fuel Cell	EFOY	EFOY Pro 600	
Batteries	Sonnenschein	Gel Dryfit, cycling, 30 to 100 Ah.	
	YUASA	AGM cycling, 30 to 100 Ah.	
	Victron	Gel or AGM cycling, 30 to 100 Ah.	
	Enersys	Cyclon	
	Shaft	Lithium Sulfuryl Chloride	Non rechargeable. Mainly used for the measurements in the oceanic domain.
	Victron	Lithium $FePO_4$	Rechargeable battery.

8 Place of Research Infrastructures on the technological market

8.1 Interactions of RIs with the markets

The core of the scientific business dedicated to environmental measurements and climate change observations can be seen in interactions of producing companies with the consumers of their products. Such interactions are developed, facilitated, and actively promoted. However, these interactions are not always beneficial or successful due to the different views and capabilities of producers and consumers communities. Thus, producers do not always have the possibility to understand the needs of consumers due to the lack of communication or inability to dedicate the funds for the market research. This results in the production of low-functional, expensive devices and, consequently, decrease of companies revenues and incomes. At the same time, the end-users do not have the chance to explain the producers their needs and cannot afford purchasing expensive devices directly from them. Research infrastructures are the bodies that act as intermediates between producers of the technologies, their end-users and third parties, such as grant holders, providing benefits for all market players as shown below at figure 10.

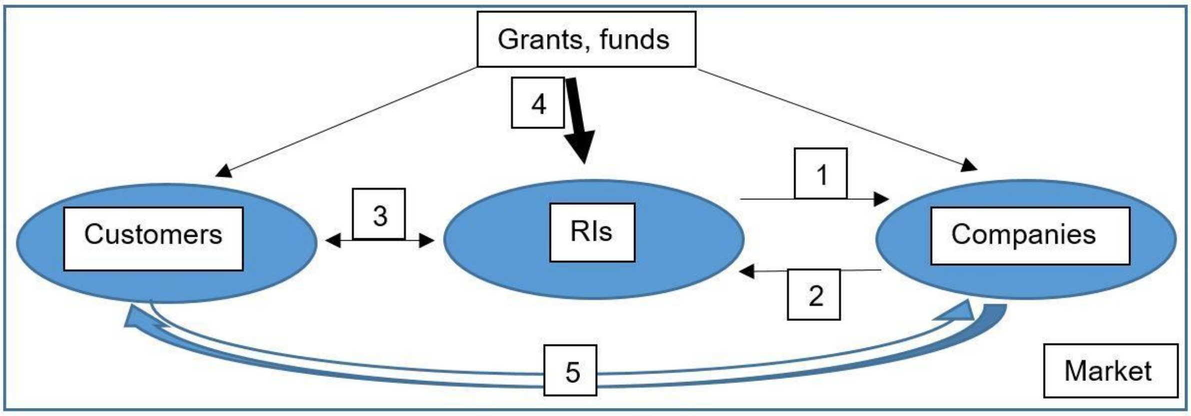

FIGURE 10 INTERACTIONS OF RIS WITH OTHER PARTICIPANTS IN THE MARKET.

The arrows between the RI body and the companies represent:

1. Services that can be provided by RIs to the companies
   - Representing large groups of the end-users, RIs are capable of purchasing products of high cost, which can be shared among the multiple end-users.
   - As large entities, connecting numerous research institutes and governmental structures, RIs can collect the demands for the standardization and metrology and pass them to the companies for the future implementation.
   - RIs can predict natural disasters affecting business and human well-being. This is a valuable capability for business management and crisis prevention.
   - Co-designing innovation. RIs can promote the development of new products and services as well as to adapt them to the market needs and rules.

- RIs can provide the facilities, necessary for testing of new technologies
- RIs can perform data collection and management, to support companies and generate income

2. Services that companies can provide to RIs
    - Companies can sell their innovative devices to RIs. In case the devices are of high cost, RIs will be able to purchase them in contrast to the single users/ scientists.
    - Companies can provide new services to the RI, in larger extent than to the single users.
    - Data collection and transmission. While using the facilities of RIs, companies can collect data at low cost. This data can be shared with the members of RIs to make their work more efficient.
3. Services that RIs can provide to customers (end-users)
    - RIs can assure that all the customers (end users) have equal possibilities to access the facilities for the environmental measurements and climate change investigations, as well as to the data provided by each and every RI.
    - RIs provide transferable and reusable data and knowledge.
4. RIs become an attractive receiver of grants and funding
    - Given the same amount of financial support, RIs can provide the access to the research facilities to larger amount of scientists or other interested communities.
5. Direct interactions between the end users and producing companies
    - Direct interactions are possible, but are never as beneficial as interactions through the RIs due to the reasons mentioned in points 1-4.

8.2 RIs as innovative business partners

From the types of interactions described above, it can be seen that RIs can catalyse the development of technologies by being their direct users and acting as innovation partners:

RIs as contributors to new products and services – RIs can work as competitive infrastructures for businesses. Start-up companies with limited possibilities of purchasing of high-tech devices can become more beneficial by using shared devices within RIs. Such access to the systems through the RIs will reduce the cost of system operation, ensure the full time-load of devices and, thus, increase the effectiveness of work.

RIs as users of innovative techniques – Upon their development and growth, RIs will demand new technological solutions with better measurement characteristics and thus promote research, development and manufacturing of new technological devices for environmental measurements and climate change investigations.

RIs as innovation partners – RIs will work closely together with the companies to establish the requirements for the emerging technologies and to improve the existing ones. By doing so, the measurements precision and quality will be improved; while the companies will be able to improve their production lines and sell devices of better quality.

It is important to note, that companies, interested in the collaboration with RIs can be represented by Small and Medium sized companies (SMEs) as well as by large consortiums and conglomerates. Both SMEs and larger companies will have their own benefits from collaboration with RIs, however the interactions of the entities in such cases might differ. Table 61 compares the interactions of single researchers with SMEs and RIs with SMEs.

TABLE 61 INTERACTION OF RESEARCHERS AND RIS WITH SMES

Researcher to SMEs	RIs to SMEs
Purchases at the small scale	Purchases at the large scale
Precisely specifies the requirements for the instrument	Provides specifications for the instrument
Vision of small scientific niche	Vision of the worldwide market for research and applications
Share experience in their own scientific community	Promotes exchange of experiences between communities

Table 62 compares interactions of scientists with the large industrial agglomerates and such interactions of RIs.

TABLE 62 INTERACTION OF RESEARCHERS AND RIS WITH LARGE COMPANIES

Researcher to large companies	RIs to large companies
Provides knowledge in very specific field of expertise	Provides all spectra of knowledge in the field
Interested to use the infrastructure of large company	Provides infrastructure for business
Improves image of innovative industrial company	Broadcast the image of innovative industrial company

8.3 Addressed technologies

On the way of development, technologies pass several stages. These stages are represented by the Technology Readiness Level (TRL) ranging from 1 to 9, where 1 refers to the least developed technology and 9 to the most developed one. Usually it is assumed, that technologies with the TRL from 1 to 5 are immature technologies, developed and worked on by individual scientists. Contrary, technologies with the TRL from 8 to 9 are mature technologies, ready to become commercial products. As can be noticed, technologies with the TRL 6-7 are in the intermediate state. In this stage they cannot be further developed with the capacities of scientists, as such development would require significant allocation of funds. At this intermediate stage, they are also unlikely to attract funds from the commercial sector, as the companies are not ready to invest in the technologies that will not bring the profit in the short-term perspective. TRL scale is illustrated in figure 11.

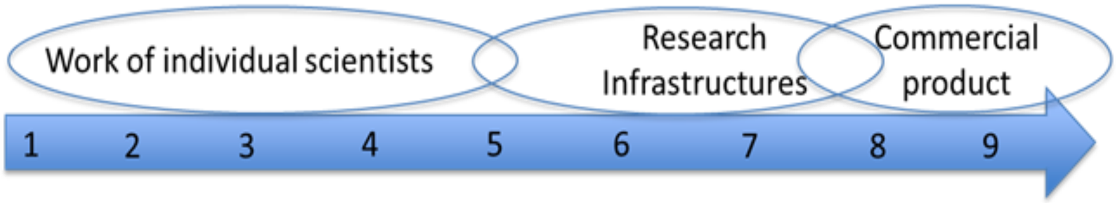

FIGURE 11 TECHNOLOGY READINESS LEVEL AXIS (1-9) AND STAGED OF THE TECHNOLOGICAL PRODUCT.

RIs thus refer to the emerging technologies with the TRL from 6 to 7, to ensure that they will overpass the financial barrier and become the commercially successful technologies with the great potential of further development and improvement. Also RIs will target improvement of technologies, such as their miniaturization and bettering of precision, as these parameters can also be referred as innovation.

8.4 Traditional and innovative business models

RIs provide a great basis for the development of numerous businesses, both within well-known and established business networks and within the new business niches, which are not fully developed by today. In general, these businesses can be divided into two groups, such as production and services.

Development and sales of hardware - research and development of technologies as well as manufacturing of the devices based on these technologies is one of the main pillars of business in science. At the same time, this business consumes many financial and time resources and requires long time to bring the profit. To start this type of business one needs to own a “know-how”. RIs can provide free access to scientific facilities to perform the initial R&D activities and potentially can help to acquire start capital for the SMEs through interactions with grant holders.

Software development – development of software products is a modern and effective business solution that does not require large investments. The basic need to start this business includes the access to the computer, knowledge in programming and in environmental science. Development of software for climate change monitoring is especially profitable nowadays, when the companies use software programs to monitor the GHG emissions based on the amount of used fuels. In the future, when the direct measurements of GHG fluxes will be required by the governments, software companies may develop the interfaces for the devices, or develop the solutions to integrate multiple devices in one network. RIs can help software companies to develop their products by providing network of contacts of SMEs and researchers, in need of their products.

Reselling and advertisement – reselling of goods is probably the most profitable business, as it does not require large investments at the initial stage of business, and the markets around the globe are always saturated non-equally, meaning that there are always possibilities for the export of devices from the country of producer to the country of consumer. RIs as the international projects can help the customers to get in contact with the producers or distributors of the technological devices and to facilitate spreading of new technologies globally. RIs can also serve as advertising platform to make the information about the new developments of high-tech sector available to all interested parties.

Service and transportation – every newly produced device need to be carefully transported to the customer and mounted on site. Transportation of fragile scientific devices is a business opportunity that has a good potential as there are no many companies on the market that provide this specific service. Companies providing transportation service can also provide the installation and tuning services too. RIs can open access to the contacts of producers and customers to let the transportation and installation companies to establish their business more effectively.

Standards and calibration – Communities dealing with environmental measurements strongly depend on the standard substances and calibration of their devices. Providing of calibration services or standardized substances can be a side business of companies producing the scientific devices or installing/tuning them.

Subscription for the data/products – this is the novel model of business, when the company owning the device for climate change investigations performs the measurements of interest and sells the results to the interested parties on the basis of long-term contracts. Such approach allows the customers to buy the data or products based on the data without purchasing the expensive device. At the same time, companies providing these services get stable income over long-time period and can sell the same data to several customers at the same time. RIs can assist such business by providing the access to this service to the large interested community.

Business consulting – this is the possibility for experienced entrepreneurs and consulting agencies to help the young companies to establish and develop. Help might be provided in performing market analysis, determination of business niches, etc.

Legal affairs – every company needs the legal counselling. This is especially true for the scientific SMEs because they deal with Intellectual property. Assistance can be provided with registering patents, registration of devices in the regulatory bodies, communicating with environmental agencies and other governmental and over-governmental structures nationally and internationally.

As main objective, environmental RIs strive for the societal challenge of sustainably manage natural resources. Towards this goal, ERI support regulation and entrepreneurship. Policymakers depend on the scientific community to establish an enabling environment. They complement this input with socio economic studies. Environmental RIs should proactively propose measures to policymakers for mitigation and adaptation purposes. They ensure an informative role to society at the same time. Integrate the circular economy requires adaptation from the private sector and consumers. Policy makers need to stimulate these markets. Environmental RI support act as one of the incentives to the private sector to engage in environmental monitoring technologies.

8.5 Summary

RIs are relatively new entities, not sufficiently known by the scientific community or technology producers. As can be seen from chapter 9, they represent genuine interest to both communities. For the producers, such as construction, instrumentation and informatics companies, RIs represent large and important market, mainly due to the high constructional and operational cost of RIs. For the end-users, RIs represent a good chance to be heard and taken in account by other market players. For the executives, existence of RIs is a great opportunity to get support for their businesses and significantly decrease the cost of business running. Thus, one of the main aims of RIs on the market is to become well-known and acknowledged players in order to realize their full potential.

9 Industrial producers in the framework of ENVRIplus workshops

Within the framework of ENVRIplus and particularly work package one, "new sensor technologies, innovation and services" it is of paramount importance to emphasize the relation of the current document with the views of SMEs on the development of research infrastructures, and particular importance of existing and emerging technologies. For these purposes authors would like to summarize the opinions of industrial partners of ENVRIplus, gained during the meeting in Grenoble (18-19 May 2017), as well as their views on the most important technological advances of sensors and data communication systems.

CSUG (Space Center of Grenoble University) paid special attention to the miniaturized spectrometric instrumentation such as Nono-carb drone, based on a hyperspectral sensor. The sensor is highly suitable for the studies of vegetation, can work in 14 spectral channels between 400 and 1000 nm wavelength, and has 30x30 pixels of field and spatial distribution of 20 cm. They have also mentioned some highly innovative technologies, such as cubesat satellites, equipped with the SPOC imaging spectrometer or VIPA, high spectral resolution echelle spectrometer. They have mentioned several companies, such as Swifts Technology and Resolution Spectra Systems, producing such innovative devices as laser spectrum analyser wavelength meters, Bragg Interrogators and RAMAN analysers with excellent characteristics.

Representatives of EMSODEV[37] introduced the EGIM, EMSO Generic Instrument Module. EGIM was designed to measure parameters of interest for most major science areas (covered by EMSO) in a consistent and continuous manner. It is expected to operate on any EMSO node,

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[37]http://www.emsodev.eu/

mooring line, seabed station, surface buoy, in cabled or non-cabled mode. The main aim of this instrument is to have a number of ocean locations, where the same set of core variables could be measured homogeneously, using the same hardware, sensor references, same qualification and calibration methods, data format and access, as well as same maintenance procedures. The device is capable of measuring a number of variables, including temperature, conductivity, pressure, concentration of dissolved O_2, turbidity, ocean currents. It is also capable of passive acoustics. EGIM is ready to be used for such challenges as global ocean warming and acidification, impact and sustainability of marine resource exploitations and real time observations of earthquakes and tsunamis.

German Centre for Integrative Biodiversity Research (iDiv) together with the Helmholtz Centre for Environmental Research presented the iDiv Ecotron, a scientific unit produced by EMC GmbH and UGT GmbH and aimed to monitor the ecosystems under controlled environmental conditions. Representing a good compromise between natural and laboratory conditions, iDiv Ecotron is equipped by LED lights, ventilation, irrigation, air humidity and temperature control systems. It can also control soil temperature, moisture and tension. The unit is equipped by openings for sampling and acrylic tubes for root scanner, soil cooling device and soil water sampling.

Representatives of EGI foundations has focused on the EGI Information and communication technology (ICT) e-infrastructure and services. This infrastructure federates tje digital capabilities resources and expertise of national and international research communities in Europe and worldwide. It empowers researchers from all disciplines to collaborate and carry out data and compute-intensive science and innovation.

Colleagues from GASMET, the leading producer of gas analysers and monitoring systems for industrial, environmental, health & safety and research applications has presented their solutions for GHG measurements, particularly the FTIR gas analysers for soil flux measurements. The announced mission was to produce portable and easy-to-use tool, capable of quick analysis and cheap in handling and operation, performing online concentration readings and providing trend view with full sample spectrum. Resulting instrument satisfied the above-mentioned criteria and was capable of measuring six GHG with the possibility of measurement of other 350 GHG from the library of device without any special modifications of hardware. Variable calibration ranges and simultaneous measurements of several gases are available to the potential users. No recalibration was needed during further applications.

METEC GmbH presented their new approach in 3D wind and turbulence sensing, such as multipath sonic set-up. This set-up is unique, because possible interferences are detected at early stages of signal processing, the detection mode is highly reliable and potential data gaps are avoided. Moreover, special “diagnostic operation mode” provides detailed information on acoustic transducer health status.

PerkinElmer reported about their portable chromatography solutions for detection of volatile and semi volatile organic compounds. Their TORION T-9 GC/MS portable machine is fully capable of field applications and easy to use for many purposes, such as safety and security, environmental or food and fragrances analysis. It is equipped with the active real time display, easy to use sample injection port, can analyse dozens of chemical compounds, and has a light weight of 14.5 kg and short time of work initiation and finish.

SENOW together with partners spoke about their innovative developments in the field of sensors for the detection of dissolved gases. Their sensors are characterized by very fast response time, high sensitivity, possibility to analyse multiple species in situ and large range of applications, such as oil and gas offshore monitoring, process studies, etc.

MIRICO overviewed their technologies for real time precision gas sensing. MID-IR Laser Gas Sensing allows higher sensitivity (ppb/ppt), wide selection of target molecules and robustness, while high resolution spectroscopy is not influenced by interfering species and provides accurate and precise measurements. Presented product lines included open path and extractive gas analysers. Open path analysers were characterized as highly sensitive, resilient to optical interferences, and capable of measurements at ultra-long path lengths and at 360 degrees for large area mapping. Extractive gas analysers were manufactured as modular platforms for multi-species analysis highly sensitive, real time analysers, which could perform auto calibration and work over broad range of concentrations.

Airmodus Oy, Ltd, presented technologies for counting the airborne submicron particles in a wide range of sizes. Their sensors were capable of counting neutral and charged aerosol particles down to 1 nm in diameter as well as to provide size distribution for smallest nanoparticles. These solutions could be readily applied in field campaigns and laboratory studies around the world to study the exhausts of vehicles and natural gas engines

PICARRO representatives were talking about various environmental measurements as the company is represented in numerous sectors, such as agriculture, soil science, ecology, plant physiology, GHG flux emissions testing, atmospheric science and global GHG monitoring networks, urban and air quality, hydrology and ground water, aquatic chemistry and oceanic carbon cycling and many others. The company works hardly to provide the possibilities of various measurements in rugged field conditions. Their devices and sensors are made extremely compact, compatible with continuous measurements during walking or driving. They are demanded to perform measurements of multiple species in a wide range of concentrations and be easy-to-use.

Another well-known producer of sensors for multiple applications, LI-COR focused on the sensors for light, soil gas flux, photosynthesis, leaf area index detection and Eddy Covariance. They said that the main characteristics of these sensors are robustness and reliability, accurate data and careful design, and powerful software. According to their opinion, devices need to perform fast, real-time and cost-effective non-destructive measurements.

NEON (National Ecological Observatory network) focused on the ways of public and private science engagement, what is of crucial importance to the research infrastructures and development of innovations. They have concluded that different models of engagement shall be available. The main structural elements for such engagement would be various synthesis activities, legal protection, availability of physical workspace, provision of business and financial services, availability of correct management and governance, etc.

From the examples mentioned above, it can be clearly seen that producers of sensors and new technologies in general agree on the future requirements for the devices for environmental measurements and paths for their future development. The tendencies of technologies and sensors development are summarized in the Summary section.

10 Conclusions

New market demands constantly challenge companies to develop new sensors and platforms for environmental measurements. Advances of technology and manufacturing processes have led to the miniaturization of existing sensors, their increased energy efficiency, enhanced speed and quality of work as well as possibility to work in assemblies to carry out specific measurements. Current section summarizes the trend of technology development based on the information presented in the current document.

Miniaturization and power efficiency - The global trend for sensors for all measurements is to become smaller and more energy efficient. Smaller size of sensors means that more sensors can be installed at one platform and less materials shall be used for their manufacturing. To decrease the size of sensors, companies use advanced technologies, such as MEMS (Micro-Electro-Mechanical-systems) and nanotechnology solutions. Enhanced energy efficiency of sensors allows longer deployment of sensors. To allow longer functioning, companies develop novel accumulator or devices capable of producing electricity from wind, sunlight, tides, etc. Future sensors will be smaller, lighter and easier to deploy and retrieve from the measurement site.

Integration of multiple sensors on a single platform - here is a tendency to use single platform to install multiple sensors, connected through the system integrators. System integrators can be represented by hardware devices or software that synchronize the work of sensors and enable their connection. Integrators can combine several sensors into a system to carry out a specific measurement, provide data collection and transmission of obtained data. Integrators are also key solution for development of modular technologies, which can integrate sensors and platforms of different brands and producers.

Rugged sensors and instrumentation – nowadays, human activity has expanded to the regions with the severe climate conditions, such as Polar Regions, deep sea, high altitude regions (airborne measurements) and even space. To work in these conditions, there is a strong request for the equipment with greater robustness, energy efficiency, longer lifetime and capability to work remotely. Measures to protect the sensors from the severe conditions are also developed.

Market consolidation - the diversity of requirements for various sensors has created a large amount of small companies on the market. In an effort to enlarge the production line and produce the sensors of higher quality, some companies purchase other smaller companies and start-ups, becoming market leaders. Such acquiring help companies to share technological knowledge, cover larger segments of the market and be more economically profitable. Such mergers and acquisitions represent global trend and likely will continue in the future.

Price decrease and mass-production - large market players are interested in mass production of sensors, accounting thousands or millions of sensors. Mass production of sensors according to the well-known and established technology is getting cheaper, what can be taken as a general future trend.

Application of sensors in various fields of human activity - it is a common mistake to think that existing and novel sensors can find their applications only in the scientific research. Common application areas also include private and public healthcare, education and increasing general information and awareness. Increase of number of spheres where the sensors will be applied is another well-seen trend.

TABLE 63 APPLICATIONS OF SENSORS FOR AIR AND WATER QUALITY MONITORING

Application	Description	Example
Research	Scientific studies and experiments to track air or water pollution	Network of sensors aimed to measure atmospheric and water quality/state in urban or natural areas
Personal exposure monitoring	Monitoring air and water quality, that a single individual is exposed to in normal, everyday conditions	Monitoring air and water quality in the private location of (for air) in the car
Control of health	Monitoring pollution levels that might promote patient sickness	A person having a clinical condition wears a sensor to identify the sudden change in ambient pollution of air or water, potentially affecting his/her health
Supplementing Existing Monitoring Data	Sensors are placed within local monitoring area to fill the coverage	Increasing the density of sensor network to improve the understanding of pollution gradient

Identification of source of pollution	Identification of pollution source by deploying a network of sensors in the vicinity of suspected source	A network of sensors can be installed near to the industrial facility to monitor the pollution gradient as a function of time
Education activities	Using various sensors to educate students about the source of pollutions and means of its measurement	Sensors are provided to students to understand the principles of measurements and importance of climate change tracking
General information and awareness	Using sensors in public places To increase the awareness of people about pollution	Install the sensors in the zones of public access to illustrate the current state of pollution of air and water

As a result of this work, authors present the table, summarizing the technologies mentioned in the current document, in relation to the RIs, they are applied in and in relation to the domains, where they are used. The table can be found in a separate annex 1.

Impact on project

The quality of scientific measurements performed within the RIs strongly depends on the used instrumentation, such as sensors and platforms for sensors installation. Even though new instruments are constantly under development, there are only few physical principles, underlying all measurements. Such similarities is a great basis for the RIs to share their efforts in development of innovation, inter-exchange measurements data and co-run the available facilities. Such approach will save the time and financial resources to RIs and RIs users within the European framework. Current deliverable stays in a good fit to the ENVRIplus project because it defines the parameters, most important for the future environmental measurements, consolidates the requirements for existing and emerging sensor technologies and gives the overview of the markets and business activities related to environmental measurements.

Impact on stakeholders

The main objective of the current deliverable is to stimulate the industry innovation by opening new market opportunities. The work is devoted to both RIs and companies, producing the sensors and technologies. Due to this work, RIs get the chance to overview the potential innovations and to integrate them in timely and smooth manner. Companies, (both large producers and SMEs) observe the market needs and identify the future market requests. Scientific partners, responsible for the current deliverable impose their instrumentation needs and show both producers and RIs the direction of environmental research development in the future.

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12 Appendices

Appendix 1: Table, summarizing important measurement parameters and measurement techniques (both existing and emerging), required for the measurements of these parameters.

	Domains	Atmospheric			Biosphere	Marine					Solid Earth
	RIs	ICOS	IAGOS	ACTRIS	ANAEE	EURO-ARGO	EMSO	JERICO	GROOM	EUROFLEETS	EPOS
Measurement parameters											
CO_2	ATM+MAR+BIO	FTIR, CRDS, GC, NDIR	CRDS		NDIR	Optode (New float)	Optode (Yearly Visit)	Wet Chem (Ferry Box)	Optode		
CH_4	ATM+MAR+BIO	FTIR, CRDS, GC, Near infrared laser spectroscopy	CRDS		Near infrared laser spectroscopy		Electric Sensing, Optical (Yearly Visit)				
Other GHG	ATM+BIO	CRDS, OA-ICOS, GC - MS (isotopes), NDIR, Quantum cascade laser			NDIR, Quantum cascade laser						
Aerosol concentration	ATM+BIO		Condensation Particle Counter (CPC)	Condensation Particle Counter (CPC) / Differential mobility Particle Sizer / Aerosol lidars / Sun Photometry	Fast OPCs						

	Domains	Atmospheric			Biosphere	Marine					Solid Earth
	RIs	ICOS	IAGOS	ACTRIS	ANAEE	EURO-ARGO	EMSO	JERICO	GROOM	EUROFLEETS	EPOS
Aerosol optical properties	Atmospheric		CAPS PMex light extinction	Nephelometers, Absorption Photometers, aerosol lidars, sun-photometry							
Aerosol chemistry				ACMCC, off-line chemistry							
Aerosol Size			Optcal Particle Counter (OPC)	Optical Particle Counters, DIfferential Mobility Particle Sizer, sun-photometry							
Aerosol Hydroscopicity				CCN, HTDMA, aerosol lidars							
Turbulence	Biosphere	Sonic anemometry			Sonic anemometry						
VOCs					PTR-MS						
Photosynthesis					Fluorescence						
Plant Stress					Multi/Hyperspectral imaging						
GAI		DHP, ceptometer									

	Domains	Atmospheric			Biosphere	Marine					Solid Earth
	RIs	ICOS	IAGOS	ACTRIS	ANAEE	EURO-ARGO	EMSO	JERICO	GROOM	EUROFLEETS	EPOS
Soil Respiration		Chambers									
Phenology		PhenoCam									
Microorganisms	BIO+MAR				UV-LIF			Phytoplangton-Flux Cytometry and Image Analysis Zooplancton-Image analysis			
Temperature	Marine	Thermistance				Thermistance	Thermistance (Yearly Visit)	Thermistance	Thermistance	Thermistance	
Salinity						Conductivity	Conductivity (Yearly Visit)	Conductivity	Conductivity	Conductivity	
Density						Refractometry	Refractometry (Yearly Visit)				
Dissolved oxygen						Optode	Optode (Yearly Visit)	Optode	Optode		
Sea currents							ADCP (Yearly Visit)			ADCP	
Chemicals concentration							RAMAN Spectro (Yearly Visit)			RAMAN Spectro (ROV)	
							Mass Spectro (Yearly Visit)			Mass Spectro (AUV)	

	Domains	Atmospheric			Biosphere	Marine					Solid Earth
	RIs	ICOS	IAGOS	ACTRIS	ANAEE	EURO-ARGO	EMSO	JERICO	GROOM	EUROFLEETS	EPOS
pH	Marine	Carbon data						Wet Chem (Ferry Box)			
						Isfet (New float?)			Isfet		
						Optode (New float?)	Optode (Yearly Visit)		Optode		
Alkalinity		Carbon data						Wet Chem (Ferry Box)			
Nitrate						UV Spectro(Bio Argo float)	UV Spectro(Moorings)(Yearly Visit)	UV spectro(Moorings & FB)	UV Spectro(Glider)		
Ammonia								Wet chemistry - Lab On Chip (Moorings & FB)			
Phosphate								Wet chemistry - Lab On Chip (Moorings & FB)			
Iron							Wet chemistry Lab On Chip (Seafloor) (Yearly Visit)	Wet chemistry - Lab On Chip (Moorings & FB)			
Sulfure							Wet chemistry Lab On Chip (Seafloor) (Yearly Visit)				

	Domains	Atmospheric	Biosphere			Marine					Solid Earth
	RIs	ICOS	IAGOS	ACTRIS	ANAEE	EURO-ARGO	EMSO	JERICO	GROOM	EUROFLEETS	EPOS
Silicate	Marine							Wet chemistry - Lab On Chip (Moorings & FB)			
Chlorophyll						Fluorescence (Bio Argo float)		Multi Spectral Fluo (Ferry Box)	Fluorescence (Glider)		
PAHs											
Pollutants							SBSE	Passive sampling			
Sound							Hydrophones	Hydrophones	Hydrophones		
Big organisms imagery								Image analysis			
							EchoSounders (Seafloor)			Echo Sounders (From ship)	
							Video Imaging (Seafloor)				
Seismology (seismic ground motion recording)	Solid Earth										Seismometer (short-period, mid-period)
											Geophone
											Rotational seismometer
											Accelerometer (classical)
											Accelerometer (MEMS)
											Ocean-bottom seismometer (package)
											Hydrophone

	Domains	Atmospheric	Biosphere			Marine					Solid Earth
	RIs	ICOS	IAGOS	ACTRIS	ANAEE	EURO-ARGO	EMSO	JERICO	GROOM	EUROFLEETS	EPOS
Seismology (seismic ground motion recording)	Solid Earth										Seismic data logger / Digitizer
Geodetic (position and (slow) velocity)											GPS receiver (single frequency)
											GPS receiver (dual frequency)
Gravity											Absolute Gravimeter
											Relative Gravimeter
											(Superconducting Gravimeter) *[a special type of relative gravimeter]*
Magnetic field											Vector magnetometer
											Scalar (total field) magnetometer

Appendix 2: Complete list of terminology

No	Acronym	Definition
1	ADCP	Acoustic Doppler Current Profilers
2	APS	Aerodynamic Particle Sizer
3	APSD	Aerosol Particle Spectrometer with Depolarization
4	ATP	Adenosine triphosphate
5	AUV	Autonomous Underwater Vehicle
6	CAP	Common Agricultural Policy
7	CDOM	Coloured Dissolved Organic Matter
8	CPC	Condensation Particle Counters
9	CRDS	Cavity Ring Down Spectroscopy
10	CTBTO	Comprehensive Nuclear-Test-Ban Treaty Organization
11	DIAL	Differential Absorption Light Detection and Ranging
12	DIC	dissolved organic carbon
13	DIN	Dissolved Inorganic Nitrogen
14	DMPS	Differential Mobility Particle Sizer
15	DNA	Deoxyribonucleic acid
16	DO	Dissolved Oxygen
17	EEA	European Economic Area
18	EGIM	EMSO Generic Instrumentation Module
19	ENVRI	Environmental Research Infrastructures
20	EOV	Essential Ocean Variables
21	ER	Ecosystem Respiration
22	ESA	European Space Agency
23	ESFRI	European Strategy Forum of Research Infrastructures
24	EU	European Union
25	FIA	Flow Injection Analysis
26	FRRf	Fast repetition Rate fluorometer
27	FTIR	Fourier Transform InfraraRed spectroscopy
28	GHG	Green House Gases
29	GLONASS	Global Navigation Satellite System
30	GNSS	Global Navigation Satellite System
31	GPP	Gross Primary Productivity
32	GPS	Global positioning system
33	HALE	High Altitude Long Endurance
34	HD (video)	High Definition
35	HTDMA	Humidified Tandem Differential Mobility Analyzer
36	ICL	Inter Band Cascade Laser
37	IFCB	Imaging FlowCytoBot
38	IFSOO	Integrated Framework for Sustained Ocean Observing
39	IPCC	Intergovernmental Panel on Climate Change
40	IR	Infra Red

41	ISFET	Ion Selective Field Effect Transistor
42	LALE	Long Altitude Long Endurance
43	LAME	Low Altitude Medium Endurance
44	LDS	Laser Dispersion Spectroscopy
45	LIBS	Laser- Induced Breakdown Spectroscopy
46	LIDAR	Light Detection And Ranging
47	LoC	Lab-on-a-chip devices
48	LOD	Limit Of Detection
49	LPAS	Laser Photoacoustic Spectroscopy
50	MALE	Medium Altitude Long Endurance
51	Mid-IR	Mid Infra Red
52	MOX	Metal Oxide
53	MPPT	Most Power Point Tracking
54	MWIR	Medium Wavelength Infra Red
55	NADH	Nicotinamide Adenine Dinucleotide
56	NDIR	Non Dispersive Infra-Red Sensor
57	NIR	Near Infra Red
58	NPP	Net Primary Productivity
59	NTU	Nephelometric Turbidity Units
60	OBS	Optical BackScatter
61	OI	Oceanology International Conference
62	OPC	Optical Particle Counters
63	ORP	oxidation-reduction potentials
64	PAS	Photoaccoustic Absorption Spectroscopy
65	PAX	Photoaccoustic Extinctiometer
66	PC	Personal Computer
67	PCASP	Passive Cavity Aerosol Spectroscopy Probe
68	PCR	polymerase chain reaction
69	POC	Particulate Organic Carbon
70	PTR-MS	Proton Transfer Reaction Mass Spectrometry
71	PTR-TOF-MS	Proton Transfer Reaction to a Time Of Flight Mass Spectrometer
72	PWM	Pulse Width Modulation
73	QCL	Quantum Cascade Laser
74	R&D	Research and Development
75	RFIA	Reverse Flow Analysis
76	RI	Research Infrastructures
77	RNA	Ribonucleic acid
78	ROV	Remotely Operated Underwater Vehicle
79	RS	Raman Spectroscopy
80	SERS	Surface Enhanced Raman Scattering
81	SFA	Segmented Flux Analyzers
82	SIA	Sequential Injection Analysis
83	SIF	Solar Induced Fluorescence

84	SME	Small and Medium Enterprise
85	SMPS	Scanning Mobility Particle Sizer
86	TA	Total Alkalinity
87	TCCON	Total carbon Column Observing Network
88	TDL	Tunable Diode Laser
89	TDLAS	Tunable Diode Laser Absorption Spectroscopy
90	TOF-AMS	Time of Flight Aerosol Mass Spectrometer
91	TRL	Technology Readiness Level
92	UAV	Unmanned Aerial Vehicle
93	UCSD	University of California, San Diego
94	UNAVCO	non-profit university-governed consortium that facilitates geoscience research and education using Geodesy
95	UNESCO	United Nations Science and Culture Organisation
96	UNFCCC	United Nations Framework Convention on Climate Change
97	US/ USA	United States of America
98	UV	Ultra Violet
99	UV-DOAS	Ultra Violet Differential Optical Absorption Spectroscopy
100	VCSEL	vertical cavity surface emitting laser
101	VOC	Volatile Organic Compounds
102	VRLA	Valve Regulated Lead Acid
103	WMN	wireless mesh networks
104	WOC	World Ocean Council
105	WP	Work Package
106	WSN	wireless sensor network
107	WTO	World Trade Organisation
108	µTAS	Micro Total Analysis Systems