Project funded by
EUROPEAN UNION

Promoting Technology Innovation in Environmental Monitoring and Modelling for Assessment of Fish Stock and Non-fish Resources

Deliverable D.T1.2.1

Inventory on Technology Innovations in marine environmental monitoring and assessment of fish stock and non-fishing recourses

TIMMOD

Reference No. BSB-1029

January, 2021

Common borders. Common solutions.

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<tr><td>Document ID:</td><td colspan="2">D.T.1.2.1</td></tr>
<tr><td>GA, Activity:</td><td colspan="2">T1: Deliverable DT1.2.1
Inventory on Technology Innovations in marine environmental monitoring and assessment of fish stock and non-fishing recourses
Activity A.T.1.2: Inventory on Technology Innovations in marine environmental monitoring and assessment of fish stock and non-fishing recourses, and review on Best Practices</td></tr>
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ABBREVIATIONS

AUTh	Aristotle University of Thessaloniki, Greece
BDCA	Black Sea – Danube Association for Research and Development, Bulgaria
DDNI	Danube Delta National institute, Romania
IFR	Institute of Fish Resources, Bulgaria
NEA	LEPL National Environmental Agency, Georgia
RECM	Regional Environmental Centre, Moldova

ADCP	Acoustic Doppler current profiler
ASV	Autonomous surface vehicle
AUV	Autonomous underwater vehicle
BRD	Bycatch reduction device
DEM	Digital-elevation map
CMA	Common Maritime Agenda (for Black Sea)
CMEMS	Copernicus - Marine Environment Monitoring Service
DSLR	Digital single-lens reflex
FILLS	Fluorescent imaging laser line scanning
FLIR	Forward-looking infrared imaging systems
FLOE	Fish Lidar, Oceanic, Experimental (NOAA's airborne fish lidar)
Fps	Frames per second
GigE	Gigabyte Ethernet
GIS	Geographic information system
GOOS	Global Ocean Observing System
GUI	Graphical user interface
IOOS	Integrated Ocean Observing System
MBES	Multibeam echo sounder
MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial Planning
NOAA	National Oceanic and Atmospheric Administration (USA)
PAR	Photosynthetically active radiation
ROV	Remotely operated vehicle
SBES	Single beam echo sounder
USV	Unmanned surface vehicle
UUV	Unmanned underwater vehicle
VICASS	Video image capturing and sizing system
VMS	Vessel Monitoring System
WFD	Water Framework Directive

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INTRODUCTION

This report presents an Inventory on Technology Innovations in marine environmental monitoring and assessment of fish stock and non-fishing recourses, aiming to provide recommendations to possible application of efficient modern monitoring technologies in Black Sea area in order to improve cooperation and data sharing between Black Sea countries.

The report is Deliverable DT1.2.1, elaborated within Group Activity T1, activity T1.2, in the period May 2020-January 2021, in accordance with the work plan of TIMMOD BSB-1029 project within the Black Sea Basin Program 2014-2020.

The report was developed as a collective effort of the 6 TIMMOD partners from the Black Sea region, from Bulgaria, Georgia, Moldova, Romania, and Greece, under the coordination of the Group Activity T1 Leader, BDCA, in cooperation with the Lead Beneficiary IFR.

Assessment of fish stock is the process of collecting, analyzing, and reporting demographic information to determine changes in the abundance of fishery stocks in response to fishing and, to the extent possible, predict future trends of stock abundance. Similarly, assessment of non-fish living resources (invertebrates, shellfish) requires estimation of the abundance, as well as analysis on all factors influencing the ecosystems. Managers use stock assessments as a basis to evaluate and specify the present and probable future condition of fishery and use of non-fish (shellfish) resources.

A comprehensive assessment of fish or shellfish resources requires long-term measurements and monitoring, aiming to provide data for achievement of the following three main objectives:

(1): Assessing status of stocks. Collect data on stock abundance (fish census count), fisheries catch, bycatch and other important observations to analyze all factors for assessing the current state and forecasting the future state of fishery, as well as of catchment of non-fish living resources.

Key parameters which are to be measured/monitored include

- fish or shellfish census count: biomass [*tones*] / specimen size distribution [*cm*], by category
- fisheries catch volume/mass [*tones*], including from illegal fishing
- bycatch volume/mass [*tones*], by species

(2): Assessing the impact of changing biological and physical properties of the coastal waters and continental shelf ecosystems which influence the sustainable productivity of the living marine resources.

Key parameters which are to be measured/monitored include physical, chemical, and biological parameters of water, and (where appropriate) of sediments:

- Physical: water temperature (*°C*), salinity (*‰*), turbidity (*ntu*), total suspended solids TSS (*mg/l*); physical parameters of sediments.

- Chemical: pH; conductivity (S/m), Biochemical oxygen demand (BOD); Chemical oxygen demand (COD); Dissolved oxygen (DO); Total hardness (TH); Heavy metals; Nitrate; Orthophosphates; Pesticides; Surfactants.
- Biological: ichthyo- and zoo-plankton composition; chlorophyll-a fluorescence; coliform bacteria, escherichia coli (E. coli); Ephemeroptera; Plecoptera; Mollusca; Trichoptera.

In addition, standard weather observations (wind speed, waves, precipitation, air temperature) are needed to complete assessment of factors influencing properties of marine waters and ecosystems.

(3): **Providing analysis and forecast (by numerical simulations) in order to assist management of marine living resources**, to produce estimates of impact of important factors on fishery management and sustainable use of non-fish resources. For example, assessment models estimate stock abundance from survey index and other data and calculate the fraction of the population removed by fishing or reduced due to poor environmental condition. Key tools used for the above purpose are:

- software for data handling and visualization, including recent cloud technologies and web base solutions,
- high-generation numerical simulation models,
- GIS tools, and other.

The importance of data collection and use of various ICT tools in assessment of stocks of marine living resource as a part of the holistic approach in fisheries management is illustrated here below on Figures 0.1-1 to 0.1-3.

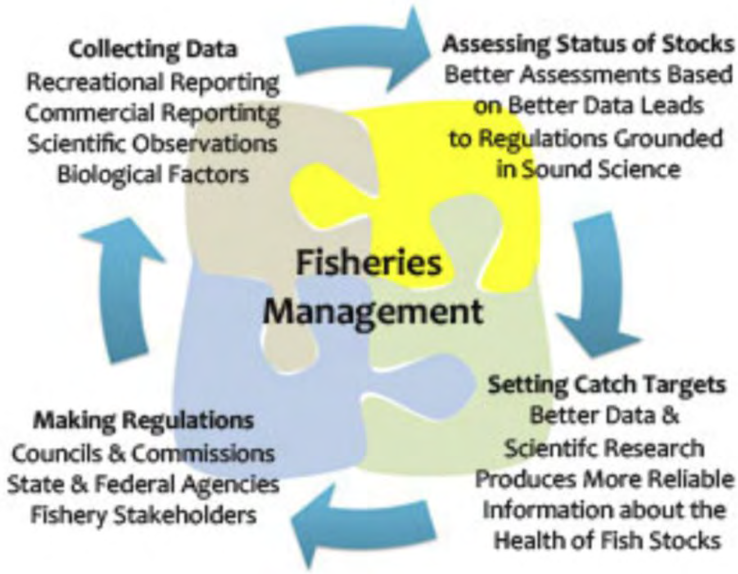


Figure 1.1-1 Fisheries management approach based on data collection and stock assessment

The EU system for fisheries controls is the vessel monitoring system (VMS), which is a satellite-based monitoring system, which at regular intervals provides data to the fisheries authorities on the location, course and speed of vessels. VMS is nowadays a standard tool of fisheries monitoring and control worldwide, but it was the EU which led the way, becoming the first part of the world to introduce compulsory VMS tracking for all the larger boats in its fleet. The EU legislation requires that all coastal EU countries should set up systems that are compatible with each other, so that countries can share data and the Commission can monitor that the rules are respected. EU funding is available for Member States to acquire state-of-the-art equipment and to train their people to use it.

New control technologies become crucial nowadays to ensure effective monitoring and control of fishing fleets and streamlined management of qualitative and reliable fisheries data. The Electronic recording and reporting system (ERS) is used to record, report, process, store and send fisheries data (catch, landing, sales and transshipment). The key element is the electronic logbook where the master of a fishing vessel keeps a record of fishing operations. The record is then sent to the national authorities, which store the information in a secure data base.

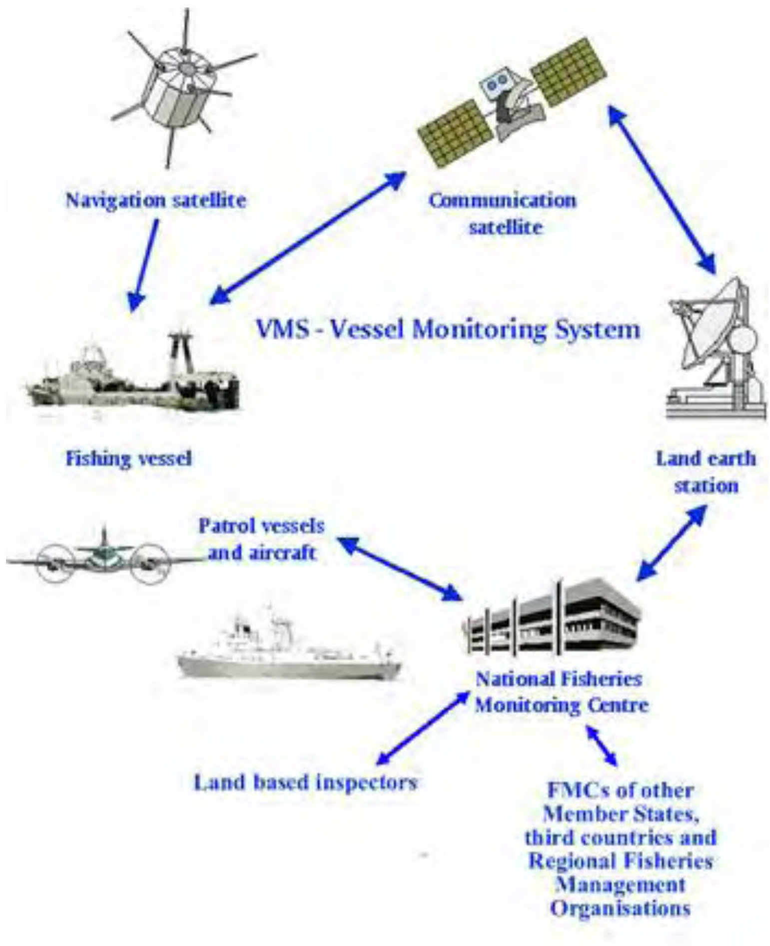


Figure 1.1-2 Electronic recording and reporting system (ERS)/Vessels Monitoring System (VMS)

VMS/ERS approach is also used in Black sea. In Romania the number of fish-boat going for fishing, as well as the course followed by the vessels registered in the fishing journal, is checked by two systems: the VMS (Vessels monitoring system) and the Integrated System for Observation, Surveillance and Control of the Traffic at the Black Sea SCOMAR. The coordinates of the fishing gears are also checked from logbooks and comparison is made with information received from the SCOMAR and VMS. The Bulgarian Fleet Vessel Register (FVR) contains and maintains information on registered fishing vessels including their gross tonnage and their maximum continuous engine power according to Council Regulation 26/2004. The information is being updated in real-time, and the data is submitted to DG MARE at the European Commission. The data on the Bulgarian fishing vessels registered in the FVR contains the information on: vessel length; gross tonnage; maximum main engine power; registration number; age of the vessel; the owner of the vessel; number of the active vessels during the year; days at sea.

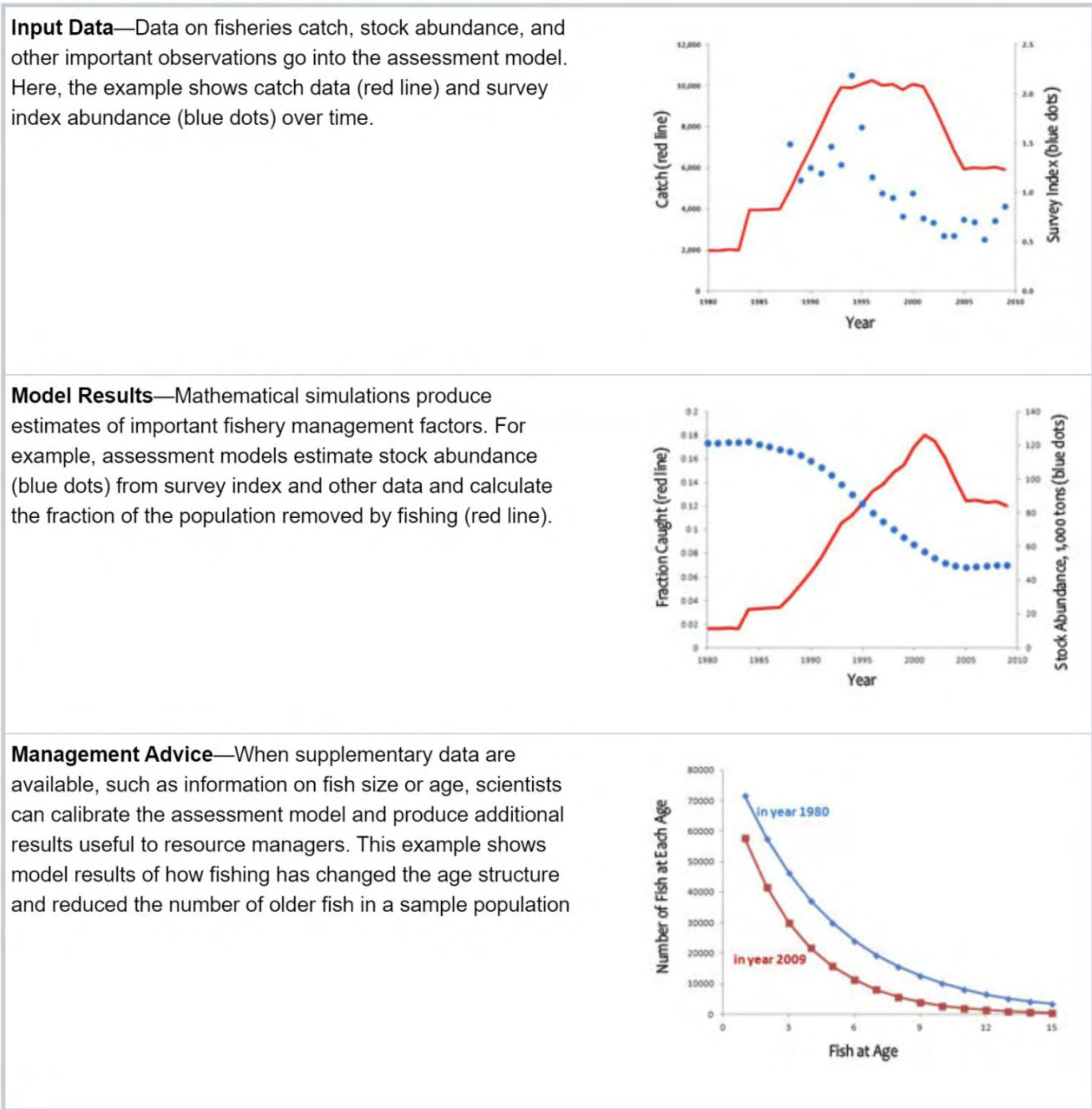


Figure 1.1-3 Integrated (data – model) approach to fish (and shellfish) stock assessment

Following the above classification of the 3 objectives and types of relevant monitoring for assessment of stock and of environmental parameters, the inventory and analysis presented in this report cover:

- new-generation sensors for in-situ measurements, presented by technology (e.g., acoustics, infrared), and by objective and type (e.g., nitrate sensor for WQ assessment, or high-resolution camera with imagery processing for fish census count)

- various sensor-carrying platforms, i.e., survey boats, buoys, satellites, autonomous surface vehicles, remote operated vehicles, including equipment for collection of samples from water, from sediments, or from shellfish or seaweeds (used for further laboratory analysis);
- remote sensing technologies, satellite imagery, aircraft-based sensor technologies, radar technologies, etc.
- multiple ICT tools including smart methodologies for image and data processing (e.g., satellite imagery); methods/tools of real-time measurements (e.g., radio telemetry, GPRS transfer); GIS tools; software for data handling and visualization, including recent cloud technologies and web base solutions; new generation high-resolution numerical simulation models.

Inventory and analyses in this report are presented in 3 main chapters:

Chapter 1 of the report presents a review on existing innovative technologies, already proven in operational conditions.

This review is based on collecting comprehensive information on existing technological breakthrough solutions and relevant technical and operational approaches. The mapping of existing technology innovations covers all geographical areas (all European seas, and the world ocean), as well as any innovative solutions relevant to monitoring of parameters concerning fish and shellfish abundance.

This analysis distinguishes between technological readiness levels (TRL 4 to 9) of innovations, separating technologies in research/testing/verification phase, and other used in operating practices with already proven efficiency. The latest are analysed in order to suggest appropriate modern technologies applicable in Black Sea.

Chapter 2 of the report is focused on review and analyses on good practices. The mapping of good practices is primarily focused (but not limited to) the Black Sea region. However, the focus is put on such practices that are suitable and can be replicated for the typical conditions of Black Sea. These good practices will be presented at the Thematic Transboundary Meeting 2 (in Thessaloniki Greece in 2021).

It is worth to note however, that further detailed analysis (including elements of environmental impact assessment and cost-benefit analysis) as well as selection and promotion of selected innovative technologies and best practices, will be carried out within TIMMOD Activity 1.3 and will be reported in deliverable DT1.3.1 "*Recommendations on adoption of appropriate technology innovation and best practices for marine environmental monitoring at Black Sea*". In addition, the recommended technology solutions will be discussed by the project consortium and stakeholders at 5 national workshops, best selected of them will be published in the internet site of the project, will be showcased, and therefore promoted for further replication in the Black Sea basin.

Chapter 3 presents future and emerging technologies (TRL 1 to 3, i.e., which are still in concept phase, but where serious potential for further application is expected). This special review gives a prospective view to next decades, as well as a long-term perspective for the suggested technological upgrade of fish and non-fish monitoring services, which is a basic requirement to provide sustainability of future regional cooperation in the Black Sea area.

The final section of the report presents conclusions and recommendations, summarizing findings of the inventory and analysis carried out by the international team of TIMMOD.

The analyses, conclusions and recommendations in this report are intended primarily for researchers, surveyors, decision makers, and relevant stakeholders concerned with fisheries and environmental protection of Black Sea, but at the same time this report provides valuable information that can be used by a wider range of public institutions, industry companies and the general public.

1. REVIEW ON LATEST INNOVATIVE TECHNOLOGIES IN ECOSYSTEM MONITORING, FISH AND SHELLFISH STOCK ASSESMENT

Monitoring programmes relevant to fish (or shellfish) stock assessments employ a variety of platforms from which equipment or sensors are deployed to measure the variables and parameters of interest. New technology and innovative methodologies have always changed the way in which we monitor our seas.

Two basic technology categories for marine monitoring are outlined:

- a particular sensor / methodology used to take the measurement (i.e., a multibeam sonar, a seabed camera, a chemical analysis of a taken sample).
- a platform from which a measurement is taken (i.e., a research vessel, a static observatory, or an unmanned automated vehicle)

In recent years, data collection and continuous monitoring of sea water and ecosystems have developed, with a rapidly increasing role for:

- remote sensing technologies, including satellite image processing and aircraft-based photo technologies
- advanced ICT tools for data processing (model data), visualization, analysis and forecasting for decision-making support.

All the above categories rapidly advance and it is essential to take the right technology for the task implemented, to understand the implications of using those technologies, .

An overview of innovative technologies in the above listed categories is outlined here below in this report.

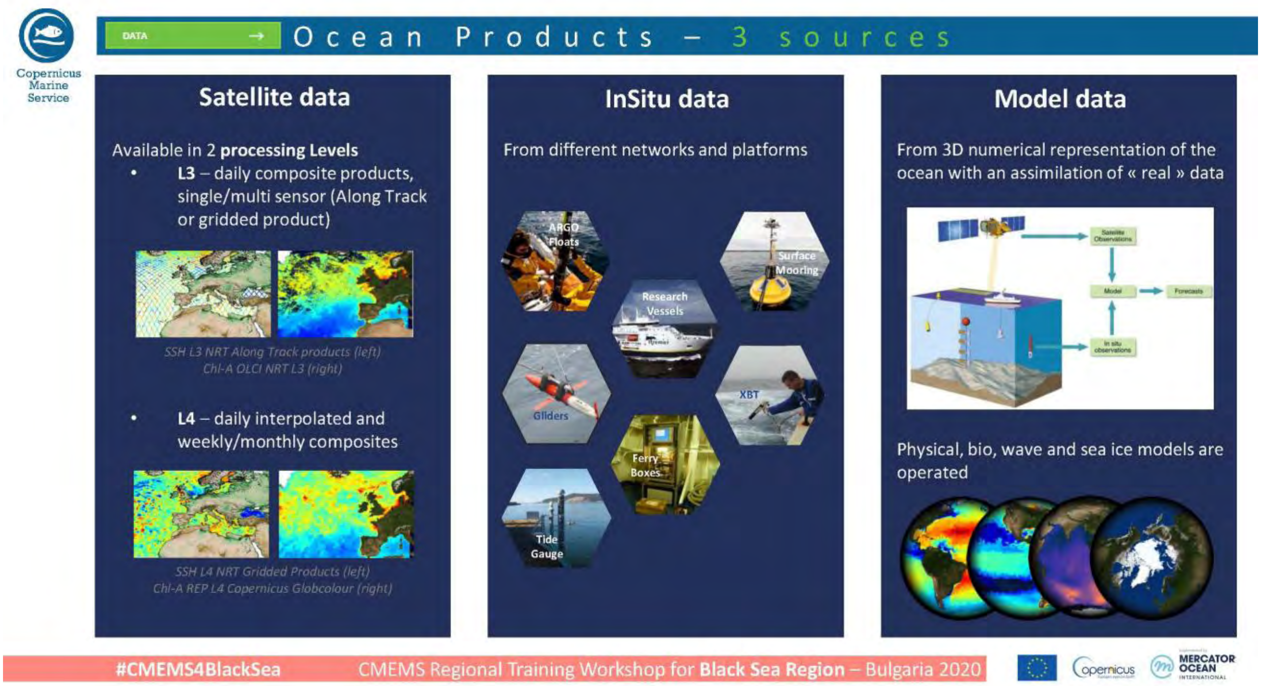


Figure 1.1-1 Three sources of ocean research data (Copernicus Marine Service) (https://marine.copernicus.eu/)

1.1 Innovative in-situ technologies. Advanced instruments, sensors and platforms.

Sustainable marine environment monitoring requires small-sized, more powerful sensors, multi-parameter at reliable accuracy, interoperable standardized protocols, low maintenance and user-friendly operational interface.

The challenges are related to data sharing and sensor integration with increasing numbers and diversity of sensors and the volume of numerical data produced.

1.1.1 Water Quality monitoring instruments (physical, chemical and biological parameters)

Marine water quality monitoring is performed for compliance with EU and national regulatory issues, trend detection, model validation and assessment of the effectiveness of adopted policies. Marine water quality monitoring requires clearly set objectives and sampling design. A wide range of methods is available for the process and analysis of data sets. Integrated approaches should be carried out including socio-economic aspects. Most international conventions and directives include marine monitoring programs.

Marine environment monitoring and fish marine living resources exploitation need 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 operate industrial process supervision. New generation water quality sensors for marine environment monitoring provide measurement data for the chemical, biogeochemical, physical, and biological parameters and allow measurement of several parameters by one instrument. A wide range of instrumentation are interoperable and are deployed on mooring lines or carried on platforms such as profiling floats and drifting buoys, ROVs, AUVs or ASVs.

The following WQ parameters are of interest concerning fish and other marine living resources assessment:

- Physical: water temperature (^oC), salinity (*‰*), turbidity (*ntu*), total suspended solids TSS (*mg/l*); current speed (*m/s*), physical parameters of sediments.
- Chemical: pH; conductivity (*S/m*), Biochemical oxygen demand (BOD); Chemical oxygen demand (COD); Dissolved oxygen (DO); Total hardness (TH); Heavy metals; Nitrate; Orthophosphates; Pesticides; Surfactants.
- Biological: ichthyo and zooplankton composition; chlorophyll-a fluorescence; coliform bacteria, escherichia coli (E. coli); Ephemeroptera; Plecoptera; Mollusca; Trichoptera.

Physical parameters sensors

Conductivity, temperature, and depth sensors have been in use for many decades, suspended on mooring lines, mounted to ship-board rosettes, and integrated into AUVs. Sensors on autonomous platforms can also measure physical variables, such as current velocity.

Acoustic Doppler Current Profilers (ADCP) are widely used on research vessels, moorings, and more recently on AUVs including gliders although they are not routinely installed on gliders because of power requirements and data processing challenges.

Multi-beam echosounders, sidescan sonars, and sub-bottom profilers are now widely used, not only for hydrographical surveys, but also to study fish schools and seabed habitats. Sonars are also often fitted on Autonomous Underwater Vehicles. The weight and power requirements of these sensors demand large AUVs that have short endurance and require research vessel support, but they have still proven the concept of automating some survey applications.

Turbidity sensors have the potential to provide a deeper understanding of particulate nutrient fluxes that can easily be obtained by grab sampling. High turbidity has a number of detrimental effects on aquatic ecosystems: decrease in light penetration (limiting plant growth), fish movements and the ability of predatory fish and birds to see their prey. High turbidity means high concentration of suspended solids, which can harm fish and other aquatic fauna. These suspended solids in the process of settling down to the ocean bottom have a choking effect on bottom dwelling organisms and aquatic habitats.

Physical indicators of water quality monitoring are typically assembled as multiparameter measuring instrument. Here below some example instruments are presented.

Aqua TROLL 200(https://in-situ.com/) includes water depth and pressure, conductivity and temperature, or Aqua TROLL 600 Multiparameter Sonde that measures temperature, pressure, conductivity, pH/ORP, Rugged Dissolved Oxygen, turbidity, chlorophyll a, Phycocyanin, Phycoerythrin, Rhodamine, ammonium, chloride, and nitrate (Figure 1.1-1).

Figure 1.1-2 Multiparameter monitoring sonde "In-Situ - Aqua TROLL 600"
(water depth, pressure, conductivity, and temperature, *https://in-situ.com*)

A typical example of a turbidity sensor is the optical backscatter sensor OBS501- Smart Turbidity Meter with Antifouling Features, produced by Campbell Scientific (Figure 1.1-2). The OBS501 is a submersible turbidity probe with active antifouling capabilities for better measurements in biologically active water with both high and low turbidity. It outputs an SDI-12, digitally processed signal that many of our data loggers can measure.

Figure 1.1-3 Optical backscatter sensor OBS501
(https://www.campbellsci.com/obs501)

Acoustic Doppler Current Profilers (ADCP), or Acoustic Doppler Profilers (ADP) are now widely used on research vessels, moorings, ASV, to provide data on littoral current velocity profiles, together with water temperature, water depth, and other parameters. Most popular Doppler profilers are distributed by the companies Teledyne and SonTek. Recent (2020) models of Doppler profilers are presented here below.

The Sentinel V, the first of Teledyne series of V products, is loaded with new features and capabilities destined to redefine and revolutionize user's profiling activities. Sentinel V provides multiple simultaneous sampling strategies: now, two users with vastly different interests in the same environment can share a single ADCP to accomplish the data collection goals of both, essentially doubling hardware output. Wireless functionality allows users to fly through their data download and instrument reconfiguration, without cables. Basic features of Sentinel V are as follows.

- Available in 3 profiling ranges; 20m, 50m, 100m
- Multiple simultaneous sampling stages
- Off-the-shelf battery operation
- High-speed wireless data download
- Record every measurement
- Multiple bandwidths
- Captured O-rings
- Flood-resistant electronics chamber
- Increased portability
- One-touch activation
- Individual transducers
- real-time and bottom track options, with data rates up to 16Hz

Sentinel V ADCP is illustrated on Figure 1.1-4 (left).

The HydroSurveyor is an Acoustic Doppler Profilers (ADP®) system designed by SonTek (a Xylem brand) to collect bathymetric, water column velocity profile, and acoustic bottom tracking data as part of a hydrographic survey. The two key components of the system are the HydroSurveyor Acoustic Doppler Profiler platform, and the powerful, yet user-friendly, data collection software. With the HydroSurveyor platform, SonTek offers a 5-beam depth sounding device, with built-in navigation, full water column velocity (currents) profiling, full compensation for speed of sound, and integrated positioning solution. Main features of HydroSurveyour include:

- Sound speed integration and interpolation (with CastAway-CTD)
- Speed over ground (Acoustic Bottom Tracking)
- 5-beam depth soundings (50° swath)
- Water column velocity (currents) mapping
- Automatic data gridding and interpolation
- 360° compass and two-axis tilt sensor
- Interface for customer-supplied GPS and/or heading sensor

HydroSurveyour ADP is illustrated on Figure 1.1-4 (right).

Sentinel V ADCP (Teledyne)
http://www.teledynemarine.com/rdi#

HydroSurveyor ADP (SonTek)
www.sontek.com/productsdetail.php?HydroSurveyor-13

Figure 1.1-4 Recent makes of Acoustic Doppler (Current) Profilers

Chemical parameters sensors

Chemical parameters of seawater of interest are pH; conductivity (S/m), Biochemical oxygen demand (BOD); Chemical oxygen demand (COD); Dissolved oxygen (DO); Total hardness (TH); Heavy metals; Nitrate; Orthophosphates; Pesticides; Surfactants, and other.

A typical example of multi-sensor WQ instrument for measuring chemical (and physical or biological) parameters is the EXO multiparameter sonde. EXO 2 is the latest generation of water-quality sondes marketed by YSI Inc, Xylem, U.S.A., and are designed as a replacement for the six series family of sondes. Overall, the EXO series sondes feature updated electrical connectors; strengthened housings for sonde and sensors; digital sensor technology with onboard signal processing and internal memory; and a centralized, antibiofouling wiper for improved long-term monitoring. The EXO2 (Figure 1.1-5) has seven sensor ports (the center port is generally used for the central wiper when it is installed on the sonde), and a six-pin expansion port for future interfacing with third party sensors.

Figure 1.1-5 EXO2 multiparameter water quality sonde
(https://www.ysi.com/exo2)

The sondes have several communication protocols, including Bluetooth wireless, Universal Serial Bus (USB), RS‑485, RS‑232, and SDI‑12. EXOs can be operated with a computer, the EXO handheld, or a data logger. Table 1-1 lists the EXO2 sonde manufacturing specifications.

Table 1-1 EXO2 multiparameter sonde technical specification

Parameters	Characteristics	Application
- Conductivity and Temperature - Dissolved Oxygen (optical) - fDOM (Fluorescent Dissolved Organic Matter, surrogate for CDOM) - pH or pH / ORP Depth (integral) - Total Algae (Dual-channel Chlorophyll and Blue-green Algae) - Turbidity - PAR (Photosynthetic Active Radiation) - Single or Dual sensor	- Medium: Fresh, sea or polluted water - Depth: 250m - Temperature -5 to +50°C (Operating), -20 to +80°C (Storage) - Communications: Bluetooth wireless technology; USB cable RS-485, RS-232, SDI-12 - Software KOR® - Dimensions: Diameter: 7.62 cm, Length (no depth): 71.10 cm, Weight: 3.60 kg (batteries and sensors installed) - Power: External: 9 to 16.5 V DC; Internal: 4 D-size alkaline batteries - Sensor material: rugged titanium housing	Water quality monitoring in oceanographic, estuarine, or surface water

Another example for a new generation multiparameter instrument can be given by the MPx Autonomous multi-parameter probe for Conductivity, Temperature, Depth, Turbidity, Fluorescence, Dissolved Oxygen, pH (NKE Instruments, https://swaleocean.co.uk/nke/). This probe is used for water quality control, environmental survey, and monitoring in shellfish farming. Main features include:

- Depth: range from 0 to 20m, accuracy: <0.06m, resolution: 0.006m
- Temperature: range from -5°C to +35°C
- Conductivity: range from 0 to 70mS/cm, ±0,05mS/cm in the range 10 to 60mS/cm
- Salinity: 2 to 42 PSU, accuracy ±0.1 PSU
- Dissolved Oxygen: using Aandera Optode optical sensor
- Saturation: 0 to 120%, accuracy <5%, resolution: 0.01%
- Concentration: range from 0 to 16mg/L, accuracy <5%, resolution 0.01%
- Turbidity: using Seapoint optical sensor range (configurable at works) 25, 125, 500 or 750 FTU (non-linear above, max. 1500 FTU) Linearity <2%, deviation 0-750 FTU
- Fluorescence: using Turner Design optical sensor Chlorophyll-a
- pH: range 0 to 14pH, resolution 0.0003pH
- Time: Internal clock with calendar (clock drift<1mn/month)
- Energy autonomy: 18 months battery life, for a MP6 version at 5min recording rate
- memory: 4Mb, >24 months at 5mn recording rate, 1 month at 10s recording rate, for a MP7 version
- Mechanical characteristics: max. sizes: diameter 95mm, length 440mm, weight in the air 2,5kg

MPx Autonomous multi-parameter probe is illustrated by a photo on Figure 1.1-6

Figure 1.1-6 MPx Autonomous multi-parameter probe
(NKE Instruments, https://swaleocean.co.uk/nke/)

Polycyclic aromatic hydrocarbons (PAHs) and chromophoric dissolved organic matter (CDOM)

Optical instruments have a successful record in measuring major chemical and biogeochemical parameters of the marine environment with great potential for multifunctional observations. Techniques utilizing inherent optical properties like fluorescence and absorption are potentially applicable in long-term monitoring approaches. These properties are independent from ambient light conditions and can provide information about many components of the marine environment. Contaminants are among those, as well as dissolved and particulate constituents of the biological carbon cycle such as polycyclic aromatic hydrocarbons (PAHs) and chromophoric or colored dissolved organic matter (CDOM). PAHs are part of the most carcinogenic, mutagenic, and toxic contaminants found in the marine environment. To evaluate their impact on marine ecosystems, a reliable and continuous monitoring of these substances is furthermore necessary.

Facilitating such observations, a new generation of multi-parameter instruments has been invented within European Union funded project NeXOS (Next generation Low-Cost Multifunctional Web Enabled Ocean Sensor Systems Empowering Marine, Maritime, and Fisheries Management, www.nexosproject.eu).

Fluorescence sensors provided with a matrix of wavelength combinations deliver detailed information on both water constituents and relevant contaminants which are optically active in the respective spectral regions at the same time. These include PAH and FDOM (the fluorescing fraction of CDOM), both precisely detected by their fluorescence signatures (Carstea, 2012; Ferdinand et al., 2017). However, these signatures do partially overlap and may lead to ambiguities. To overcome these, matrix fluorescence concept offers a greater capacity towards enhanced discrimination. This approach is flexible in application and can be adapted to different target components or new, even unknown contaminants.

Figure 1.1-7 MatrixFlu-UV optic fluorescence sensor TriOS
(www.nexosproject.eu)

Within the NEXOS project sensor system based on the Ecosystem Approach to Fisheries (EAF) was developed that builds upon the RECOPESCA (A new example of participative approach to collect *in situ* environmental and fisheries data) concept and technologies. The system consists of STPO2 dissolved oxygen sensor and STPFluo fluorescence sensor (both sensors are selected for their application to fish population assessment), and in hull sensor for the temperature measured during the fishing activities. The so-called concentrator of data is installed on board of fishery vessels, which is an electronic board with microprocessor, memory storage, software embedded and a radio transmitter/receiver circuit board, a GSM/GPRS modem and collects data measured from the sensors installed on the fishing net or on trawl door (fig.1.1-8).

a) b)

Figure 1.1-8 Innovative EAF system: concentrator of collected data (a) and dissolved oxygen and fluorescence sensors (b)
(www.nexosproject.eu)

Biochemical sensors

There are many types and many applications of sensors for chemistry and biology. Nutrient cycles (nitrate, phosphate, and silicate) participate in carbon dioxide (CO_2) sequestration in the ocean and are linked with the global carbon cycle. Observing their concentration in the Black Sea will allow researchers and decision maker to better understand the major biogeochemical cycles.

The optode sensors are commonly used to measure oxygen (Bittig et al., 2015, 2018) and there is also work to further extend these sensors to measure CO_2 (Atamanchuk et al., 2014;

DeYoung et al., 2018). These sensors are small, operate at low power and have good stability for multi-year deployments. The stability characteristics for the CO_2 version of the sensors have yet to be demonstrated. Another approach to measuring CO_2 is through pH, which requires some knowledge of how alkalinity relates to CO_2 but avoids direct measurement of CO_2.

The most widely used method to detect nutrients is based on colorimetric detection using traditional, discrete shipboard-sampling techniques and onboard analyses (Ma et al., 2014). Over the past decade, significant progress has been made in developing in situ nutrient sensors, and a few are commercially available to measure nitrates, phosphates, and silicates (Legiret et al., 2013; Worsfold et al., 2016). For autonomous operations, using reagents introduces challenges. The reagents must be replenished regularly, their stability is of concern, their cross calibration with standards needs to be done, and they have potential limitations from chemical interferences and refractive effects (McKelvie et al., 1997). Optical sensors can also measure alkalinity (pH), using a pH-sensitive dye and a wide-band emission LED. The technique is straight forward but sensitive to temperature, which can cause significant errors if the sea water temperature differs significantly from that of the sample container.

Biological parameters

Biological parameters of interest in seawater are: ichthyo- and zoo-plankton composition; chlorophyll-a fluorescence; coliform bacteria, escherichia coli (E. coli); Ephemeroptera; Plecoptera; Trichoptera.

Zooplancton

Several devices allow imaging of zooplankton (Cowen and Guigand, 2008; Picheral et al., 2010). Active acoustics can be used to look at biomass, including plankton (Benoit-Birdand Lawson, 2016), but more detailed analyses of individual cells are done with flow cytometers (Brownlee et al., 2016; Hunter-Cevera et al., 2016). The imaging flow cytobot (IFCB) (Sosikand Olson, 2007) developed by WHOI is an example of a commercially available system that has been modified to work in autonomous vehicles (https://mclanelabs.com/imaging-flowcytobot/). Its size and depth limitations (102 cm length and 40 m maximum depth) generally make it usable on ASVs.

A comprehensive review of other sensors for monitoring plankton illustrates the many alternative techniques and their commercial availability (Lombard et al., 2019). What is notable in that summary and the literature of sensor providers is the increasing interest and capability for operations on autonomous vehicles. Examples are the IFCB by McLane Labs, the LISST-200by Sequoia:
(https://www.sequoiasci.com/product/lisst-200x/), and the UVP6-LP by Hydroptics:
(http://www.hydroptic.com/index.php/public/Page/product_item/UVP6-LP).

Phytoplankton

The Continuous Plankton Recorder (CPR) is an instrument used to sample and to continuously collect plankton. Analysis is done in two ways: Determination of the Phytoplankton Colour Index (PCI) and Microscopic analysis.

Phytoplankton emits light in the red portion of the spectrum called fluorescence. Monitoring fluorescence can help scientists describe the physiological state of phytoplankton, determine the cause of population decreases, and make accurate estimates of primary productivity. For in situ monitoring fluorescence sensors or fluorometers are used to induce chlorophyll fluorescence by shining a beam of light of the proper wavelength into the water and then measuring the higher wavelength light which is emitted.

<u>The ECO-PAR™ sensor</u> provides highly accurate measurements of photosynthetically avaiable radiation (400–700 nm) in all aquatic environments. Equipped with quality precision optics and proven Bio-wiper™ technology, the ECO-PAR™ sensor can be deployed for extended periods without a reduction in data quality caused by biofouling.

Figure 1.1-9 ECO Photosynthetically Active Radiation (PAR) sensor

Microbes and higher organisms

An emerging field for marine biological assessment is nucleic acid analysis, especially the use of environmental DNA (eDNA). The number of sensors demonstrating successful eDNA detection has increased rapidly in recent years, for example MBARI's Environmental Sampling Processor (ESP) (Beja-Pereira et al., 2009; Foote et al., 2012; Scholin et al., 2017). This detection method has become an effective tool for genetically monitoring species presence and extending the work to address abundance, diversity, and functionality of both microbes and higher organisms (Thomsen et al., 2012; Scholin, 2013; Kelly et al., 2014). This evolution has led to new studies of ecology and a framework for understanding this ecology (Barnes and Turner, 2016). One challenge in these applications is in building eDNA analysis systems that can work on autonomous vehicles; however, recent steps toward a full in situ eDNA measurement system onboard an autonomous vehicle involves collecting and preserving samples for laboratory analysis (Scholin et al., 2017; Birch, 2018; Evans et al., 2019) (Figure 1.1-10).

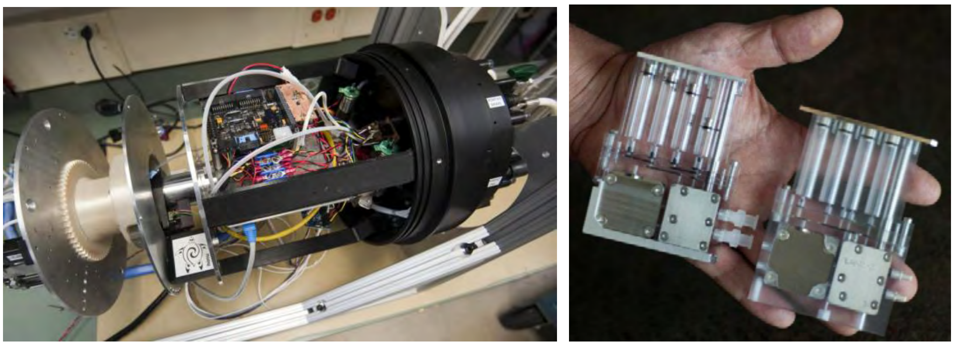


Figure 1.1-10 Inside of the latest model of the third generation ESP: (a) Single cartridges use with self-contained reagents (b)
Source: https://www.mbari.org/ Photo: Todd Walsh © MBARI.

The MBARI's third generation (3G) ESP initial goal was to be mounted on an autonomous underwater vehicle (AUV); giving the sensor mobility. The scientific team developed the idea of a "cartridge" where all reagents to be carried on each cartridge creating a self-contained, use-once entity arranged around a toroid ring. They developed a 60-cartridge "turbine" with each cartridge individually accessed and processed at a shared processing station. Cartridges are of two types: archival and lyse-n-go. Archival cartridges filter water, apply preservative, and await recovery once the vehicle's mission is complete. Lyse-n-go cartridges are more complex, requiring heater circuitry and slightly more convoluted fluid pathways through the cartridge. The goal of these cartridges is to create homogenate and then pass that homogenate off the cartridge to a downstream analytical processing module. Latest work of the team involves collaborators to develop a Surface Plasmon Resonance (SPR) module, a digital droplet PCR (ddPCR) module, and a Total Internal Reflection Fluorescence (TIRF) module. (https://www.mbari.org/technology/emerging-current-tools/instruments/environmental-sample-processor-esp/esp-how-it-works/)

DNA-based monitoring

DNA metabarcoding is an efficient method for measuring biodiversity, but the process of initiating long-term DNA-based monitoring programs, or integrating with conventional programs, is only starting. DNA increases the number of metazoan species identified and provides high resolution taxonomy of groups problematic in conventional surveys (e.g. larval echinoderms and hydrozoans). Metabarcoding also generally produces more detections than microscopy, but this sensitivity may make cross-contamination during sampling a problem. In some samples, the prevalence of DNA from large plankton such as krill masks the presence of smaller species.

1.1.2 *Sensor-based, Acoustic and Hydro-acoustic technologies for fish and non-fish stock assessment*

Recent studies suggest that if catches in all of the world's fisheries could be adjusted to meet scientifically determined targets, and if fishery economics could be optimized, fisheries could produce much more food and profits while at the same time increasing the number of fish left in the water for keeping ocean ecosystems healthy (Costello et al., 2012; Costello et al., 2016; Gaines et al., 2018). That is why the exact estimations of the stock biomass, and of catch and bycatch are among the priorities of monitoring of fish and shellfish resources.

In fishery, acoustic techniques are well known and used daily for biomass assessment by fishery scientists through echo-integration and isolated fish target strength measurement with split-beam techniques, such as single beam echo sounders (SBES) calibrated by standardized methods.

Fish density estimation using acoustic waves has been under investigation for almost 70 years (Trout et al., 1952; Simmonds and MacLennan, 2008). Martignac et al. (2015) presented review of development of the acoustic systems during the last years. **Acoustic systems** are the only way to penetrate the aquatic environment over great distances. Echo-sounders are electronic devices that transmit acoustic pulses through a transducer into water. When a pulse is emitted into the environment, it spreads until it meets a target with a different density from the propagation environment. Thus, fish and other objects can be detected (Simmonds and MacLennan, 2005). The acoustic pulse is reflected from this target and returns to the transmitter. The transducer acts as a receiver, detecting some of the returning energy. Echosounders can emit acoustic pulses at several frequencies, but only acoustic waves of the initially emitted frequency are received (Lucas and Baras, 2000). The detected acoustic echoes are displayed on an echogram, on which target echoes may be represented by coloured patches which colour scale refers to the strength. Hydroacoustic methods are widely used in fisheries management to monitor fish stocks efficiently because they are quantitative, non-invasive, fast, and synoptic (Foote 2009). They convert physical measurements into relevant ecological units describing the fish population (Trenkel et al. 2011), minimizing the disturbance on its behaviour or its integrity in comparison with capture methods. Echosounder systems provide a remote sensing device to monitor the distribution of pelagic environment, typically plankton and fish distribution (Simmonds and MacLennan, 2005). However, the main limit to hydroacoustic tools is their difficulty in identifying species. Nevertheless, limitations of these methods have been proved (Walters et al. 2005) and have led managers and scientists to develop others monitoring methods, such as video-counting (Perrier et al. 2010). So, despite their limits, notably in species identification, hydroacoustic methods have been increasingly used in fish ecology studies at sea (Kracker, 2007), providing more accurate monitoring of migratory fish (Taylor and Elison, 2010). About ten years ago, a **dual-frequency identification acoustic camera**, the DIDSON (Sound Metrics Corp., Lake Forest Park, WA, USA) (Belcher et al. 2001), appeared enabling more accurate monitoring of migratory fish due to better species identification. This technological improvement leads to the development of a new generation of hydroacoustic devices: the acoustic cameras. This innovation is now exploited by several companies which also tested high-frequency devices in fisheries science topics, such as the **Blue View Technologies Pro-Viewer D900** (Cronkite et al., 2008) or the **Kongsberg Mesotech Ltd. M3 sonar** (Melvin et al., 2012). Nevertheless, whatever hydroacoustic method is used, it is restricted to a population level, as individual fish are not sampled, preventing analysis of life-history strategy through individual studies.

Initially designed for military purposes, **dual-frequency identification sonar (DIDSON)** has been used in environmental management for a decade. The Dual-Frequency Identification Sonar (DIDSON) has sufficiently high resolution and rapid refresh rate that it can substitute for optical systems in turbid water where optical systems fail (Belcher et al., 2002). This acoustic camera uses higher frequencies and more sub-beams than common hydroacoustic tools, which improves image resolution and then enables observation of fish morphology and swimming behaviour. The ability to subtract static echoes from echograms and directly measure fish length improve the species-identification process. However, some limits have been identified, such as automatic data set recording and the low range of the detection beam, which decreases accuracy, but efficient tools are now being developed to improve the accuracy of data recording (morphology, species identification, direction, and speed). The new technological properties of acoustic cameras, such as the video-like visualization of the data, have greatly improved monitoring of fish populations (abundance, distribution, and behaviour), helping fisheries managers and researchers in making decisions.

Besides these traditional echosounders that form 2D images of the pelagic environment by utilizing depth and vessel displacement information, new multibeam systems offer finer-scale 3D images with an additional transversal dimension.

Figure 1.1-11 shows improvement of fishery research hydroacoustic technologies over time, while Figure 1.1-12 depicts typical examples of the 3D structures which appear more complex with a multibeam echosounder than captured through a 2D echosounder. The 3D image (multibeam echosounder) is at finer scales and provides description of fish schools in the water column.

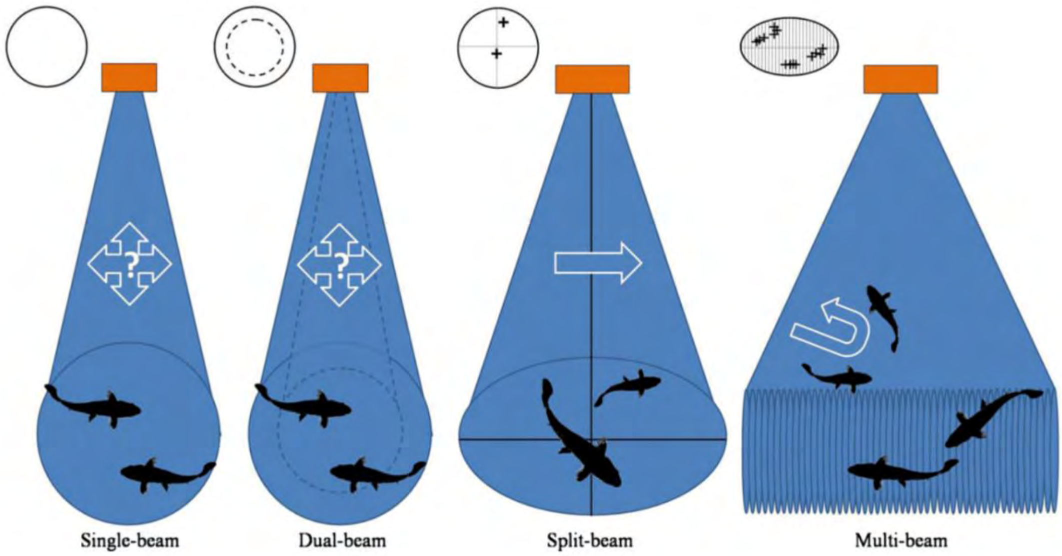


Figure 1.1-11 Improvement of fishery research hydroacoustic technologies over time

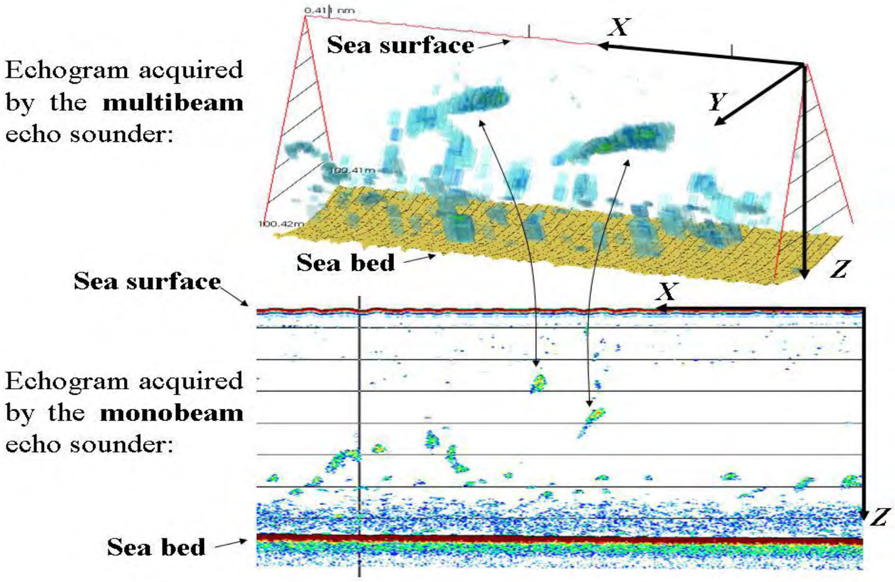
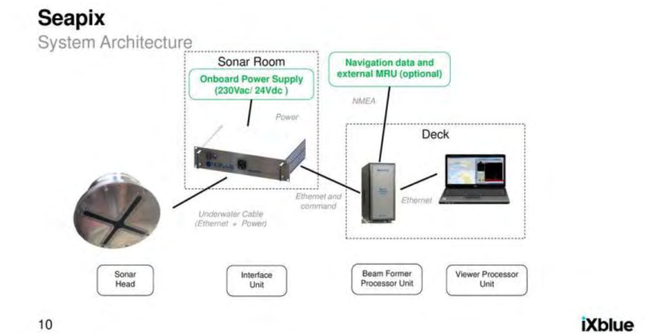


Figure 1.1-12 Multibeam echosounder (top) versus a mono-beam echosounder (bottom)
(redrawn from Lefort et al., 2012)

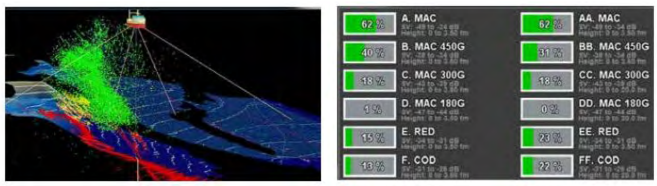
The application of the new opto-acoustic systems for fish monitoring in the Black Sea agrees with the recommendations, made by the Scientific, Technical and Economic Committee for Fisheries (STECF) of EU. In 2015, In the STECF 2015/15-16 report for the Black Sea is written: “STECF considers that it is desirable that demersal and hydro acoustic surveys are expanded to cover a greater proportion of the Black Sea and be conducted annually”. STECF also considers that “current assessments are hindered by the lack of internationally coordinated hydro-acoustic surveys for sprat, whiting, horse mackerel and anchovy and demersal internationally coordinated trawl survey for turbot, red mullet, piked dogfish and thornback ray. Moreover, there is a general lack of landings data, catch at length and catch at age data and catch per unit effort (CPUE) from Georgia and Russia. The Black Sea assessments will benefit from an internationally coordinated data collection program for catch data, covering the entire Black Sea”.

Multibeam echo sounders (MBES) have considerable advantages over conventional fishery SBES. First, they offer a much larger volume coverage (120° athwartship aperture for the MBES versus 7° to 12° for the standard SBES). This then allows precise positioning of athwartship fish detection thanks to a small angular beam aperture of, between 0.5° to 2°. Small beam aperture and lobe reduction enable near-bottom fish to be detected.

For example, three-dimensional analysis of the geometric parameters of fish schools that further develops the geometry-based school identification methods already in place for single beam echo sounders. These morphological indicators might be height, width or elongation of the school, the volume backscattering coefficient, or, more recently, the internal density structure of the school as the rate of vacuoles. Improvement in volume coverage as well as angular and range resolution significantly increase the number of individual echoes in comparison with standard SBES. This higher detection value allows statistical analysis of fish echoes to be considered. This may provide a new insight into fish shoals in terms of density or multi- species composition. Finally, volume analysis of the school and its evolution over time allows school dynamics to be studied and to evidence some collective behaviour such as avoidance strategies. All these features for water column and bottom analysis and the building of 3D space and time-referenced databases, provide scientists with new relevant information for fish classification and entire ecosystem management.



a) SeapiX-R system architecture



b) Geographic Biomass Analyzer processing

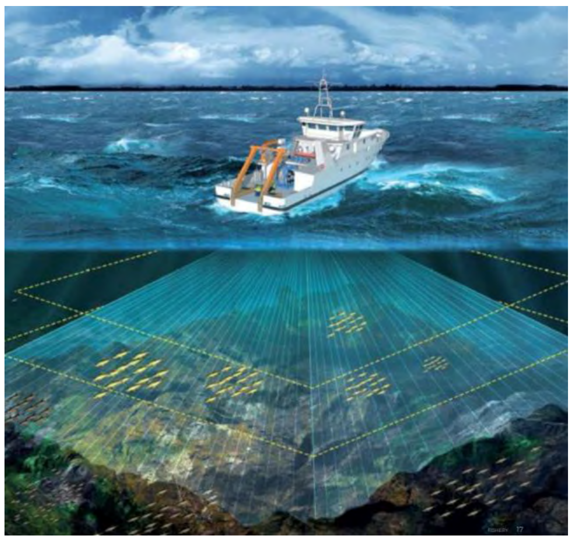


Figure 1.1-13 SeapiX-R Volume 3D sonar for fishery research
(Source: https://www.ixblue.com/)

The innovative multibeam multiswath echosounder SeapiX provides high level of sensitivity, directivity, and accuracy. As a military technology covered by a number of patents, SeapiX is the first compact civilian system comprising a dual Mills Cross multibeam sonar transducer (fig.1.1-13). This technology provides unique volume coverage and the highest volume resolution. Split beam is processed in all individual beams with both real-time phasic and amplitude measurements. Its array geometry provides a unique target positioning accuracy of +/- 0.15°, making its split beam calculation the most accurate in fishery acoustics.

SeapiX-R can be hull mounted with it high-seas tried and tested stainless steel housing or used in a mobile configuration with its lightweight composite materials and fanless compact PC (SeapiX-P). The configuration gives opportunity for vessel surveying and in situ monitoring (buoys, ASV, etc.).

SeapiX-R key features are:
• Water column echo-integration and target strength measurements with split beam, fully stabilized
• 120° X 120°, volume coverage, downward-looking or side-looking for near-surface survey
• 3D shoal behavior and fish avoidance study
• Real-time species classification
• Factory calibrated, in situ calibration,
• Raw data recording, HAC and EVD exports for Echoview post processing
• Acoustic dynamics of 139 dB

SeapiX-R provides accurate water column coverage, a real-time full 3D biomass assessment and bathymetry from shallow to deep waters and provides unique sea-tested fish classification results for demersal or pelagic species. Thus, with real-time visualization and realistic quantitative and qualitative biomass distribution, skippers can make strategic fishing decisions and conduct more efficient and selective fishing operations. (fig.1.1-14)

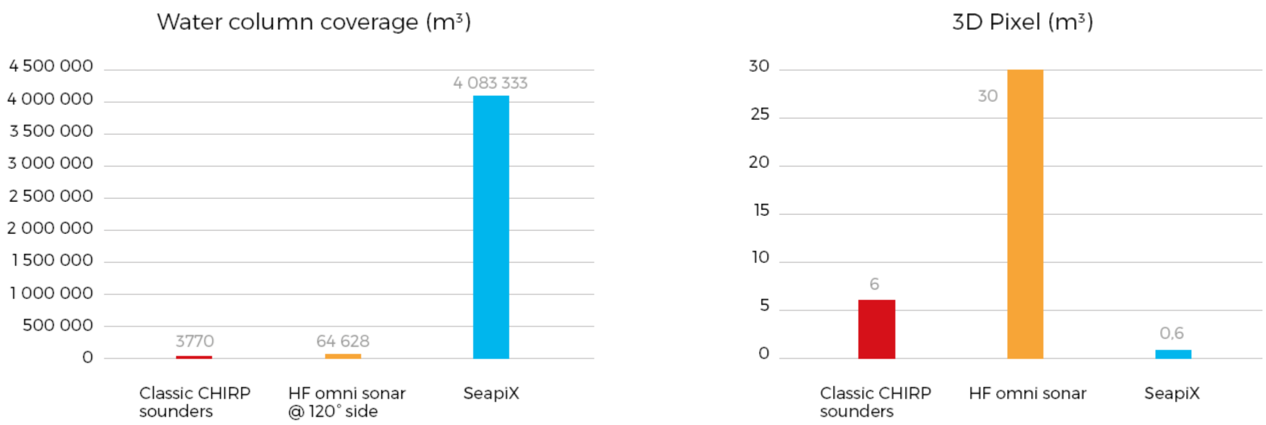
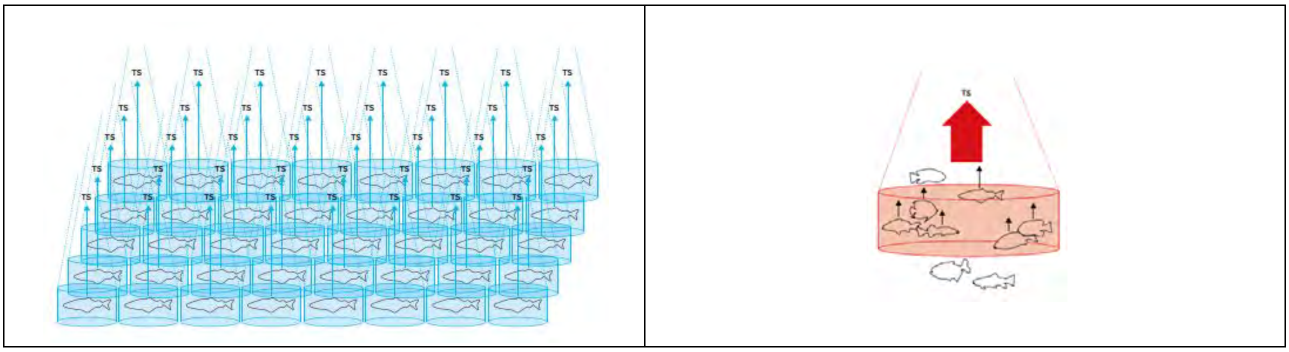


Figure 1.1-14 SeapiX-R water column coverage comparison.

Fish discrimination and fish classification is one of the most challenging goals for fishery acoustic devices. The innovative 3D sonar technology provide improved “split beam” method in order to better discriminate fish species and weights, providing researchers with the ability to carry out classification through postprocessing operations. The high resolution is a key feature to the “fish by fish” process that brings “Volume Echo Integration” (VEI) of an entire shoal into very small 3D pixel boxes (called “voxels”). The smaller the voxels are, the more individual fish measurements are accurate. To comply with this requirement, SeapiX provides elementary voxels of 0.6 m3 each, ensuring a realistic fish backscattering echo level related to each individual (fig.1.1-15).



SeapiX-R's True target strength (TS) measurements of individuals in each of the 128 narrow split beams

Standard split beam sounder, confusion of TS measurements of individuals, providing volume backscattering strength (SV) values most of the time

Figure 1.1-15 SeapiX-R 3D "Volume Split Beam" technology for biomass discrimination
(Source: https://www.ixblue.com/)

Deployed in many fisheries worldwide, SeapiX provides unique sea-tested classification results, for both pelagic and demersal fish species. An example performance of SeapiX demonstration of an Alaskan fishing trip on board the fishing vessel "Alaska Victory" in species discrimination is given on (Figure 1.1.3-3). Based on 1200 metric tons caught through 45 tows, the SeapiX GBA classification tool achieved a 11% accuracy rate for Atka mackerel, 6% for redfish and 5% for Pacific cod. For every tow, the results were compared to National Oceanic and Atmospheric Administration (NOAA) scientific findings and Geographical Biomass Analyzer (GBA) samples (fig. 1.1-16).

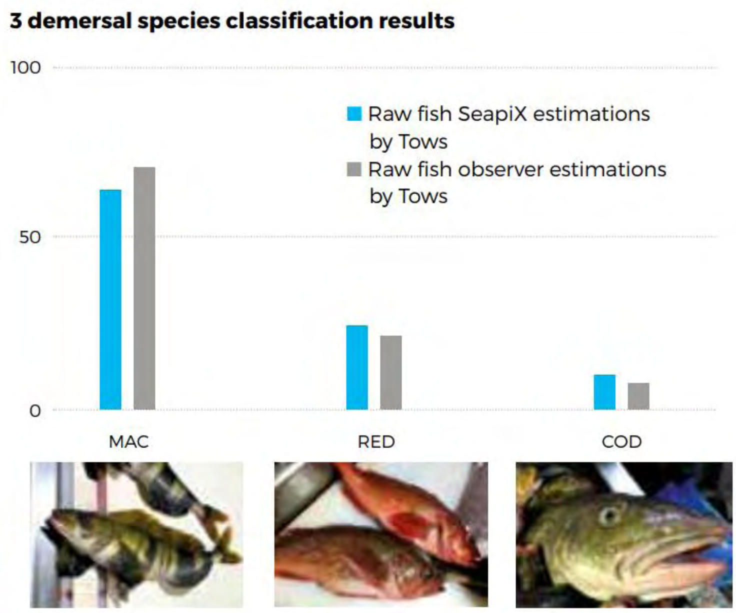


Figure 1.1-16 A demonstration of SeapiX performance
(Source: https://www.ixblue.com/)

The multibeam acoustic sonars (MBES) can provide information about bathymetry, bottom type and fish school cross-section simultaneously and in real-time. Acoustic systems have been identified among the most promising tools available to scientists for the **Ecosystem Approach for Fishery (EAF)** (Koslow, 2009). These systems have the potential to fulfill many of the needs identified for the discipline as the characterization and identification of targets in the water column or benthic habitat mapping. **The multibeam echo sounder (MBES)** have considerable advantages over conventional fishery single beam echo-sounder (SBES), as they offer a much larger volume coverage, which corresponds to 120–150◦ athwartships aperture for MBES versus 7–12◦for standard split-beam SBES. **SEAPIX is a multibeam echo sounder (MBES)**, using a steerable symmetric Mills Cross, that allows to image water column and sea bottom in both athwartships and fore-and-aft direction (Table 4). Then, it permits a fine positioning of fish detection athwartships (Fig.2), thanks to a small angular beam width. Finally, small beam aperture and secondary lobe reduction allows fish detection close to the bottom (Mosca et al., 2016).

Table 4. SEAPIX main characteristics (data from Mosca et al., 2016).

Central frequency Bandwidth	150 kHz 10 kHz
Source level	206 dB (re.1 μPa at 1 m)
Pulse type	CW or Linear-frequency modulated
Pulse length	100 μs to 20 ms
Number of beams	64 (equiangle on ±60◦)
Beamwidth(TX/RX)	1.6◦ x 1.6◦(0◦beam) to3.2◦ x 1.6◦(±60◦ beam)
Secondary-lobe level	−13 dB(Standard); −20 dB (Apodized)
Self-noise level	22 dB (re.1 μPa/√Hz)
Instantaneous/overall dynamic	66 dB/123 dB
Sampling frequency (beamforming/ baseband)	3 M Hz/35 kHz
Dimension (Ø/D)	480 mm/180mm
Weight in air/water	53 kg/27 kg
Power supply/installation	220 V AC/24 V DC ;20 m wet mateable cable

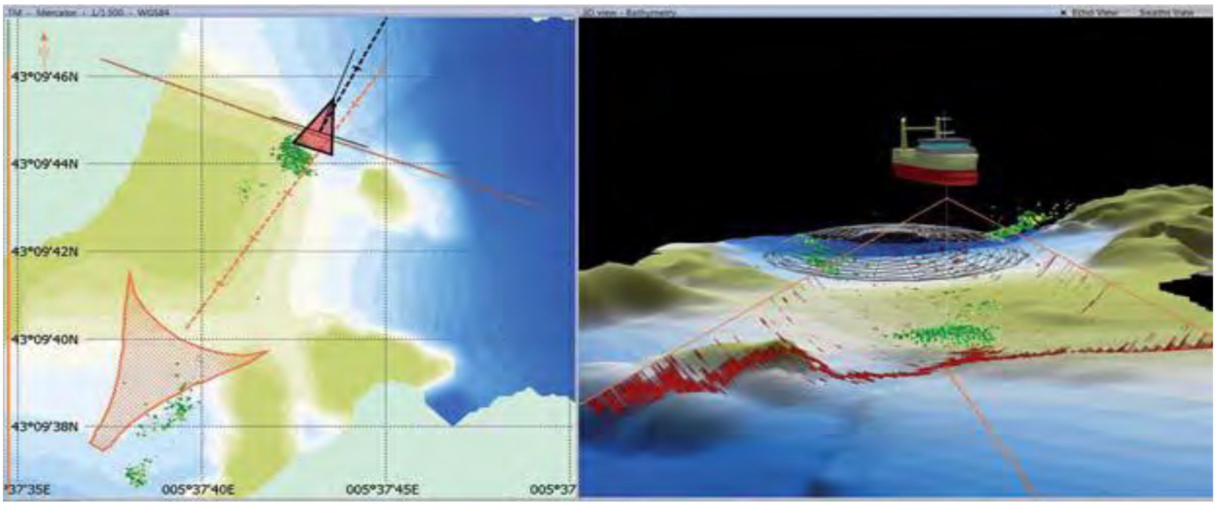


Figure 1.1-17 SeapiX advanced integration of acoustic detection together with fishing environment information
(redrawn from (SEAPIX: A SMARTER WAY TO FISH, 2015).

Seabed and water column data, vessel and net gear navigation data support understanding of fishing situation. Built in navigation system shows vessel tracks parameters together with biomass and bathymetry data

Application of such systems increase opportunities for new research. For instance, we can receive a three-dimensional analysis of geometric parameters of school - height, width, or elongation of the school, the volume backscattering coefficients, as well as the internal density structure of the schools (Gerlotto and Paramo, 2003; Guillard et al., 2011). This larger number of detections allows considering statistical analysis of fish echoes, that can provide new insight on fish shoal, like density or multi-species composition (Stanton and Clay, 1986; Frouzova et al., 2011). All these features for water column and bottom analysis, coupled with database construction referenced in space and time, are intended to define the characteristics of the habitat of fish (Schimel et al., 2010; Brown et al., 2011).

The sonar includes **Geographical Biomass Analyzer (GBA),** since SeapiX provides Calibrated "Split Beam" fish measurement from all swaths. Single fish and entire shoal can be processed to show realistic biomass assessment. Classes of fish are mapped in 2D/3D to ease understanding of fish distribution patterns.

Figure 1.1-18 shows the position of the fish schools in relation to the bathymetry. The spatial analysis permits to identify two different statistical target strength (TS) measurements and therefore, presumably two different species. The position of these schools relative to the terrain of the area is clearly highlighted. These schools are then georeferenced on the navigation chart and can be entered as an object in the database. These tools allow a combined analysis of the bottom - bathymetry and type and of the potential fish and schools locations, depending on place and time of the year. Supplemented by other sensors, SEAPIX could be used as a tool able to provide partial information on ecosystem analysis on a large scale through greater use and data sharing (Mosca et al., 2016).

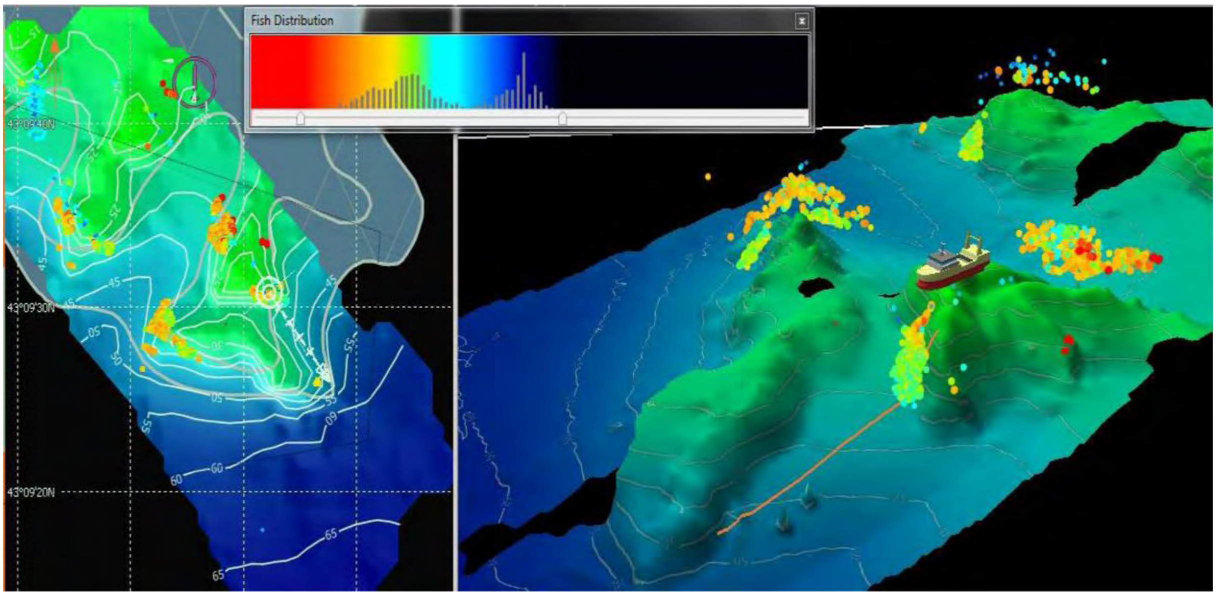


Figure 1.1-18 Ecosystem mapping and analysis. Bathymetry and school positioning and analysis

(redrawn from Mosca et al., 2016).

In general, the benefits from application of the multi beam echo sounder include:

– detecting and characterizing objects in the water column in a large volume under the vessel, with calibrated repeatable and reproducible data of scattering cross-section for point, surface, and volume target,

- measuring bathymetry and characterizing the seabed,
- getting georeferenced data in real-time and standardized (Mosca et al., 2016).

It is possible to **combine the application of SEAPIX with CTD measurements** (instrument: conductivity, temperature, depth) that allow collection of a wide set of information about abiotic - temperature, salinity, oxygen content and biological properties (chlorophyll a) and will foster analysis of the impact of environmental variables on biomass, size, and routes of fish schools. Some traditional methods for sampling, targeted on estimation of hydrochemical (N-and P-forms) and hydrobiological parameters (phytoplankton, zooplankton, zoobenthos), will be applied in combination with the hydroacoustic surveys that will facilitate **application of ecosystem approach to fisheries data**.

SeapiX generates one or more scan swaths along or across a vessel's axis, providing total three-dimensional coverage of the water column (in order to provide metrological target strength and volume backscattering strength) as well as a bathymetric profile, biomass estimations, shoals behaviour and allows application of selective fishing strategy.

Pros and cons of the acoustic methods

Acoustic emissions on sea ecosystem contribute to the noise pollution phenomenon of oceans, which impacts living marine organisms (Dotinga and Oude-El-ferink, 2000). The influence on fish behaviour is more important when the platform moves: in this case, the avoidance of the populations could be a source of bias (Freon and Misund, 1999). The time between emission and reception of the pulse provides an estimate of the distance between the target and the transducer. Used vertically in marine or lacustrine environments, echo sounding can estimate fish density from the energy reflected from fish inside a given water volume (Simmonds and MacLennan, 2005). Fish density is generally too high, however, to allow visual counting of individuals on the echogram. Echo-integration, which integrates the return-echo strength in the echosounder's sampled volume, is used to estimate the number of fish in the detection beam (Simmonds and MacLennan 2005). This method has been used efficiently in numerous studies of marine fish populations (Doray et al., 2010). Furthermore, echo properties provide descriptive information about the targets themselves. Target Strength (TS), the difference (in decibels) between emission and reception, is proportional to the echo intensity (Simmonds and MacLennan 2005). According to Ona (1999), a relation between target size and echo response exists. Many equations relating echo strength to fish length have been published, such as the common equations of Love (1977), whose general formulas to estimate length of individual fish are still used in multispecies population approaches (Emmrich et al., 2012). TS must be used with caution, however, especially when fish diversity is high, because if two fish of different species have the same length, their TS could differ (Horne and Jech, 2005). Indeed, more than 90% of the scattered energy is reflected by the swim bladder, a gas filled organ whose shape and size differ among species (McClatchie et al., 1996). Moreover, relations between TS and length are complex and variable because they depend mainly on position of the target (Horne, 2003). Therefore, these relations must be approached statistically (Simmonds and MacLennan, 2005). Thus, hydroacoustic scan describe the structure of a population; size distribution, cohort organization and distribution in the water column can be consequently observed at small spatial scales (Guillard et al., 2012).

Use of acoustic cameras in shallow waters and estuaries

Different methods (e.g., capture by trap or net, telemetry, hydroacoustics) are used to evaluate the efficiency of fish passes to estimate the migratory species abundance and analyse changes in their within-river distributions. Among these methods, hydroacoustics is non-intrusive, allowing long-term observation and description of fish populations based on physical properties of sound in water. However, the main limit to hydroacoustic tools is their difficulty in identifying species. Initially designed for military purposes, dual-frequency identification sonar (DIDSON) has been used in environmental management for a decade. This acoustic camera uses higher frequencies and more sub-beams than common hydroacoustic tools, which improves image resolution and then enables observation of fish morphology and swimming behaviour. The ability to subtract static echoes from echograms and directly measure fish length improve the species-identification process. However, some limits have been identified, such as automatic dataset recording and the low range of the detection beam, which decreases accuracy, but efficient tools are now being developed to improve the accuracy of data recording (morphology, species identification, direction, and speed). The new technological properties of acoustic cameras, such as the video-like visualization of the data, have greatly improved monitoring of diadromous fish populations (abundance, distribution, and behaviour), helping river and fisheries managers and researchers in making decisions.

Recent sonars increase the number of beams, and then widen the angle of detection, increasing the echogram resolution, but cannot easily measure TS of single targets, unlike split-beam echosounders. However, multibeam devices have been used to monitor fish populations in shallow waters. Some multibeam sonar integrates TS values, but its large physical dimensions and capacities can only be used by offshore scientific vessels for now. The properties of multibeam sonars could be also helpful to distinguish pelagic and bentho-pelagic fish schools. Ultimately, hydroacoustics can provide quantitative (abundance or density estimates), and qualitative (direction, speed, activity rhythm, length) assessment of migratory fish populations without greatly interfering with their behaviour, but these methods are still limited by the uncertainty in identifying species. Indeed, the main limit of hydroacoustic methods concerns the identification of fish species.

Unlike common hydroacoustic methods, skin and fins are better perceived by acoustic camera's very high frequencies. Thus, fish morphology and swimming behaviour can be visualized). Consequently, parasite echoes such as those from bubbles or debris can be visually identified and deleted from the echogram. In fact, the shape of a fish and its non-linear movement differ from echoes of debris drifting with the flow (constant velocity and direction). Measurements of size from the recorded data can be made directly from fish body images, without the uncertainty and inaccuracy of TS conversion, Figure 1.1-19.

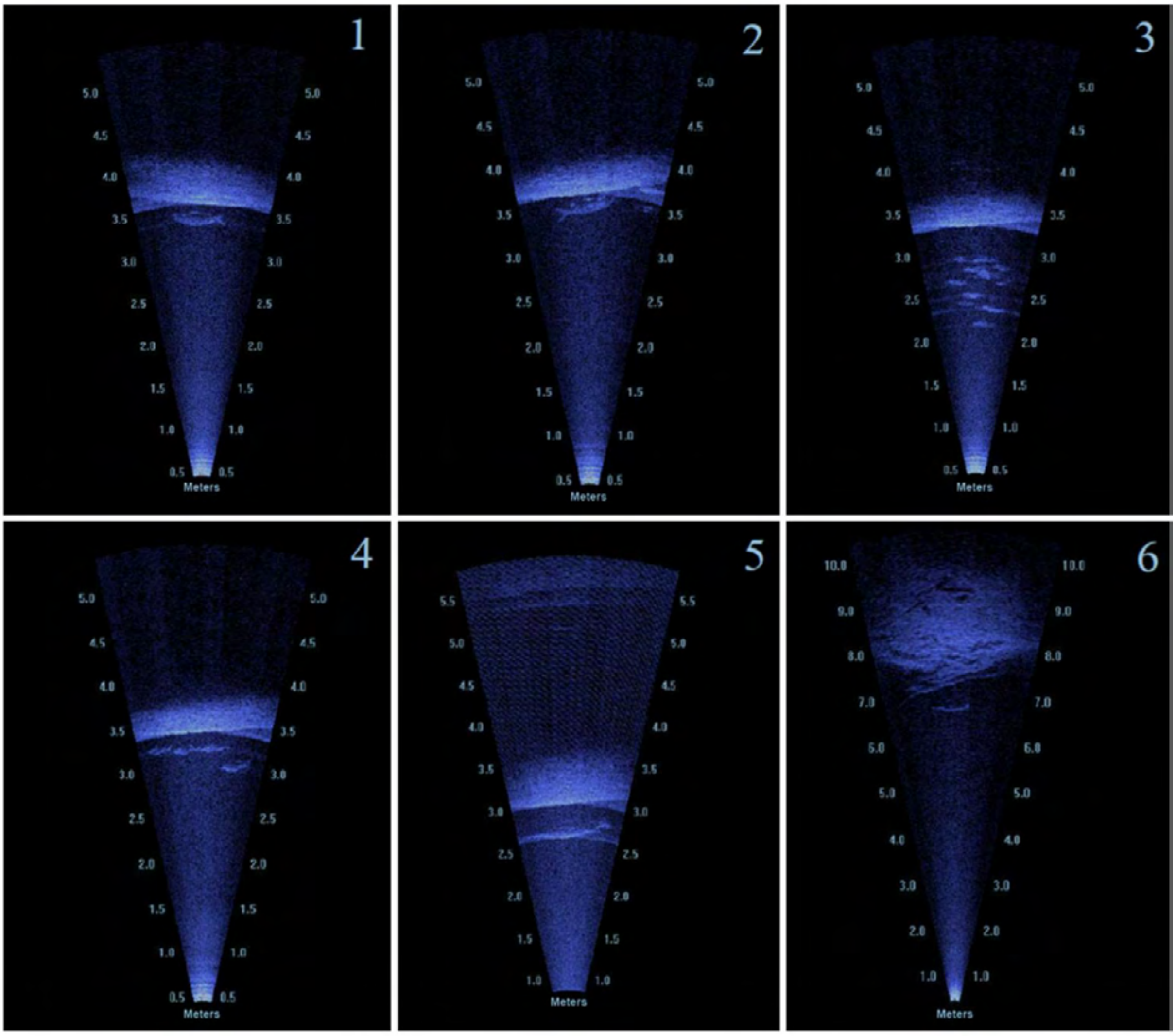


Figure 1.1-19 Snapshots of data recorded by DIDSON
(source: Hughes 2012): (1, 2) large fish (70 and 77 cm), (3, 4) fish schools, and (5, 6) longnose gar (Lepisosteus osseus, Lepidosteidae), identified by their length and body shape

1.1.3 Optical Systems Applied in Fishery Research

Despite the difficulties, optical systems have been widely applied in fishery research and management. These applications include but are not limited to: abundance surveys using video and still cameras, airborne LiDAR (light detection and ranging), supporting data for acoustic measurements, behavioural studies, observations of fishery operations, and habitat classification. New applications are continually being developed and made possible by the array of optical technologies available. Many researchers use simple digital still or video cameras. For operation at depths greater than a few tens of metres, where there is little ambient light, low-light-level cameras and artificial lighting are often used. Lasers have found application in a number of configurations, including airborne lidars that operate like vertical echosounders, holographic cameras, and laser-imaging systems designed to increase image contrast in the presence of scattering in the water. There are a number of practical factors that affect the performance of optical systems. These include the capability of the platform, geolocation, data processing, metadata, calibration, and of course estimate of measurement uncertainties.
There is a wide variety of in-water platforms that have been fitted with optical systems. These include surface vessels, towed vehicles, platforms fixed to the bottom, moorings, packages that

are lowered on a cable, drifters, manned submersibles, and autonomous underwater vehicles (AUV). The number and variety of systems are far too extensive, here below some example innovative approaches are presented.

Video-observation networks

Currently, the largest existing video-observatory networks, include the European Multidisciplinary Seafloor and water column Observations unit (EMSO; www.emso-eu.org, with data for the Black Sea http://emso.eu/observatories-node/black-sea/), the Ocean Network Canada unit (ONC; www.oceannetworks.ca/), and the Japanese Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET; http://www.jamstec.go.jp/donet/e/).

The newly established **Black Sea Security System - EUXINUS**, the result of the MARINEGEOHAZARD project, is a cross-border Romanian–Bulgarian cooperation and was developed as a solution for long-term environmental monitoring and for the prevention / mitigation of the marine geohazards (e.g., earthquakes, active faults, and submarine landslide) which affect the entire Black Sea coastal area. The system, unique in the Black Sea area, is able to collect long-term real time data for several key environmental parameters (e.g., CTD, water current, water pressure, etc.). The system consists in three offshore moored observatories, each including underwater modules and a coastal gauge limited to the surface module. The offshore observatories are moored 160 km from the Romanian Black Sea coast at about 90 m water depth. The Coastal gauge (CG) is installed in front of the Mangalia harbor, Romania (1,5 km from the seashore) at 15 m water depth (http://emso.eu/observatories-node/black-sea/).

Figure 1.1-20 Locations of EMSO Regional Facilities and Test Sites
(*taken from* EMSO ERIC LONG-TERM VISION AND STRATEGIC PLAN 2018 - 2020)

Currently, very few journal papers propose methodologies for recognizing fishes, and all of them are based on small datasets where the images of the fishes are easy to be processed (e.g. no turbidity, no fouling, shape, and texture of the fishes are clearly visible, etc.). Conversely, there are abundant conference-papers proposing different recognition approaches, but also with very simple data sets (few images processed, few days analysed, single species approach, etc., Marini et al., 2016).

Towed-Camera Systems

TowCam is a commonly used name for a towed-camera system. The TowCam developed by the Canadian Department of Fisheries and Oceans (Figure 1.1-21) is a towed, bottom-following, video, and still photographic system for benthic and geological surveys (Gordon *et al.*, 2007). It is towed at a speed of ca. 1 ms^{-1} at an altitude (controlled by the winch) ca. 2 m off the seabed. The maximum working depth at present is 200 m. Real-time video imagery is displayed in the ship's laboratory and on the bridge. Video imagery and navigation data are recorded for later analysis.

This system consists of a simple towed body containing a high-resolution, digital still camera and flash, a colour video camera and incandescent lamps, an acoustic altimeter, and an electronic module containing pitch, roll, and depth sensors. A software package that was developed in-house monitors, displays, and logs the vehicle flight characteristics and sends control signals to the hydraulic system on the winch, causing it to adjust the cable length to maintain the towed body at a constant altitude above the bottom.

Figure 1.1-21 TowCam - towed-camera system, Canadian Dept. of Fisheries and Oceans

(Gordon *et al.*, 2007)

Towed-camera systems have proven to be an excellent tool for conducting general reconnaissance surveys. Major habitat features, such as fish, large epibenthic organisms, including crabs, scallops, starfish, etc. (greater than ca. 10 cm), as well as sediment type and bedforms, can be discerned from the video imagery. Towed-camera systems do not damage the seabed and has the potential to carry other sensors. They can be used over any kind of seabed (e.g., mud, sand, gravel, cobble, boulder, bedrock), provided that the relief is relatively low. Towed-camera systems become an often-used stock assessment tool for commercial fisheries and shellfish research.

Use of Video-Based Electronic Monitoring for catch and bycatch assessment

Fujita et al. (2018) gave a review of electronic monitoring system used currently for catch and bycatch assessment. Key among those are vessel monitoring systems (VMS), electronic monitoring (EM), and electronic reporting (ER). Vessel monitoring system, or VMS, is a technology used to track vessels in near real time using devices on board which transmit location via satellite to shore based enforcement facilities. This is different from an automatic identification system (AIS), a vessel location system which uses the VHF radio band to transmit similar data and is accessible to anyone with the right equipment. VMS began as a tool to aid in fisheries enforcement in the 1990s in several fisheries worldwide (Fujita et al., 2018).

The use of camera-based Electronic Monitoring (EM) systems in industrialized fisheries is described by Michelin et al. (2018). EM systems use cameras, gear sensors and sophisticated data analysis to provide full accountability for fishing activities; this generates several benefits, including high levels of compliance, documentation of sustainable fishing practices and access to markets that demand high levels of transparency and sustainability. However, less than 1% of the world's fishing vessels are subject to EM (Michelin et al., 2018) due to several constraints, including lack of infrastructure; costs; and lack of capacity to analyze and use EM data. Michelin et al (2018) provide more detail on these constraints, and Fujita et al. (2018) provide guidance on how to design and implement EM systems by overcoming these obstacles.

The commercial catch of target and non-target species is monitored primarily using independent observers. Due to cost and efficiency, many are now transitioning to electronic monitoring (EM) using mounted cameras. In particular, small boat fishermen have been interested in switching over to fixed camera technology to ease the burden of carrying an additional person on board. EM is being tested around the country in various phases, depending on region. Innovation in camera technology, such as species identification using artificial intelligence is also well underway. Think about the artificial intelligence behind a mobile banking app, which reads a check deposited using a smartphone. EM makes catch and discard monitoring more efficient on board for those fishermen already required to carry observers.

Another technology that is becoming more common across fisheries is electronic reporting (ER). ER is the digitization of fish tickets or landings reports that fishermen have traditionally submitted to regulators in paper form. Depending on the sophistication of the ER software, it can also be a powerful tool to provide real-time data to fishermen. It saves time when entering logbook data and calculating catch totals while allowing fishery managers to process landings data much more quickly, accurately, and efficiently. ER has been developed on devices ranging from special hardware to desktop computers and now is prevalent on tablets and smartphones. Many tablets and most smartphones running ER software also have GPS chips built in and may be able to serve as a low-cost alternative to VMS, particularly in fisheries where vessel tracking has not yet been implemented. East Coast fishermen are most familiar with reporting requirements through the submission of vessel trip reports (VTRs). Since March 2018, party and charter vessel operators in the Mid-Atlantic region have been submitting mandatory electronic VTRs (eVTRs), primarily using either free or paid apps on smartphones and tablets. The Mid-Atlantic and New England Fishery Management Councils have been deliberating on eVTR reporting and its potential application to all commercial federal fisheries in both regions. According to the Mid-Atlantic Council website, the Council chose in December to implement eVTRs in the region with a 48-hour deadline for submission after completion of a trip. The New England Fishery Management Council is currently deciding on the issue.

Each technology serves a different purpose for fishermen and fishery managers. Adopting any new technology on a fishing vessel presents its challenges. Embracing the various EM, ER, and VMS solutions, however, can provide an opportunity to empower one's own business operation with the specific advantages these innovative technologies can provide while fishing.

Compliance with catch, bycatch, discard, and effort limits is usually monitored by fishermen who record their catch in logbooks; with surveys conducted by enumerators at ports where fish are landed; or in a small proportion of fisheries by human observers or EM systems capable of measuring and identifying catch or effort (Michelin, 2018). Each of these methods has its limitations.

Logbooks have the potential for quantifying total catch and bycatch (including discards) but are often inaccurate or incomplete, and more errors are introduced when they are transcribed into electronic form for analysis (Stop Illegal Fishing, 2018).

Enumerators at ports can collect reliable data on landings, but cannot quantify total catch, as they cannot account for discards at sea. Moreover, some portion of actual landings will be missed if there are unmonitored landing sites.

While human observers and EM systems generate very high quality, rich catch data that usually result in high compliance (Michelin, 2018), they require infrastructure, resources and a degree of governance lacking in most of the world's fisheries. Several other technologies for monitoring catch that have potential for reducing costs and other barriers to implementation have been tested, and a few have been adopted at the fleet-wide scale. Electronic logbooks, smartphone apps and low-cost camera systems are now in use at the pilot or fishery scale, albeit in only a few fisheries currently, many of which are recreational (Girard and Du Payrat, 2017).

The advantages and disadvantages of video-based EM have been compared with observer programmes – the only other method that provides credible and trustworthy data (ICES Report "Fishery applications of optical technologies", P.M. Clement et Al, 2012). Table 1-2 outlines the advantages and disadvantages (pros and cons) of EM against the observer alternative in terms of operational issues and monitoring efficacy.

Table 1-2 Electronic Monitoring vs. Observers–Pros and Cons (P.M. Clement et. Al, 2012)

Operational Issues		EM Pros/Cons Relative to Observers
1. Vessel suitability	Pro	• EM on-vessel space requirement is much less (observers require ample accommodation and workspace)
2. Intrusiveness	Pro	• EM is less intrusive than observers; does not disrupt crew dynamics • EM does not slow on-board handling and processing
3. Equipment reliability	Con	• EM equipment can break down
4. Equipment tampering	Con	• EM equipment can be made tamper-resistant and tamper-evident, but not tamper-proof • Regulatory system needs to recognize and penalize tampering
5. Data credibility	Pro	• 100 % observer coverage is required to prevent "observer bias" (i.e. strategic behaviour of skippers on observed trips), but there also are logistical issues to getting observers on board scheduled trips (e.g. weather-related events) • EM offers more precise recording of time and location
6. Observer reliability	Pro	• Unlike a person, an EM camera does not get sick
7. Viewscape	Pro	• EM provides multiple views of a vessel simultaneously, whereas an observer can only be in one place at a time and requires rest periods
Monitoring efficacy		
8. Continuous, permanent record	Pro	• Fishing event imagery can be sampled or reviewed in full • Reviewers have a range of playback controls, such as speed, replay, frame capture, etc., to optimize viewing conditions • An observer has one chance to record a fishing event
9. Species identification	Con	• Observers are better positioned to distinguish hard-to-identify species, but EM is good for most species • Number of cameras and quality of camera placement affects EM resolution • EM performs better when catch is landed in a serial manner (e.g. groundfish trawl can present challenges)
10. Catch volumes	Con	• EM can only record catch in pieces, not weight • Observers have a better opportunity to weigh the catch
11. Real-time capability	Con	• Observer data can be in real time, EM cannot
Cost		
12. Cost-effective	Pro	• EM is 1/3 or less the cost of 100 % observer programme in most applications • An EM programme requires less labour
Other		
13. Health and safety	Pro	• EM can alleviate health and safety concerns tied to an observer being aboard a fishing vessel
14. Biosampling	Con	• Observers can do biosampling, EM cannot

Trawl cameras

The use of trawls for verifying the species composition of backscatter dates back to the first fishery applications of underwater acoustics. The combination of trawling and acoustics has been successful for fishery management and will continue to be a very useful tool for managing fisheries. The downsides of trawls are that: they are lethal to the organisms that are captured; fragile organisms can be destroyed to the extent that identification is problematic; and, in most cases, only a subset of the fish caught is actually used for biological measurements (e.g., length, weight, sex, maturity, age, and diet). In addition, although acoustic data provide high-resolution information on the spatial distribution of organisms, trawls tend to spatially integrate over larger volumes than do acoustic measurements.

Stereo cameras, LED strobes, computer, microcontroller, sensors, and a battery power supply make up the system used by NOAA's Alaska Fisheries Science Center (K. Williams *et al.*, 2010), Figure 1.1-22. The machine-vision cameras are Joint Architectural Intelligence (JAI; www.jai.com) high-resolution, high-sensitivity cameras capable of capturing multimegapixel images at reasonable FPS rate. Machine-vision camera systems are more complex than consumer systems but provide greater control over image acquisition. Current efforts are directed at automated processing of the images for species identification and organism length.

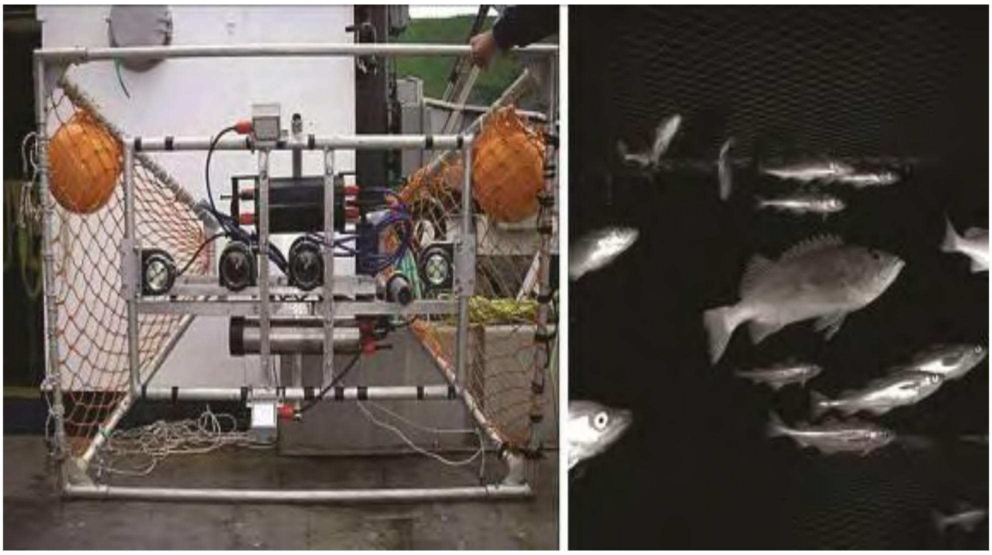


Figure 1.1-22 Illustration on camera system used by NOAA's Alaska Fisheries Science Center (K. Williams et al., 2010)

LiDAR surveys

Detection of fish schools by airborne LiDAR was demonstrated since more than 30 years. More recently, comparisons of LiDAR and echosounder measurements of various species (capelin, herring, mullet, baitfish, zooplankton, epipelagic juvenile fish, etc.) have demonstrated good agreement, provided that the measurements were made within a few days, and that both LiDAR and acoustic data were appropriately filtered to remove unwanted signals (Clement et al., 2012). Another study to compare airborne LiDAR and photography for surveys of menhaden, has concluded that LiDAR was more reliable, with fewer missed schools, fewer false detections, and less variability in repeated surveys of the same area (Churnside et al., 2011).

Underwater Time-Of-Flight Imaging Acquisition System (UTOFIA)

The UTOFIA camera, an Underwater Time-Of-Flight Imaging Acquisition system capable to overcome some of present-day limitations in the use of range-gated systems in oceanographic exploration.

The UTOFIA consortium was created in 2015 within the European Commission Horizon 2020 framework, bringing together experts in imaging, lasers, optics, ocean science, and marine hardware (https://www.utofia.eu/). The consortium has developed a new underwater range-gated camera system which can capture high-contrast images and 3D information in a single compact video camera platform. Improved capabilities for underwater imaging are recognized as an important technological advance in the ocean economy, helping to address both environmental challenges in the sustainable use of ocean resources, and ocean related economic activities, by improving surveillance, inspection and mapping operations. UTOFIA provides an essential step towards enabling biomass estimation and object sizing by imaging acquisition systems (Figure 1.1-19).

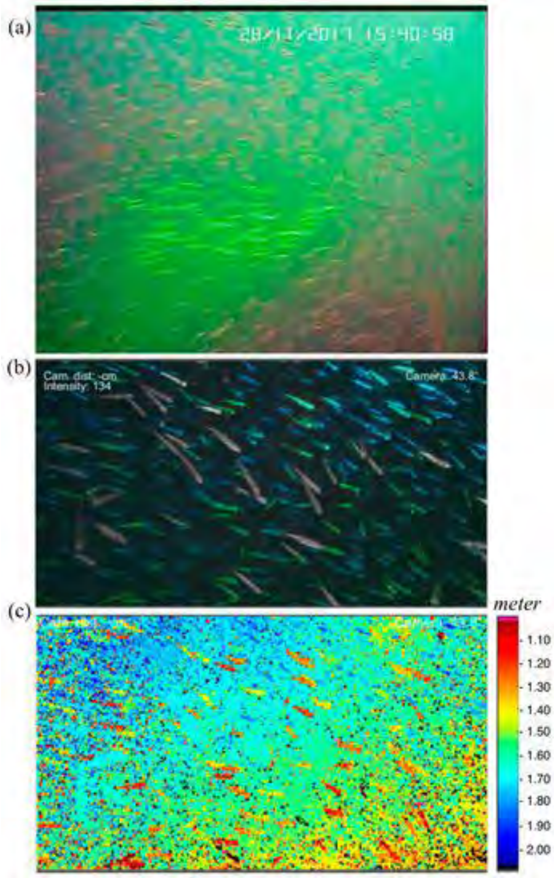


Figure 1.1-23 Observation of fish schools by UTOFIA (https://www.utofia.eu/)
(a) Regular underwater camera with visible the green laser light; (b) UTOFIA images: combination of intensity and distance measurement (false colour); (c) Distance measurements (in meter) of the different fish in the school

Several devices allow also imaging of Zooplankton. Active acoustics can be used to look at biomass, including plankton, but more detailed analyses of individual cells are done with flow cytometers. The Imaging Flow CytoBot (IFCB) developed by at the Woods Hole Oceanographic Institution is an example of a commercially available system(https://mclanelabs.com/imaging-flowcytobot/) that has been modified to work in autonomous vehicles. The IFCB is a submersible or benchtop device that combines the fluorescence detection capabilities of the flow cytometer with the imaging and species identification capabilities of the FlowCam. A key feature of IFCB is automated classification of the images to provide genus- (or species-) specific cell abundance estimates. In order to identify individual species, the instrument can be "trained" using neural network approaches. Its size and depth limitations (102 cm length and 40 m maximum depth) generally make it usable on ASVs.

An example of IFCB is shown here below, developed by McLane Labs (Figure 1.1-24), a similar device LISST-200 is developed also by Sequoia (https://www.sequoiasci.com/product/lisst-200x/).

Figure 1.1-24 Imaging FlowCytobot (IFCB), an in-situ automated imaging flow cytometer (by McLane Labs)

The Underwater Vision Profiler UVP (the French National Centre for Scientific Research CNRS patent) is designed to study large (>100 µm) particles and zooplankton simultaneously and to quantify them in a known volume of water. The UVP system makes use of computerised optical technology with custom lighting to acquire digital images of zooplankton IN SITU down to depths of 6000m. The instrument UVP6-LP developed by Hydroptics is shown on Figure 1.1-25 (http://www.hydroptic.com/index.php/public/Page/product_item/UVP6-LP). The UVP6 has been designed for low speed, limited space and low power vectors like profiling floats, gliders, floats, moorings, AUVs.

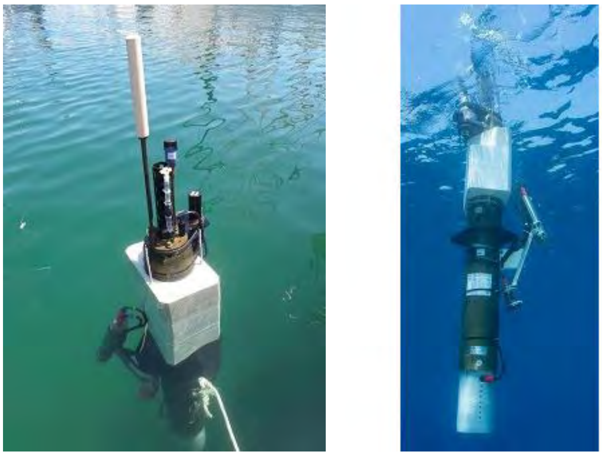


Figure 1.1-25 Underwater Vision Profiler / UVP6-LP (by Hydroptic SARL, France)

1.1.4 Automated, non-invasive, opto-acoustic systems for stock assessment

Non-invasive autonomous opto-acoustic systems are one of the newest technologies applied to fishery & ecosystem research. A system of this type is being developed within the project Symbiosis, funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 773753.

The SYMBIOSIS project (A Holistic Opto-Acoustic System for Monitoring Marine Biodiversities) develops a mature, cost effective autonomous opto-acoustic prototype for the characterization, classification, and biomass evaluation of six target pelagic fish that are important to the fishery industry and that reflect on the health of the environment. The processing will be made in a real-time fashion onsite, and the results will be sent to a shore station. The system will be completely autonomous and will withstand three-month deployment without recharging. We will demonstrate the capabilities of the system and its readiness to a TRL6 stage over three sea and ocean mooring sites.

SYMBIOSIS is devised as a blend of acoustic and optical components. The acoustic unit will include an active underwater acoustic array of 2X3 elements, to detect, classify, evaluate the biomass, and localize the predefined pelagic fish in the far field of 500m. The optical component will comprise of a fixed frame of six underwater optical cameras and will perform machine learning-based classification and biomass evaluation in the near field of 2-3 attenuation lengths in low-light conditions (Figure 1.1-26).

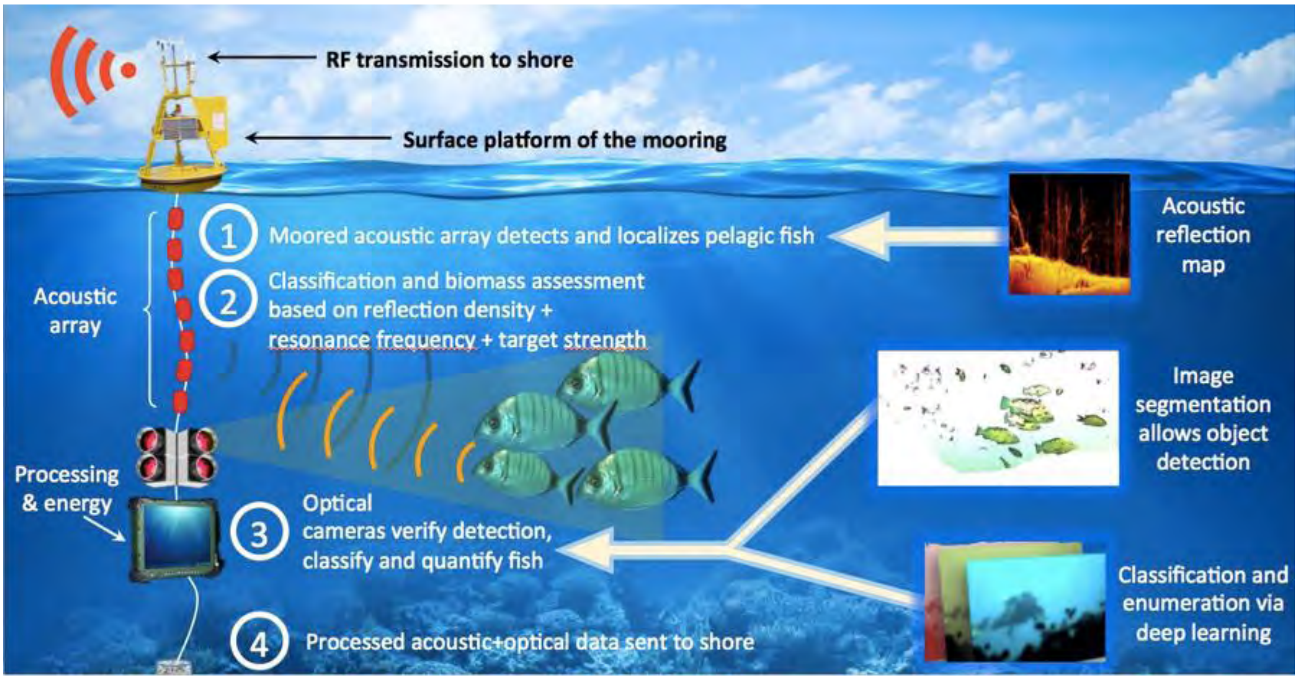


Figure 1.1-26 Principle of operation of the SYMBIOSIS autonomous opto-acoustic system http://symbiosis.networks.imdea.org

To conserve power the optical unit will be triggered upon detection from the acoustic unit and will use the results from the acoustic localization. The system will be modular, both in term of performance and in terms of composition and will adapt to different scenarios and cost requirements.

The system will be environmentally friendly, not only in its operation which will be non-invasive and will not impact the marine ecosystem, but more importantly because it will provide reliable information about the condition of marine fish stocks.

The system developed by SYMBIOSIS will collect underwater data in real time over long periods and transmit this information – including the size and movements of the fish stock – to a coastal centre. The system will be completely autonomous and will withstand three-month deployment without recharging.

The SYMBIOSIS monitoring process begins with the acoustic discovery and classification of fish, based on their typical speed and movement characteristics. Acoustic sensors also measure the size of the fish and the total biomass of the fish in the area. After identification of one of the six target fish species, the optical system is activated. This component includes several cameras and can process sophisticated data with various image identification algorithms using deep learning. When the optical system confirms the identification of one of the six selected species, it transmits the information via underwater acoustic communications, and then by radio communications to a coastal station.

The project aims to test the performance of its prototype system in three different marine environments: shallow Mediterranean, deep Mediterranean, and a tropical environment in the Canary Islands. The six selected large fish species covered by the project are especially in high demand by the fishing industry. It is expected that SYMBIOSIS will offer novel solutions to the distributed and large-scale monitoring of the underwater environment, with a positive impact on marine biology research, conservation, and policy making for fisheries in Europe and worldwide. (source:https://cordis.europa.eu/article/id/124141-can-schools-of-fish-be-identified-without-human-intervention-an-international-initiative-show)

Combination of opto-acoustics and ultrasound imaging

Data from the report "Ultrasound is a well-developed technology with broad application to resource management and research endeavours (2012)" are used. Ultrasound has evolved from the bulky, stationary units developed for human medicine in the 1960s to rugged, portable, high resolution units that can be used aboard boats, in adverse field conditions and at fish facilities. These new units were developed in response to requirements of veterinarians for durable, portable, easy to use instruments for use both in the office and on the farm. Aquaculturists seized on the technology early on and have been using this equipment routinely in their hatchery operations since the early 1990s. The first application to fish research was initiated by the University of Washington in Using Ultrasound as a Tool for Fish Research and Management 1980. Early research efforts were conducted on steelhead in the Columbia River in the late 1990s and early 2000s and on declining sturgeon species in the Missouri and Mississippi Rivers also during that same period.

The advantages of the new generation of ultrasound machines include:

- Analysis and results are rapid, providing more timely information
- Methods are non-invasive and non-lethal
- Machines are portable, rugged, resolution is high
- Analyses are accurate (reductive maturity with > 90% accuracy and gender with > 90% accuracy)
- Analysis can reduce the number of handling events (maturity sorts) from 4 to 2
- Ultrasound can effectively determine body fat and muscle thickness for body
- condition determination
- Technology can be used with a wide variety of species—from madtoms to sharks,
- from fish to reptiles to birds and large mammals.

The following applications for ultrasounds show promise for direct application to fishery science:

(1) Gender and reproduction. Ultrasound imaging is a non-invasive method to determine gender that is more accurate that visual methods. Egg development within the ovary can be measured non-invasively by measuring egg diameter on the screen. Knowing sex and reproductive condition of fish would allow Reclamation to better manage fish facilities (diversions, ladders, hatcheries, counting stations). It provides a good tool for brood stock selection for captive rearing programs.

(2) Species determinations. This technique could be used to determine the difference between resident rainbow trout and anadromous steelhead. This will greatly assist in recovery and management efforts for threatened and endangered steelhead stocks.

(3) Habitat restoration. Ultrasonic imaging could be used in conjunction with habitat restoration efforts to measure the response of many T&E species in terms of reproductive condition. It is extremely difficult to monitor the response of populations of many T&E species such as sturgeons. Ultrasonic imaging would allow the direct assessment of reproductive stages of sturgeons and other species in the field with minimal impact to the fish. This technology is minimally invasive, yet sufficiently sensitive to allow investigators to track the progress of individual fish through the reproductive cycle and to determine whether spawning has occurred. Fecundity of fish in restored areas can be measured and compared against fish in adjacent areas to determine if environmental cues needed to trigger development and release of eggs are present in newly restored habitats.

(4) Fish handling. Reclamation fish facilities routinely handle a large number of fish, including threatened and endangered fish species. Injury assessment is currently done using visual estimates which are often inaccurate, resulting in an underestimation of delayed mortalities. Ultrasound would allow rapid non-invasive non-lethal imaging to detect internal injuries so that the causes of any such injuries can be more readily identified and rectified. Conversely, ultrasonic imaging could be used to demonstrate to regulatory agencies (US Fish & Wildlife Service, NOAA Fisheries) that fish emerging from Reclamation fish facilities are uninjured and in good health.

(5) Fish predation. Predation at diversion dams and bypass facilities is a significant source of out-migrating juvenile salmonid losses. Predation studies have been hampered by the need to assess consumption of juvenile salmonids through stomach pumping of piscivorous birds such as cormorants and gulls which is inefficient and often ineffective; or killing fish predator such as 5269+smallmouth bass and examination of stomach contents. Ultrasound scanning of birds and fish predators would be non-lethal and efficient and could expand the scope of predation studies, making them more relevant to Reclamation operations.

Underwood et al. (2014) described application of the acoustic-optical system (AOS) concept that combines scientific echo-sounder technologies with video and paired digital stills cameras in a self-contained autonomous platform with an operating depth in excess of 1000 metres. Fishing industry representatives saw the potential value of this type of system to an industry managed fishery and sought to obtain a version of the system that could be used during their normal fishing operations. To meet these industry partner needs, a system was developed to take the AOS from a “science instrument” and translate it into an industry owned and managed platform which could be operated directly by industry with minimal technical and scientific support.

Achieving translation from scientific instrument to industrial tool required several design changes including: reducing software complexity while providing increased operational robustness with a failsafe philosophy; making data downloading more straightforward; taking steps to ruggedize components that require handling during operations; and adjusting which data sets are collected to meet industry rather than science needs. A version of the new AOS platform was delivered to industry partners, and then deployed in the waters of New Zealand, and Mauritius. These trials produced valuable lessons in the development of scientific instrumentation for use by non-experts.

The instrument has been designed for attachment to the headline of trawl nets which are deployed from commercial fishing trawlers (Figure 1.1-27). Deployment of the system from trawl nets overcomes a number of problems associated with shipboard systems which are particularly evident in deep water fisheries studies where range dependant errors due to beam spreading, platform motion, estimation of seawater absorption and acoustic near bottom dead zone can be significant. The novel approach of deploying the instrument via the trawl net integrates with the existing infrastructure of a single commercial vessel, greatly reducing the cost and complexity of acoustic biomass surveys. Previously two survey vessels were required, one for acoustics to deploy a deep towed body system via a dedicated optic fibre winch and a catcher vessel to obtain biological samples. The AOS is sufficiently robust to withstand the environmental challenges of cold, depth, vibration, and impact to which the platform is exposed in normal trawling operations.

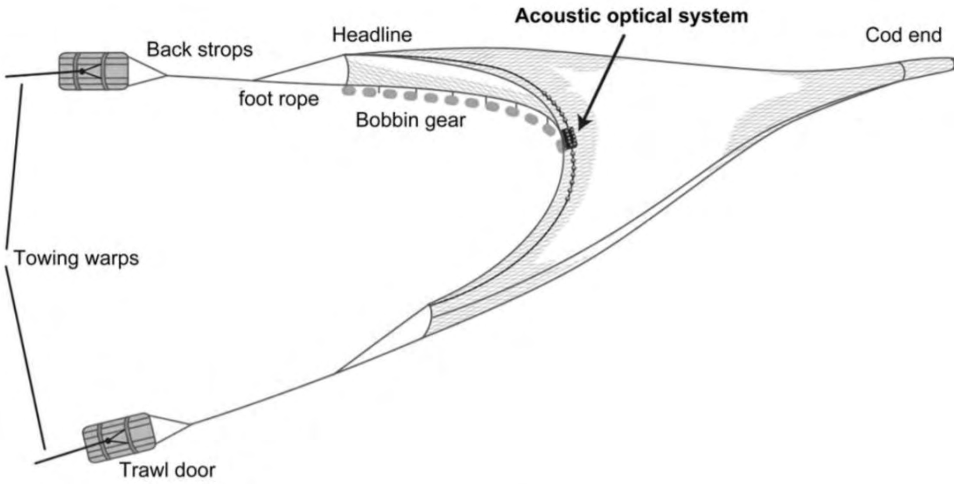


Figure 1.1-27 Diagram of demersal trawl net with Acoustic Optical System, attached to the headline

The AOS system comprises a stainless-steel frame (fig. 1.1-28) with protective top cover. A rigid flat instrument plate is bolted into the frame. Pressure cases containing electronics, cameras, batteries, strobes, lights, and control computer are fixed to this plate along with acoustic transducers. A total of three transducers are used to cover a range of frequencies (38 kHz, 120 kHz, and 12 kHz). A video system provides a visual record of the seabed and trawl catch, while a set of stereo cameras provides high resolution images of acoustic targets. A set of deep-rated plastic floats are attached to the top of the protective cover to give the complete system neutral buoyancy in water. The system is self-contained, and when deployed can be programmed to collect acoustic, video, and stereo imaging data simultaneously. This data can then be downloaded and reviewed upon system recovery

While the MkIII AOS is a powerful scientific instrument, its successful operation relied upon the presence of trained technical staff on board the fishing vessel. These staff were required to ensure high quality data is collected and that the instrument is correctly prepared and deployed for each shot.

Figure 1.1-28 Acoustic Optical System platform during wharf trials

Counting methods in aquaculture

Object counting in aquaculture is an important task and has been widely applied in fish population estimation. As underwater object counting is challenging for biologists and marine scientists because of the diversity of backgrounds, the uncertainty of the object motion, and the occlusion between objects. With the rapid development of sensor, computer vision, and acoustic technologies, advanced and efficient counting methods are available in aquaculture.
Li et al. (2020) (Table 1-3, Figure 1.1-29), provide a survey on the development of various non-invasive methods and technologies applied in object counting in aquaculture over the last decades (incl. machine vision, acoustics, environmental DNA, and resistivity counter) and listed the advantages and disadvantages of those methods including sensor-based, computer vision based, and acoustic based.

Table 1-3 Counting methods in aquaculture -advantages and disadvantages (Li D. et al.2020)

Counting methods		Advantages	Disadvantages	Application
Sensors based		Fast response, easy to implement	Required equipment to restrict the fish movement and damage to fish; prone to underestimated for overlapping fish	Integrated into the counting device for fry counting or ornamental fish count
Computer vision based	Image processing	Non-invasive, better accuracy with better algorithm architecture and optimization	Computing power of the hardware required, light attenuation underwater, unable to continuous counting	Population or abundance estimation of animal in underwater images by ROV
	Video analysis	Real-time, efficient		
Acoustic based	Hydroacoustic methods	Fast and efficient, not affected by water turbidity and light	Difficult to recognize small and overlapping fish.	Fish population estimation in waters such as lakes or rivers.
	Acoustic imaging	Able to obtain images close to the video images in dim murky water		

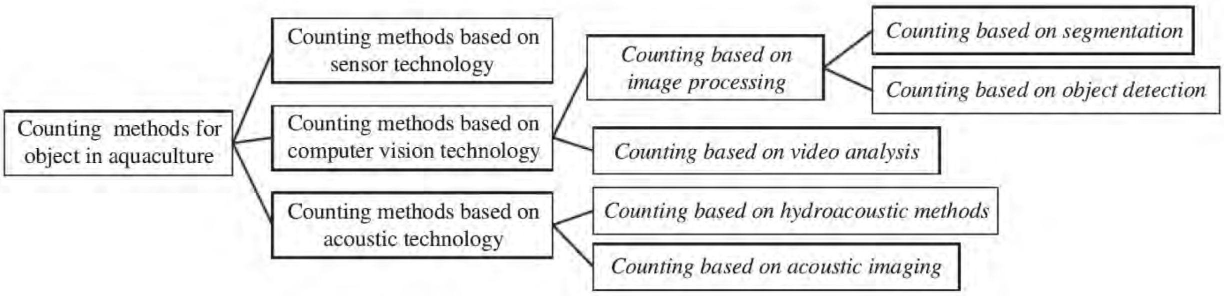


Figure 1.1-29 Counting methods based on different approaches and principles
(Redrawn from Li D. et al.2020)

1.1.5 Seafloor observatory technologies. Detection of benthic organisms.

Stock assessment methods applied to sedentary and semi-sedentary living resources

Imaging data are increasingly used for habitat assessments (Davie et al., 2008; Kocak et al., 2008) of status and trends in species distribution and abundance. Stereo and multi-camera imaging and underwater light detection and ranging (LIDAR, Sasano et al., 2016) also enable increasingly quantitative levels of imaging that help us better understand environmental variability and changes over time (Mortazavi et al., 2013). There are eye-safe LIDAR systems for classifying marine life based on imagery (Cao et al., 2017).

LIDAR systems have become more ubiquitous for sensing suspended particle fields, solid objects, and surface characteristics (Wedding et al., 2019). As these systems become more widespread, so has the need for extensive data support systems to store and process large data sets (Pirenne et al., 2015). A major area of biological observations is monitoring of plankton. Many sensors, instruments, platforms, and methods are available for in situ operational observations of plankton (Boss et al., 2018; Lombard et al., 2019). The goal of observing plankton is to better understand the basis of the food chain, which is responsive to changes in the environment due to natural abiotic and biotic forcing and due to direct human pressures, such as fisheries, other extractive practices, and pollution (Muller-Kargeret al., 2014; Muller-Karger et al., 2018).

Biomass estimates and distribution

Estimates of biomass and densities are important to asses' available stock as well as to evaluating the performance of stock enhancement initiatives. Abundance estimates of shellfish need to be expressed as a total quantity by stock, shellfish bed or management area, with some measure of the associated variance.

Latest approaches and equipment to estimate biomass quantity and distribution are presented further below in this section

Assessment of Growth & Mortality

A major concern in enhancement programmes is to optimize stocking densities, concurrently with the corresponding growth and survival rates that determine the relative success of the initiative. The identification of factors limiting growth (e.g., food, space, density) is also a critical step in enhancement protocols, because a precise knowledge of these factors should avoid economic losses derived from low growth and high mortalities caused by density-dependent mechanisms. Techniques directed to estimate growth and mortality usually consist of collection of samples of shellfish and analyzing in laboratory by different methods (e.g., age reading by external reading or acetate peels and validated by e.g., stable isotope analysis, strontium/calcium ratios (Sr/Ca) analysis, etc.). These methods/instruments fall beyond the subject of this report and are therefore not studied here.

Macrophytobenthos and Macrozoobenthos

Macrophytes are the attached organisms inhabiting coastal biotopes, which to greater degree undergo anthropogenic impact and are the most valuable for monitoring.

The biggest problems connected with macrophytes monitoring are:

- underwater visual observation using higher technology equipment (diving outfit, underwater camera, ROV and others);
- expensive methods of sampling;
- destruction of natural community structure under the breaking waves on the upper horizons (loss of real phytobiomass).

The collection of a large number of samples, especially seasonally, will lead to significant changes in the studied community. The method of photographing the areas of particular size along transects for further analysis using special software is recommended.

Extracting biomass from Images (indirect method)

Image analysis is a suitable tool to indirectly estimate biomass because it is non-destructive, time- and cost-effective and allows continuous observation of individual development. Estimating mass of single individuals from images is a common concern and different solutions have arisen (e.g. in aquaculture; zooplanktology; palaeontology; or botany).

Camera loggers are increasingly used to provide data as input to estimate biomass, as well to examine behavioural aspects of free-ranging animals. However, often video loggers are deployed with a focus on specific behavioural traits utilizing small cameras with a limited field of view, poor light performance and video quality. Yet rapid developments in consumer electronics provide new devices with much improved visual data allowing a wider scope for studies employing this novel methodology. Video data recorded on free-ranging animals not only provide a wealth of information recorded from a single deployment but also necessitate new approaches with regards to analysis of visual data.

Here below an example is presented on Figure 1.1-30 for the use of devices with high video resolution and wide field of view.

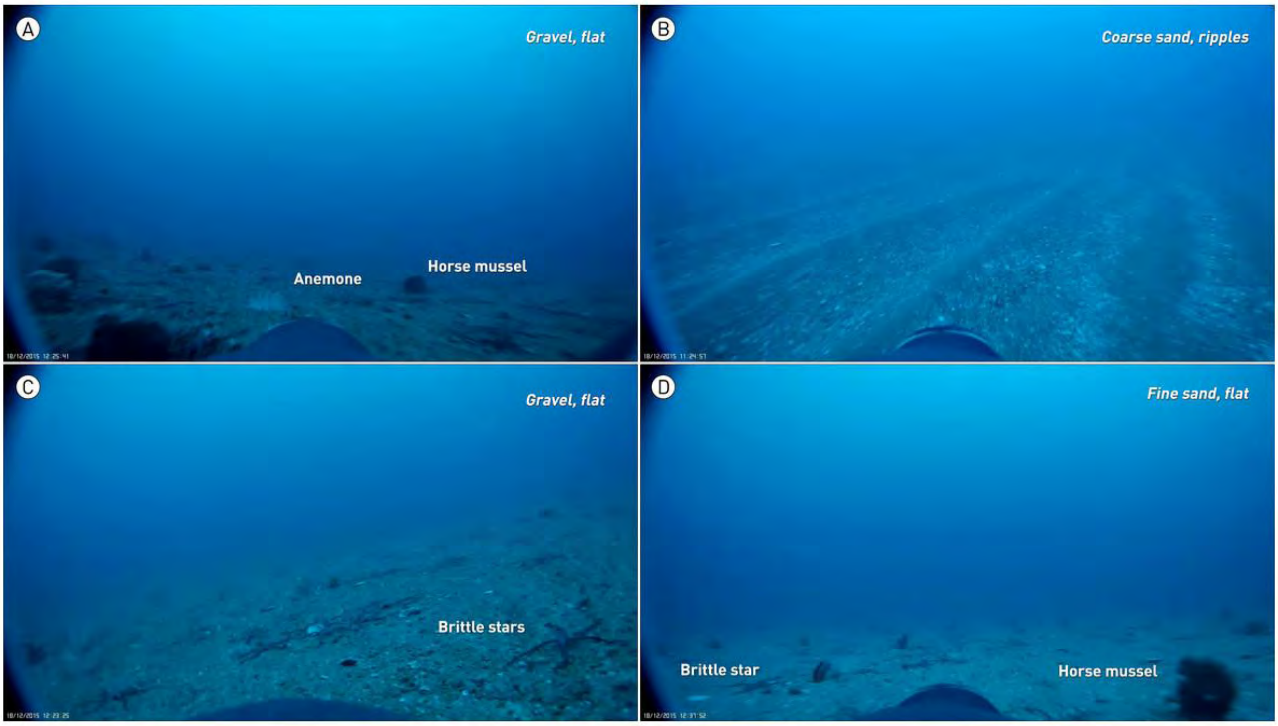


Figure 1.1-30 Types of benthic habitat fitted with wide-angle, full HD camera logger (Mattern et al., 2018)

Benthic habitat mapping using spectral features of multibeam echosounders

Automatic methods of seafloor mapping are still in their early stage of development, despite the technical progress made in recent years. A serious imperfection is the limited types of predictor features available for seabed classification. It is therefore desirable to introduce new class of spectral features to benthic habitat mapping. A good example is presented in the study of Trzcinska et al. (2020), where it is demonstrated that most applicable for this approach were MBES, which delivered bathymetry, as well as co-registered and geolocated backscatter of the seabed. Results on mapping seabed habitats are illustrated on Figure 1.1-31. The innovative results of this study suggest further application of the spectral features for predictive benthic habitat mapping, including research based on multi-frequency multibeam echosounder datasets.

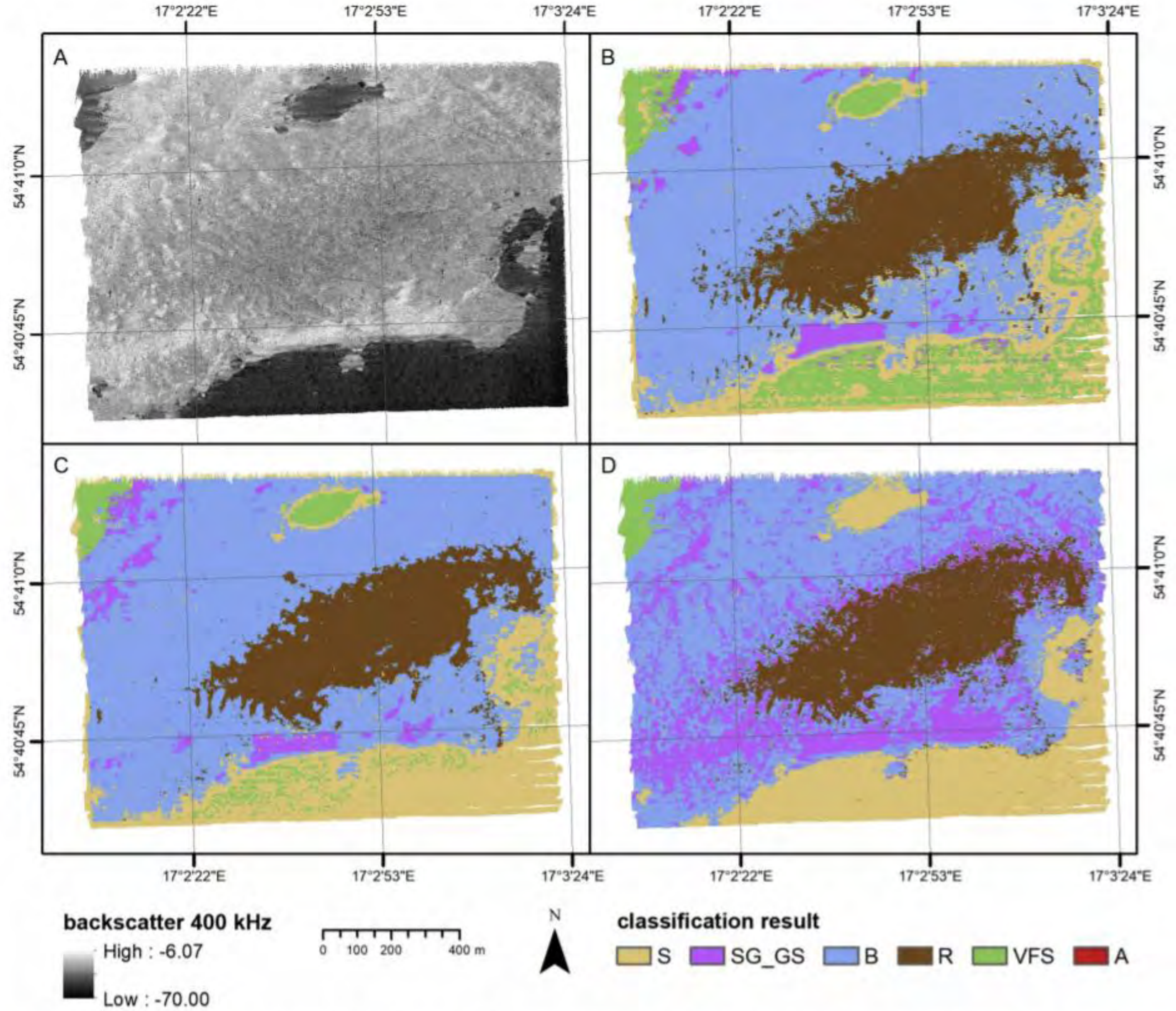


Fig. 7. Comparison between (A) backscatter 400 kHz grid and (B) classification results for all relevant features; (C) uncorrelated features; and (D) only primary features. S - sand, B - boulders, R - red algae on boulders, SG_GS - sandy gravel or gravelly sand, and VFS - very fine sand. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Figure 1.1-31 Benthic habitat mapping using spectral features of NORBIT MBES (redrawn from Trzcinska et al., 2020)

Satellite-based remote sensing of benthic environment

Remotely sensed data have the potential to provide a broad-scale synoptic view of benthic environments and provide temporal data. Satellite-based remote sensing technologies have found widespread use over the past decade. These technologies are discussed in more detail in section 2.2. Here below an illustration of the use of images from the ICONOS satellite to study the seabed is presented. An IKONOS image was used for seafloor observatory in combination with checkpoint ground sampling and classified using a supervised maximum likelihood classifier (ENVI 4.5). As a result, a map of the supervised classification of the marine benthic habitats have been produced, as illustrated on (fig.1.1-32).

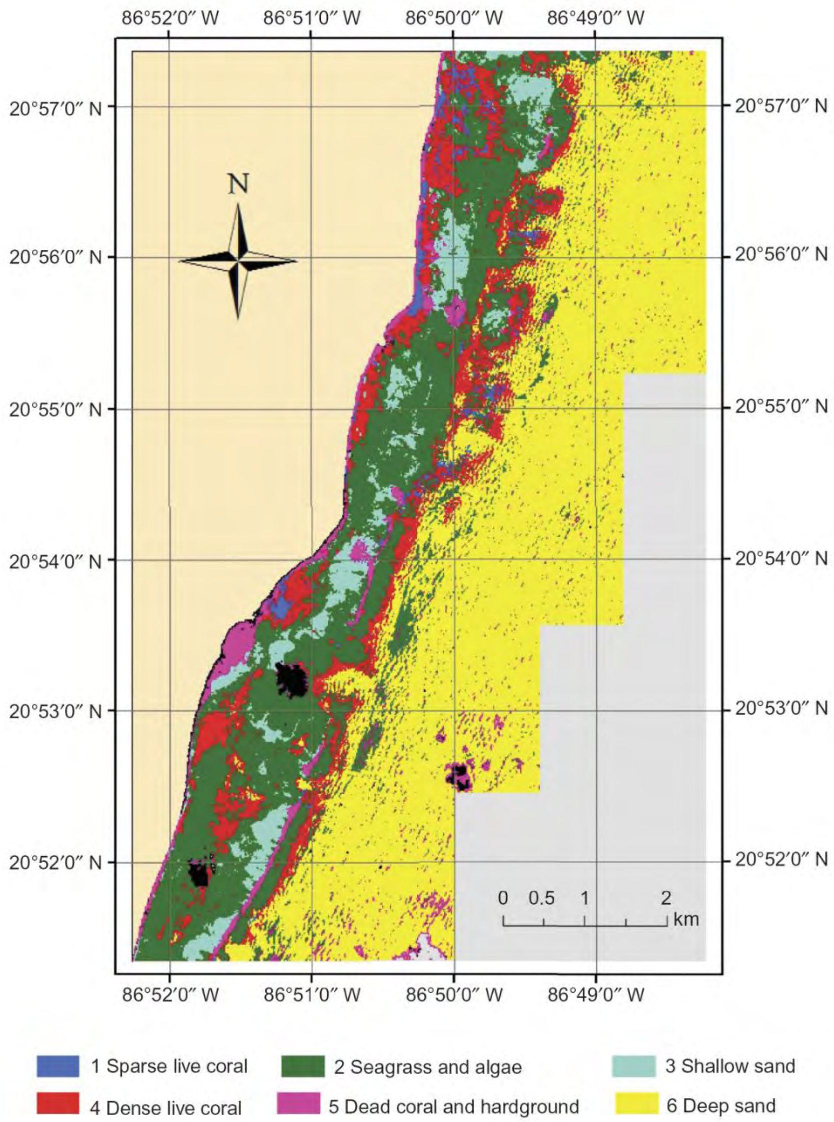


Figure 1.1-32 Map of the supervised classification of the marine benthic habitats located at Puerto Morelos by IKONOS satellite imagery (Zapatta-Ramirez et al., 2013)

Automated Image Analysis for the Detection of Benthic organisms

The development and deployment of sensors for undersea cabled observatories is presently biased toward the measurement of habitat variables, while sensor technologies for biological community characterization through species identification and individual counting are less common. An example is given here for the VENUS cabled multisensory network, installed close to Vancouver Island, Canada (Aguzzi et al., 2011) where seafloor camera systems were deployed at several sites. The objective in the study was to implement new automated image analysis protocols for the recognition and counting of benthic decapods (i.e., the galatheid squat lobster, Munida quadrispina), as well as for the evaluation of changes in bacterial mat coverage (i.e., Beggiatoa spp.), using automed image analysis. For the counting different species series of digital photos were acquired (e.g., 100–200 digital photos) at hourly intervals within several days. Further, the automated image analysis protocols for were created using specialized software. As a result, a method for the efficient recognition of animals and bacterial mat patches have been suggested.

Marine cabled observatory networks for the large-scale ecosystem monitoring

Novel seafloor video-cabled observatory technology that is progressively being installed into large oceanographic networks, it is now possible to explore and monitor ecosystems at sampling frequencies and over temporal durations never attained before. In this activity, we propose for the first time to use video-platforms located in different oceans form coastal areas to abyssal plains, to carry out a centralized video and multiparametric habitat data collection, aimed to explore the fauna of geologically different environments, to study its behavioural rhythms, and to characterize the resulting community dynamism at day-night, seasonal, internal-tidal, or inertial (i.e., atmospheric-driven) periodicities. Fluctuations in video-counted individuals will be considered as a proxy of populational behavioural rhythms in response to habitat cycles also contemporary measured through different oceanographic, chemical, and geologic sensors. Novel automated video-imaging protocols for animal classification and counting, will be consistently customized at each video-source. This project will pioneer a new line of thinking in marine environmental monitoring and multiparametric

Use of ROV and AUV for seabed surveys, benthic, and demersal characterization

Remotely operated vehicles (ROVs) and AUVs are becoming common for surveying localized areas. A number of applications for these vehicles, which can be used for habitat characterization and management, are related to seabed, benthic, and demersal characterization.

There are a number of ROV and AUV manufacturers worldwide, and the models and capabilities are constantly improving. One of the greatest advantages of AUVs is also one of their greatest limitations: power. Vehicles tethered to a ship have essentially unlimited power, but the surface vessel must be in proximity to the vehicle. Although AUVs have much greater freedom, they must be powered by batteries or by solar or wave energy. Batteries are the most common source of power, and a variety of types are used, according to the application. One of the largest energy sinks on an AUV is the lighting, which explains the interest in LED technology. AUVs come in a variety of sizes and shapes (see section 1.2.2) and offer a variety of optical and acoustic configurations.

1.1.6 Hydro-acoustic technologies for underwater noise measurements

The European Maritime Strategy Framework Directive 2008/56/EC requires that the Member States of the European Union achieve and maintain good Environmental Status in European waters by the year 2020 (European Commission, 2008). The operational implementation of the directive is adaptive and is reviewed every six years. It includes five main items which are:

- The assessment of marine waters state (article 8),
- The determination of the Good Environmental Status (GES, article 9),
- The establishment of Environmental Targets (ET, article 10),
- The establishment and implementation of a monitoring program (article 11),
- The establishment and implementation of a program of measures (article 13).

The directive gives a list of qualitative descriptors on which the GES is based upon. **The eleventh descriptor (D11)** deals with the introduction of energy in the marine environment by human activities. It states that the "introduction, including underwater noise, must be at levels that do not adversely affect the environment". In this regard, the MSFD recognizes **underwater noise** as a marine pollutant.

Underwater noise pollution caused by human activities has long been an emerging issue between problems of environmental conservation that have negative effects on animal species.

The increase in maritime traffic, pile driving activities, the geophysical surveys are all activities that generate high levels of underwater noise and require tools that can accurately monitor this phenomenon.
The upmost purposes of underwater noise data collection and analysis are the following:

- To determine the background noise level in the absence of the major selected noise source(s) to monitor;
- To measure noise levels caused by anthropogenic sources;
- To estimate noise frequency composition;
- To predict sound propagation in the area on the basis of the collected data, and, hence;
- To predict the possible impact on local species of marine mammals;

Methodology noise measuring systems.

A generic single channel continuous underwater noise measuring system consists of a hydrophone, signal conditioning electronics, A/D convertor, data storage and/or data transmission device (Figure 1.1-33)

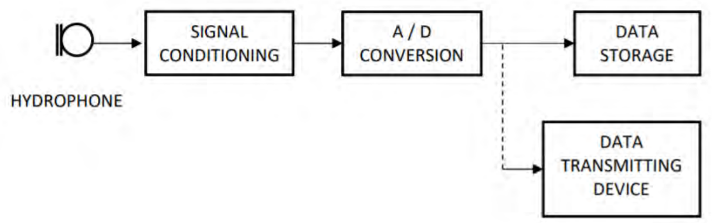


Figure 1.1-33 A generic single channel continuous underwater noise measuring system (source: http://www.quietmed-project.eu)

Hydrophone is an electro acoustic transducer which, in case of passive (listening) systems, converts variations in the underwater pressure caused by underwater noise source to the variations in electrical voltage on its output. Typical specifications are sensitivity, frequency range (bandwidth), linearity, directivity pattern, maximum operating depth (or pressure), self-noise, operating temperature range and impedance.
In the broader sense a generic underwater noise measuring system would include equipment for the deployment and recovery of the measuring part of the system. This equipment depends on the specific methodology used (e.g., drifting, bottom) and may include acoustic releasers, anchors, cable and cable drivers, drogues etc.

a) Bottom mounted systems

In case of the bottom mounted systems a generic continuous underwater noise measuring system is deployed on the sea bottom. All system parts except the hydrophone are placed into the waterproof pressure resistant housing (container) to ensure their functionality under the water. The hydrophone is usually packed separately but close to the container to which it is connected with a short cable. The power is supplied from battery pack also placed inside the container. The system stores (records) the underwater noise data for the period of its deployment. After it is recovered from the bottom, data are downloaded to the external computer for final storage and processing. The most common memory media are memory cards or hard disc and the downloading can be done by connecting to the system container with some kind of interface cable.

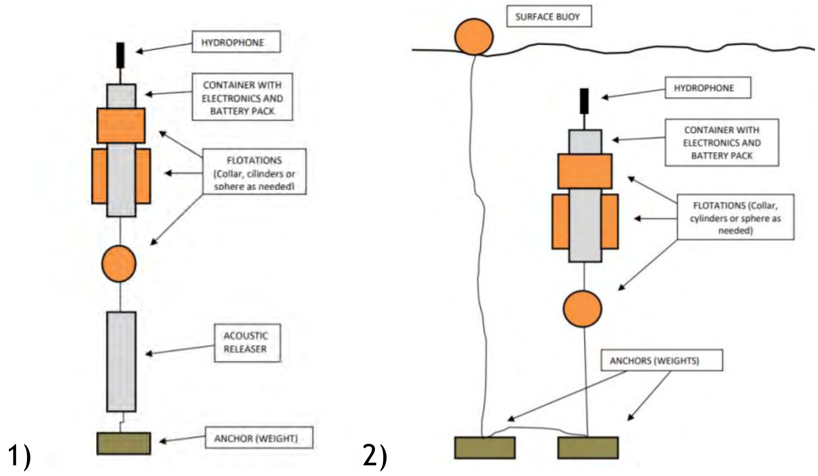


Figure 1.1-34 Continuous underwater noise measuring system setup using: 1) acoustic releaser and 2) surface buoy for deployment.
(source: http://www.quietmed-project.eu)

Bottom mounted system's main advantages include:

- The minimized unwanted parasitic sounds (noise) caused by surface platform, water-air surface (wind, waves);
- Long deployment periods. With the technological advancement in memory and battery capacity, combined with suitable recording parameters and on-off recording schemes, deployment periods up to two years can be achieved.
- Independence of weather conditions and remote locations. The recording of the underwater noise data is performed regardless of the weather conditions. Also, data can be recorded from distant and remote locations as no connection with the shore, or attendance of the location is needed.
- Relatively simple and inexpensive implementation, especially in shallow and mid-shallow waters.

Bottom mounted system's main shortcomings include:

- Offline operation. Data are available only after the deployment period. Incorrect and missing data as well as the functionality of the system cannot be checked during the deployment period.
- Possibility of the loss or damage of the equipment (and data) due to fishing and other sea going activities, mainly trawling. As the system is left unattended and unmarked on the bottom there is possibility to be trawled up or caught by fishing gear.
- Not suitable for the location with strong current or tidal flows. Such flows can cause high levels of flow noise as the system hydrophone is stationary.

b) Drifting systems

In case of the drifting systems a generic continuous underwater noise measuring system is deployed suspended from the surface buoy that drifts freely driven by wind, waves, current or tide. All system parts except the hydrophone are usually placed inside the buoy. The hydrophone is suspended from the surface buoy at the desired depth and connected to the buoy with a cable. However, configuration with all system parts within waterproof pressure housing which is also suspended from the buoy is also possible. The most important feature of the drifter design is the positioning of the hydrophone to be stationary to the body of the water moving horizontally. The drogue (e.g., sea anchor, "underwater parachute") is used for that purpose. The drogue also decouples the motion of the surface buoy from the hydrophone.

Figure 1.1-35 shows a typical configuration of the drifting continuous underwater noise measuring system.

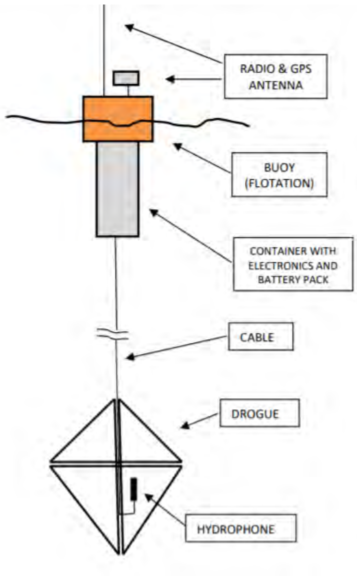


Figure 1.1-35 Typical configuration of a drifting underwater noise measuring system (source: http://www.quietmed-project.eu)

Drifter system's main advantages are:

- Suitability to measure underwater noise in strong flows avoiding the flow noise;
- Simple and inexpensive implementation.

Drifter system's main shortcomings are:

- More complicated processing and the analysis of the results due to its mobility;
- Possibility of the loss or damage of the equipment;

c) Surface based systems

In case of surface-based systems, a generic continuous underwater noise measuring system is deployed from a surface platform, most commonly a vessel. The vessel can be free floating, or more usually, anchored. All system parts except the hydrophone are placed aboard the vessel, while the hydrophone is suspended from the vessel at the desired depth and connected to the equipment aboard with a cable. The platform based underwater noise measuring systems are the most usual entry (starting) level for underwater noise measurements. The reason is that small vessels are easy to find and handled and the measuring equipment (amplifier, filter, A/D converter, etc.) can be easily available general purpose laboratory equipment. Surface vessel based underwater noise measurement in shallow water not far from the coast is a relatively easy task. The great advantage of this methodology is that it is real time. The functionality of the system is always under control, measurement parameters can be adjusted, and data monitored in real time. Observed underwater noise signals can be directly linked to the events (e.g., vessel movements). Also, one can be sure that recordings are correct and there are no missing data, unlike the bottom-based system where missing data cannot be corrected.

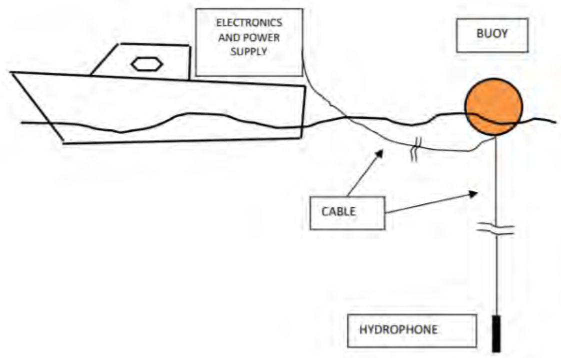


Figure 1.1-36 Surface platform based continuous underwater noise measuring system setup using auxiliary buoy for mitigating platform self noise
(source: http://www.quietmed-project.eu)

The platform-based system's main advantages are:

- Relatively simple measurements possible with small boat and general-purpose equipment (except the hydrophone);
- Real time measurements and recordings;
- Easy deployment and recovery;
- No danger of the loss or damage of the equipment and data.

The platform-based system's main drawbacks are:

- Platform induced parasitic (unwanted) sound (platform self-noise);
- Restricted operability due to weather conditions;
- Increased cost for longer deployment periods.

d) Land based systems

In case of the land based systems a generic continuous underwater noise measuring system is deployed on the land e.g. sea shore. All system parts except the hydrophone are located on land. The hydrophone is placed on the sea bed and connected to the rest of the system equipment ashore with the long cable. The hydrophon usually contains the part of signal conditioning electronics allowing for use of long cables without signal quality loss. Besides connection for underwater noise signals, the cable provides power for the underwater parts of the system. From a technical point of view, land based continuous underwater noise measuring system are close to the optimal system idea. This methodology is real time with all advantages as referred to in the section on surface platform-based systems. In addition, these systems do not suffer from potential lack of memory or power, deployment period is virtually indefinite, weather conditions on the hydrophone location are irrelevant, attending staff enjoy more safety and comfort while observing and/or processing recorded data.

The land-based system's main advantages are:

- Real time operation;
- Memory and power requirements are not an issue;
- Deployment period virtually indefinite;
- Weather conditions on the hydrophone location are irrelevant;
- Low chance of equipment being stolen;

The land-based system's main drawbacks are:

- The complex and expensive cable laying and connection to the land-based equipment.

Examples of innovative systems for noise measurements

- ✓ Innovative system (CE.TU.S. Research Centre, Italy).

It comprises a hydrophone and a digital CTD probe, able to provide more reliable and complete environmental measures compared to analog systems commonly used. The system allows to acquire simultaneously along the water column both environmental noise measurements and oceanographic measurements such as temperature and salinity, necessary for the subsequent analysis of sound propagation. The hydrophone digital contains an analog/digital two-channel converter, directly connected to the ceramic using two preamps with different gains. This configuration is particularly innovative and results in an instrument with high sensitivity up to -148 re 1V/uPa, low self-generated noise, wide dynamic spread on two channels and high bandwidth up to 80 KHz. The digital output makes the hydrophone also immune to electromagnetic interference and signal loss along the transmission cable. The main benefits of this system can be summarized as: Hydrophone with low noise, wide band, large dynamics, high sensitivity; Simple integration with CTD probe and non-acoustic data; Portability; Easy to use; High-quality data.

- ✓ The Cetacean Research™ CR1-200-SP.

A powerful and portable underwater noise recording, measurement, and analysis system when interfaced with your Windows laptop. With a linear frequency response from 16Hz to 48kHz (usable from 5Hz to 68kHz), this system provides recording, as well as real-time and post-processing analysis of a vast array of underwater signals and noise. Because this system can withstand large signals without overloading (up to 220dB), it is ideal for measuring very loud noises such as those produced by pile drivers, air guns, low-frequency and mid-range sonar, and explosives. In addition, the low system noise and large dynamic range of the CR1-200-SP also allows it to measure quieter ambient sound levels (down to 55dB).

a) b)

Figure 1.1-37 Illustration on innovative systems for noise measurement:
a) Hydrophone by CE.TU.S. Research Centre, Italy; b) CR1-200-SP Cetacean Research™

- ✓ NeXOS A1 Smart Hydrophone.

The objective of NeXOS project is to develop cost-effective, innovative, and compact multifunctional sensor systems in ocean optics, ocean passive acoustics and for an Ecosystem Approach to Fisheries (EAF), which can be deployed from mobile and fixed platforms. NeXOS addresses the whole data chain from the sensor to the end users adopting the Open Geospatial Consortium's (OGC) Sensor Web Enablement (SWE) framework to improve interoperability, data-sharing and multiplatform integration. Using this framework, the instrument data flows directly from the sensor to the Sensor Observation Service (SOS), where it is stored.

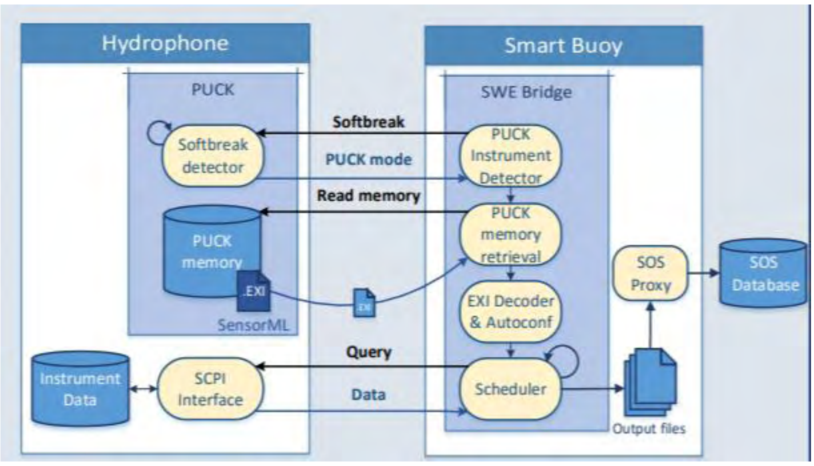


Figure 1.1-38 NeXOS A1 Hydrophone - Smart Buoy interoperability

The hydrophone is deployed using the Smart Buoy as a host platform, which has a Linux embedded computer with RS-232 and Wi-Fi interfaces, encapsulated into a buoy-shaped case.

1.2 Sensor-Carrying Platforms

Sensor-carrying platforms can be grouped in *stationary* devices such as landers and moorings to *dynamic platforms* - ships, marine robotics, aerial systems, and *remote-sensing satellites* from space.

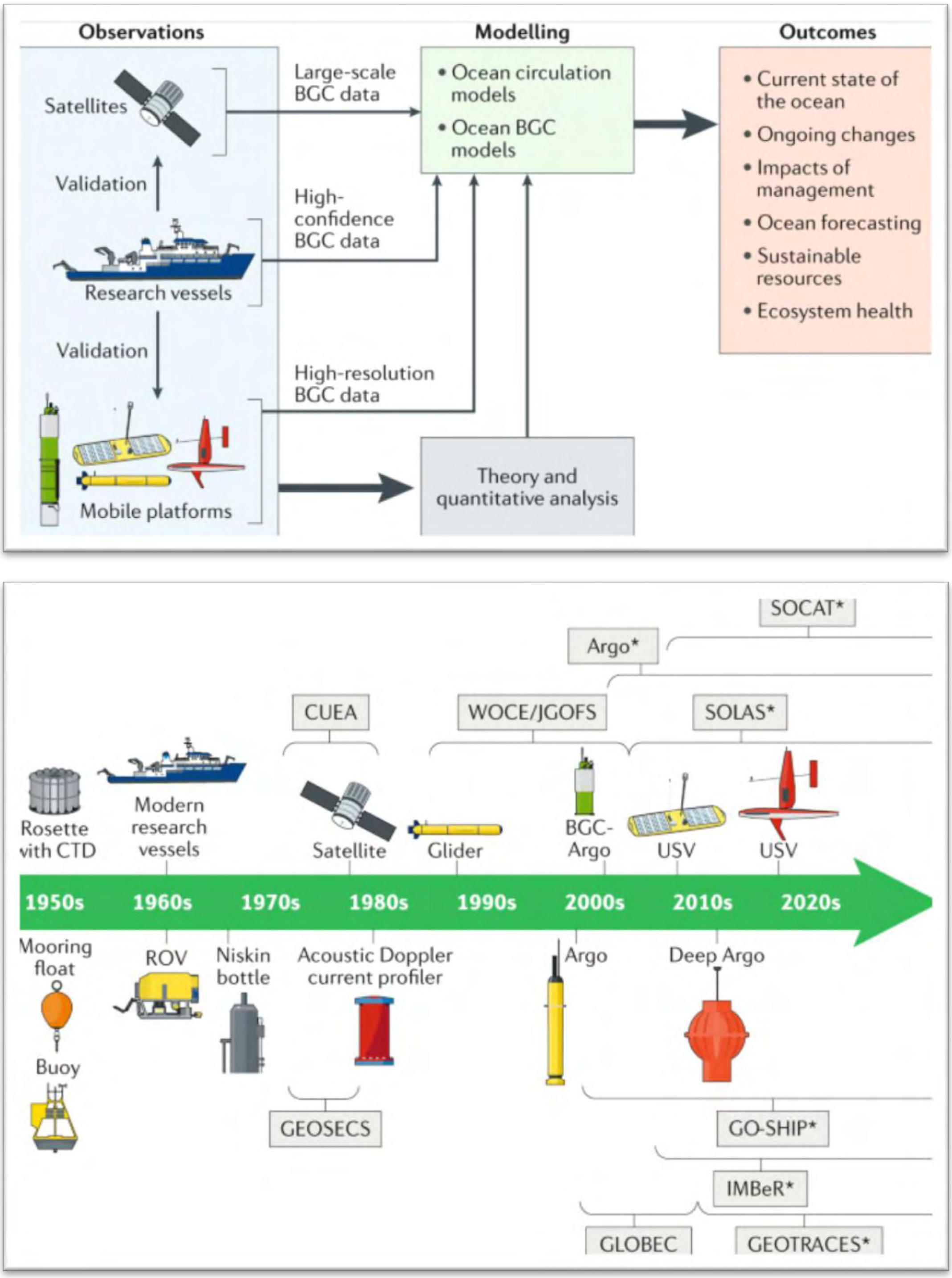


Figure 1.2-1 Chronology of platform development 1950 - 2020
(Sørensen A.J. et al. 2020)

Here below in section 1.2 some advanced achievements in stationary devices and dynamic platforms are presented, while remote-sensing satellites are described in section 1.3.

In Table 1-4 an overview of currently used Marine Environment Monitoring Platforms, corresponding sensors carried on board, their use and potentials are given.

Table 1-4 Summary on Marine Environment Monitoring Platforms (types, sensors, and use)

Platform	Carrying Sensors (availability)	Uses and potentials
Research Vessels (RV)	CTD, sample collection, acoustics, passive sampler, visual taxonomy, FerryBox, camera/light imaging, hydrophone	all monitoring; used as platform to launch autonomous vehicles and service fixed point observation systems
Voluntary Observing Ships(VOS) and Ships of Opportunity(SOO)	CTD, sample collection, acoustics, camera/light imaging, FerryBox, hydrophone	Fisheries research and monitoring, sea-bed mapping
Fixed Point Marine Observation Systems	CTD, some sample collection, camera/light imaging, passive sampler, hydrophone	Wave height, water quality, mounting for biosensors, mounting for plankton microscopy
Mobile platform (Subsurface Floats, Remotely Operated and Autonomous Vehicles)	CTD, limited water sample collection, acoustics, camera/light imaging	Argo Float fleet; sea-bed mapping, oceanographic measurements
Unmanned aerial vehicle (Remotely-Piloted Aircraft)	GPS, Camera	Commercial shoreline surveys, launch from RV(up to 1 km from pilot)
Satellite	Camera/light imaging, data transfer from automated platforms	Water quality(algal bloom)
Citizen Science	eDNA sample collection, species ID, litter sample collection, catch diaries, samples for shore based and shallow water studies	Non-indigenous species, marine litter; limited biodiversity recording, recreational fishing

1.2.1 Robotised autonomous surface water monitoring systems (aquatic drones). Unmanned / Autonomous Surface Vehicles USV/ASV

Autonomous monitoring systems are increasingly being utilised as fundamental data-gathering tools by research institutions and scientists across the globe, allowing further exploration of our waters and greater understanding of our planet. Previously, these explorations seemed to only be noted amongst the scientific community, but highly publicised events, such as the industrial disaster in 2010 of the oil spill in the Gulf of Mexico from the Deepwater Horizon platform, have drawn focus to the use of robotics in order to combat and measure the environmental damage to the area and its inhabitants.

One obvious advantage of utilising ASVs for environmental monitoring is that they allow examination of difficult to access locations (e.g. shallow water), as well as of events that are too dangerous, or impossible for humans to undertake. The ability to measure these events with unprecedented distances covered and in quicker timescales provides crucial efficiency to dealing with large scale environmental disasters and increases our knowledge of the our widely un-investigated oceans. The other crucial advantage of using ASVs for environmental monitoring is the reduction of on-site time and maximisation of operational hours, which on the whole reduces the carbon footprint of the operation and the effect of the mission on the area. Further to this, for small scale operations for data collection, smaller ASVs can be utilised in order to reach difficult areas such as caves, harbours and bridges without the need for a support vessel.

Maritime autonomous systems – in particular, USV/ASVs – provide low impact solutions for marine observations and data collection across a range of environmental monitoring tasks such as water quality monitoring and sample acquisition, fish and aqua culture tracking and current and wave profiling. As technological advances continue to improve these systems gain even more traction across the scientific and research community enabling to achieve greater understanding of the marine environment and its inhabitants and intricacies. As opposed to traditional manned platforms, ASVs have a very low noise signature. For such environmental monitoring tasks such as passive acoustic monitoring (PAM), it is crucial that the vessel utilised has a low noise signature so as not to skew the data.

Nowadays there are many USV/ASV products available on market, offering various features. A screenshot illustration on the variety of these is presented on Figure 1.2-2

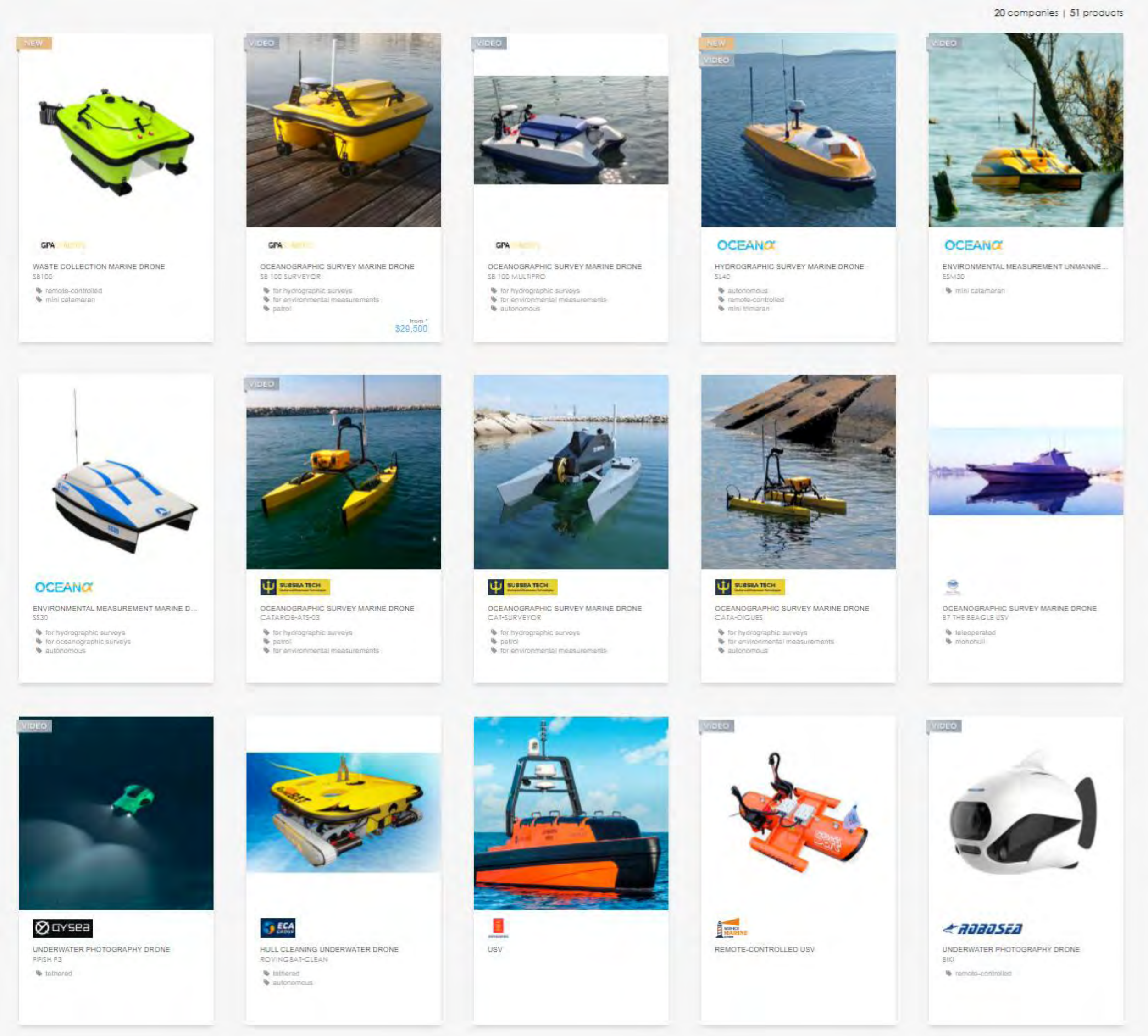


Figure 1.2-2 illustration on the variety of different USV / ASV
https://www.nauticexpo.com/boat-manufacturer/marine-drone-23029.html

Although various types of autonomous vehicles have been described in the literature, they all have limited autonomy (even in the long term) as regards operational time and covering the seabed. Therefore, recent evolution of such devices is connected to use of solar, wind and wave power, as shown in the following examples.

A typical example for an ASV is the SR-Utility 3.0 by SeaRobotics, Figure 1.2.3 (https://www.searobotics.com/products/autonomous-surface-vehicles/sr-utility-class).SR-Utilyu 3.0 was originally designed as a Heavy Load Water Sampling ASV, however in 2019 it has been developed to carry an interchangeable suite of customizable sensors and payloads. The base vehicle was designed to support large multibeam sonar systems and a 15 m cast winch. The following interchangeable sensors and payloads can be installed on board:

- Single/Multi-beam echo sounders
- Sub bottom profilers
- LiDAR
- DGPS / RTK GPS / Vector GPS
- Sidescan sonar
- Backscatter
- ADCP/ADP
- USBLs
- Spectrometer/Magnetometer

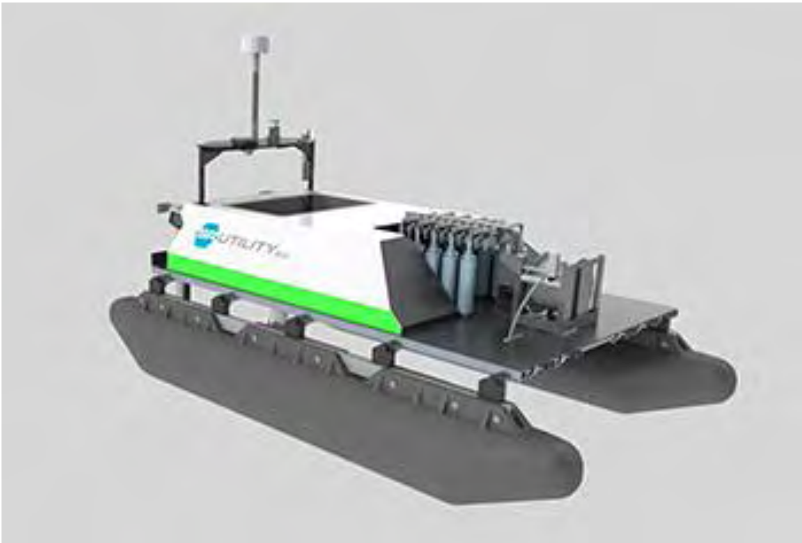
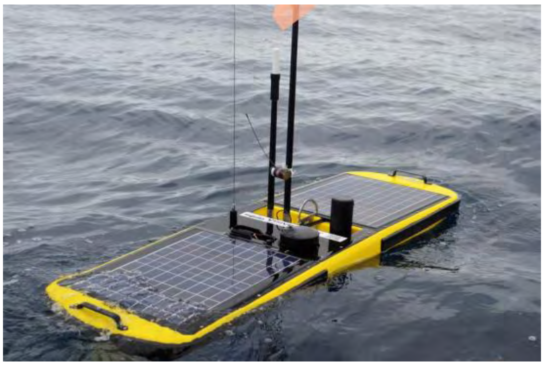


Figure 1.2-3 SR-Utility 3.0 by SeaRobotics,

Three ASVs operated by the UK's National Oceanography Centre (NOC) in their Marine Autonomous Systems in Support of Marine Observations (MASSMO), are shown here below on Figure 1.2-4. Powered partially or completely by solar, wind and wave power, these robotic marine platforms are able to undertake long-duration missions that often last for a number of months. The three ASVs are tracking tagged fish and monitoring the sea. These ASV have been used by the scientists from the Marine Biological Association (MBA) in Plymouth, to shed light on the private lives of some fish species and show whether new protected areas are effective in conserving stocks.



a) b)

c)

Figure 1.2-4 ASV fleet operated by NOC, UK: a) Global C-Enduro; b) Liquid Robotics SV3 Waveglider, and c) Seiche AutoNaut (https://projects.noc.ac.uk/massmo/frontpage)

ASVs typically carry a payload consisting of multiple instruments, and their persistent surface presence provides an advantage for monitoring and gathering weather information. The instruments that can be carried by ASVs are many and varied. Unlike gliders, each design can carry a payload of several instruments. The biggest limitation with ASVs is the lack of depth profiling, although they can carry out some deployments to 100 m using winches. The biggest strength of an ASV is its persistent surface presence. This can be used for things like photographic monitoring and weather information. They also have a future as data harvesters, where an underwater vehicle or moored device talks to the ASV acoustically, and the data is relayed over Iridium.

Examples of instruments that have been installed to ASVs for demonstration projects such as the MASSMO series are:

- Vemco fish tracker
- Decimus passive acoustic monitor with a Seiche acoustic array
- UK Met office self contained meteorological instrument suite
- Kongsberg sidescan sonar
- single beam echosounder
- pyranometer
- Chelonia PAM and SMRU SoundTrap (PAM)
- GoPro cameras
- SeaOWL oil and chlorophyll detector.

Another example for a robot-based observatory, consisting of an autonomous solar-powered marine robot with specialized sensing systems designed to carry out long-term observation missions in the inland sea is BUSCAMOS-RobObs, deployed in the Mar Menor in southeastern Spain, Figure 1.2-5 (González-Reolid et al., 20180).

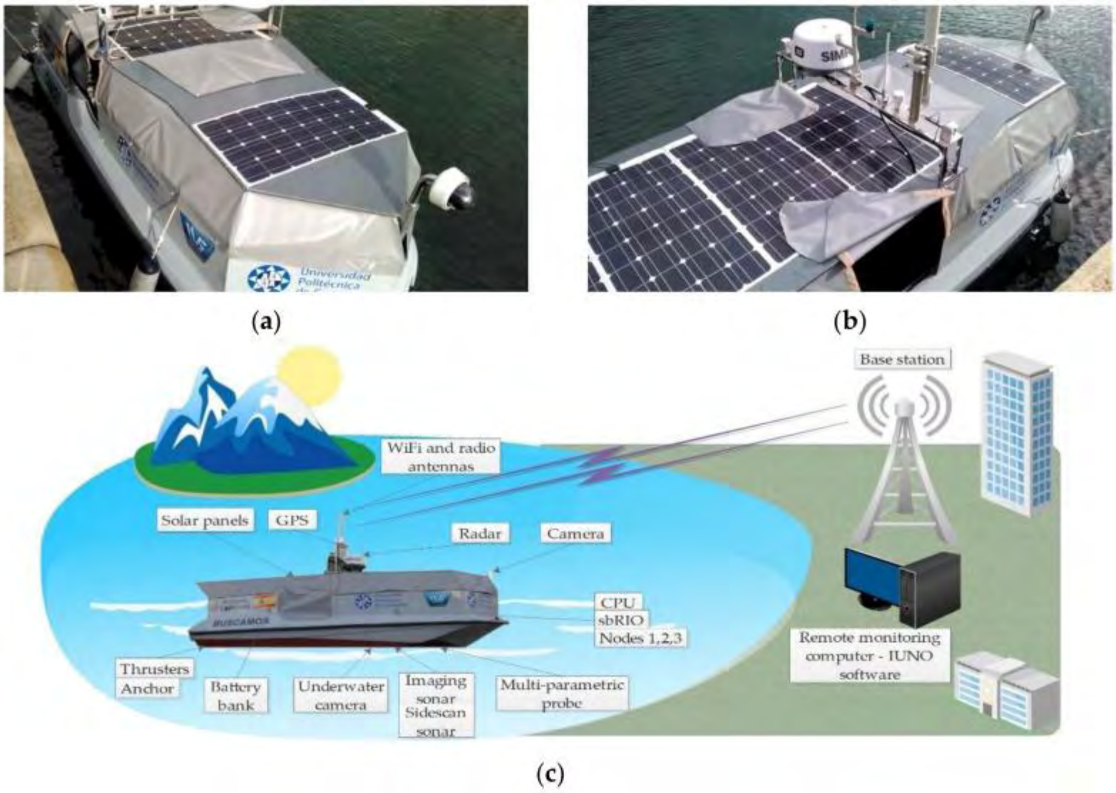


Figure 1.2-5 BUSCAMOS-RobObs pictures (a,b), and general scheme (c)
(González-Reolid et al, 2018)

This highly specialised device is unique because it has the capacity to anchor itself to the seabed and become a "buoy", either to take measurements at specific points or to recharge its batteries. The robot is equipped with a broad range of sensors, including side scan sonar, sub-bottom sonar, laser systems, ultrasound sonar, depth meters, a multi-parametric probe and a GPS, which can collect georeferenced oceanic data.

1.2.2 Underwater technologies. Autonomous / Unmanned Underwater Vehicles (AUV / UUV). Remote Operated / Towed Vehicles (ROV/ROTV)

Remotely Operated, Unmanned, Autonomous Underwater Vehicles (ROV, UUV and AUV) are generally used as a platform from which to make measurements and observations under the control of an active operator. The cabling supplies power and transfers data making intensive and detailed operations possible. They provide the opportunity to make observations in new and difficult environments and inspect and guide specific measurements or activities during the survey.

Powered, autonomous underwater vehicles (AUV) maintain many of the capabilities of ROV operation although under their own propulsion, thus extending the range and area covered relative to a control base. Mission parameters are generally predefined or refined when remote communications are established and mission lengths generally vary from hours to days (Wynn et al., 2014). Advances in size and power of AUVs are enabling missions lasting weeks or months with ranges of 1,000s of km that can reach 1,000s of m deep (Furlong et al., 2012). These developments have been trialed for use in ecosystem monitoring (Suberg et al., 2014).

A good example for a modern UUV is the “Iver4 580”, revealed in September 2020. This UUV offers users a 200-meter depth survey system featuring hot-swappable battery sections that can be changed in the field without any special tools. Built with Iver4 next-generation technology, the Iver4 580 features a full suite of sensors in a portable size and small mission footprint. Iver4 580 is built to serve as a vehicle for commercial and defense survey missions, however the combination of transportability and in-water efficiency makes it an appropriate vehicle for any underwater marine research. Main features of this UUV:

- Durable titanium and carbon fiber construction
- 208 cm Length, 14.7 cm Diameter; Carbon Fiber Tube 45 kg weight
- Full sensor suite, including side scan sonar, inertial navigation system, sound velocity probe and doppler velocity log
- High-speed data download with GigE speed
- Unmatched shallow water and surf zone performance, shore avoidance autonomy

Figure 1.2-6 UUV survey system "Iver4 580"
(https://www.l3harris.com/all-capabilities/iver4-580-uuv)

Another example is given here below, of a small scale underwater drone called RangerBot, designed by Queensland University of Technology to monitor the health of the Great Barrier Reef. RangerBot helps reef's health monitoring by creating 3D maps to observe changes in the ecosystem. The drone can stay down much longer than divers can and venture into places too dangerous for humans, such as shark- or crocodile-infested waters. It is fitted with real-time computer vision technology to survey sea bed, and detect crown-of-thorns starfish. RangerBot is able to identify this kind of fish with 99.4% accuracy.

Figure 1.2-7 RangerBot underwater drone

An AUV model system is proposed by Salhaoui et al. 2020, designed to track a species of Mediterranean fan mussel, using cloud computing services with edge computing as alternative processing units. An innovative algorithm was proposed to autonomously track the target species without human intervention by integrating the object detection system into the AUV control loop. The proposed model is capable of detecting, tracking and georeferencing specimens with software interface for unmanned drones. The system is designed to collect and interpret underwater images to track the fan mussel population in real time, using georeferenced mosaics generated from the images by an automatic processing method. This automated approach is based on DL image processing techniques such as convolution neural networks (CNN) to detect the position of a possible specimen in a captured photo. An algorithm on the IoT gateway establishes the connection between the AUV control system and cloud image processing techniques. The results of the suggested system are then compared with cloud image processing methods in terms of latency and certainty.

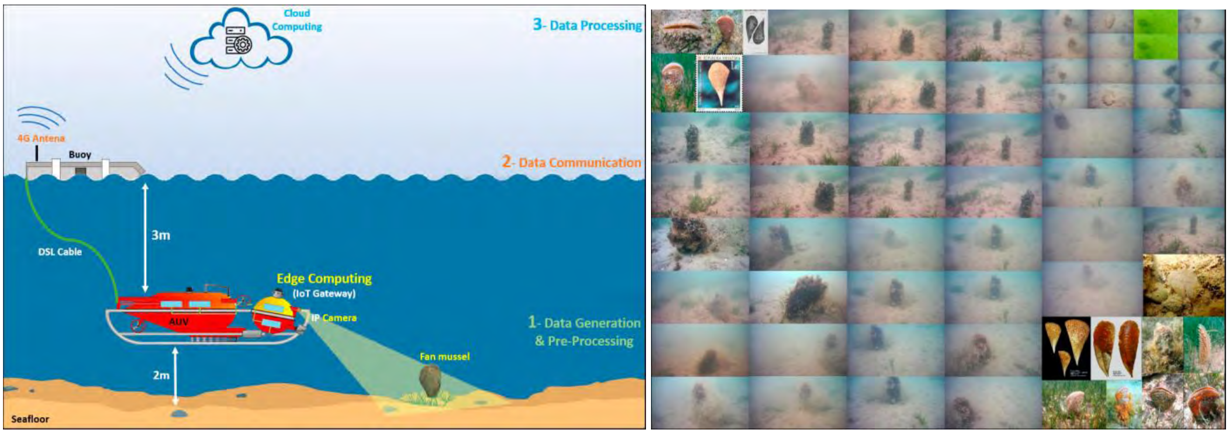


Figure 1.2-8 AUV-IoT Platform, cloud-based custom models for detecting Mediterranean fan mussel
(Salhaoui et al. 2020)

Underwater vehicles can hold modern imaging devices which can be used as valuable tools that complement other biological and oceanographic monitoring devices for the understanding of marine ecosystems and their biodiversity. Such an example is given by Lopez-Vazquez et al. (2020). Since marine areas host complex ecosystems, it is important to develop spatially widespread monitoring networks capable of providing large amounts of multiparametric information, encompassing both biotic and abiotic variables, and describing the ecological dynamics of the observed species. Nevertheless, large amounts of images or movies cannot all be manually processed, and autonomous routines for recognizing the relevant content, classification, and tagging are urgently needed. It is proposed a pipeline for the analysis of visual data that integrates video/image annotation tools for defining, training, and validation of datasets with video/image enhancement and machine and deep learning approaches. Such a pipeline is required to achieve good performance in the recognition and classification tasks of mobile and sessile megafauna, in order to obtain integrated information on spatial distribution and temporal dynamics. A prototype implementation of the analysis pipeline is provided in the context of deep-sea videos taken by one of the fixed cameras at the LoVe Ocean Observatory network of Lofoten Islands (Norway) at 260 m depth, in the Barents Sea, which has shown good classification results on an independent test dataset with an accuracy value of 76.18% and an area under the curve (AUC) value of 87.59%.

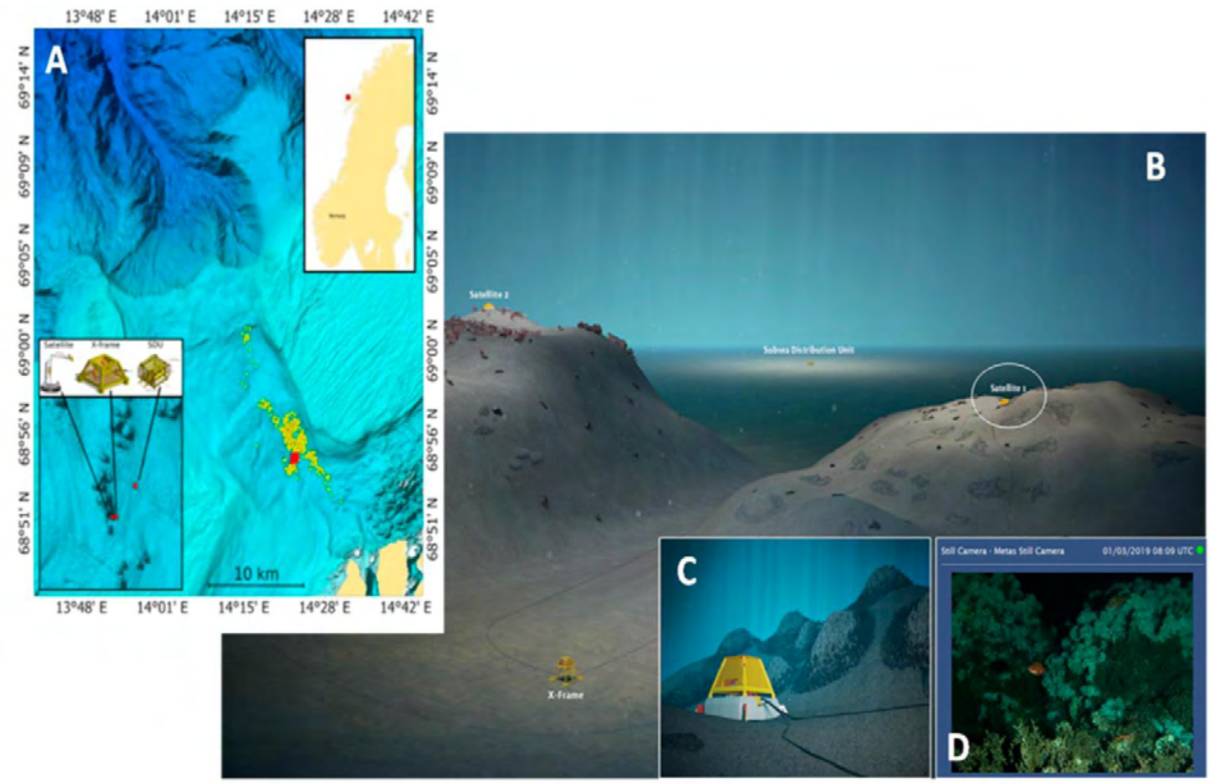


Figure 1.2-9 Overview of LoVe underwater observatory (https://love.statoil.com/).

Where (A) Bathymetric map of the canyon area, (B) the area in 3D showing (encircled in white) the video node providing the footage, (C) enlarged view of the areas surrounding the node where D. Pertusum reefs are schematized, and finally (D) the field of view as it appears in the analyzed footages (B, C, and D).

This study presents a novel automatic pipeline that can be used for analysis of video image with the goal of identification and classification of organisms belonging to multiple taxa. The environment is difficult due to the turbidity that can sometimes be seen in the water, which makes it hard to appreciate the species; the small size of the dataset, which limits the appearance of some of the animals; the colours of the species detected, as well as the size of some of them, which sometimes blend in with the environment. All this can sometimes lead to incorrect classifications. In this particular example, successful classification results have been obtained by the image pre-processing pipeline.

Remote Operated Towed Vehicles (ROTV)

ROTV function as a multi-purpose platform with the capabilities of performing exploration, searches and surveys. Exploring the seabed is extremely difficult regarding the immense depths and harsh conditions an underwater craft has to endure. Therefore, a ROTV is a solution to explore unknown depths, to seek out new life, to go where no one has gone before. Implementing the related tasks independently on resurfacing, charging batteries or unload data simplifies tasks and provides an advantage for the towed ROV, by providing real-time video and sensor data(which is impossible to achieve with a cable-free AUV).

In the example presented here, TRIAXUS ROTV of MacArtney is a vehicle with unique hydrodynamic design, the systems are highly stable, very manoeuvrable and able to effectively collect quality data at high speeds with true 3D towfish technology for fishery research. TRIAXUS is developed for high-speed oceanographic data acquisition work and is designed to undulate between 1 and 350 metres. Lateral offsets of up to 80 metres to either side of the ship is possible, enabling the vertical profiling to be carried out in an undisturbed water column. Towing speed between 2 and 10 knots and vertical speed of up to 1 metre per second are possible.

Figure 1.2-10 TRIAXUS ROTV for fishery research (MacArtney, DK)

TRIAXUS has been designed using the latest carbon fibre moulding technologies, and the Danish Maritime Institute (DMI) has supplied the hydrodynamic design. The embedded telemetry system is based on the successful MacArtney NEXUS fibre optic multiplexer system, allowing interface of up to 9 additional sensor packages using the plug-and-play principle.

The man machine interface is an easy-to-use Windows based software package. The system is designed to carry a broad range of sensor packages from the leading manufacturers of oceanographic monitoring equipment including: Survey equipment (CTD, Optical plankton counter, PAR and radiation sensor, Fluorometer, Transmissometer, Video plankton recorder, Camera and light, Other oceanographic sensors.

Another ROTV example is the Multi-purpose ROTV for oceanographic surveys EIVA ScanFish Rocio. This is a multi-purpose ROTV solution covering a wide variety of oceanographic survey disciplines. It has a high payload, allowing users to fit several different pieces of equipment.

It is equped with EIVA ScanFish Rocio including altimeter, motion and depth sensors, as well as with EIVA ScanFish III Flight control and monitor software.

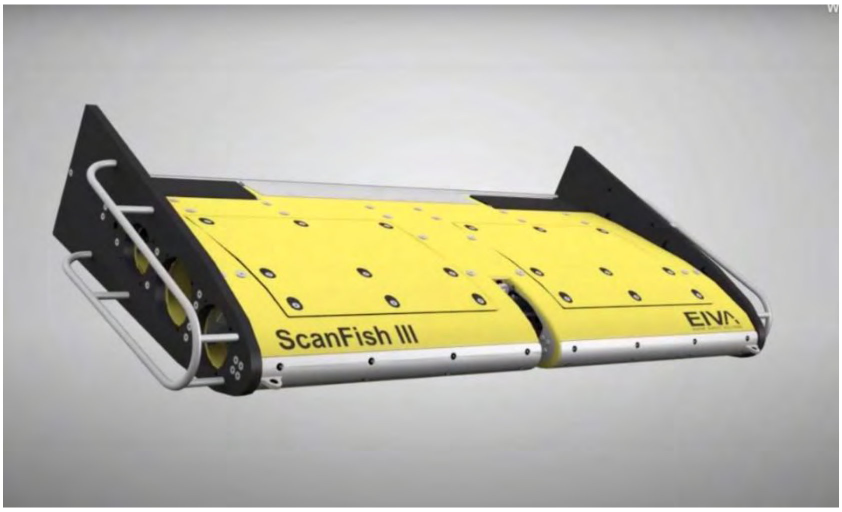


Figure 1.2-11 ScanFish devices installed on a ROTV platform
https://www.eiva.com/products/hardware/scanfish-rotvs/scanfish-rocio

The next example presents a Towed Optical Video (TOV) System that provides a cost-effective method for underwater search and inspections. The JW Fishers TOV-2 HD system is a next generation towed video camera with full-HD video standard. HD-TVI technology supports longer cable transmission distances while allowing the picture to still travel over standard coax cable, producing a zero-latency, at high definition video experience. The TOV system is shown on Figure 1.2-14.

Figure 1.2-12 Towed Optical Video (TOV) System, JW Fishers TOV-2 HD
http://www.jwfishers.com/products/tov2.html

The system is deployed over the side of the vessel and lowered to the bottom. The TOV-2 HD uses the boat's propulsion to move it through the water in the tow configuration. The camera is mounted in the housing at a downward angle giving a field of view of 50 degrees. The system can also be suspended over the side of the vessel and used as a dropped camera. Large areas can be searched and recorded without incurring time consuming check-out dives. Topside the TOV-2 HD connects to a video monitor or standard TV. The video can also be recorded on VRM-2 HD video recorder that records up to 12 hours of video on an SD card. The TOV is in use by U.S. and foreign military, dive rescue groups, commercial fisherman, and other.

1.2.3 New generations (solar powered / portable / smart) monitoring buoys

Portable buoys

Portable buoys serve as sensor-carrying floating platforms that are relatively small size & weight, and can be moved from one location to another.

An example for a portable, solar powered buoy is the CB-150 Data Buoy. The CB-150 data buoy is designed for smaller water bodies, portable or short-term deployments, and applications requiring compact or low-power sensors.

Figure 1.2-13 Illustration on CB-150 Data Buoy in operation
(source: https://www.nexsens.com/products/data-buoys/cb-150)

SWIFT buoys

SWIFT stands for Surface Wave Instrument Floats with Tracking - will drift along the sea surface measuring ocean turbulence, wave properties, salinity, water, surface meteorology, and capture images of clouds.

Floats (oceanographic instrument platform)

A float (not to be confused with a drifter) is an oceanographic instrument platform used for making subsurface measurements in the ocean without the need for a ship, propeller, or a person operating it. Floats measure the physical and chemical aspects of the ocean in detail, such as measuring the direction and speed of water or the temperature and salinity.

A float will descend to a predetermined depth where it will be neutrally buoyant. Once a certain amount of time has passed, most floats will rise back to the surface by increasing its buoyancy so it can transmit the data it collected to a satellite. A float can collect data while it is neutrally buoyant or moving through the water column.

Often, floats are treated as disposable, as the expense of recovering them from remote areas of the ocean is prohibitive; when the batteries fail, a float ceases to function, and drifts at depth until it runs aground or floods and sinks. In other cases, floats are deployed for a short time and recovered.

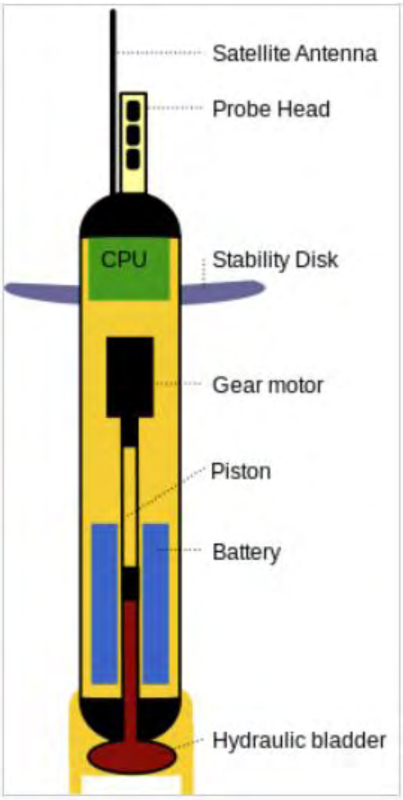


Figure 1.2-14 A typical float for oceanographic measurements

1.2.4 Ocean Gliders and GPS Drifters

Ocean gliders / underwater gliders

Review based on publications in: https://oceanservice.noaa.gov/facts/ocean-gliders.html

An ocean glider is an autonomous, unmanned underwater vehicle used for ocean science. Since gliders require little or no human assistance while traveling, these little robots are uniquely suited for collecting data in remote locations, safely and at relatively low cost.

An underwater glider is a type of autonomous underwater vehicle (AUV) that employs variable-buoyancy propulsion instead of traditional propellers or thrusters. It employs variable buoyancy in a similar way to a profiling float, but unlike a float, which can move only up and down, an underwater glider is fitted with hydrofoils (underwater wings) that allow it to glide forward while descending through the water. At a certain depth, the glider switches to positive buoyancy to climb back up and forward, and the cycle is then repeated.

While not as fast as conventional AUVs, gliders offer significantly greater range and endurance compared to traditional AUVs, extending ocean sampling missions from hours to weeks or months, and to thousands of kilometers of range.[1] The typical up-and-down, sawtooth-like profile followed by a glider can provide data on temporal and spatial scales unattainable by powered AUVs and much more costly to sample using traditional shipboard techniques. A wide variety of glider designs are in use by navies and ocean research organizations, with gliders typically costing around US$100,000.

Gliders may be equipped with a wide variety of sensors to monitor temperature, salinity, currents, and other ocean conditions. This information creates a more complete picture of what is happening in the ocean, as well as trends scientists might not otherwise be able to detect from satellites or large research ships.

While there are many glider designs that use different techniques to move through the water, all gliders share the ability to travel far distances over long periods, without servicing. Unmanned gliders sample the ocean in places where it is impractical to send people, and at a fraction of the cost, allowing us to collect data even in the middle of a hurricane. It is these characteristics along with advancements in sensor technologies that make gliders increasingly important as tools for collecting ocean data.

The glider illustrated here below on figure 1.2-17 is the Slocum glider. It looks like a torpedo, but it doesn't have propellers or an internal engine. Instead, it uses a pump to gently change its buoyancy over time. This allows the glider to slowly move up and down through the water. And as it does so, the big fins sticking out of the sides of the craft create lift to propel it forward. It's similar to how a glider in the air works, except the ocean glider can glide up as easily as it glides down, as illustrated on Figure 1.2-18.

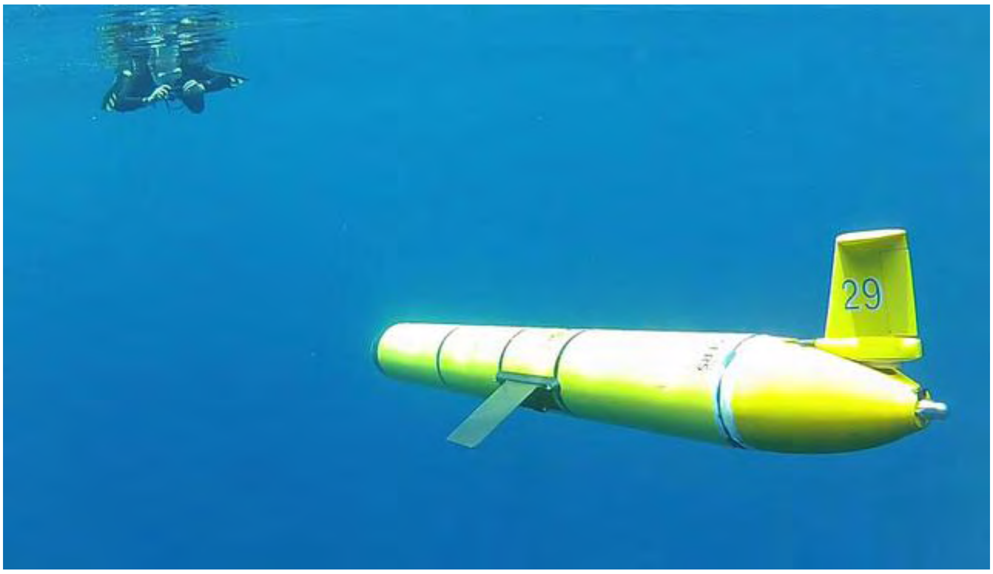


Figure 1.2-15 A typical glider for oceanographic measurements

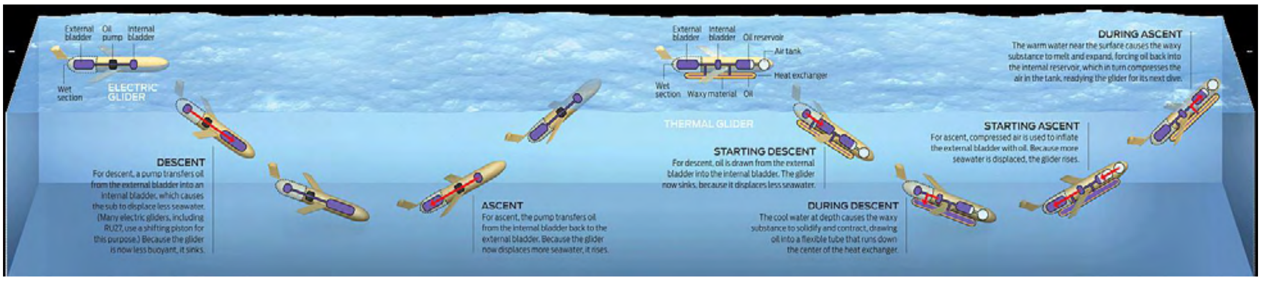


Figure 1.2-16 Principle of up and down gliding of an ocean glider

Gliders can have various application to ecosystem monitoring and fish stock assessment, as illustrated in graphical form in Figure 1.2.19.

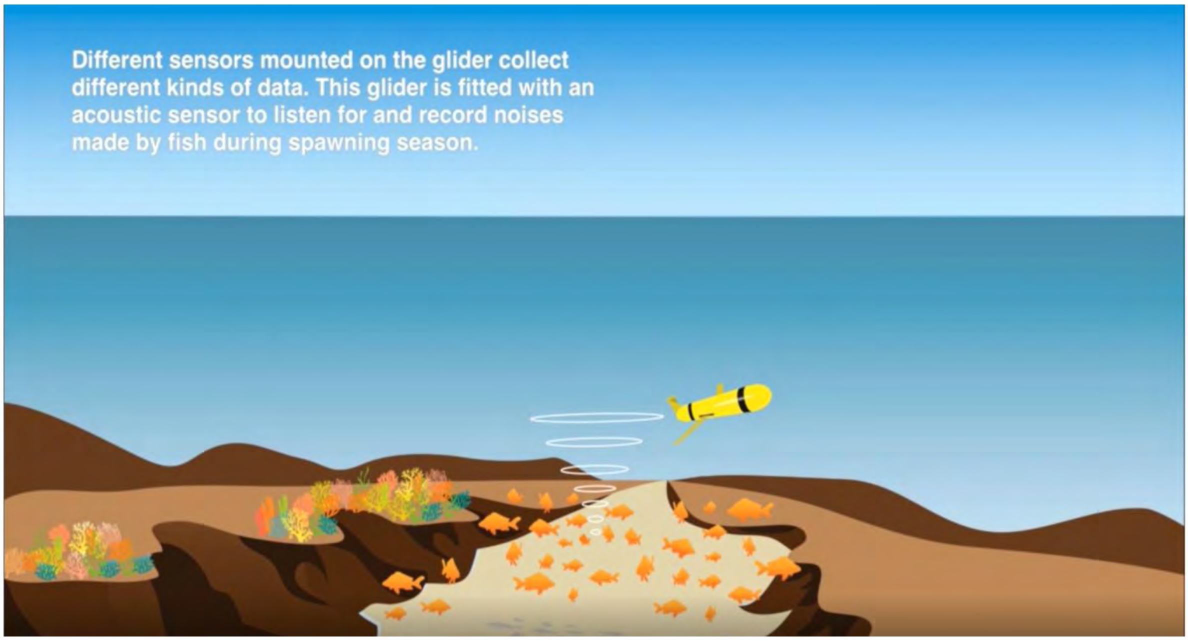


Figure 1.2-17 Illustration on a glider with acoustic sensor to record noises made by fish
https://research.noaa.gov/article/ArtMID/587/ArticleID/2582

Wave gliders

Wave gliders are wave-propelled, solar-powered autonomous surfboards capable of sustained deployment over multiple seasons that convert the energy of waves into thrust. Each wave glider is made up of surfboard-like floats tied to a submerged glider that controls speed and direction along a programmed or remotely-piloted path.

Wave gliders measure wave properties, currents, ocean temperature and salinity, exchanges between the air and water, along with surface weather. Data are transmitted to shore via satellite.

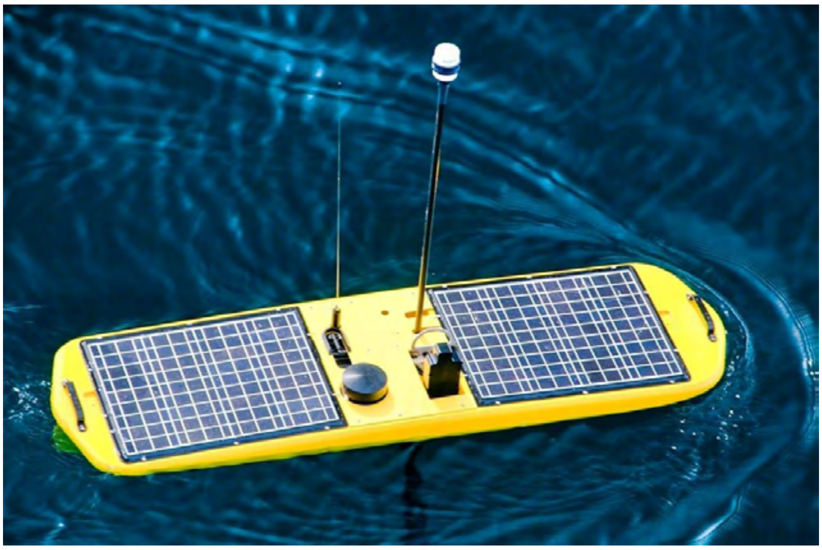


Figure 1.2-18 A solar-powered wave glider

Ocean Drifters

A **drifter** (not to be confused with a float) is an oceanographic device floating on the surface to investigate ocean currents and other parameters like temperature or salinity. Modern drifters are typically tracked by satellite, often by GPS. They are sometimes called Lagrangian drifters since the location of the measurements they make moves with the flow. A major user of drifters is the Global Drifter Program.

"Drifters" are composed of a surface float, which includes a transmitter to relay data via satellite, and a thermometer that reads temperature a few centimeters below the air-sea interface. Drifters may be equipped with various sensors (e.g. salinity sensor, pH sensor, etc.). The surface float is usually tethered to a holey sock drogue (a.k.a. "sea anchor"), centered at some water depth. The drifter follows the ocean surface current flow integrated over the drogue depth.

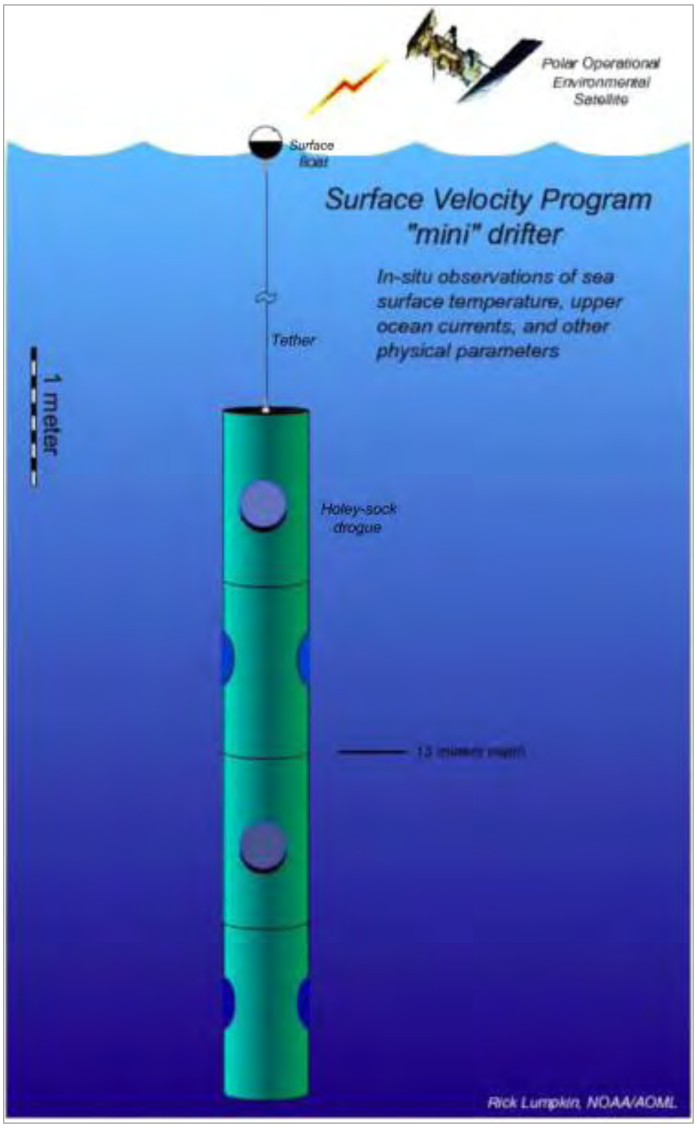


Figure 1.2-19 An ocean drifter for in-situ observations

1.3 Remote sensing technologies

1.3.1 Satellite imagery

Some examples of recent developments in satellite remote sensing for ocean dynamics and coastal environmental assessment in the Black Sea are given below.

Osadchiev and Sedakov (2019) used near simultaneous ocean colour satellite imagery from NASA's Landsat 8 and ESA's Sentinel-2 missions to reconstruct surface currents along the northeastern shore of the Black Sea and study the spread of a small river plume formed in this area. Sparsity of annual pass over orbits of the Landsat 8 and Sentinel-2 satellites above the study area is discussed. Analysis of near simultaneous ocean colour composites obtained during these periods assists on accurate reconstruction of surface currents. It is especially efficient to detect motion of frontal zones associated with river plumes which are visible in optical satellite imagery, and then use optical flow algorithms to reconstruct coastal surface currents and river water plume dynamics (*Figure 1.3-1*).

Figure 1.3-1 Sentinel-2 ocean colour composites,

plume spreading scheme (left), and surface velocity field within the Mzymta plume (right) reconstructed by the optical flow algorithm.

Kajiyama et al. (2018) report on the development of specific algorithms merged for the determination of chlorophyll-a concentration in the Black Sea. The latter are bio-optical algorithms that need to cover regional needs. The first is a band-ratio algorithm that computes chl-a as a function of the slope of Remote Sensing Reflectance (RRS) values at two wavelengths using a polynomial regression that captures the overall data trend, enhancing extrapolation results. The second algorithm is a Multilayer Perceptron neural network based on RRS values at three individual wavelengths that features interpolation capabilities helpful to fit data non-linearities. The authors have devised a new merging scheme to benefit from the complementarity of the two approaches. Remote sensing data employed to demonstrate the merging of regional results for the Black Sea are those acquired by the Ocean and Land Colour Instrument on board Sentinel-3A to acknowledge the need for data products of higher accuracy within the long-term Copernicus program.

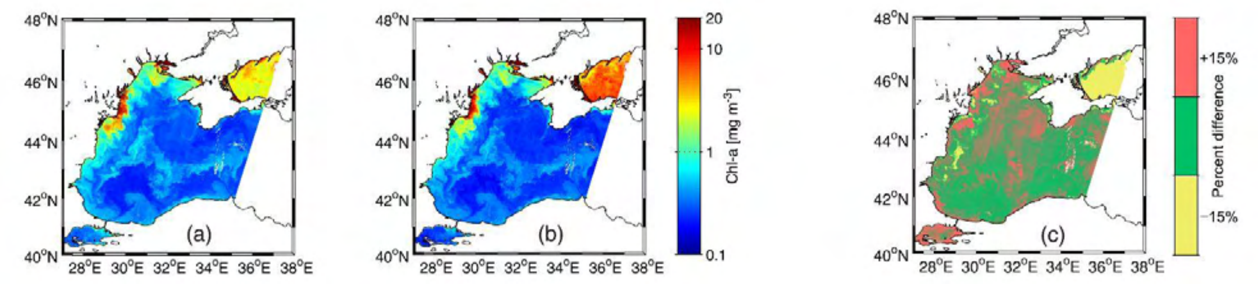


Figure 1.3-2 Maps of Chl-aB/R and Chl-aMLP respectively. (c) Percentage differences between the results of the neural network and the B/R algorithm, courtesy of Kajiyama et al. (2018).

Bondur et al. (2018) report on monitoring anthropogenic impact on coastal waters of the Black Sea using multispectral satellite imagery. Multispectral satellite imagery and sea truth hydrooptical and hydroacoustical data acquired aboard research vessels were used as the main information sources. While monitoring, more than 300 multispectral Resurs-P, GeoEye, WorldView, Landsat, Sentinel-2 and other satellite images of water areas near Sevastopol and Gelendzhik were systematized and analyzed. For processing the multispectral satellite imagery, they used an approach based on the calculation and analysis of distributions of relative variability characteristics of the backscattering signal in different regions of the electromagnetic spectrum, i.e. colour indices. The *in situ* measurements were carried out using a SIPO9 light attenuation index spectral meter and an ADCP acoustic Doppler profilometer, to detect submerged pollutant plumes and validate the results of satellite data processing. The potential of processed multispectral satellite imagery was corroborated by sea-truth field data, revealing disruptions at the outfalls located in coastal waters.

Kubryakov et al. (2018) investigated the thermohaline structure, transport, and evolution of Black Sea eddies from satellite data. Altimetry-based methods of eddy identification were used to analyze the thermohaline and dynamic structure of the Black Sea gyres and its relationship with eddy intensity, eddy age and season of a year. Anticyclonic eddies (AEs) are characterized by negative salinity anomalies, which can reach −1.7 psu at the depth of the main halocline. The temperature anomalies are positive in their upper layers, and negative in the deeper layers, because of the vertical displacement of the waters of the Cold Intermediate Layer (CIL). Cyclonic eddies (CEs) have the opposite structure with increased salinity, colder upper layers, and warmer deeper layers. Thermohaline anomalies in the eddies of both signs are maximal in summer, while in winter they are shallowest and minimal. The displacement of pycnocline in eddies causes the decrease/increase of stratification in the upper layer of AEs/CEs and opposite increase/decrease in their deeper layers. It also causes the deepening/uplift of the layer of maximum geostrophic vertical shear in AEs/CEs. The latter is the probable reason of the observed higher intensity and deeper penetration of orbital velocities in AEs than in CEs. The changes of isopycnals positions during the eddies' lifetime are used to quantify the evolution of vertical velocity in AEs and CEs. In the beginning of AEs life during intensification phase, vertical velocity is directed downward, while during the decaying phase it changes its sign and is directed upward. The opposite is observed in CEs. Eddies thermohaline structure and altimetry-derived orbital velocity is tightly related. This relation obtained in the study and altimetry-derived data on the distribution of eddy frequency, translational speed and orbital velocity is used to quantify eddies salt, heat content and transport in the basin. Such slowing causes the "relative" transport of eddies against the mean flow direction. This effect leads to the accumulation of brackish and cold water in the deep layers of east Black Sea and maintain the observed east-west asymmetry of the basin thermohaline fields (*Figure 1.3-3*).

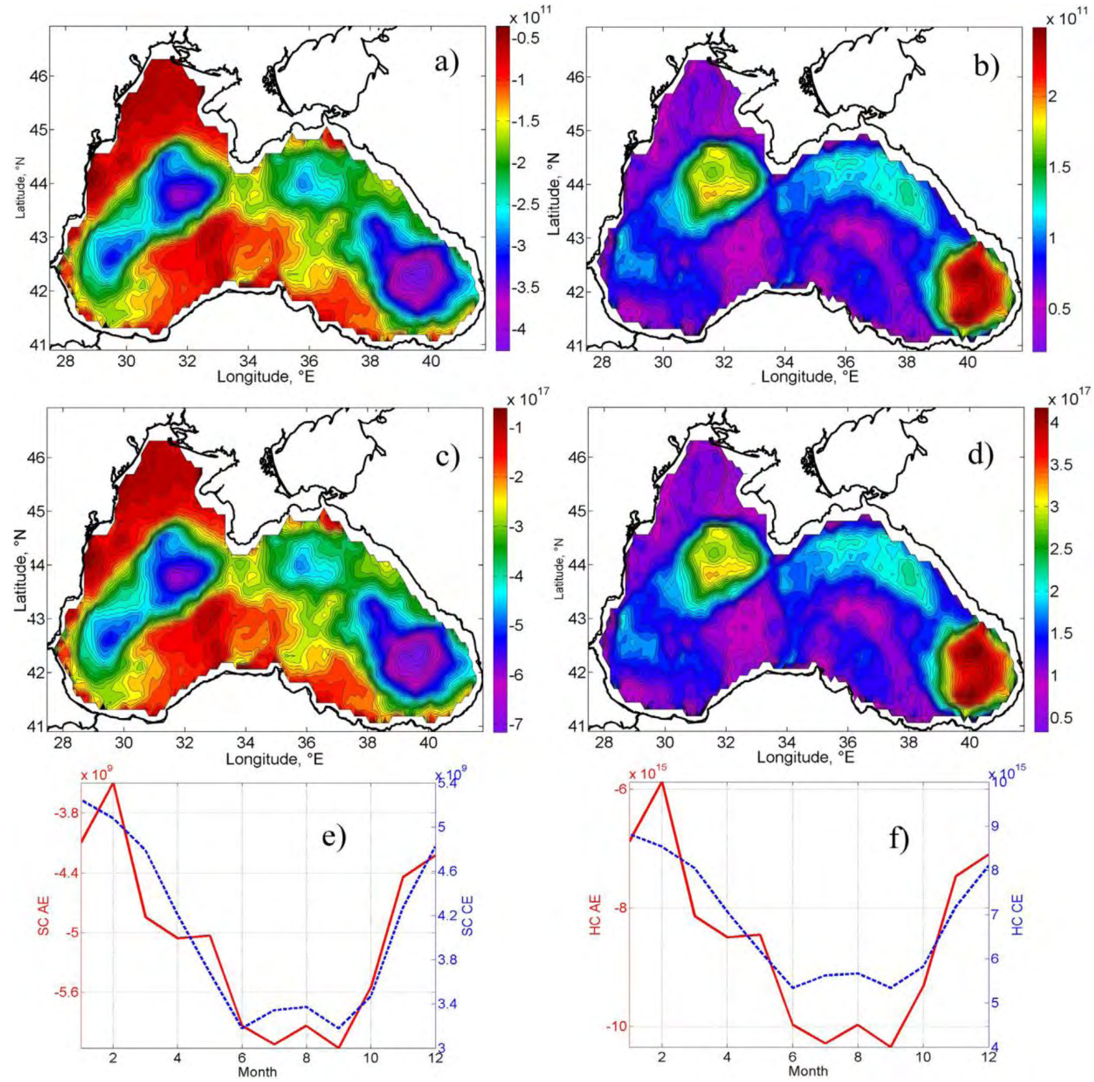


Figure 1.3-3 Averaged spatial distribution of total salt content sc (kg) in the upper layer (top) of AEs (a) and CEs (b); total heat content hc (J) (middle) in the upper layer of AEs (c) and CEs (d); Seasonal changes of basin-integrated salt (kg) (e) and heat (J) (f) content in the Black Sea for AEs (red line) and CEs (blue line) integrated over the basin; courtesy of Kubryakov et al. (2018).

Mityagina and Lavrova (2015) used satellite Synthetic Aperture Radar (SAR) data for monitoring of the Black Sea surface pollution by oil spills. SAR data onboard of Envisat satellite (until the spring of 2012) and Sentinel-1 satellite (starting from October 2014). The regions of the heaviest pollution in the Black Sea were outlined, suggesting certain types of surface pollution detected by SAR imagery are caused by natural hydrocarbon seeps at the Black Sea bottom (*Figure 1.3-4*).

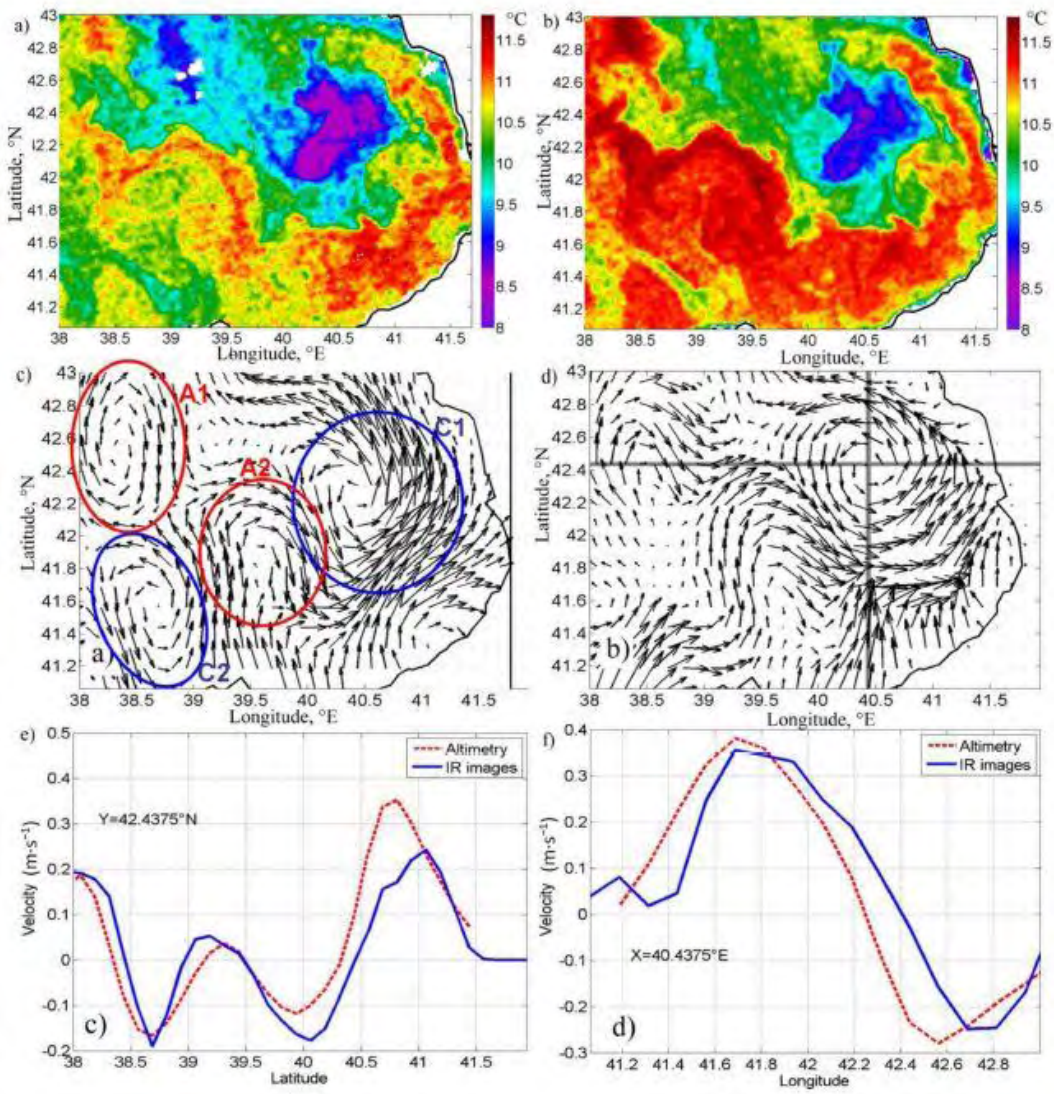


Figure 1.3-4 (a,b) AVHHR SST; (c,d) Surface current from altimetry and IR images (solid line—sections); (e,f) meridional and zonal sections of current velocities (red line—altimetry; blue—IR images) courtesy of Mityagina and Lavrova (2015).

Some examples of recent developments in satellite remote sensing for ocean dynamics and marine water quality assessment globally are given below.

Liu et al. (2017) present computing methodologies, such as maximum cross-correlation (MCC), for coastal ocean surface currents from Moderate-Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) satellite imagery. Improvement of this method can be achieved by combinations of thermal infrared (IR) and ocean colour (OC) imagery with sensors and optical channels. By merging the MCC velocity fields inferred from IR and OC products, the spatial coverage of each individual MCC field is increased by 65.8% relative to the vectors derived from OC images. Weekly, seasonal, and 5-year mean flows provide a unique space-time picture of the oceanographic variability of the coastal study area (*Figure 1.3-5*).

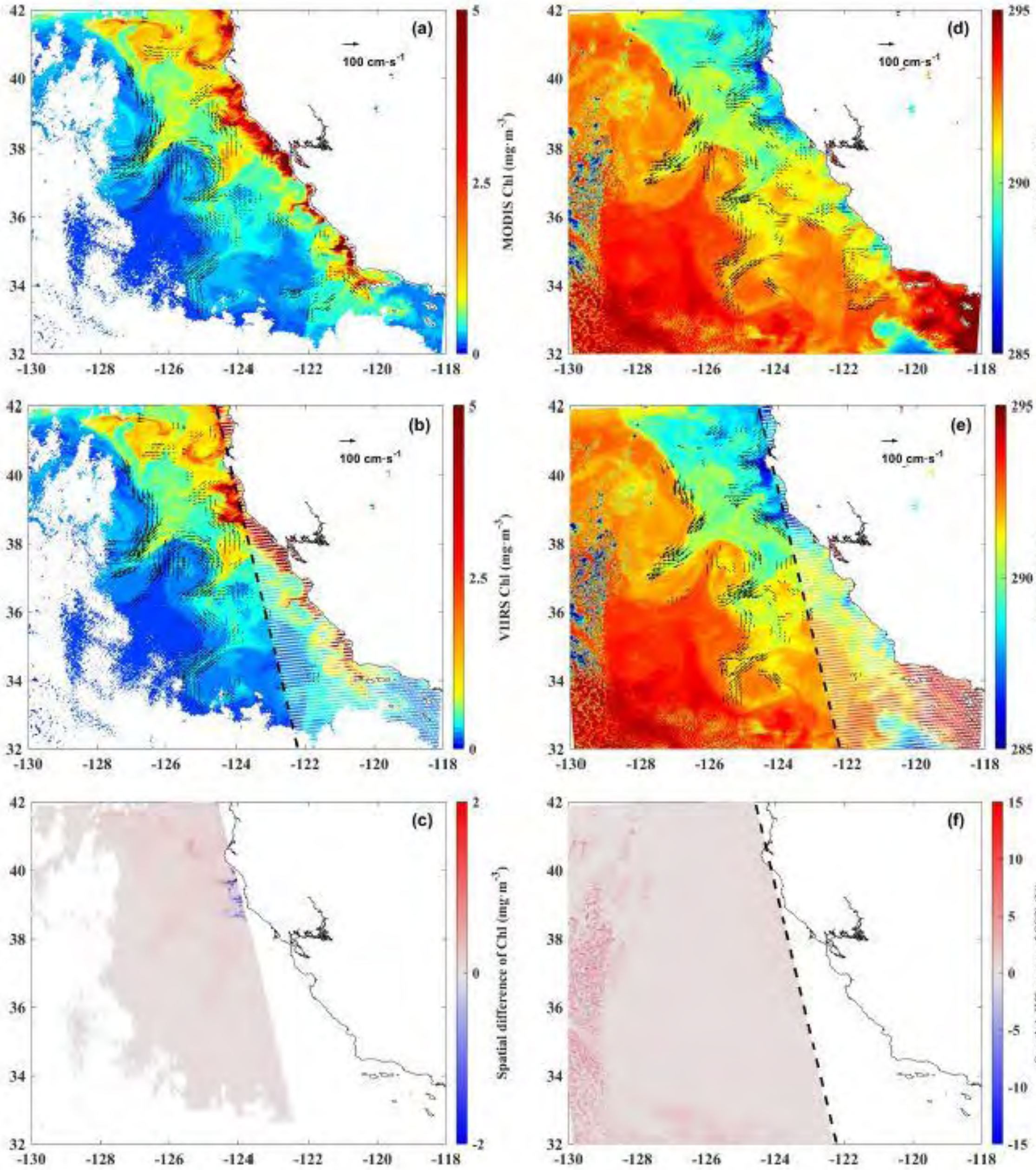


Figure 1.3-5 Chl imagery from (a) MODISA and (b) VIIRS and MCC vectors derived from these images and the corresponding Chl image from MODIST.
(c) is the spatial difference of (a,b); The non-nadir area of the VIIRS is avoided. SST imagery from (d) MODISA and (e) VIIRS at the same time and MCC vectors derived from these images and the MODIST images used in (a,b); (f) is the spatial difference of (d,e).
Courtesy of Liu et al., 2017.

Sun et al. (2016) estimated sea surface currents based on ocean colour remote-sensing image analysis. Accurate quantification of the sea surface current speeds with high spatial resolution and in near real-time is beneficial for many applications of physical oceanography and can be implemented by processing ocean colour remote-sensing imagery data. The robust optical flow (ROF) approach applied to sub-image processing is described in detail in this article and compared with a conventional maximum cross-correlation (MCC) block matching algorithm with sub-pixel operation. ROF results obtained from Geostationary Ocean Colour Imager (GOCI) imagery are shown to be in good agreement with sea surface currents derived from Ocean Surface Current Analyses-Real time (OSCAR) data, providing a validation of the ROF method.

Mouw et al. (2017) reviewed satellite remote sensing techniques for multiple phytoplankton groups in the global ocean. The phytoplankton characteristics, modulated by their physiological state, impact their light absorption and scattering, allowing them to be detected with ocean colour satellite radiometry. There is a growing volume of literature describing satellite algorithms to retrieve information on phytoplankton composition in the ocean. The satellite input and output products, their associated validation metrics, as well as assumptions, strengths, and limitations of the various algorithm types are described, providing a framework for algorithm organization to assist users and inspire new aspects of algorithm development, capable of exploiting the higher spectral, spatial, and temporal resolutions from the next generation of ocean colour satellites. Thus, a variety of approaches are currently emerging in an attempt to discriminate "phytoplankton functional types" (PFT), which include algorithms that retrieve phytoplankton size classes (PSC), phytoplankton taxonomic composition (PTC), or particle size distribution (PSD) (*Figure 1.3-6*). The authors provide an algorithm overview.

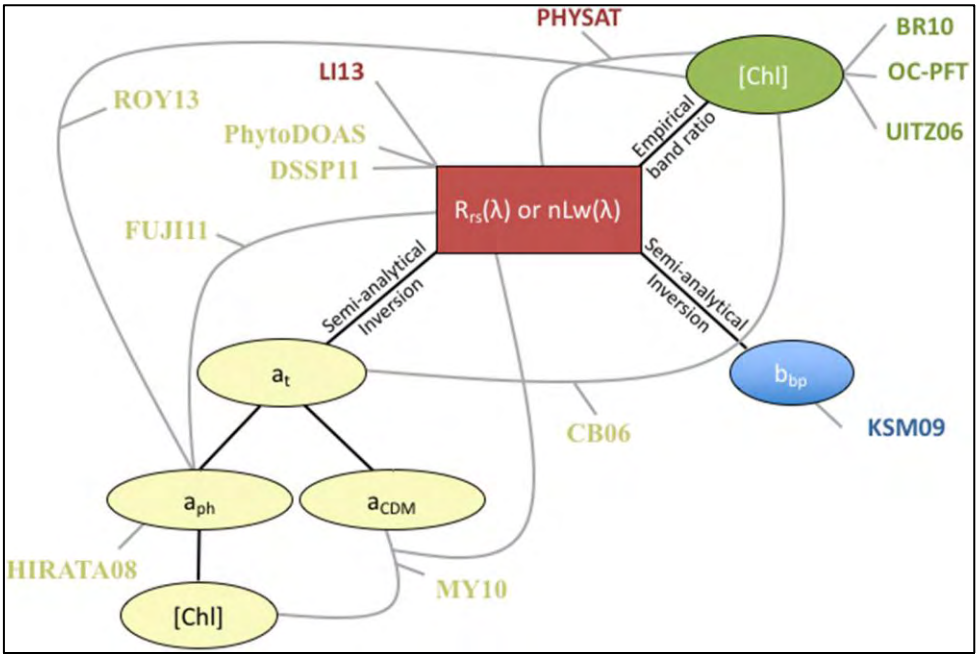


Figure 1.3-6 Schematic of satellite product inputs utilized in each PFT algorithm.

McCarthy et al. (2017) review the successful applications of satellite remote sensing for coastal management. Accuracy and robustness of satellite remote sensing imagery in coastal areas is a perpetual unanswered issue in research. Emerging techniques in this field are set to meet the demands of overcoming relevant discrepancies in the near future. Management of coastal and marine natural resources presents several challenges as a growing global population and a changing climate require us to find better strategies to conserve the resources on which our health, economy, and overall well-being depend. A tendency in collaborative and innovative efforts between resource managers, academic researchers, and industry partners is becoming increasingly vital to keep pace with evolving changes of coastal natural resources. Synoptic capabilities of remote sensing techniques allow assessments that are impossible to do with traditional methods. The sectors of implementation comprise coral reefs, wetlands, water quality, public health, fisheries, and aquaculture.

Shutler et al. (2016) have presented a comprehensive progress study in satellite remote sensing for studying physical processes at the ocean surface, they provide a catalogue of the main sensor types that are used to observe the oceans (visible, thermal infrared and microwave) and the specific observations that each of these sensor types can provide. Future advances include the use of multiple sensors in synergy to observe temporally varying ocean parameters. The authors review recent advances and capability, and thus provide a forward look at future prospects and opportunities, e.g. under the Copernicus programme, the potential of the International Space Station and commercial miniature satellites, etc. The increasing availability of global satellite remote-sensing observations means that humanity is now now entering an exciting period for oceanography during the 21st century. The easy access to these high-quality data and the continued development of novel platforms is likely to drive further advances in remote sensing of the ocean and atmospheric systems.

Within this future challenge, El Mahrad et al. (2020) investigate the contribution of remote sensing technologies to a holistic coastal and marine environmental management framework, such as the DAPSI(W)R(M) framework, i.e. the Drivers–Activities–Pressures–State changes–Impacts (on Welfare)–Responses (as Measures), an updated version of Drivers–Pressures–State–Impact–Responses. The six broad classifications of remote data collection technologies are also reviewed for their potential contribution to integrated marine management, including:

- Satellite-based Remote Sensing
- Aerial Remote Sensing
- Unmanned Aerial Vehicles
- Unmanned Surface Vehicles
- Unmanned Underwater Vehicles
- Static Sensors

A possible significant outcome of the aforementioned is the support of implementation of environmental goals, descriptors, targets, and policies, such as WFD, MSFD, Ocean Health Index, and United Nations Sustainable Development Goals.

Groom et al. (2019) present the current status and future perspectives of satellite ocean colour. Spectrally resolved water-leaving radiances (ocean colour) and inferred chlorophyll concentration are key to studying phytoplankton dynamics at seasonal and interannual scales, for a better understanding of the role of phytoplankton in marine biogeochemistry. Ocean colour data by MERIS, Aqua-MODIS, SeaWiFS, VIIRS, and OLCI also have a critical role in operational observation systems monitoring coastal eutrophication, harmful algal blooms, and sediment plumes (*Figure 1.3-7*).

By contrast, the next decade will see consistent observations from operational ocean colour series with sensors of similar design and with a replacement strategy. Also, by 2029 the record will start to be of sufficient duration to discriminate climate change impacts from natural variability, at least in some regions. The key role of in situ validation and calibration is highlighted as are ground segments that process the data received from the ocean-colour sensors and deliver analysis-ready products Satellite Ocean Colour to end-users.

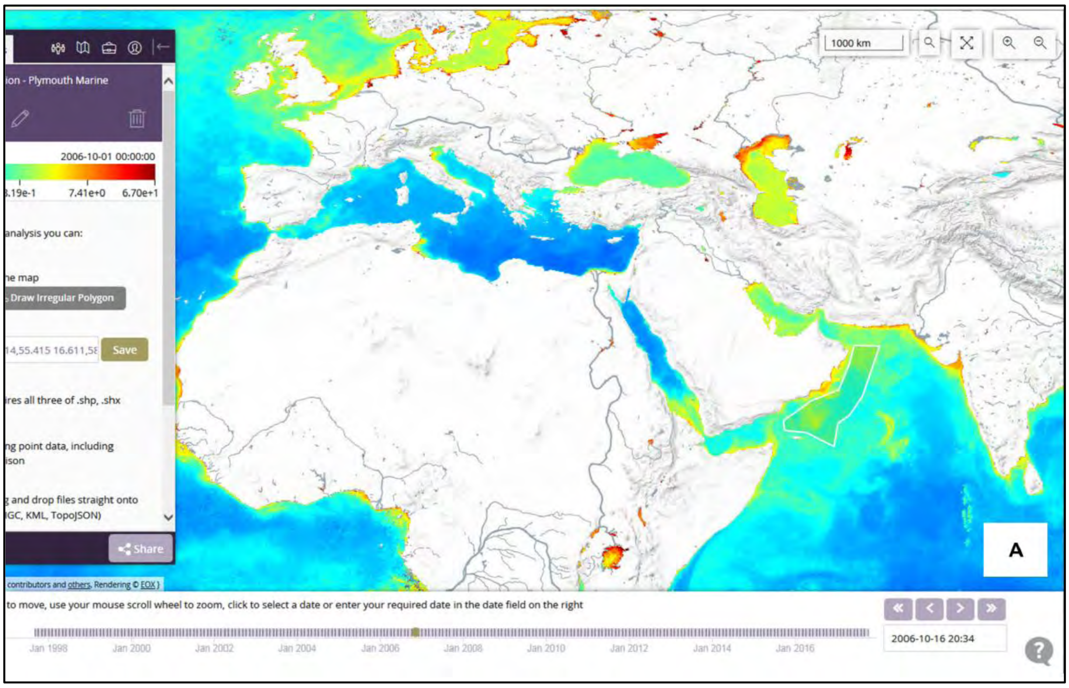


Figure 1.3-7 Screenshots of ESA ocean colour CCI OGC-compliant visualisation/analysis portal for global chl-a map (comprising merged bias-corrected SeaWiFS, Aqua-MODIS, MERIS and VIIRS) with uploaded shapefile for image data extraction; courtesy of Groom et al. (2019).

Links of web services and comprehensive pages featuring remote sensing products and satellite imagery are the given in the following for referencing:

- https://oceanservice.noaa.gov/facts/satellites-ocean.html
- https://marine.rutgers.edu/cool/sat_data/
- https://www.euspaceimaging.com/Rapid+Delivery+Satellite+Imagery
- https://www.ospo.noaa.gov/Products/imagery/ocean.html
- https://www.nhc.noaa.gov/satellite.php
- https://www.ssd.noaa.gov/
- https://eos.org/science-updates/interactive-online-maps-make-satellite-ocean-data-accessible
- https://eos.org/science-updates/interactive-online-maps-make-satellite-ocean-data-accessible
- https://www.euspaceimaging.com/maritime
- https://earth.esa.int/web/guest/earth-topics/oceans-and-coasts/ocean-currents-topography
- https://airandspace.si.edu/exhibitions/looking-at-earth/online/orbital-vistas/ocean.cfm
- https://ocean.weather.gov/shtml/satellite_imagery.php
- https://oceancolor.gsfc.nasa.gov/
- https://earthobservatory.nasa.gov/features/FalseColor/page5.php
- https://www.flir.com/browse/camera-cores-amp-components/thermal-camera-cores/swir/
- https://oceancolor.gsfc.nasa.gov/atbd/ipar/
- https://oceanobservatories.org/instrument-class/parad/
- https://www.copernicus.eu/en/copernicus-satellite-data-access
- https://scihub.copernicus.eu/
- https://spacedata.copernicus.eu/web/cscda/home

1.3.2 *Aircraft-based sensor technologies*

The tendency in the last two decades in aerial vehicle monitoring of the oceans and coastal zones is to switch from manned expeditions with aerial vehicles or small aircrafts (with photogrammetric and radar mapping devices) to drones and Unmanned Aerial Vehicles (UAVs). These are either automatically piloted (for large flight ranges) or remotely controlled by land or boat/ship pilot commands, due to the expensive costs for the first kind of flight operations compared to the cost-effective latter choice. Drones and UAVs are used in ocean monitoring mostly for: oil spill tracing; marine pollution identification; Harmful Algal Blooms (HABs) inspection; green and red tide identification; measuring of metocean weather properties; micro-plastics tracking; maritime shipping inspection; coastline mapping, dune erosion monitoring, post-flood coastal impact identification; biodiversity management, coastal habitat environmental monitoring; sea mammal, sea turtles and marine vertebrates tracking, etc.

Reineman et al. (2016) report on recent developments in the use of ship-launched fixed-wing UAVs for measuring marine/ocean surface processes. The deployment and recovery of autonomous or remotely piloted platforms from research vessels have become a way of significantly extending the capabilities and reach of the research fleet. UAVs can nowadays measure ocean surface processes, e.g., Equatorial Mixing (EquatorMix) experiment in the central Pacific or Trident Warrior experiment off the Virginia coast. The latest technology instrumented UAVs may provide unprecedented spatiotemporal resolution in atmospheric and oceanographic measurements in remote ocean locations, demonstrating the capabilities of these platforms to extend the range and capabilities of the research fleet for oceanographic and atmospheric studies (*Figure 1.3-8*).

Schofield et al. (2019) review the drone technologies for research on sea turtles and other marine vertebrates. UAVs are being deployed to study the abundance and behaviour of sea turtles, identifying some of the commonalities and differences with studies on other marine vertebrates, including marine mammals and fish stock. UAV studies of all three groups primarily focus on obtaining estimates of abundance, distribution, and density, while some studies have provided novel insights on the body condition, movement, and behaviour of individuals (including inter-specific interactions). There are emerging possibilities of how UAVs can become part of the standard methodologies for marine ecologists through combining information on abundance and behaviour. Overall, UAVs provide a low-cost approach of quantifying the flexibility of marine animal behaviour, allowing one to integrate information on abundance to establish how individuals respond to the presence of other organisms and the immediate environment.

Kislik et al. (2018) review the UAVs ability, current applications, and future opportunities to support algal bloom identification. As HABs have become a major public health and ecosystem vitality concern globally, especially in urbanized and engineered coastal zones, various remote sensing methods of detection, analysis, and forecasting have been developed. The prevalence of HABs is likely to increase in the future due to climate change, warming waters, coastal pollution, and additional nutrient inputs into aquatic systems. Satellite imaging has proven successful in the identification of various inland and coastal blooms at large spatial and temporal scales, yet airborne platforms offer significantly higher spatial and often spectral resolution at targeted temporal frequencies focusing on confined areas of interest. UAVs are currently emerging as a potent tool for algal bloom detection, providing users with on-demand high spatial and temporal resolution at low costs. UAV-based algal bloom studies are bound to gain critical traction in the 21st century.

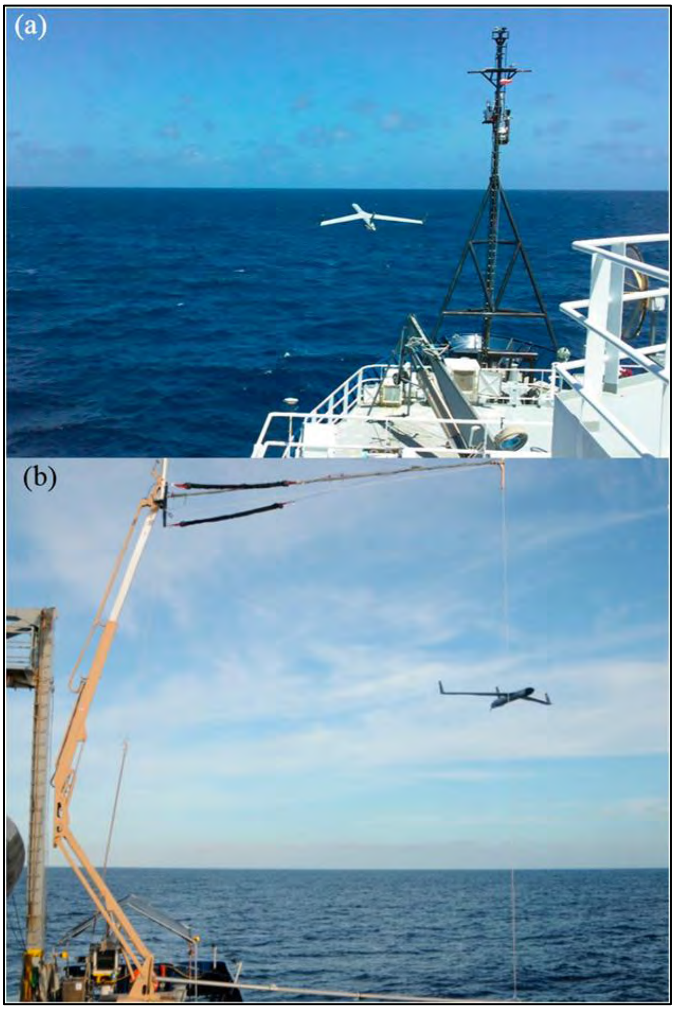


Figure 1.3-8 S Photographs of ScanEagleUAV

(a) launch and (b) recovery aboard the R/V Roger Revelle during EquatorMix [photo (a) courtesy of Jerome Smith; Reineman et al., 2016].

Bella et al. (2019) present breakthroughs in research and practices of a centralized autonomous system of cooperation for UAVs-monitoring and cleaning of maritime areas with unmanned surface vehicles (USVs). A new cooperative agent-based planning approach is proposed for heterogeneous unmanned vehicles with different roles. Due to the rapid deployment of UAVs and USVs, and the increase of ocean pollution incidents, the use of vehicle fleets is advised.

Bukin et al. (2020) refer to new remote sensing applications for marine monitoring of oil pollution using UAVs. Emerging objectives in this technology is to build a hardware-software complex system based on UAVs with the possibility of splashdown for monitoring marine areas for the detection of oil spills. These should focus on rtesting of assembled complexes of laboratory measurements of the induced fluorescence spectra of solutions of low-viscosity marine fuel, performed under conditions of solar illumination and software implementations with elements of artificial intelligence for semantic image segmentation to identify oil spills on the sea surface.

Zappa et al. (2020) present ship-deployed high-endurance UAVs for the study of ocean surface. Unmanned aerial vehicles (UAVs) are proving to be an important modern sensing platform that supplement the sensing capabilities from platforms such as satellites, aircraft, research vessels, moorings, and gliders. UAVs, like satellites and aircraft can provide a synoptic view of a relatively large area. However, the coarse resolution provided by satellites and the operational limitations of manned aircraft has motivated the development of UAVs, offering unparalleled flexibility of tasking. Cutting-edge payload instrumentation for UAVs provides a new capability for ship-deployed operations to capture a unique, high resolution spatial and temporal variability of the changing air-sea interaction processes than was previously possible (*Figure 1.3-9*). Novel techniques include vertical take-off and landing (VTOL) from research vessels, which is safer and requires less logistical support than previous ship-deployed systems. The payloads developed include thermal infrared, visible broadband and hyperspectral, and near-infrared hyperspectral high-resolution imaging (see Subsection 3.3). Additional capabilities include UAV-deployed dropsonde micro-buoys for seawater physical properties recording.

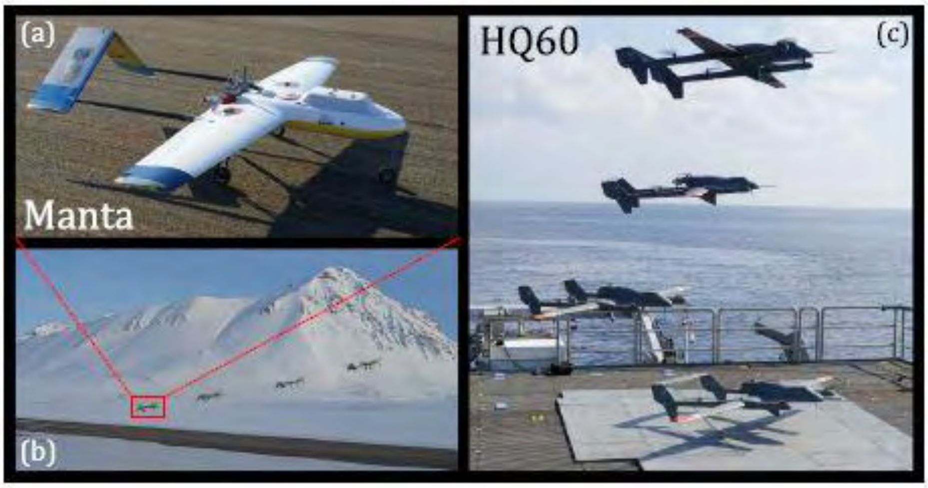


Figure 1.3-9 Manta UAV with the LDEO RAD Payload (b) performing a wheel-take-off. (c) Latitude Engineering HQ-60 performing a vertical take-off from the deck. Photos courtesy of Zappa et al. (2020).

Kim et al. (2018) give an inclusive overview of designing UAV surveillance frameworks for smart coastal cities and oceans with differential perspectives. They focus on the emerging technology of multi-level deployment of multiple heterogeneous smart UAVs. For coastal oceanography studies they propose the development of loose hierarchical-based frameworks engaging three types of UAVs, which allows replenishment among heterogeneous UAVs at different layers through airborne docking (*Figure* 1.3-10).

Wu et al. (2019) provide a recent comprehensive review on drone-based HABs pollution monitoring. Rapid development and applications of UAVs provide promising solutions to and new opportunities for environmental monitoring. Owing to their flexibility in flight scheduling, high spatial resolution, and costs-effectiveness, UAVs have become a popular tool for monitoring dynamic environmental processes, such as emergence and outbreak of HABs and related kinds of pollution. The HABs outbreak, often linked with anthropogenic eutrophication, has become a serious environmental health problem that threats our communities. Existing studies show that UAV-based HABs monitoring is a cost-effective means of assisting environmental managers in developing precautionary warning system and coping strategies.

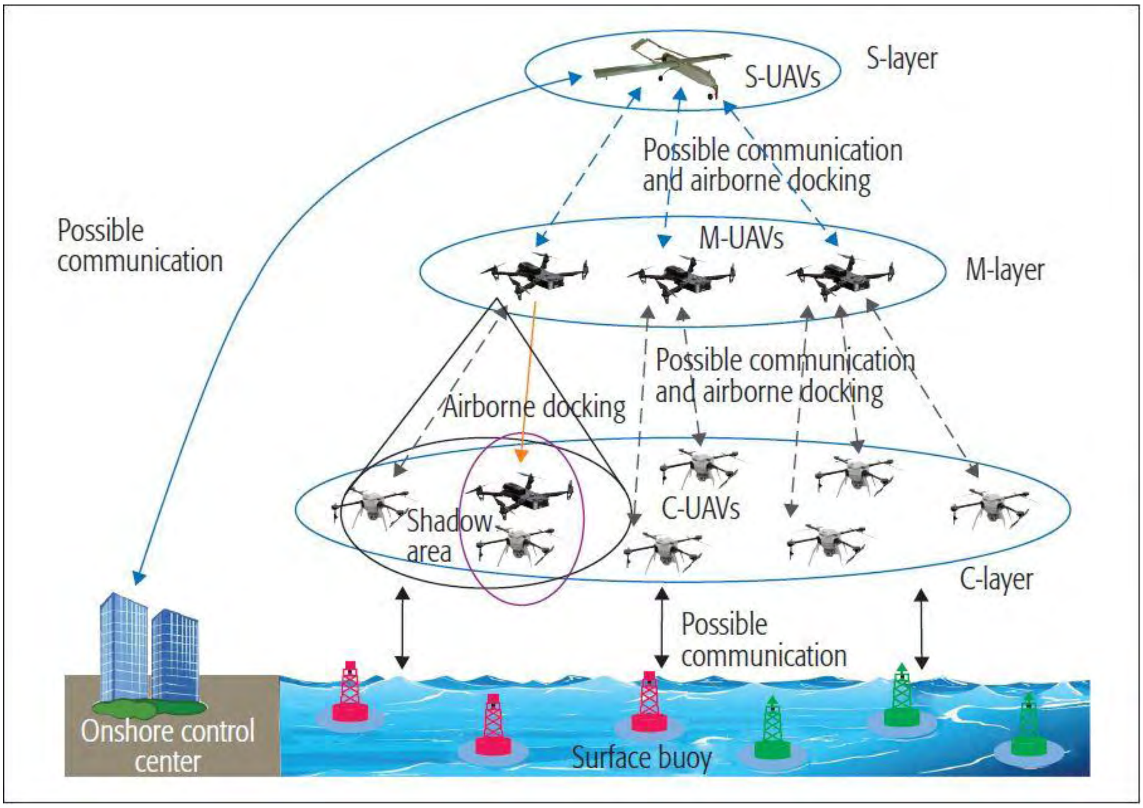


Figure 1.3-10 A multi-level UAV framework for monitoring an extensive coastal ocean photo courtesy of Kim et al. (2018).

State-of-the-art UAVs are combined with lightweight onboard multispectral sensors for HABs monitoring from the perspective of quantitative remote sensing. Hot topics of relevant research includes:

- Developing algal bloom removal robotic systems (ARROS).
- Mounting onboard water sampling equipment on UAVs to collect water samples for enhanced in situ measurements.
- Pre-setting sampling campaigns and locations for automatic collection of seawater samples.
- Integration of UAVs and other technologies (e.g. automation technologies, Internet of Things, and Artificial Intelligence).
- Overcoming technical challenges and limitations, such as:
    - Battery power autonomy
    - Extending duration and spatial range of a UAV flight mission
    - Enhancing power capacity and image resolution
    - Airspace flight restrictions (e.g. in no-fly zones)
    - Absence of adequate legal network and regulations in many countries
    - Capability of flights in any (un-)desirable weather condition
    - Increasing optical capacity of mounted HSI, radar and camera technologies to UAVs to reduce noise, image blurring, etc.

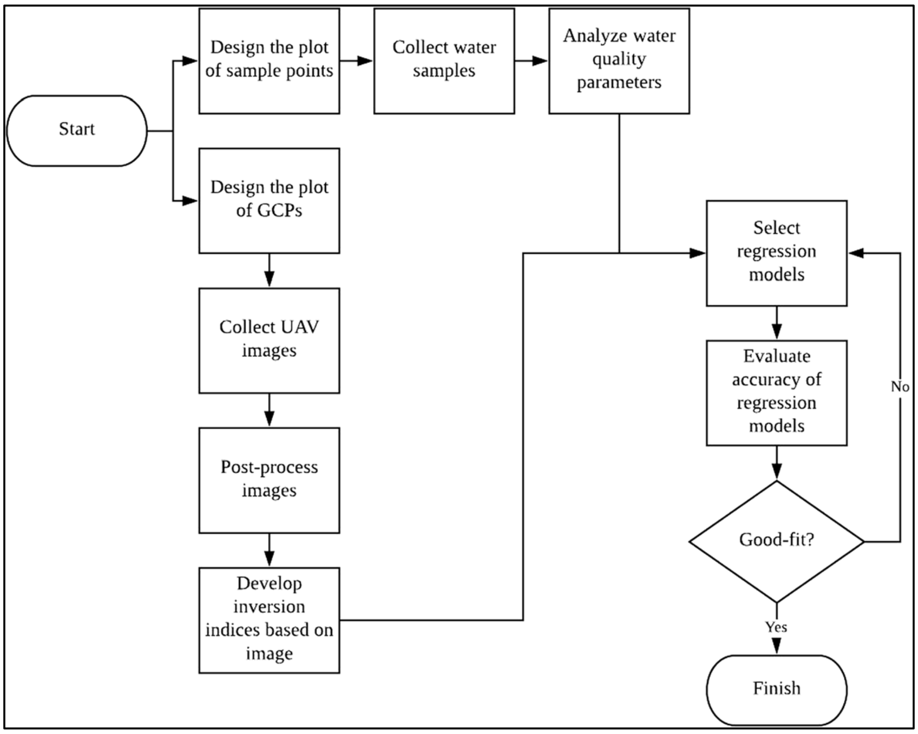


Figure 1.3-11 The workflow logical diagram for HABs monitoring with the use of UAVspectral images and algae concentrations; courtesy of Wu et al. (2019).

1.3.3 Radar technologies

Synthetic-aperture radar (SAR) in oceanology and marine environmental technology is used to create 2-D images or 3-D reconstructions of oceanic landscapes. SAR uses the motion of the radar antenna over a target region to provide finer spatial resolution than conventional beam-scanning radars. SAR is typically mounted on a moving platform, such as an aircraft (MAVs) or spacecraft (satellites) and has its origins in an advanced form of side looking airborne radar (SLAR). The distance the SAR device travels over a target in the time taken for the radar pulses to return to the antenna creates the large synthetic antenna aperture (the size of the antenna). Typically, the larger the aperture, the higher the image resolution will be, regardless of whether the aperture is physical (a large antenna) or synthetic (a moving antenna) – this allows SAR to create high-resolution images with comparatively small physical antennas. Additionally, SAR has the property of having larger apertures for more distant objects, allowing consistent spatial resolution over a range of viewing distances. SAR is capable of high-resolution remote sensing, independent of flight altitude, and independent of weather, as SAR can select frequencies to avoid weather-caused signal attenuation. SAR has day and night imaging capability as illumination is provided by the SAR.

Li et al. (2018) present the capabilities of the Chinese Gaofen-3 SAR imaging techniques in selected topics for coastal and ocean observations. These comprise the monitoring of intertidal flats, offshore tidal turbulent wakes and oceanic internal waves, to highlight the GF-3's full polarimetry, high spatial resolution and wide-swath imaging advantages. Constant evolution of the aforementioned technologies has shown the large capabilities in ocean and coastal or even nearshore monitoring with SAR, though further improvements, particularly in radiometric calibration and stable image quality.

Recent advances in SAR technology for oil spill detection and classification indicatively refer to Garcia-Pineda et al. (2017) and Chen et al. (2017) with the use of deep Networks for polarimetric SAR images. Their results show that oil spill classification achieved by deep networks outperformed both support vector machine (SVM) and traditional artificial neural networks (ANN) with similar parameter settings, especially when the number of training data samples is limited.

Focusing on the Southern Europe several SAR applications have been concluded in the Mediterranean Sea in the recent past.

Stuhlmacher and Gade (2020) have used SAR for the statistical analyses of eddies in the Western Mediterranean Sea. They analysed Sentinel-1A SAR images acquired in a 3-year period for the Western Mediterranean basin and found imprints of thousands of oceanic eddies with diameters ranging from 0.4 to 160.1 Km. That helped them decide on the predominant mechanisms responsible for their formation (*Figure 1.3-12*). SAR imagery seems to be well suited to answer open questions related to the explicit processes of the formation of submesoscale eddies and to the influence of hydrometerological parameters on the shape and orientation of eddies in semi-enclosed basins such as the Mediterranean and Black Seas. Emerging technologies in the field is the formulation of automated eddy detection algorithms that may help in the systematic analyses of nearly four decades of SAR data (from various sensors), and future satellite missions.

Karimova (2017) has shown that SAR imagery is a valuable tool for surface circulation observations in the western Mediterranean regional aquatic basin, by a combination of Aqua-MODIS Sea Surface Temperature (SST) products and sub-mesoscale vortices by Envisat Advanced SAR imagery. This technology can significantly assist on seasonality tracking of predominant eddy formations in the upper water layer with obvious turbulent features (*Figure 1.3-13*).

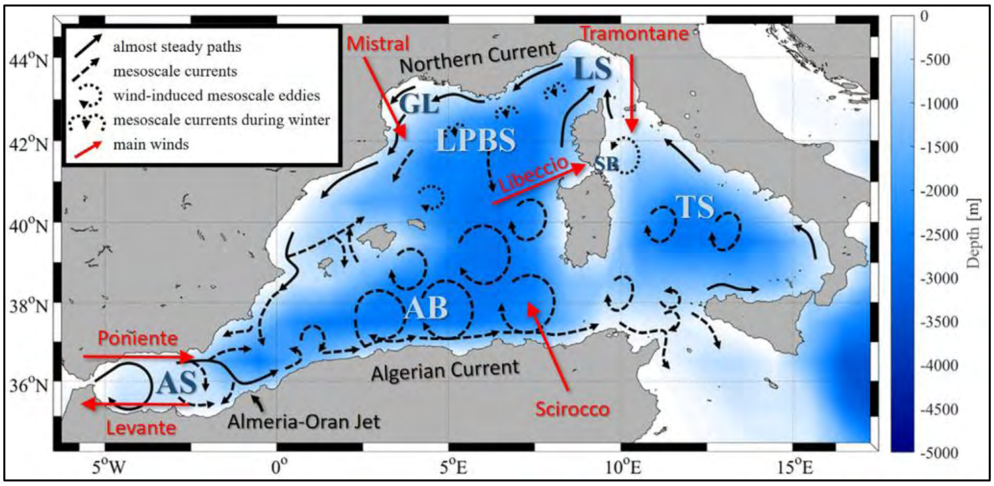


Figure 1.3-12 Schematic representation of surface circulation and concomitant main wind patterns in the Western Mediterranean Sea.
Black arrows and names denote currents, red arrows and names denote regional winds; courtesy of Stuhlmacher and Gade (2020).

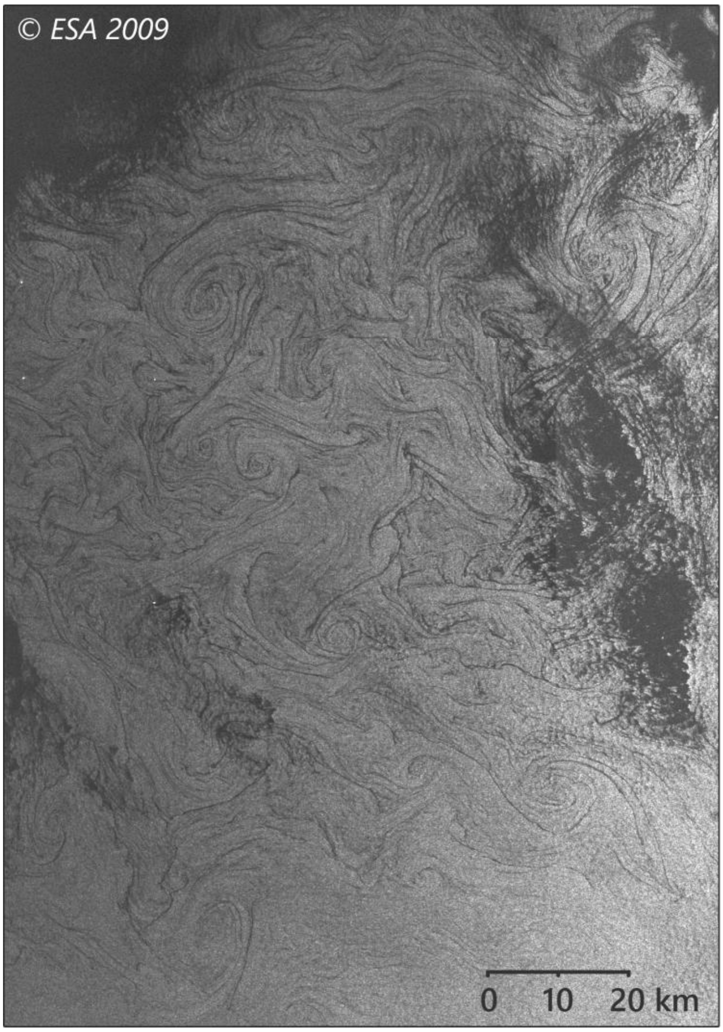


Figure 1.3-13 Submesoscale turbulent field in a Mediterranean area to the northeast from the Gulf of Lion
Envisat-A SAR, courtesy of Karimova (2017).

Other prominent High-Frequency (HF) radar technologies include Coastal Ocean Dynamics Applications Radar (CODAR), LiDAR, Special Sensor Microwave Imager (SSM/I), and FOcused Phased Array Imaging Radar (FOPAIR) in ocean monitoring.

CODAR describes a type of portable, land-based, HF radar developed at NOAA. CODAR is a non-invasive system that permits to measure and map near-surface ocean currents in coastal waters. It is transportable and offers output ocean current maps on site in near real time. Moreover, using CODAR it is possible to measure wave heights and it provides an indirect estimate of local wind direction. Modern CODAR can measure out to 100–200 km offshore with a resolution of 3–12 km. The emerging CODAR technologies focus on increasing the frequency and resolution down to 100-200 m with adequate observation ranges, and also removing noise from obtained data in high frequency mode observations. Main applications refer to coastal engineering and public safety projects, planning of navigational seaways, mitigation of ocean pollution, search and rescue operations, oil-spill mitigation in real time and larval population connectivity assessment. Also, data obtained by using CODAR are used as inputs for global resource monitoring and weather forecasting models and are particularly helpful for tidal and storm-surge measurements.

Helzel et al. (2019) review the potential of monitoring coastal zones by CODARs:

- more reliable forecasts of currents achieved by data assimilation of the accurate radar data with high temporal and spatial resolution,
- automatic eddy detection method which can identify zones of up- or downwelling,
- surface current information can be used to provide drift predictions, useful for Search and Rescue operations or environmental protection issues,
- improved wave forecasting based on radar data from up to 100 km offshore.

Mantovani et al. (2020) define the best practices on HF radar deployment and operation for ocean current measurements. Land based remote sensing instruments such as CODARs are capable of measuring surface currents and ocean waves at ranges up to 200 km or more. HF radar technology is widely acknowledged as a cost-efficient tool to monitor coastal regions and has potential use to monitor coastal regions all over the world. Globally, the number of HFR stations is steadily increasing. Regional networks provide real-time data in support of operational activities such as search and rescue operations, fast response in case of maritime accidents and spill of pollutants, and resource management. Future research will focus on a set of harmonized quality assurance and quality control procedures, along with an effective approach to HFR data discovery and dissemination, to provide high quality measurements to the end users, by Direction Finding (DF) or Beam Forming (BF) systems.

1.4 Numerical simulation systems for hydrodynamic ocean circulation and marine biochemical and water quality

1.4.1 Hydrodynamic Ocean circulation numerical models

A wide variety of ocean circulation models is currently used around the world. Although these models aim to solve similar problems, one can detect crucial differences among them. These mainly regard the formulation of their governing equations, the employed numerical schemes, and computational grid setups. Another major distinction of ocean circulation modeling refers to their scale of implementation, i.e., General Circulation Models (GCMs; solving only the primitive equations by just considering the topography) or Regional ones (RCMs; modeling more processes with higher spatial resolution within confined areas). Moreover, the characteristics of each model and activation of operational modules, depend on the scope of the specific problems it addresses. These may include climate modelling, general circulation modelling, ocean–ice modelling, forecasts, monitoring, chemical oceanography, biological oceanography, geological oceanography, and other purposes.

The following list contains information about most of the commonly used ocean circulation models:

ADCIRC (ADvanced **CIRC**ulation model)**:** The model is based on the shallow water equations; thus, its use is mainly aimed at nearshore regions and it is frequently coupled to wind wave models. ADCIRC can be used as a 3-D or 2-D depth-integrated model on triangular unstructured grids utilizing the finite element method. Its use is widespread in the USA.

COCO (**C**CSR (Center for Climate System Research) **O**cean **C**omponent **M**odel): COCO is a Japanese ocean GCM. It was developed by the AORI ocean modelling group and JAMSTECRIGC Advanced Ocean Modelling Research Team, both on the University of Tokyo. COCO was also the oceanic part of the general circulation model MIROC. CCSR was merged with ORI (Ocean Research Institute) on April 2010 and became a part of AORI. So, the name COCO is no longer regarded as an acronym.

COHERENS (**CO**upled **H**ydrodynamical **E**cological model for **RE**gio**N**al **S**helf seas): COHERENS is a Flemmish open-source ocean circulation model first developed during the 1990's by several European institutions and the Management Unit of the North Sea Mathematical Models and the Scheldt estuary (MUMM, now OD Nature). The model's later versions up until 2015 implement updates developed and carried out in the framework of a series of European funded projects and backed by the Flemmish Government. COHERENS is a 3-D multi-purpose numerical model, designed for application in coastal and shelf seas, estuaries, lakes, reservoirs etc. The model is available as a free source code for the scientific community under the GNU General Public License principles and can be considered as a tool for a better understanding of the physical and ecological processes and for the prediction and monitoring of waste material in shelf seas, the coastal zone and estuaries. The program structure allows users to perform process academic as well as predictive and operational setups without knowledge of the detailed model structure.

FVCOM (**F**inite **V**olume **C**ommunity **O**cean **M**odel): FVCOM is a prognostic, unstructured-grid, finite-volume, free-surface, 3-D primitive equation coastal ocean circulation model developed by UMASSD-WHOI joint efforts. The model consists of momentum, continuity, temperature, salinity, and density equations and is closed physically and mathematically using turbulence closure sub-models. The horizontal grid is comprised of unstructured triangular cells and the irregular bottom is presented using generalized terrain-following coordinates. The present version of FVCOM includes several options and components. These include: (1) choice of Cartesian or spherical coordinate system, (2) a mass-conservative wet/dry point treatment for the flooding/drying process simulation, (3) the General Ocean Turbulent Model (GOTM) modules (Burchard et al., 1999; Burchard, 2002) for optional vertical turbulent mixing schemes, (4) a water quality module to simulate dissolved oxygen and other environmental indicators, (5) 4-D nudging and Reduced/Ensemble Kalman Filters (implemented in collaboration with P. Rizzoli at MIT) for data assimilation, (6) fully-nonlinear ice models (implemented by F. Dupont), (7) a 3-D sediment transport module (based on the U.S.G.S. national sediment transport model) for estuarine and near-shore applications, and (8) a flexible biological module (FBM) for food web dynamics study. FBM includes seven groups: nutrients, autotrophy, heterotrophy, detritus, dissolved organic matter, bacteria, and other. With various pre-built functions and parameters for these groups, FBM allows users to either select a pre-built biological model (such as NPZ, NPZD, etc.) or to build their own biological model using the pre-defined pool of biological variables and parameterization functions. FVCOM was originally coded for sigma-coordinates in the vertical and now has been upgraded to a generalized terrain-following coordinate system with choices of various topographic-following coordinates. FVCOM is written with Fortran 90 with MPI parallelization and runs efficiently on single and multi-processor machines.

HOPE (The **H**amburg **O**cean **P**rimitive **E**quation General Circulation Model): HOPE is a primitive-equation model of the global ocean circulation but may also be used for regional studies. Prognostic variables are the 3-D horizontal velocity fields, the sea-surface elevation, and the thermohaline variables. The discrete equations are prescribed on horizontal surfaces using Arakawa-E-type grids. Two-time levels are used for the integration. A Hibler-type dynamic sea-ice model allows a prognostic calculation of sea-ice thick-ness, compactness, and velocities. The thermodynamic growth of sea ice is calculated with heat balance equations using simple bulk formulae. A snow layer is included. HOPE is particularly useful for altimetry data assimilation purposes because of the prognostic calculation of the sea-surface elevation.

LSG (The Hamburg **L**arge **S**cale **G**eostrophic Ocean General Circulation Model): The rationale for the Large Scale Geostrophic Ocean general circulation model (LSG-OGCM) is based on the observation that for a large scale ocean circulation model designed for climate studies, the relevant characteristic spatial scales are large compared with the internal Rossby radius throughout most of the ocean, while the characteristic time scales are large compared with the periods of gravity modes and barotropic Rossby wave modes. In the present version of the model, the fast modes have been filtered out by a conventional technique of integrating the full primitive equations, including all terms except the nonlinear advection of momentum, by an implicit time integration method. The free surface is also treated prognostically, without invoking a rigid lid approximation. The numerical scheme is unconditionally stable and has the additional advantage that it can be applied uniformly to the entire globe, including the equatorial and coastal current regions.

OPYC (The **O**cean Iso**PYC**nal General Circulation Model): OPYC utilizes a Sub-Grid Scale (SGS) form for mesoscale eddy mixing on isopycnal surfaces for use in non-eddy-resolving ocean circulation models. The mixing is applied in isopycnal coordinates to isopycnal layer thickness, or inverse density gradient, as well as to passive scalars, temperature, and salinity. After the calculations, the mixing forms are transformed to physical coordinates.

HYCOM (**HY**brid **C**oordinate **O**cean **M**odel): HYCOM is a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model. The model's ongoing development and evaluation is a multi-institutional effort sponsored by the National Ocean Partnership Program (NOPP), as part of the U. S. Global Ocean Data Assimilation Experiment (GODAE). The GODAE objectives of 3-D depiction of the ocean state at fine resolution in real time, provision of boundary conditions for coastal and regional models, and provision of oceanic boundary conditions for a global coupled ocean-atmosphere prediction model, are being addressed by a partnership of institutions that represent a broad spectrum of the oceanographic community. The academic, governmental, and commercial entities involved in the partnership have long histories of supporting and carrying out a wide range of oceanographic and ocean prediction-related research. All institutions are committed to developing and demonstrating the performance and application of eddy-resolving, real-time global, Atlantic, and Pacific Ocean prediction systems using HYCOM.

MICOM (**M**iami **I**sopycnic **C**oordinate **O**cean **M**odel): MICOM is another isopycnic coordinate ocean circulation model. It is a 3-D primitive equation numerical model that describes the evolution of momentum, mass, heat, and salt in the ocean. The model is mainly used in global and/or watershed scales.

MITgcm (M.I.T. **G**eneral **C**irculation **M**odel): **MITgcm** is designed for study of the atmosphere, ocean, and climate. Its non-hydrostatic, finite volume method formulation enables it to simulate fluid phenomena over a wide range of scales; its adjoint capability enables it to be applied to parameter and state estimation problems. By employing fluid isomorphisms, one hydrodynamical kernel can be used to simulate flow in both the atmosphere and ocean. It was developed at the Massachusetts Institute of Technology and was one of the first non-hydrostatic models of the ocean. It has an automatically generated adjoint that allows the model to be used for data assimilation. The model debuted in 1997 and is still being used and further developed.

MOM (GFDL **M**odular **O**cean **M**odel): The Modular Ocean Model (MOM) is a 3-D ocean circulation model designed primarily for studying the ocean climate system. The model is developed and supported primarily by researchers at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, NJ, USA. Its numerical representation of the ocean fluid allows applications from the process scale to the planetary circulation scale. According to NOAA, its most recent version, MOM6, is a major algorithmic departure from the previous versions of MOM and offers a more versatile framework for simulating the ocean. The recent changes include the following features:

- It is currently based on the horizontal C-grid stencil, which is preferred for simulations that include an active mesoscale eddy field (MOM5 and earlier used the B-grid).
- It uses vertical Lagrangian remapping (a variant of the Arbitrary Lagrangian Eulerian (ALE) algorithm) to enable the use of any vertical coordinate, including geopotential (z or z*), isopycnal, terrain-following, or hybrid/user-defined.
- A new implementation of vertical ALE removes the vertical advection CFL restriction on the time-step so that the model is unconditionally stable to thin (or even vanishing) layers. The ability to handle vanishing layers allows for the conservative representation of wetting and drying, which is a process essential for representing the evolution of ice shelf grounding lines as well as coastal/tidal estuaries.
- Physical closures that include scale-aware parameterizations for mesoscale eddy-permitting regimes; boundary layer schemes that incorporate Langmuir mixing; a suite of parameterized mixing from breaking gravity waves; and a new method for performing neutral diffusion that precludes the spurious creation of extrema. ,

NEMO (Nucleus for **E**uropean **M**odelling of the **O**cean): NEMO (Nucleus for European Modelling of the Ocean) is an ocean modelling framework which is composed of "engines" nested in an "environment". The "engines" provide numerical solutions of ocean, sea-ice, tracers and biochemistry equations and their related physics. The "environment" consists of reference configurations, pre- and post-processing tools, interface to the other components, user interface, computer dependent functions and documentation of the system. The latest stable release of NEMO is the version 4.0.2 (March 2020).
The NEMO ocean model has 3 major components:

- NEMO-OCE models the ocean thermodynamics and solves the primitive equations.
- NEMO-ICE (SI3: Sea-Ice Integrated Initiative) models sea-ice thermodynamics, brine inclusions and subgrid-scale thickness variations.
- NEMO-TOP (Tracers in the Ocean Paradigm) models the oceanic tracers transport and biogeochemical processes (using PISCES).

The NEMO Consortium is responsible for the ongoing sustainable development and evolution of the modelling framework since 2008. It is consisted of 5 European institutes: CMCC (**C**entro Euro-**M**editerraneo sui **C**ambiamenti **C**limatici, Italy), CNRS (**C**entre **N**ational de la **R**echerche **S**cientifique, France), Mercator Ocean (organization - company, EU funded, major contributor of the Copernicus Marine Service), Met Office (the national meteorological service for the UK), NERC (Natural Environment Research Council, part of UK's Research & Innovation organization).

POM (Princeton **O**cean **M**odel): The Princeton Ocean Model (POM) is a simple to run yet powerful ocean modeling code to simulate a wide range of problems, from small-scale coastal processes to global ocean climate change. POM is a sigma coordinate (terrain-following), free surface ocean model with embedded turbulence and wave sub-models, and wet-dry capability. POM has been a pioneering force in ocean research since the early 1980s and continues with innovative new developments by its thousands of users worldwide until today. POM is possibly the most influential among the ocean circulation models. In the late 1990s and the 2000s many other terrain-following community ocean models have been developed; some of their features can be traced back to features included in the original POM, other features are additional numerical and parameterization improvements. Several ocean models are direct descendants of POM such as the commercial version of POM known as the estuarine and coastal ocean model (ECOM), the navy coastal ocean model (NCOM) and the finite-volume coastal ocean model (FVCOM). Recent developments in POM include a generalized coordinate system that combines sigma and z-level grids, inundation features that allow simulations of wetting and drying (e.g., flood of land area) (contribution by Oey) and coupling ocean currents with surface waves (contribution by Mellor). Efforts to improve turbulent mixing also continue (contribution by Galperin, Kantha, Mellor and others).

POP (Parallel Ocean Model): The Parallel Ocean Program (POP) is an ocean general circulation model used for ocean and climate research. It is used in a variety of applications, including very high-resolution eddy-resolving simulations of the ocean and as the ocean component of coupled climate models like the Community Climate System Model (Blackmon et al., 2001). The model is developed and supported primarily by researchers at LANL (Los Alamos National Laboratory, USA). Modified versions of POP are also actively used as the ocean-model components of larger climate models, e.g., CCSM2.0 POP in the Community Climate System Model (CCSM).

ROMS (Regional Ocean Modelling System): ROMS is a free-surface, terrain-following, primitive equations ocean model widely used by the scientific community for a diverse range of applications. The model is developed and supported by researchers at the Rutgers University, University of California Los Angeles, and contributors worldwide. ROMS is used to model how a given region of the ocean responds to physical forcing such as heating or wind. It is a 4-D model, meaning a 3-D model that can be run to evaluate change over a given amount of time. It is gridded into vertical layers that make up the water column and horizontal cells that make up the coordinates of the 2D cartesian plane of the model region. ROMS can also be used to model how a given ocean system responds to inputs like sediment, freshwater, ice, or nutrients. The capabilities require the use of coupled models nested within the ROMS framework.

MIKE 3: MIKE 3 is DHI’s proprietary suite of programs built around a 3D hydrodynamic model. MIKE 3 provides simulation tools capable of modelling **3-D free surface flows** and associated sediment or water quality processes. DHI’s clients using MIKE 3 are located all over the world. MIKE 3 is built on the same technology as MIKE 21, so users that are familiar with the later may feel comfortable using MIKE 3 (DHI, 2009a). The combination of the two suites covers many aspects of coastal and marine modelling. The company claims that “MIKE 3 is widely recognised as the platinum standard for environmental and ecological studies”. Ecological modelling is carried out by the ECO Lab module of the suite (Sandberg, 2009). Other modules of the suite handle prepossessing, post processing and visualization of data and simulation results. The use cases of the suite are mainly local or regional, as opposed to the above mentioned, more sophisticated ocean circulation models. On the other hand, the overall experience is more user friendly, as almost everything is controlled and seamlessly integrated by the means of a GUI framework.

The suite is modular, and the company sells different bundles of the software at different price points, according to the choices made by the user. The MIKE modelling suites mainly run under Windows OS. Support for other operating systems is limited.

Delft3D: Delft3D is a former proprietary and now free and open-source suite of models used for hydrodynamic and ecological modelling, developed by Deltares. The suite contains the following modules: FLOW, MOR, WAVE, WAQ, PART. As each acronym suggests:

- FLOW is the 3-D/2-D model used for hydrodynamic circulation simulations.
- MOR is the morphodynamics module handling transport phenomena, including sediment transport.

- WAVE is a 3rd generation spectral wave model based on the SWAN (**S**imulating **W**aves **N**earshore) developed by TU Delft.
- WAQ is the water quality module, based on the DELWAQ model.
- PART is a particle tracking module.

Within the Delft3D FM modelling package a large variation of coastal and estuarine physical and chemical processes can be simulated. These include waves, tidal propagation, wind- or wave-induced water level setup, flow induced by salinity or temperature gradients, sand and mud transport, water quality and changing bathymetry (morphology). Delft3D FM can also be used operationally, e.g., storm surge and algal bloom forecasting.

The suite can be downloaded and used free of charge and contains a GUI with the purpose of preparing and running the simulations. Several software for pre- and post-processing can be also be downloaded. In addition, the D-Flow Flexible Mesh (D-Flow FM) engine for hydrodynamical simulations on unstructured grids in 1-D/2-D/3-D is also available for download. The latter can be freely used but is not fully open source now. Deltares stated that it would be opened sourced sometime during 2020 or early 2021.

D-Flow FM is the successor of the FLOW module. It is capable of handling curvilinear grids that may consist of triangles, quads, pentagons, and hexagons (Figure 3.8-1). This provides modelling flexibility in setting up new model grids or modifying existing ones, or locally increasing resolution. 1-D and 2-D grids can be combined, either connecting adjacent grids or a 1-D grid overlying a 2-D grid. Both Cartesian and spherical coordinate systems are supported. This facilitates tidal computations on the globe with tide generating forces, thus without imposing open boundary conditions. The grid generation tool includes new grid generation algorithms for the construction of orthogonal unstructured grids. D-Flow FM implements a finite volume solver on a staggered unstructured grid. The higher-order advection treatment and near-momentum conservation make the solver suitable for supercritical flows, bores, and dam breaks. The handling of wetting-and-drying makes it suitable for flooding computations. The continuity equation is solved implicitly for all points in a single combined system. Optionally, non-linear iteration can be applied for very accurate flooding results. Furthermore, Coriolis forcing, horizontal eddy viscosity, tide generating forces and meteorological forcing were added, making the system suitable for tidal, estuarine or river computations.

For 3-D modelling, three turbulence models are available: algebraic, k-epsilon and k-tau. Vertical transport can be solved both explicitly and implicitly. First sigma layers were implemented, with the anti-creep option based upon the Delft3D-FLOW algorithm. Fixed z-layers are also available, and z- and sigma-layers can be combined in one single model domain, but this is still ongoing research. Temperature modelling is supported either using the composite heat flux model or the excess heat flux model, which can both be driven by space-and-time varying meteorological datasets.

Time integration is done explicitly for part of the advection term, and the resulting dynamic time-step limitation is automatically set based on the Courant criterium. The possible performance penalty can often be remedied by refining and coarsening the computational grid at the right locations.

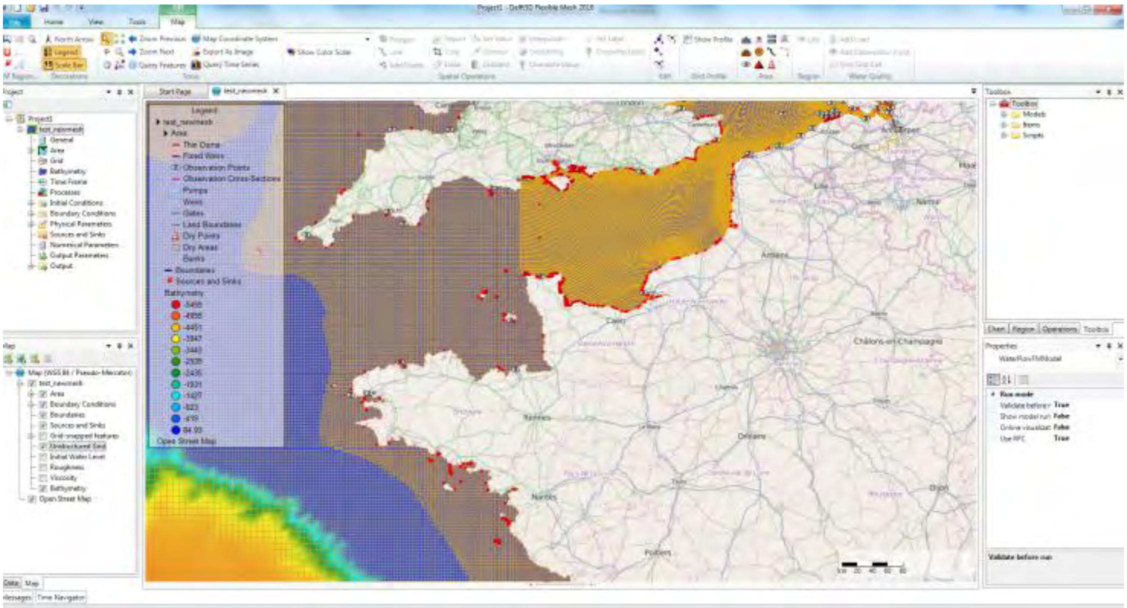


Figure 1.4-1 Delft3D Flexible Mesh – Dutch Continental Shelf model (DCSM)

(taken from https://www.deltares.nl/app/uploads/2015/10/Delft3D-Flexible-Mesh-Dutch-Continental-Shelf-model-DCSM-735x398.png)

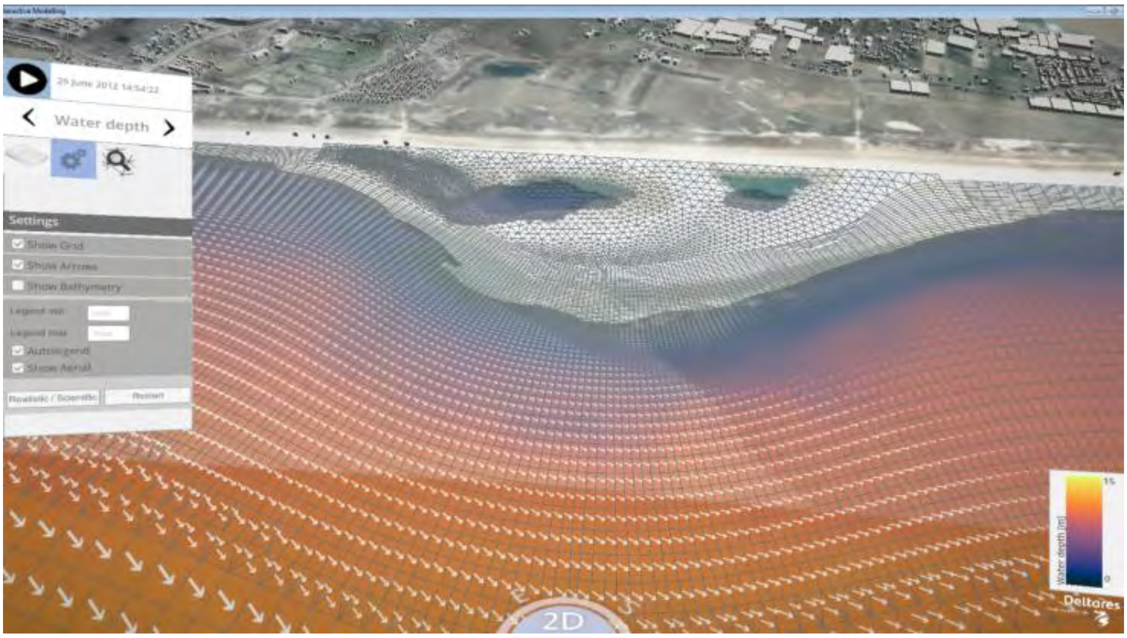


Figure 1.4-2 3D interactive modelling using Delft3D FM – Sand Motor, The Netherlands (taken from https://www.deltares.nl/app/uploads/2015/12/3D-interactive-modelling-using-Delft3D-FM-Sand-Motor-1366x768-735x413.png)

1.4.2 Marine Biochemical and Water Quality Models

Biochemical ocean GCMs are used for quantifying the marine carbon cycle and its feedback to the climate system. Such models simulate the inorganic and organic carbon cycle through a series of process parameterizations. In addition, water quality models are also used for analyzing various forms of water pollution in oceans, estuaries, and basins. The two types of models can sometimes overlap each other regarding when used for simulations within the context of ecological modeling. Nevertheless, when used for marine environment simulations, such models need to be coupled with hydrodynamic simulation models. Therefore, almost all of them can be used within general modeling frameworks or suites of computer programs, acting as dedicated components, exactly as their hydrodynamic/ocean circulation counterparts. Biogeochemical models are more general and are often used for climatic modelling within numerous Earth Model Systems. Earth System Models couple several different models, each one simulating a different subsystem of the planet (atmosphere, oceans, land, etc.), while at the same time providing the framework for their interaction.

The following (non-exhaustive) list presents some of the most well-known water quality models considering their sheer number and ongoing development.

WASP (**W**ater Quality **A**nalysis **S**imulation **P**rogram): The current WASP model is an enhancement of the original (Di Toro et al., 1983; Connolly and Winfield, 1984; Ambrose et al., 1988). This model helps users interpret and predict water quality responses to natural phenomena and manmade pollution for various pollution management decisions. WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. WASP allows the user to investigate 1-, 2-, and 3-D systems, and a variety of pollutant types. WASP also can be linked with hydrodynamic and sediment transport models that can provide flows, depths velocities, temperature, salinity, and sediment fluxes. The most current release of WASP (WASP8) contains the inclusion of a sediment diagenesis model linked to the Advanced Eutrophication sub model, which predicts sediment oxygen demand and nutrient fluxes from the underlying sediments. Because of the model's capabilities in handling multiple pollutant types, it has been widely applied in the development of Total Maximum Daily Loads (TMDL). WASP's capabilities of linking with hydrodynamic and watershed models make it suitable for multi-year analysis under varying meteorological and environmental conditions.

WASP comes with a pre-processor and a post-processor. The data pre-processor allows for the rapid development of input datasets. The ability to bring data into the model is as simple as cut and paste or queried from a database. The pre-processor provides detailed descriptions of all model parameters and kinetic constants. When linking WASP with hydrodynamic models it is as simple as pointing to the hydrodynamic linkage fil:

- Import time series from WRDB, Spreadsheet, Text Files.
- Automatically import hydrodynamic model interface information.
- Multi-session capable.
- Run time diagnosis.

The Post-Processor (MOVEM) provides an efficient method for reviewing model predictions and comparing them with field data for calibration. MOVEM can display results from all the WASP models as well as others. MOVEM allows the modeler to display the results in two graphical formats:

- Spatial Grid: a 2-D rendition of the model network is displayed in a window where the model network is color shaded based upon the predicted concentration.
- x/y Plots generates a x/y line plot of predicted and/or observed model results in a window.

WASP is actively developed by USEPA (United States Environmental Protection Agency) and is one of the most widely used water quality models in the United States and throughout the world. WASP can be run on a variety of 64-bit platforms (Windows, OS X, Linux). Its working environment is presented in Figure 3.8-3.

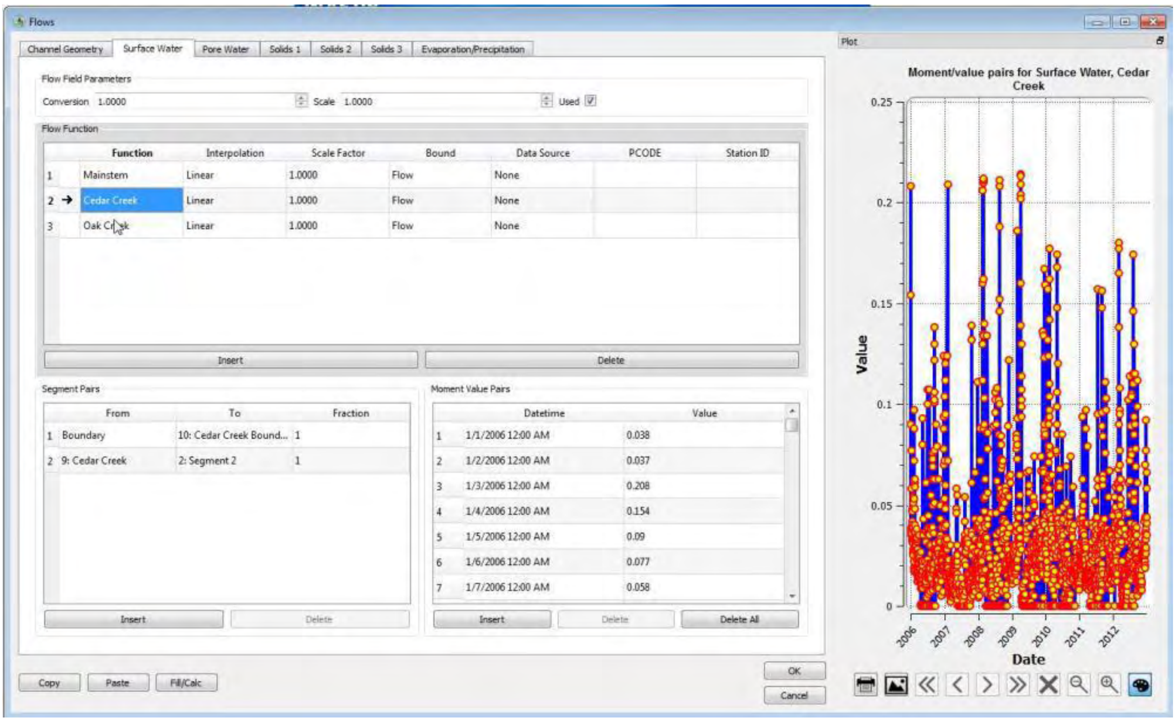


Figure 1.4-3 WASP software working environment

ERSEM (European Regional Seas Ecosystem Model): ERSEM is a planktonic ecosystem model which has been coupled to several different hydrodynamic models. It describes the biogeochemical cycling of carbon and the nutrients nitrogen, phosphorous, silicon, oxygen, and iron. The ecosystem is subdivided into three functional types: producers (phytoplankton), decomposers (bacteria) and consumers (zooplankton), and then further subdivided by trait (size, silica uptake) to create a food web. Physiological and population processes are included in the descriptions of functional group dynamics. Four phytoplankton, three zooplankton and one bacterium are represented, along with the cycling of carbon, nitrogen, phosphorous, silicon, and oxygen, through pelagic and benthic ecosystems.

ERSEM can assess how the changing environment (e.g. light availability, nutrient inputs, temperature, pH) impacts ocean productivity, community size structure, trophic transfer, and elemental cycles. ERSEM simulates low to mid trophic levels and can be used to drive fisheries and aquaculture models. ERSEM is routinely coupled to a wide variety of hydrodynamic models such as GOTM, NEMO and FVCOM using a coupling interface called FABM which enables ERSEM to be run as a simple box model or more realistically in 1-3 dimensional space at scales ranging from local, and coastal via regional to global applications.

Since its original development as a European initiative in the early nineties ERSEM has evolved significantly from a coastal ecosystem model for the North-Sea to a generic tool for ecosystem simulations from shelf seas to the global ocean. It is a UK community model which is also widely used internationally. The development of ERSEM is led by PML (Plymouth Marine Laboratory) and has more than registered 300 users from 30 countries across the world and has appeared in more than 200 peer-reviewed publications.

According to its developers, the recently released version of ERSEM can increase the capability of users by enabling comprehensive studies of the lower trophic levels of the marine ecosystem across the globe under present day and future conditions in one single framework, thus providing an ideal platform for research, operational forecasting, and projections of future climate change. Distribution of ERSEM is accompanied by a testing framework enabling the analysis of individual parts of the model (Figure 1.4-4).

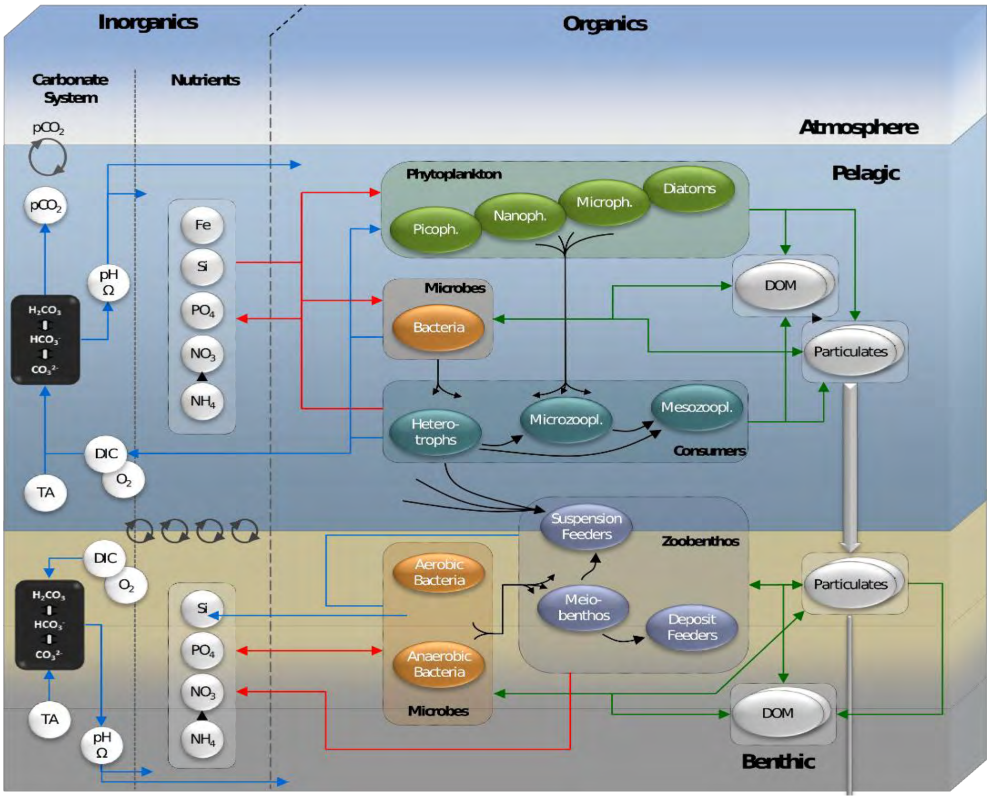


Figure 1.4-4 A schematic of the ERSEM model
(taken from ERSEM's website)

<u>**HadOCC** (The **Had**ley Centre **O**cean **C**arbon **C**ycle model):</u> HadOCC model is a simple NPZD (Nutrient-Phytoplankton-Zooplankton-Detritus) representation that uses N nutrient as its base currency but with coupled flows of C, alkalinity and O_2. The model was the ocean biogeochemistry component of the UK Met Office's HadCM3 climate model and was used for the first-ever fully coupled carbon–climate study (Cox et al., 2000).

<u>**Diat-HadOCC:**</u> Diat-HadOCC is a further development of HadOCC. Using HadOCC's infrastructure Diat-HadOCC adds two new phytoplankton classes, which are diatoms and mixed phytoplankton. Other additions to the original model consist of the inclusion of silica and iron nutrients. Moreover, the effect of nutrient limitation on growth is multiplicative, where light limitation is multiplied by successive nutrient limitation terms (Figure 24). Further details can be found in Halloran et al. (2010). The model is the ocean biogeochemistry component of HadGEM2-ES (Collins et al., 2011). The latter is the UK Met Office's Earth system model.

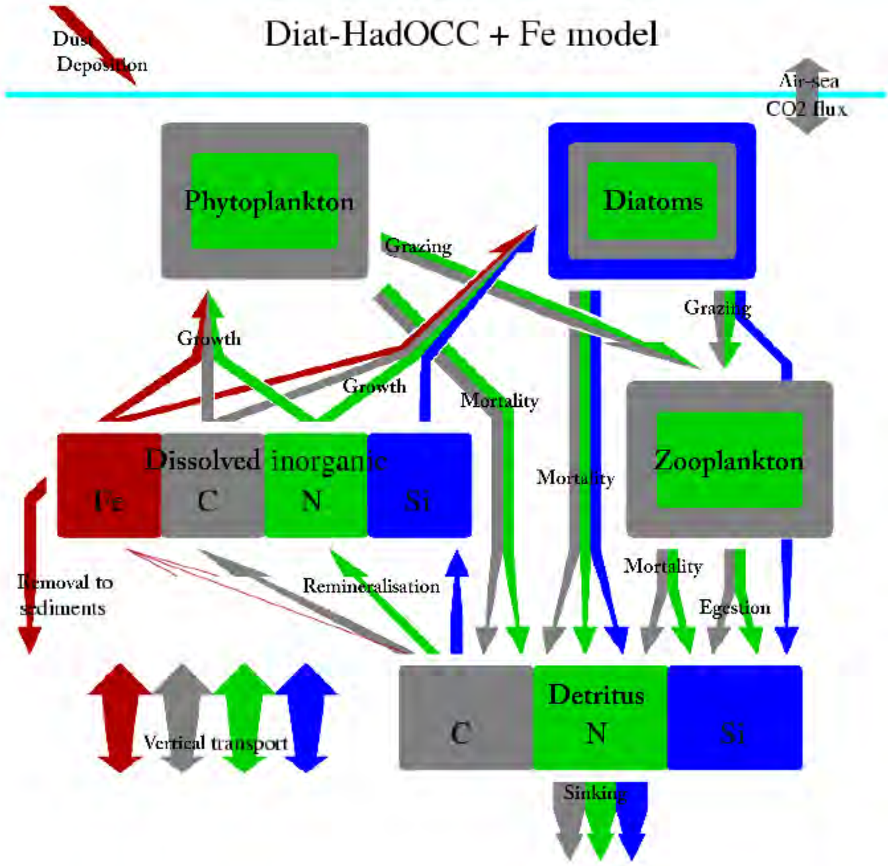


Figure 1.4-5 Diagram of the Diat-HadOCC model components and flows of nitrogen, carbon, silicon and iron.

(Totterdell, I.J., 2019). Available via license: CC BY 3.0.

<u>**MEDUSA-2** (**M**odel of **E**cosystem **D**ynamics, nutrient **U**tilization, **S**equestration and **A**cidification):</u> MEDUSA is an "intermediate complexity" plankton ecosystem model designed to address key feedbacks between anthropogenically-driven changes (climate, acidification) and oceanic biogeochemistry. It resolves a size-structured ecosystem of small (nanophytoplankton and microzooplankton) and large (microphytoplankton and mesozooplankton) components that explicitly includes the biogeochemical cycles of nitrogen, silicon and iron as well as the cycles of carbon, alkalinity and oxygen. As such, MEDUSA is broadly similar in structure to Diat-HadOCC but includes several more recent parameterizations such as variable C:chl, ballasted fast-sinking detritus, and a dynamic Si:N ratio.

<u>**PlankTOM6 & PlankTOM10:**</u> The PlankTOM series of models are being developed from the PISCES-T ocean BGC model (based on PISCES model of (Aumont et al., 2003). The series includes global 3D model with local and regional applications representing lower-trophic marine ecosystems based on plankton functional types (PFTs). Parameterisation is empirically driven, increasing validation certainty. Depending on version there are 22 to 39 variables describing the cycles of carbon and macronutrients and chlorophyll. PlankTOM is embedded in the NEMO and other GCMs. Model structure: The model represents the BGC cycles of C, N, O_2, P, Si, a simplified Fe cycle, and three types of detrital organic pools including their ballasting properties; representations of the air-sea fluxes of CO_2, O_2, DMS, and N_2O are also available. PlankTOM6 is maintained with six functional types (diatoms, coccolithophorids, bacteria, picophytoplankton, protozooplankton and mesozooplankton); the latest version PlanTOM10 has

in addition N_2 fixers, Phaeocystis, mixed-phytoplankton and macrozooplankton (Quere et al., 2005).

PISCES (Pelagic Interaction Scheme for Carbon and EcoSystem) (Aumont et al., 2003): It is a 3D ecosystem and carbon-cycle model intended to be used in global, regional, and local applications. The model includes 24 variables describing the cycles of carbon and macro-nutrients run all together at the same time. PISCES is embedded within NEMO. The model contains four living compartments (two phytoplankton and two zooplankton size classes) and uses fixed Redfield ratios. Non-living compartments include semi-labile dissolved OM, small particles, and fast sinking particles. Iron, silicon, and calcite pools are explicitly modelled, therefore can vary. Inorganic carbon is also modelled. However, the bacterial pool is not yet explicitly modelled.

ERGOM: ERGOM is a bio- geochemical model which was developed at Leibniz Institute for Baltic Sea Research, Warnemuende, Germany by Thomas Neumann and Wolfgang Fennel. It is free software and has users in several institutes and universities around the Baltic Sea (Meier et al., 2012; Eilola et al., 2011; Meier and Eilola, 2011; Meier et al., 2011). The model is 3-D with regional applications. It has nine variables and describes the cycles of phosphorus and nitrogen, diatoms, flagellates and cyanobacteria, zooplankton, oxygen and two types of detritus. ERGOM needs a host model. It can be used in a simple MATLAB model, or embedded in physical models, e.g. MOM5. As the model was originally developed for the Baltic Sea it gives robust representations of processes involved in hypoxic – anoxic cycles. The model provides a full mathematical description of photosynthesis, grazing, respiration, mortality, mineralisation, nitrification, denitrification. ERGOM is nitrogen-based and uses fixed Redfield ratios. Detritus in the sediment is either buried, mineralised or resuspended into the water column (Figure 1.4-6). The model uses marine ecology, hydrographic and climatological (i.e. to configure boundary conditions) data from ICES data center. Nutrient forcing is from riverine nutrient loadings.

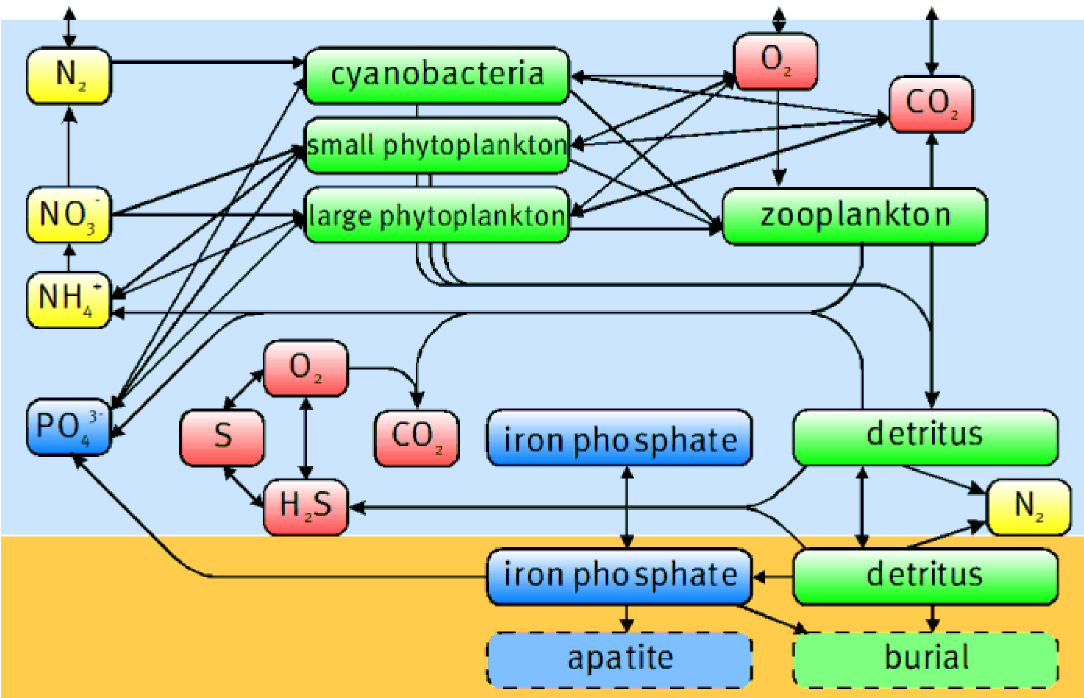


Figure 1.4-6 Schematic of ERGOM model. (taken from https://ergom.net/)

MIKE ECO Lab: MIKE ECO Lab is a numerical lab for Ecological Modelling. It is an open and generic tool for customising aquatic ecosystem models to describe water quality, eutrophication, heavy metals, and ecology (DHI, 2009b). The module is mostly used for modelling water quality as part of an Environmental Impact Assessment (EIA) of different human activities, but the tool is also applied in aquaculture, e.g. for optimisation the production of fish, seagrasses, and mussels. Another application area is in online forecasts of water quality. The demand for tailor made ecosystem descriptions is great because eco-systems vary. The strength of this tool is the easy modification and implementation of mathematical descriptions of ecosystems into the hydrodynamic engines of DHI. MIKE ECO Lab integrates with the MIKE suite of flow simulation models covering all aspects ranging from 1-D, 2-D and 3-D free surface modelling to integrated hydrology [MIKE HYDRO River (1-D), MIKE 21 (2-D), MIKE 3 (3-D), MIKE SHE (Hydrology), MIKE URBAN (1-D)].

The user can use predefined MIKE ECO Lab templates containing the mathematical descriptions of ecosystems or can choose to develop own model templates. A template is independent of grid systems and the same template can be loaded in MIKE HYDRO, MIKE 11, MIKE 21, MIKE 3, MIKE 21 FM, MIKE 3 FM and Coupled Model FM. The template can describe dissolved substances, particulate matter of dead or living material, living biological organisms and other components (all referred to as state variables in this context). The module is developed to describe chemical, biological, ecological processes and interactions between state variables and the physical process of sedimentation of components can be described (Figure 1.4-7). State variables included in MIKE ECO Lab can either be transported by advection-dispersion processes based on hydrodynamics or have a more fixed nature (e.g. rooted vegetation or mussels) and be discerned in hierarchical level (Figure 1.4-8).

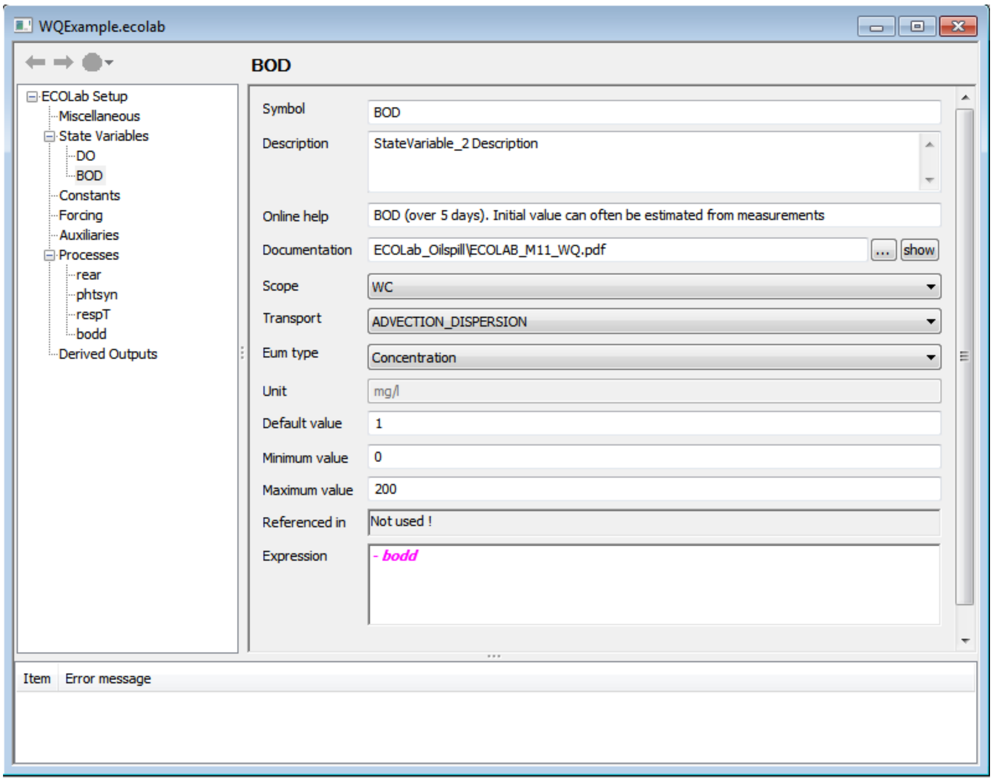


Figure 1.4-7 Software environment to create a new State Variable in the MIKE ECO Lab dialogue box.

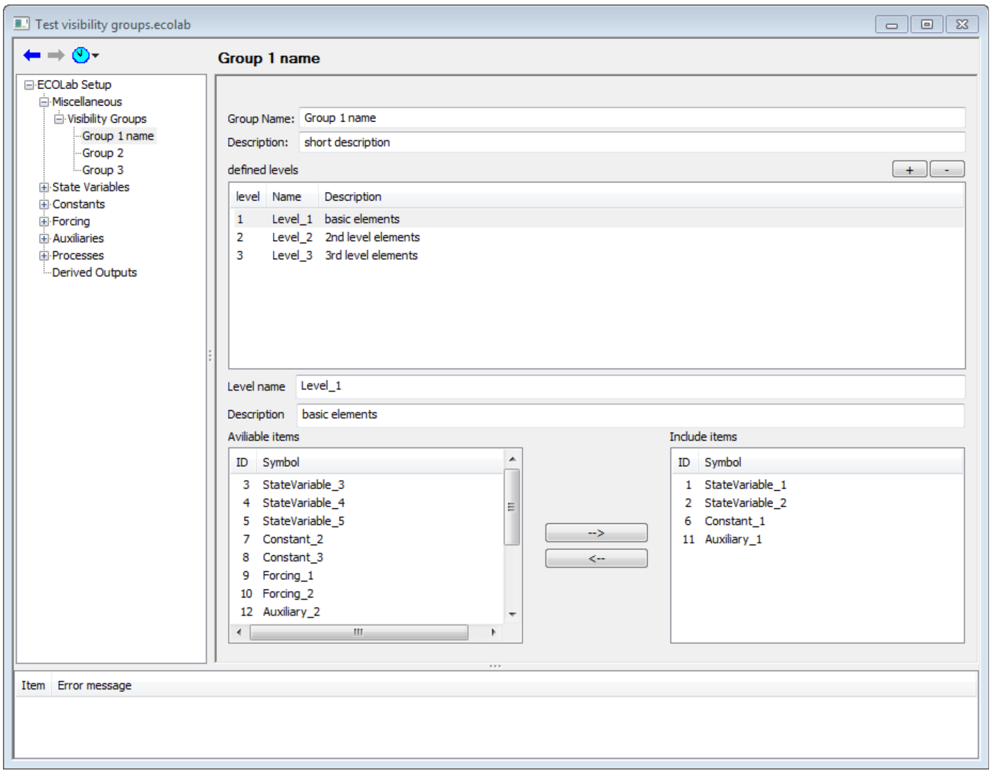


Figure 1.4-8 Software environment to define a visibility group of state variables
(with three hierarchical levels in the MIKE ECO Lab dialogue box)

DELWAQ: DELWAQ is the engine of the D-Water Quality and D-Ecology programs of the Delft3D suite. It is based on a library from which relevant substances and processes can be selected to quickly put water and sediment quality models together. The processes library covers many aspects of water quality and ecology, from basic tracers, dissolved oxygen, nutrients, organic matter, inorganic suspended matter, heavy metals, bacteria, and organic micro-pollutants, to complex algae and macrophyte dynamics. High performance solvers enable the simulation of long periods, often required to capture the full cycles of the processes being modelled. The finite volume approach underlying DELWAQ allows it to be coupled to both the structured grid hydrodynamics of the current Delft3D-FLOW engine and the soon to be open-sourced D-Flow Flexible Mesh engine (1-D/2-D/3-D) of the Delft3D Flexible Mesh Suite. It can also be used with other 3-D flow models.

1.4.3 Oceanographic Forecast Platforms

The regional-scale analysis (Aegean, Ionian, Mediterranean and other European Seas) of operational forecast systems and services (WaveForUs, POSEIDON, SOCIB, COSYNA etc.) with data-sharing portals have been presented in Subsection 3.8 of TIMMOD's Deliverable D.T1.1.1. Herein several representative forecast applications of the EU- and worldwide-scale paradigm are presented.

On a global scale, there are several fully versatile, freely provided, and widely used platforms of open data for ocean parameters, such as EU's Earth Observation Programme Copernicus (https://marine.copernicus.eu/), OPENCoastS an open-access service for the automatic generation of coastal forecast systems (Oliveira et al., 2020; https://opencoasts.ncg.ingrid.pt/), NCCR (National Center for Coastal Research in India;

https://www.nccr.gov.in/), NOAA's National Weather Service for marine forecasts and conditions (https://www.weather.gov/phi/marine), MetOceanView the complete environmental forecast system for vessels, port authorities and offshore operators (https://metraweather.com/marine/MetOceanView-environmental-forecast-system), JCOMM Expert Team on Ocean Forecast Systems (ET-OFS) (https://www.jcomm.info/), NOAA's nowCOAST (https://nowcoast.noaa.gov/) web mapping forecast platform.

For the Copernicus system a variety of information on its forecast products, applications and data sharing tools is presented in Section 3.8 referring to the monitoring data services (Figure 1.4-9).

Figure 1.4-9 Online data sharing tool of marine forecast data by the Copernicus platform in the global ocean.

The OPENCoastS service assembles on-demand circulation forecast systems for selected coastal areas and keeps them running operationally for a period defined by the user. This service generates daily forecasts of water levels, vertically averaged velocities, and wave parameters over the region of interest for 48 hours, based on numerical simulations of all relevant physical processes. Presently, all forecasts are made with the SCHISM model. Tide gauge data are provided by EMODnet Physics. The following forcing sources are used:

- Atmospheric forcings:
    - GFS (NOAA)

- ARPEGE (MétéoFrance)
  - Atmospheric forcings:
  - PRISM2017 (LNEC)
  - FES2014 (LEGOS)
  - CMEMS (Copernicus)
- Wave forcings
  - North Atlantic WW3

Access to the service is free, and a new user only needs to register. Access to the 3-D simulations is granted on request due to the large computational resources required.

Within NCCR initiatives, in order to identify the periodical changes in seawater quality, the Ministry of Earth Sciences (MoES) erstwhile the Department of Ocean Development (DOD) has been implementing a nationally coordinated research programme on "Coastal Ocean Monitoring and Prediction System (COMAPS)" since 1990 which is presently called "Sea Water Quality Monitoring (SWQM)" Programme. The data generated under this program is probably the only long-term dataset on the coastal water quality available in the country. In addition to the regular SWQM program, an additional program was designed to understand the transport, dispersion, and quantification of pollutants in the coastal waters and predict the pollution level based on the indicative water quality parameters such as temperature, salinity, dissolved oxygen, biochemical oxygen demand, nutrients, and pathogenic bacteria. NCCR aims at assessing the spatiotemporal variability of the coastal water quality and develop a prediction system with 5-day forecast for the benefit of beach goers and other coastal stakeholders.

The Marine Ecotoxicology program is being implemented to study the effects of toxic chemicals on biological organisms for pollution mitigation and regulatory measures for the sustainable maintenance of ecosystem or components of the ecosystem. Toxicity bioassay experiments are being conducted on marine organisms for priority chemicals like metals and organics. The data generated from the laboratory-based experiments are used for deriving the numerical seawater quality criteria as 'safe levels' for the designated best use classes of the coastal and marine waters of the country.

NCCR is also involved in the following activities (Figure 1.4-10):

- Detect periodical changes in coastal water quality, predict pollution levels and provide real-time information of water quality and status of the coastal waters.
- Develop numerical models for the prediction of coastal water quality and dissemination of water quality information via web and mobile application.
- Conduct coastal clean campaign for Indian beaches in line with the Coastal Clean Seas campaign of United Nations and Environment Agency (UNEA).
- Develop Seawater Quality Criteria (SWQC) for coastal waters, waste disposal zones, fishing ports, harbours and ecologically sensitive habitats for protection of marine life.
- Derive environmental quality indices through ecological risk assessment of metals in estuarine and coastal waters.

In addition to the above, NCCR is also conducting studies on Marine Litter and Microplastics. NCCR along with South Asia Co-operative Environment Program (SACEP) prepared a Country Report on Marine Litter -India which serves as a baseline report for further actions against marine litter in the country. The basic goal is to create a clean coastal seas and beaches by 2022.

Figure 1.4-10 NCCR featured activities.

JCOMM coordinates the international standards and guidance, operational intercomparisons and service quality, and outreach to users for ocean forecast systems. It works closely with the GODAE OceanView Science Team, which is focused on the development of future ocean forecast systems. Within JCOMM, it identifies requirements for observations and data management, and works with other teams developing services to users. The Team maintains the following catalogue of ocean forecast systems and products. To the resolution defined "essential" data and products to be exchanged without charge and with no conditions on use. All available in situ observations from the marine environment as well as upper air observations are regarded as "essential" by the resolution. These can be obtained by contacting any Permanent Representative of a National Meteorological and Hydrological Service (NMHS) with WMO.

The Ocean Data Portal (ODP) aims at providing seamless access to collections and inventories of marine data from the NODCs (National Oceanographic Data Centres) of the IODE network and allows for the discovery, evaluation (through visualization and metadata review) and access to data via web services. The ODP has been developed by the "International Oceanographic Data and Information Exchange" (IODE) of the "Intergovernmental Oceanographic Commission" (IOC) of UNESCO. The system architecture use Web-oriented information technologies to access non-homogeneous and geographically distributed marine data and information (http://www.oceandataportal.org/).

The WMO Information System (WIS) provides for a single coordinated global infrastructure for the collection and sharing of information in support of all WMO and related international programmes. The WIS provides an integrated approach suitable for all WMO Programmes to meet the requirements for routine collection and automated dissemination of observed data and products, as well as data discovery, access and retrieval services for all weather, climate, water, and related data produced by centres and WMO Member countries in the framework of any WMO Programme. It is being built upon the Global Telecommunication System of WMO's World Weather Watch, using standard elements and at a pace feasible for all Members. The core infrastructure of WIS is comprised of Global Information System Centres (GISCs), Data Collection or Production Centres (DCPCs), and National Centres (NCs).

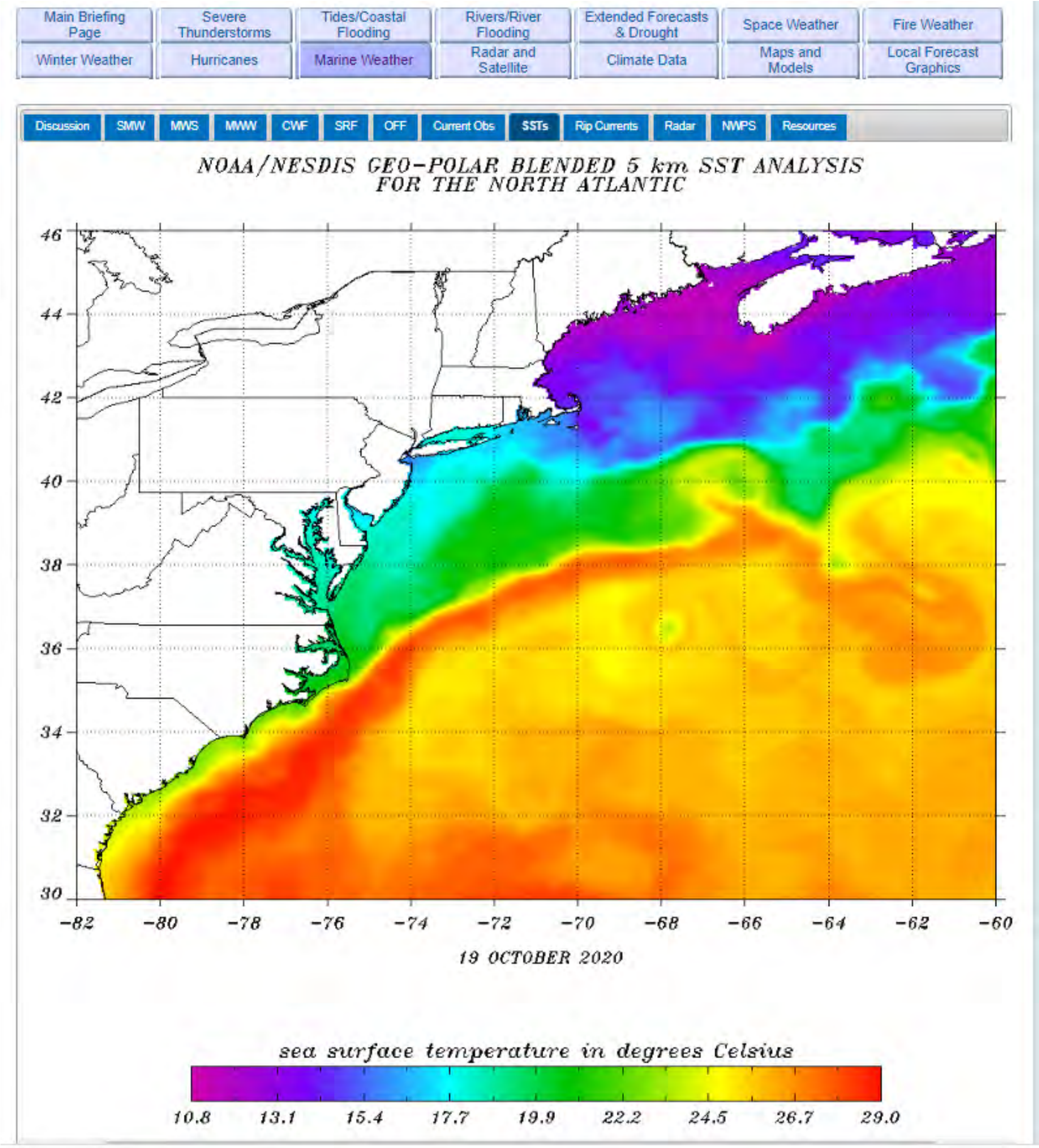


Figure 1.4-11 Online data sharing tool of marine forecast data

by the NOAA's National Weather Service platform in the northwestern part of the US coasts and the Atlantic Ocean; Ocean Forecast Parameter: sea surface temperature (in ˚C)

The National Weather Service (NWS) Marine Weather Services Program by NOAA offers a broad range of marine forecast and warning products in graphical and text formats (Figure 1.4.11). One can also get an hourly marine forecast for a single point. The menu takes one to the marine service pages of NWS Weather Forecast Offices (WFOs) and National Marine Forecast Centers, which provide forecasts and warning services for the coastal waters along the mainland of the continental US, the Great Lakes, and offshore and high seas waters of the

North Atlantic and North Pacific Oceans. Links to forecasts, warnings and products related to tropical cyclones and sea ice are also provided.

An alternative to NOAA's Web Mapping Portal for Real-Time Coastal Observations, Forecasts, and Warnings is the nowCOAST portal (Figure 1.4-12).

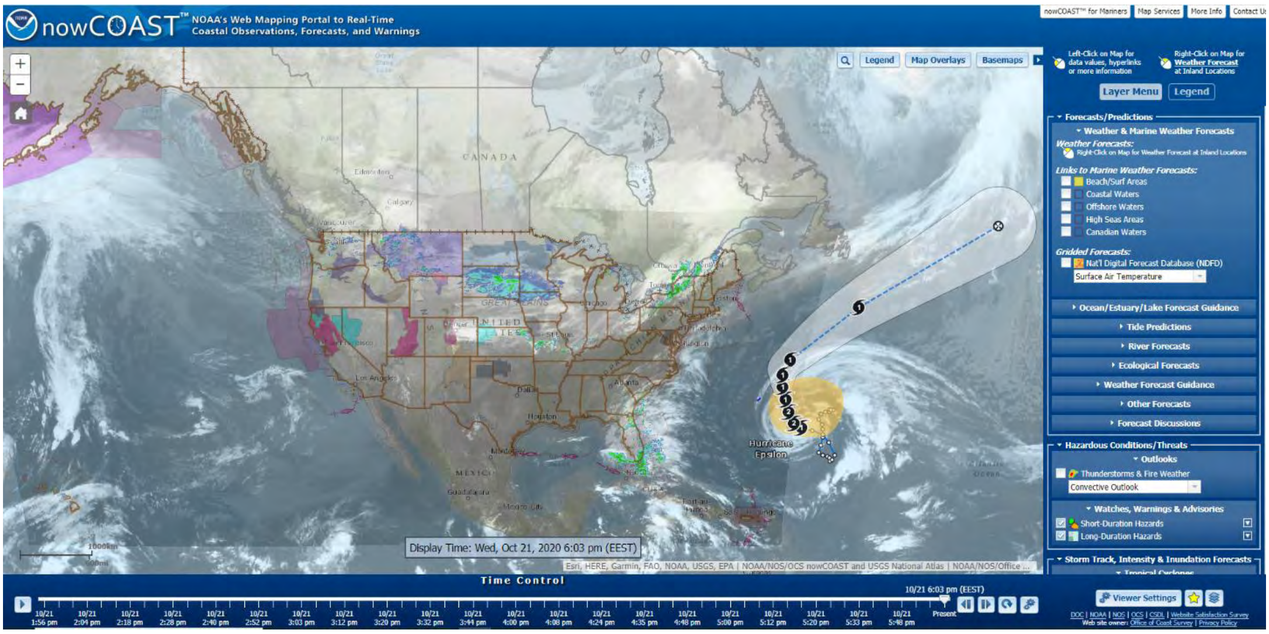


Figure 1.4-12 nowCOAST online data sharing tool of marine forecast data by NOAA's National Weather Service for the entire US region the Atlantic and Pacific Oceans

1.4.4 Marine Water Quality Forecast Platforms

All the aforementioned Oceanographic Forecast Platforms (OFPs), analyzed in Subsections 2.4.3 of the present Deliverable D.T1.2.1 and Subsection 3.8 of D.T1.1.1, incorporate forecast components that specifically refer to ocean (or marine) water quality, usually attached to and more sparsely independent of the strict hydrodynamic circulation components of them. Some of these Marine Water Quality Forecast Platforms (MWQFPs) are presented in the following.

DHI Group offers services of forecasting water quality in coastal and harbour areas, by building local bathing water forecast systems that can ensure timely and accurate information regarding seawater quality criteria for swimmers (example can be found here: https://www.dhigroup.com/global/references/apac/overview/forecasting-water-quality-in-the-waitemata-harbour). Services are based on DHI's software solution component comprising the MIKE OPERATIONS, MIKE 3 FLEXIBLE MESH, and MIKE ECO Lab, building a computational forecast suite for better water quality information.

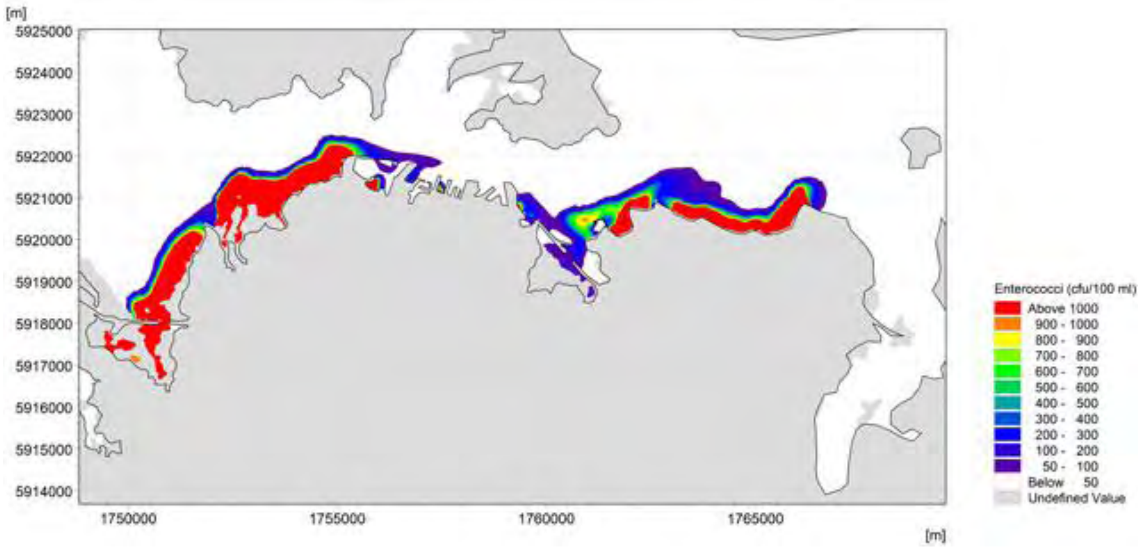


Figure 1.4-13 Main output of Contaminant Plume Tracker software suite.

© DHI (taken from https://www.dhigroup.com/global/references/apac/overview/forecasting-water-quality-in-the-waitemata-harbour*)*

DHI assures that its clients can be informed on impacts of pollutants in a more accurate and timely manner with an assessment of intervention options. The model suite allows client to assess the benefits of potential intervention options. This way public dialogue can be improved. The accessibility of water quality data can thus result in more transparent communication. As specific local bathing locations inside harbour areas can be exposed to risks of contamination where there is insufficient data on pollution levels and currents, DHI has helped in fighting general public scepticism about actions to improve coastal water quality. DHI under the MIKE suite has developed integrated local/regional Bathing Water Forecast Systems (*Contaminant Plume Tracker software suite;* Figure 1.4-13) to inform audiences about the impacts of contaminant overflows in and around harbours and coastal areas. With this kind of systems, information and warnings about water quality can be made easily accessible across multiple media platforms. The steps followed are:

- Constant monitoring of the harbour's water and prediction of the concentration of Enterococci bacteria.
- Creation of models for predictive forecasts by utilising a high-resolution 3D hydrodynamic model to simulate tidal and wind driven currents.
- Generating flow and bacteria concentration time series based on observed and predicted rainfalls time series.

DHI's solution can overcome the limitations of monitoring programmes with its ability to predict water quality outcomes ahead of time. This allows one to provide the public with water quality information and associated health risks just before they enter the water.

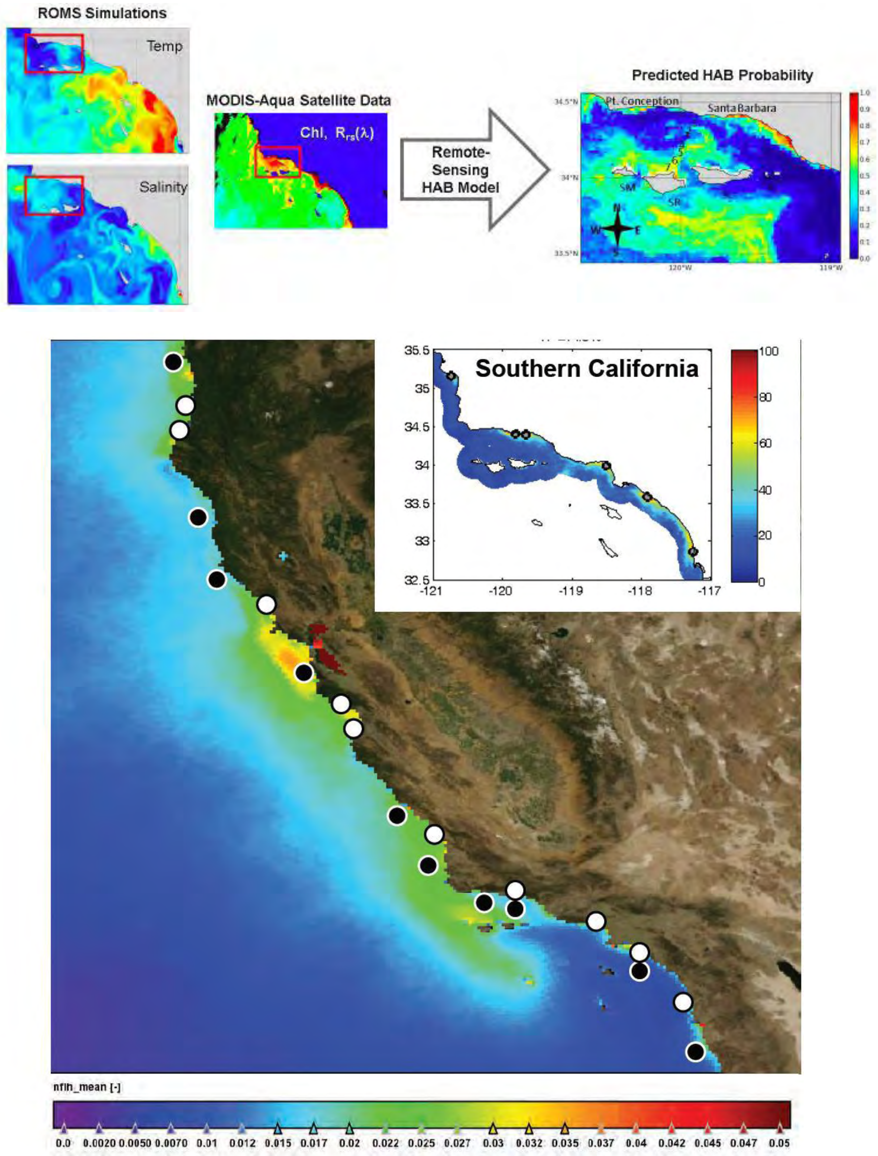


Figure 1.4-14 Main output of modelling to forecast HABs in California.

The water quality monitoring council of California US has established the *My Water Quality* platform as a collaboration between local Environmental Protection and Natural Resources Agencies (https://mywaterquality.ca.gov/) for e.g. modelling initiatives to forecast Harmful Algal Blooms (HABs) in the State of California. Their platform comprises nowcasts and forecasts of the probability of cells or toxin through combination of:

- Satellite observations of chlorophyll-a, reflectance and historical HAB data
- Ocean circulation models (temperature, salinity, and ocean currents)

The later are linked with causal ocean acidification and hypoxia modelling towards an Operational Forecasting System (OFS) for seawater quality (Figure 1.4-14).

Another Predictive Modeling Project for Water Quality is the American initiative for California named NowCast (https://ocbeachinfo.com/nowcast/). It provides information similar to a daily weather forecast except the nowcast predicts good or poor water quality for the day at specific beaches in California (US). The nowcasts are based on the results of predictive computer models that estimate fecal bacteria levels in the surf zone. Local agencies can compare the computer results to the State's bacteria health standards for contact with ocean waters to determine if the water is safe for recreational uses such as swimming and surfing. If the model estimates bacteria levels that meet the health standards, the water quality nowcast is "Good", however, if the model estimates exceed the health standard, the water quality nowcast is "Poor." The predictive beach water quality models were developed as part of a study completed by Heal the Bay and Stanford University, and funded by the California State Water Resources Control Board. Experts in beach water quality developed and tested over 700 different beach models using many years of historical data on environmental conditions and bacteria levels from 25 beaches in California. This study represents the most comprehensive study completed to date on using predictive models at marine beaches.

Currently, local health agencies use laboratory analyses of water samples collected at the beach to determine if it is safe for recreational use. Unfortunately, there is a long delay in this approach. In Orange County, it typically takes 24-32 hours to collect the samples, transport them to the lab, and analyze the beach water samples. Meanwhile, water quality can change with environmental conditions between scheduled sampling days. Most California beaches are sampled on a weekly basis, although there are some beaches that are monitored more frequently. Predictive models can provide daily water quality nowcasts based on the most recent environmental conditions at the beach. Local health agencies can then make public notifications of poor water quality in the morning before most people arrive at the beach.

Fecal bacteria levels can be affected by many factors such as rainfall, tide levels, solar radiation, wind, storm drain flows, and swell conditions. Because the effect of these factors on water quality varies from beach to beach, site-specific models are developed for individual beaches. The predictive models generally perform as well as, or better than, the current method that relies on waiting for laboratory analysis of water quality samples to determine if the water is safe for swimming. Predictive models are developed to capture variations in beach water quality caused by changes in environmental conditions but are not able to predict unusual events such as a sewage spill. By 2018, NowCast models were used at 19 California beaches, from Humboldt to San Diego. Predictive models are also used for daily nowcasts in the summertime at several beaches on the Great Lakes, including beaches in Ohio, Wisconsin, Pennsylvania, New York, and Illinois. At these beaches, local beach agencies successfully use predictive models to determine when the public should be notified of bacteria levels that exceed health standard. Predictive models are also used at Hong Kong coastal beaches where the predictive models accurately predict 30-70% of water quality exceedances.

Beachgoers will have easy access (Figure 1.4-15) to predictive forecasts on Heal the Bay's Beach Report Card Website and on the Beach Report Card mobile app. Information and links to the forecasts are also on the participating health agencies webpages: Orange County Health Care Agency, Los Angeles County Department of Public Health, and County of Santa Barbara Department of Public Health.

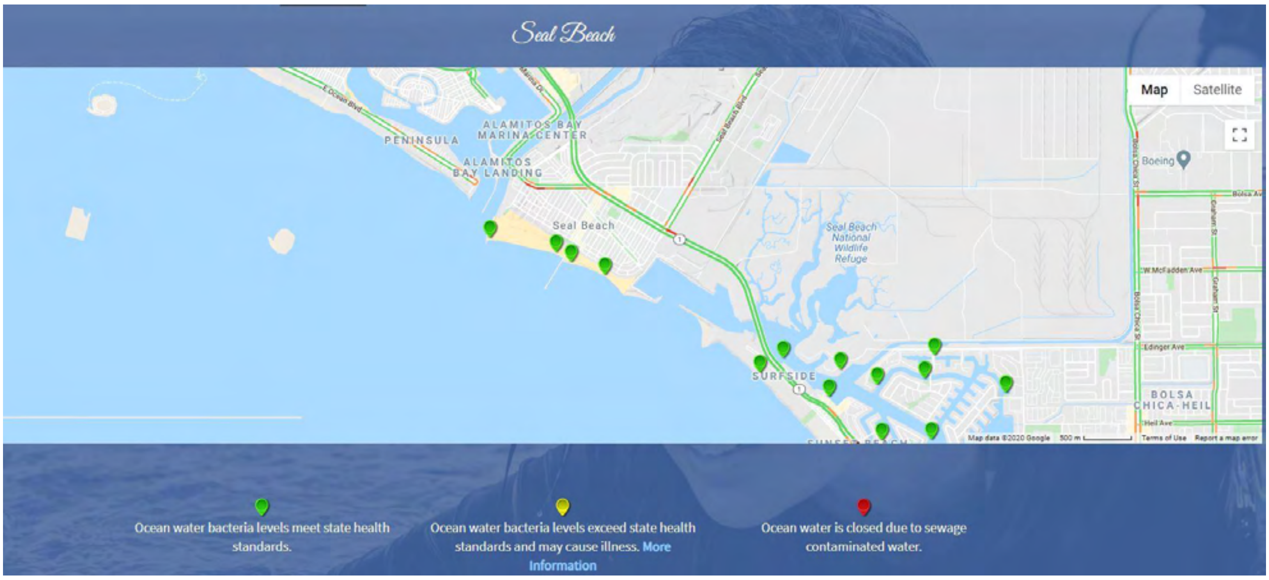


Figure 1.4-15 Main platform of NowCast project in California US.

The US Natural Resources Defense Council (NRDC) pushes for policy and infrastructure solutions that make America's beaches cleaner and safer for swimming, by tackling the problem at its source. For more than two decades, NRDC has published an annual report called Testing the Waters, which tracks water quality at beaches around the country. Research has found that the biggest cause of beach closings and advisories is stormwater runoff. When it rains, water rushes over sidewalks, roads, and parking lots and picks up all kinds of chemicals along the way. In many cities, that stormwater is fed into sewage treatment plants, but if flows are too heavy, runoff can find its way straight into waterways—including the waves that lap local beaches. Yet many communities fail to address this pollution. NRDC has won a series of influential court cases that compelled municipalities to reduce the amount of runoff ending up in beach water.

In this framework and in collaboration with USEPA (US Environmental Protection Agency) the VCrma runs an Ocean Water Quality Monitoring Program providing several mobile apps for Safe Beaches, Water Pollution Prevention, etc. through interactive maps of sampling results. The purpose of this program is to assure the protection of human health and of the environment through the routine monitoring of coastal marine waters for bacteria contamination, to provide information as to the bacteriological quality of these waters, and to coordinate with private organizations and public agencies. In September 1998, the Ventura County Board of Supervisors directed the Environmental Health Division to develop a program to monitor the bacteriological quality of ocean water at Ventura County beaches. The Ocean Water Quality Monitoring Program (OWQMP) was developed with the primary purpose of providing the public with accurate and timely information about the bacteriological quality of ocean water.

40 sites are sampled during the Dry-Weather season (April to October) and 19 sites are sampled during the Wet-Weather season (November to March). Maps of these beach locations can be found on our web page: Sample Results. Our sampling sites have been selected based on the numbers of public use and their proximity to a storm drain outfall (not outflow). Outfalls include pipes, culverts, rivers, creeks, and streams. Ocean water samples are collected in ankle-to-knee deep water and tested for three bacteria indicators: total coliform; fecal coliform; and enterococcus. These bacteria indicators, at sufficient concentrations, can indicate the presence of other strains of bacteria, viruses and protozoa in the ocean water that may cause illness.

Water samples are analyzed for concentrations of each of these "indicators" and the results are compared to the State standards for bacteria. These results are entered on a webGIS platform (https://vcrma.org/ocean-water-quality-results#map, Figure 1.4-16). If any of the State standards are not met, the beach is posted with warning signs advising the public to avoid body contact with the ocean water. This information is also made available on telephone hotline, and in press releases distributed to the media. The advisory remains in effect and the warning sign will remain posted until the next sampling results indicate that the ocean water meets State standards for bacteria. To protect oneself from a recreational water illness, avoid body contact with ocean water should be avoided for a minimum of 50 yards on either side of each posted sign.

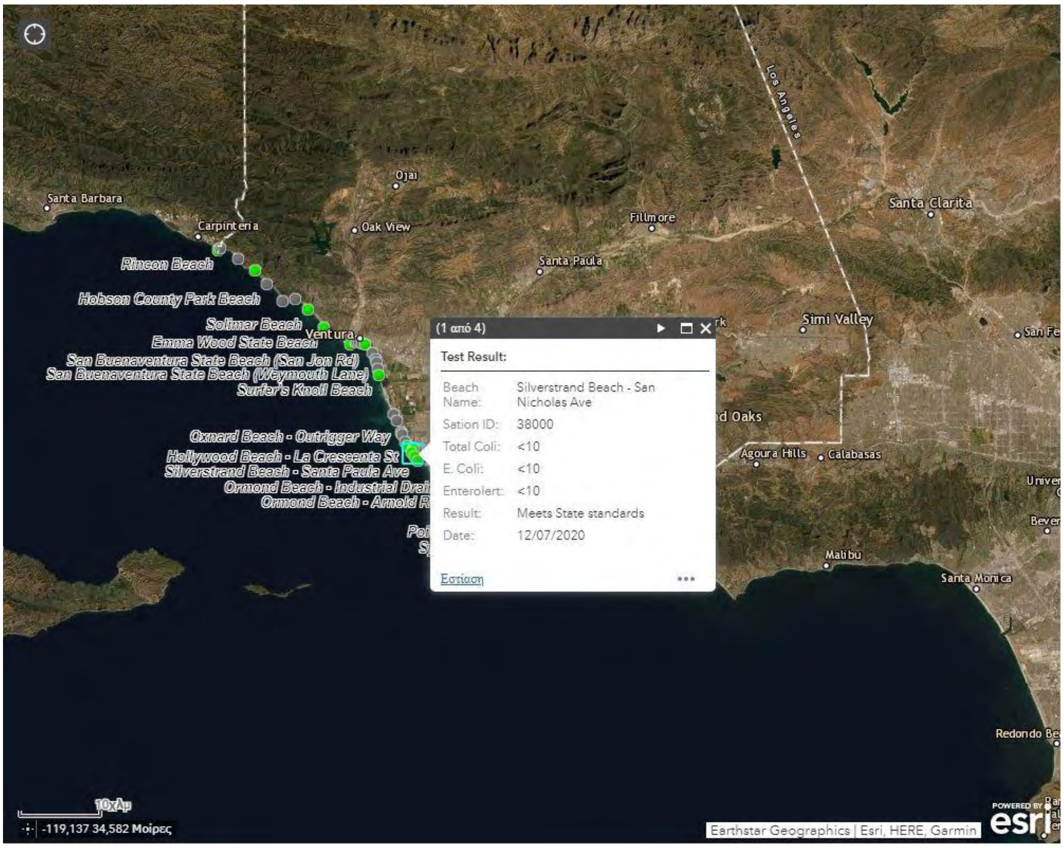


Figure 1.4-16 VCrma main webGIS platform.

The Estonian Marine Systems Institute (MSI) develops tools and services for real-time monitoring and forecasting of the nearshore environment for empowered decision making. For example, local authorities in charge of bathing water quality and coastal waters, as well as beach users, benefit from MSI services. MSI collects data, runs detailed ocean models. Downscaling is a method for obtaining high-resolution local models from the lower resolution Copernicus Marine Service Baltic model as forcing conditions. MSI provides synthetic indicators for decision making support extracted from their detailed ocean models forced by the Copernicus Marine Service boundary conditions. The benefits for users are:

- High quality information allowing realistic applied results.
- Ready to use, global coverage, expertise ocean products.
- Useful, free, and sustained information provision for downscaling purposes.

Microbial organisms, also referred to as pathogens, such as bacteria and viruses in water bodies can make waters unsafe for humans. Swimming and other recreational activities in water contaminated with pathogens can make people ill. Hence monitoring the microbial organisms in water bodies helps local authorities to protect human health.

CMEMS Analysis and Forecast model products provide with 7-day forecast of 3D ocean currents, temperature, salinity, and sea ice parameters updated daily. Models over the Baltic sea are used in this application:

https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=NORTHWESTSHELF_ANALYSIS_FORECAST_BIO_004_002_b.

The CMEMS product is called *ATLANTIC-EUROPEAN NORTH WEST SHELF - OCEAN BIOGEOCHEMISTRY ANALYSIS AND FORECAST*. The ocean biogeochemistry analysis and forecast for the North-West European Shelf is produced using the European Regional Seas Ecosystem Model (ERSEM), coupled online to the forecasting ocean assimilation model at 7 km horizontal resolution, NEMO-NEMOVAR. ERSEM (Butenschön et al. 2016) is developed and maintained at Plymouth Marine Laboratory. The description of the model and its configuration, including the products validation is provided in the CMEMS-NWS-QUID-004-002-b. Products are provided as daily 25-hour, de-tided, averages. The datasets available are concentration of chlorophyll, nitrate, phosphate, oxygen, phytoplankton biomass, net primary production, light attenuation coefficient, pH, and the partial pressure of CO_2. All, as multi-level variables, are interpolated from the model 51 hybrid s-sigma terrain-following system to 24 standard geopotential depths (z-levels). Grid-points near to the model boundaries are masked. The product is updated daily, providing a 6-day forecast and the previous 1-day hindcast (Figure 1.4-17). This model is coupled with a hydrodynamic model (NEMO) available as CMEMS product NORTHWESTSHELF_ANALYSIS_FORECAST_PHYS_004_001_bA reanalysis product is available from: NORTHWESTSHELF_REANALYSIS_BIO_004_011.

Figure 1.4-17 CMEMS Analysis and Forecast model products

provide with 7-day forecast of 3D ocean currents, temperature, salinity, and sea ice parameters updated daily. Models over the Baltic sea are used in this application: https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=NORTHWESTSHELF_ANALYSIS_FORECAST_BIO_004_002_b

The WATERMAN project concerns beach water quality forecasts and detailed information, for several coasts around Hong Kong. The Pilot Beach Water Quality Forecast System was first launched on March 22, 2010, in celebration of the International World Water Day 2010. The first launch provides daily forecast on 10 representative beaches to 200 registered users. With the success of the pilot testing in 2010, the system was made accessible to the general public on August 8, 2011. The system covers 16 representative gazette beaches (Figure 1.4-18).

Swimming in sewage-contaminated water may result in gastrointestinal and skin illnesses. Epidemiological studies of swimmers at Hong Kong beaches have demonstrated a strong relationship between the level of Escherichia coli (E. coli) and the incidence rate of swimming-associated illnesses. To protect public health, Project WATERMAN has developed a beach water quality forecast system by predicting the concentration of the E. coli concentration at a beach. The forecast system is developed from an integrated approach based on statistical methods, hydrodynamic modeling, and data-driven hydro-informatics tools. The model takes into account the most relevant environmental and hydro-meteorological parameters such as rainfall, solar radiation, onshore wind, tide level, to provide daily forecast of beach water quality.

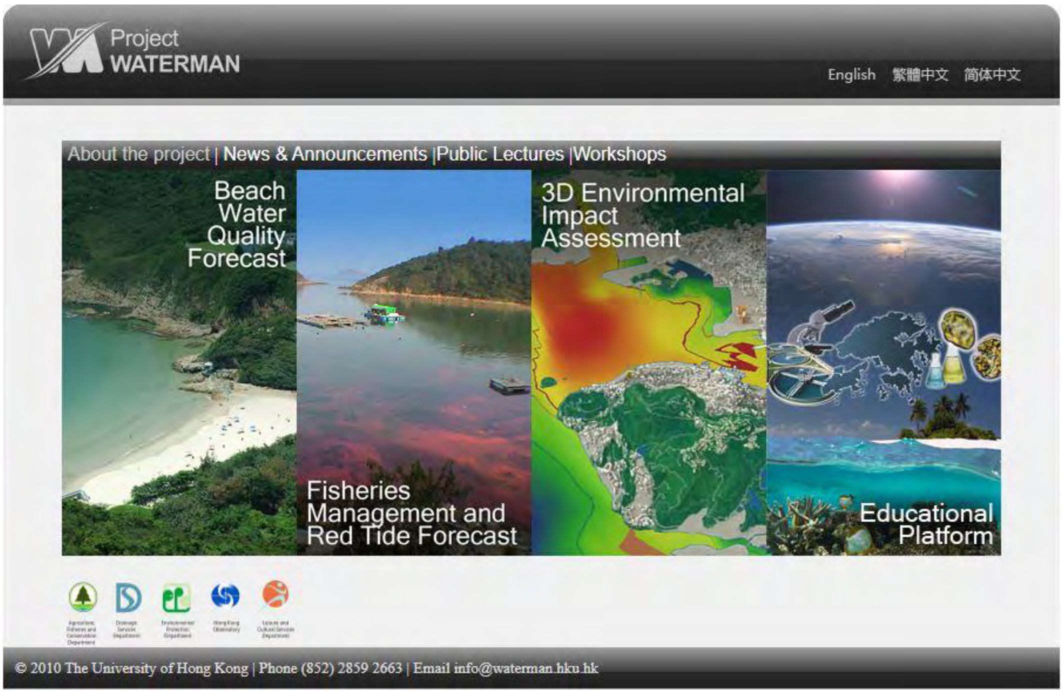


Figure 1.4-18 Project WATERMAN webpage products from Hong Kong University.

The Beach Water Quality Forecast Index (BWQFI) is a four-level index system indicating the risk of contracting swimming associated gastro-intestinal and skin illnesses. An index of 1 to 4 is issued to the beach on a daily basis, which provides clearly defined categories associated with different health risks.

Table 1-5 Beach Water Quality Forecast Index

BWQFI	Predicted E.coli concentration (counts/100mL)	Health risk
1	≤ 24	Negligible
2	25 – 180	Low
3	181 – 610	Moderate
4	> 610	High

The Beach Water Quality Forecast Index and the Environmental Protection Department (EPD)'s Weekly Beach Grading system are two different systems although they use similar grading scales. The EPD monitors the beach water quality regularly and uses the most recent 5 sets of sampling results to grade the beach to reflect the recent water quality status. The EPD beach grading does not necessarily correspond to the WATERMAN daily forecast, due to the natural fluctuation of bacteriological indicator levels in the water bodies at different time and locations. The weekly beach grading is updated on a weekly basis and is not intended to forecast beach water quality.

In recognition of the changing beach water quality, the Beach Water Quality Forecast Index predicts daily water quality status by applying the state-of-the-art mathematical model based on updated hydro-meteorological information. Nevertheless, inherent uncertainty is associated with any forecast, and the forecast results should be considered as supplementary information for reference by the beach users and should not be confused with the weekly beach gradings of the EPD.

The current forecast considers the past 3 days' meteorological information up to yesterday's midnight. As beach water quality may have changed with reference to the weather for the immediately past few hours (e.g., water quality may improve under sunshine condition, or may deteriorate shortly after heavy downpours), beach-goers are advised to take note of the current weather together with the Beach Water Quality Forecast Index.

The WATERMAN system is validated against the regular beach monitoring data of the EPD in the bathing season (March to October) in 2010. The system predicts compliances/exceedances with the beach water quality objectives with an overall accuracy 80% or above. Lower accuracy is obtained at beaches in Tsuen Wan district, where revolutionary improvements in water quality pattern have been observed in 2010 due to the implementation of disinfection facilities at the Stonecutters Island Sewage Treatment Works. System validation will continue to further improve the capability and reliability of the forecast system, and to cope with the changing water quality and hydrological conditions of Hong Kong's waters.

The HiSea (https://hiseaproject.com/) initiative is an EU-funded project that aims to develop, test, and demonstrate information services that provides high resolution data of water quality at sea. The services offered by HiSea will incorporate and process data that are being obtained through the marine, land, and climate services of Copernicus (the EU Earth Observation and Monitoring service), local monitoring data and advanced modelling. The platform will improve operation, planning and management of different marine activities, with a focus on the usage in the port and aquaculture sectors.

The HiSea information services will include

- Early Warning Service
- Real Time Crisis Management
- Key Performance Indicators
- Information for Planning Operations
- Knowledge/Database

The DELTARES marine water quality forecasting systems is formed as good water quality is a prerequisite for many economic activities in marine and coastal environments. For example, beach recreation, aquaculture and water intakes can be severely impacted by harmful algal blooms, bacterial or chemical pollution and oil spills. Timely information about expected water quality issues allows for mitigating measures and targeted monitoring. If the water quality is insufficient for safe recreation, beach managers wish to inform visitors about the risks or even need to close the beach. When toxic algal blooms occur near aquaculture areas, stocks can be moved to safe areas. In case of calamities with oil spills, spills of toxic chemicals or marine litter, prediction of the transport pathways helps to protect vulnerable nature areas or economic activities that are at risk.

DELTARES water quality forecasting systems are based on the Delft-FEWS system, often, but not exclusively, combined with Delft3D modelling software. Delft-FEWS combines different information sources to provide automated real-time forecasts and warnings. Delft-FEWS is a Deltares open interface freeware product originally designed for flood forecasting, containing a wide range of tools for automated data feeds, visualisation and validation. Over time, Delft-FEWS has been extended to also manage real-time forecasting of bacterial contamination, algae blooms, and chemical and other spills. DELTARES has developed water quality forecasting services based on Delft-FEWS world-wide in close collaboration with local partners (Figure 1.4-19).

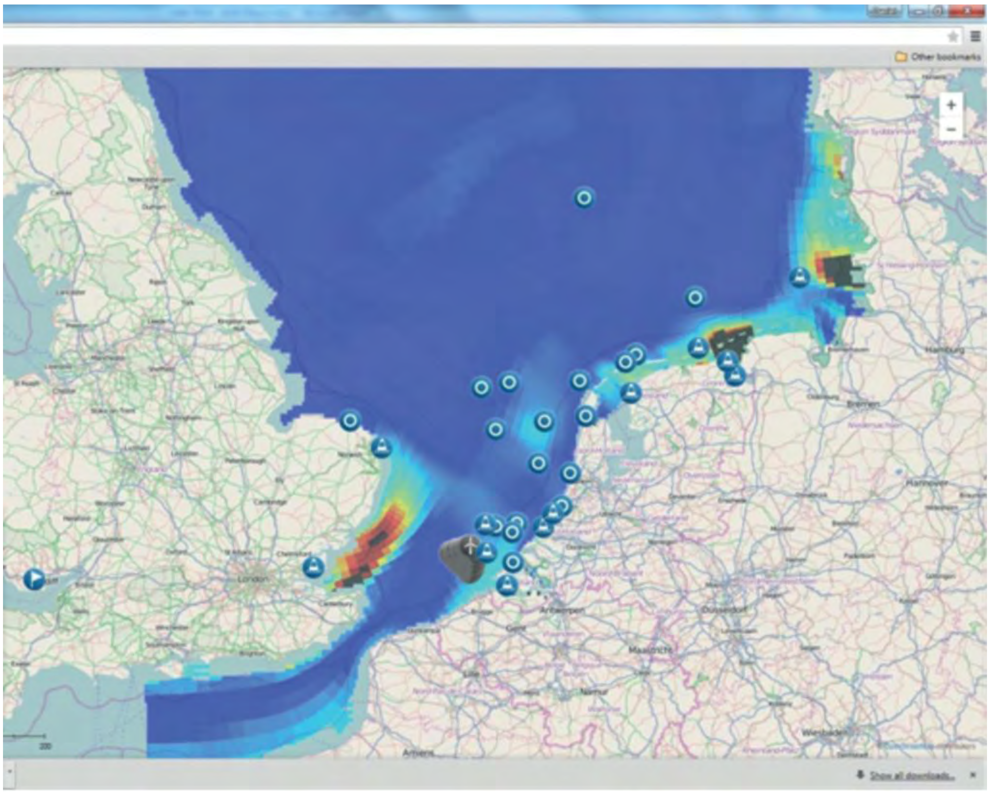


Figure 1.4-19 Snapshot from the data viewer for the North Sea, showing chlorophyll-a predictions and relevant locations (DELTARES)

The showcases comprise the following:

Singapore, where algal blooms can occasionally cause fish kills in coastal waters and are a nuisance in inland waters. To predict and mitigate these blooms Singapore water authorities use FEWS systems to provide information on algal blooms in inland and coastal waters based on real-time measurements and model forecasts. Apart from algal blooms the systems provide information on other water quality issues, such as oxygen concentrations, salinity, bacterial contamination, and oil spills.

England, where following heavy rain events, bacterial pollution from sewer overflows or pastures with cattle may negatively affect bathing water quality in coastal waters. The English Environment Agency forecasts the risk of such short-term pollution events with a FEWS system. Every day, during the bathing season expected concentrations of bacteria are estimated for each bathing site, based on rainfall data and site-specific models. These models are based on relations between rainfall and bacteria concentrations in historical data. If estimated concentrations of bacteria are above threshold local beach managers are alarmed and they signpost warnings at the beach. Citizens can check the estimated risk of short-term pollution events at their beach online at http://environment.data.gov.uk/bwq/profiles/.

1.5 Data handling & GIS tools

The basic part of the regional-scale analysis (Mediterranean and Black Sea) for operational monitoring systems and services (SeaDataNet, Poseidon-InSitu, HNODC, MonGOOS, etc.) with data-sharing portals have been presented analytically in TIMMOD's Deliverable D.T1.1.1. Herein several representative monitoring initiatives and data-sharing platforms of Black Sea regional-, EU- and global-scale applications are also presented.

Black Sea Basin

Focusing on the Black Sea Basin. with its discrete aquatic bodies and regions of interest, the marine web-GIS systems or comprehensive/integrated informational platforms refer to the following.

Belokopytov et al. (2019) report on Black Sea marine information systems. A special feature of marine GIS is that in many cases the multidisciplinary and multi-component character of scientific oceanology leads to creating narrower specialized software tools to operate oceanographic data. At the same time, the accuracy of the information system representation of the processes taking place in the marine environment and in the sea – land interactive zone is determined in a considerable degree by the comprehensiveness and quality of databases in use. MHI uses as an information basis the Black Sea database containing more than 160,000 oceanographic stations made so far since 1890. More than 80% of data have passed the quality check procedure. However, several GIS applications demand more parameters for their successful operating than the Black Sea database includes. This can be exemplified especially for datasets of the versatile and everchanging coastal zone used either for beach cadastral evaluation or any other need. A future objective is to identify and create a comprehensive universal system for a wide range of researchers, with an optimized query system while addressing the integrated database, and to develop methods of spatial data sharing which allow gaining access to shared databases of the existing applied specialized systems.

MISIS Black Sea Marine Atlas is a GIS application that provides user-friendly information to decision-makers and the public to facilitate the monitoring of Black Sea waters aiming at environmental protection of the BSB by ecosystem-based approaches under the Marine Strategy Framework Directive (MSFD). The GIS application can be found via: https://www.msp-platform.eu/projects/msfd-guiding-improvements-black-sea. The *Marine and Coastal Atlas* was developed in the frame of MISIS Project (MSFD Guiding Improvements in the Black Sea Integrated Monitoring System). The overall goal of the project was to support efforts to protect and restore the environmental quality and sustainability of the Black Sea and to develop a national integrated monitoring program in line with MSFD standards. The web-based coastal atlas plays an important role in informing regional decision and policy making across a variety of themes and it also represents a portal to coastal data and information from diverse sources. The main objective of MISIS Atlas is to offer an overview of current monitoring of the Black Sea marine environment, which represents the base for the revise of the Black Sea integrated monitoring system. It aims to identify the temporal and spatial gaps, also the type of parameters and it serves as a basis for decisions related to monitoring activities. The first main outcome of this process is the revised Bulgaria, Romania and Turkey Monitoring and Assessment Strategy. The process of development of indicators in the Black Sea region is a part of the cooperation existing between BSC and EEA.

MISIS ATLAS was developed based on MapServer application to incorporate vector and raster data and to access external data through a Web Map Service, using Smart Atlas as front-end interface. Smart Atlas is a front-end environment for developing web-mapping applications. It is built on MapServer as the core mapping engine and works with all MapServer supported data formats through MAP files. The online application includes a collection of GIS data layers (vector and raster) representing different national and international monitoring networks (from research institutes, universities, national and local authorities, and stakeholders), physical, chemical, and biological parameters, statistical analysis, protected areas, and general information. The system also features advanced data control such as layer lists, feature selection, tables with information about each item, metadata viewing and links to websites, documents, and auxiliary data.

The MISIS Atlas provides general layers (bathymetry, cities, countries boundary, economic exclusive zones, protected areas) and specific layers (MSFD and WFD water bodies, monitoring networks from different research institutes, university and other institutions and companies involved in physical, chemical, and biological monitoring). There are also included maps of spatial variability of physical, chemical, and biological parameters (Dissolved oxygen, phosphate, salinity, temperature, silicates, chlorophyll, TNOx, pH) obtained through interpolation from MISIS cruise data. It also provides an overview of the number of stations, as well as the number of main biological features, nutrients and hazardous substances parameters reported by the three countries, partners in the MISIS Project, both to BSC and EEA, in the period 2006-2012. Stations and sampling frequency were calculated for period 2006-2012 for 8 groups - biological and hydrographical parameters, nutrients, heavy metals, organic pollutants, PAHs, OCPs, PCBs using statistical tools. For each group of parameters, there are maps, charts and tables explaining in detail each indicator - frequency of samples for each point stations frequency, through different size and colors. The web-GIS application can be updated with additional data and extended to Black Sea Basin level for visualization, aiming to:

- improve availability and quality of chemical and biological data to provide for integrated assessments of the Black Sea state of environment, including pressures and impacts (in line with MSFD),
- increase number and size of protected areas in the Black Sea as well as to improve their degree of protection,
- enhance stakeholders' participation and public awareness on environmental issues.

The main practical outcome was the creation of information management tools in support of decision-making, a web-GIS application (http://smartatlas.misisproject.eu/smartatlas/) with data/information related to the MSFD.

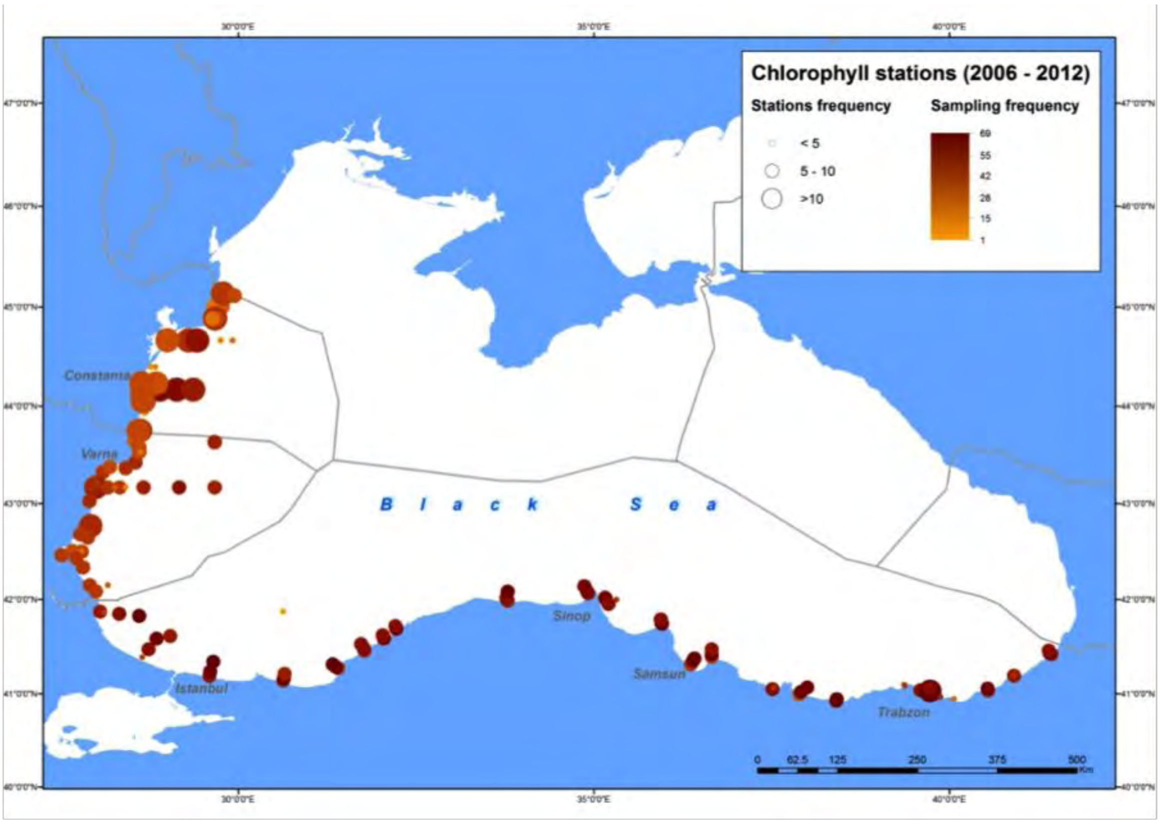


Figure 1.5-1 Static depiction of MISIS Atlas web-GIS application

(accessed via: *http://smartatlas.misisproject.eu/smartatlas/*)

The Commission on the Protection of the Black Sea Against Pollution (http://www.blacksea-commission.org/Inf.%20and%20Resources/Data%20Links/) has created a Permanent Secretariat that is in charge of providing an inclusive and comprehensive database list of Projects, Observers, Partners, Links, Metadata (about Physical Oceanography, Biology & Ecosystem, Satellite data and images, Maps and Graphics , Modeling & Forecast, GIS, etc.) directories at the Black Sea Scene project website. Information is also provided about Datasets, Cruise Summary Reports, Inventory of Data Quality Control (DQC) and Data Quality Assessment (DQA), Marine Organisations, Black Sea Scientists, Bibliography and connections to other European metadata directories, such as:

- SeaDataNet Project
- European Directory of Marine Organisations (EDMO)
- European Directory of Marine Environmental Data sets (EDMED)
- European Directory of Marine Environmental Research Projects (EDMERP)
- Cruise Summary Reports (CSR)
- European Directory of the initial Ocean-observing Systems (EDIOS)
- Turkish National Oceanographic Data Inventory
- Oceanographic Data Inventory of IMS METU

The relevant online databases and portals on BSB Physical Oceanography comprise:

- NATO SfP Black Sea Database. Database includes all main physical, chemical and biological variables for the entire Black Sea basin for period 1954 - 1996 and serves as a base line for contemporary and future research activities and management purposes in the region.
- National Oceanographic Data Centre of Ukraine (NODC). The Oceanographic Data Base of Marine Hydrophysical Institute includes more than 114 thousand hydrological for period

1890-2007. It contains all the data for the Black Sea which were obtained by MHI and other Ukrainian organizations.

- World Ocean Database 2009. WOD-2009 is the largest, most comprehensive collection of scientific information about the oceans with records dating as far back as 1800. Black Sea data can be retrieved using WOD Select and Search tool or downloaded from section Geographically sorted data.

Data Access services can be found in the SeaDataNet CDI at the Black Sea Scene project website. Satellite data and images can be traced though the Blackseacolor website with information on Black Sea Color data processing and distribution at Marine Hydrophysical Institute – MHI. The Marine portal National Space Agency of Ukraine (NSAU) provides SST from NOAA satellites, chlorophyll-a etc., accessible upon registration.

Figure 1.5-2 Black Sea Scene info-web environment of collective databases (marine research organizations).

Within the EMODnet initiative the Black Sea Checkpoint was a BSB monitoring system assessment activity aiming to support sustainable growth in the marine and maritime economy by assessing the potential of available marine observation and data services to address end-user needs (https://www.emodnet.eu/en/checkpoint/black-sea). Specifically, the Black Sea Checkpoint aimed to:

- Clarify the observation landscape of all compartments of the marine environment and highlight the existing programs at national, European, and international level.
- Evaluate fitness for use indicators that show the accessibility and usability of observation and modeling data sets and their roles and synergies based upon targeted applications.
- Prioritize user needs in order to optimize monitoring systems in terms of accessibility, availability, multiple-use, efficiency, reliability, time consistency, space consistency, etc. and the planning of the technological advancements, new accessibility, new assembly protocols and observational priorities required in the future to meet the challenges.

As with other EMODnet Checkpoints, EMODnet BlackSea assessed basin-monitoring systems on the basis of the data needs from 11 end-user applications. These were of paramount importance for: (i) the blue economy sector (offshore industries, fisheries); (ii) marine environment variability and change (eutrophication, river inputs and ocean climate change impacts); (iii) emergency management (oil spills); and (iv) preservation of natural resources and biodiversity (Marine Protected Areas).

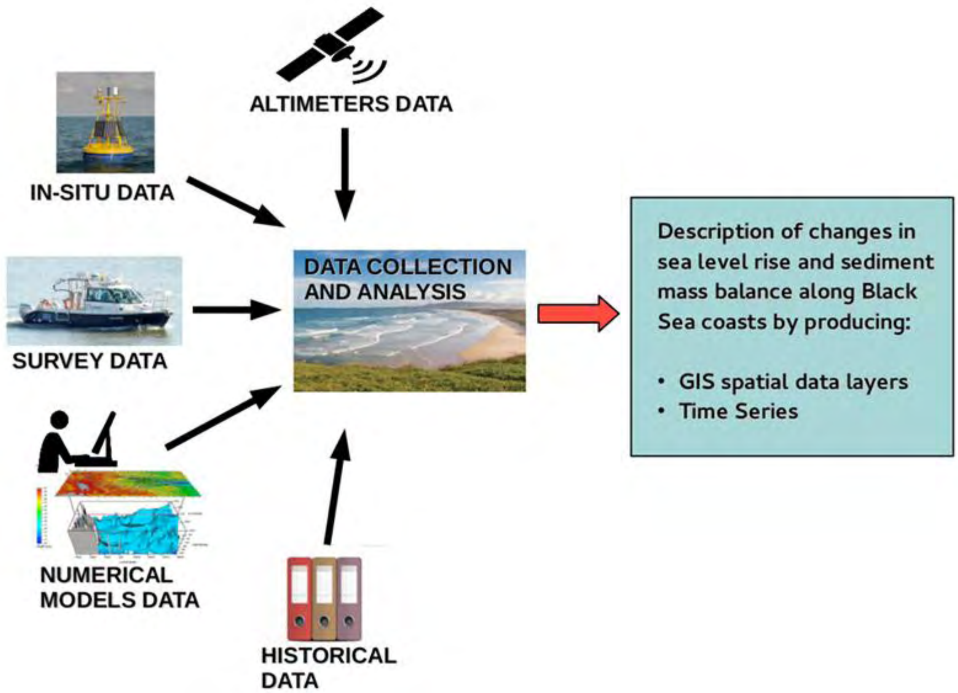


Figure 1.5-3 EMODnet Black Sea Checkpoint data integration schematics.

A major scope of this challenge is to check the fitness for use of the available marine data sets by collecting fish catch information for the whole sea basin on landings, discards, and by-catch of fish, mammals, reptiles, and seabirds (mass & number by species and year), or to indicate gaps in the current EU data collection framework. To fulfill the objective, available landing data from before and after the DCR came into force was collected and pooled together in an appropriate format. The reconstructed information provides an overall picture of the trends over the years of landing, discard, and bycatch by species. This activity of the EU Black Sea Checkpoint project was executed during 2015-2018.

The product and any resultant data produced is a consequence of these tests and provided on an "as is" basis. The information contained in the data products and in the descriptions (metadata) of the input data and of the data products making use of them is believed to be trustworthy at the time of production. However, its completeness, consistency, accuracy, and usability cannot be guaranteed. Whilst every effort was made to ensure its reliability within the limits of present knowledge, no responsibility can be accepted by those involved in its compilation or publication for any consequential loss or damage arising from its use.

Within the world-scale initiative Global Ocean Observing System (GOOS), and the EuroGOOS counterpart, the Black Sea GOOS (http://old.ims.metu.edu.tr/black_sea_goos/) established: in 2001, with institution memberships from 6 Black Sea countries: Bulgaria, Georgia, Romania, Russian Federation, Turkey, Ukraine. The Black Sea GOOS is a local association formed by the Black Sea riparian countries in order to foster operational oceanography in the region and set up links with other regional and global organizations with similar objectives; accessed via the link: https://goosocean.org/index.php?option=com_content&view=article&id=38&Itemid=137. Its goals are:

- To contribute to international planning and implementation of GOOS and to promote it globally.
- To identify regional priorities for the use of operational oceanography.
- To cooperate with the Black Sea Environmental Programme (BSEP), the Permanent Secretariat of the Black Sea Commission (Secretariat for the Bucharest Convention) and other relevant bodies, to harmonize oceanographic activities in the region.
- To develop capacity of the regional countries and promote the level to sustain GOOS activities.
- To promote the development of technology and computer systems for operational oceanography.
- To facilitate a network for real and/or near time data exchange by members.
- To provide high quality data and time series for a better understanding of, and improving of, the Black Sea ecosystem.
- To find the means to ensure the most effective use of existing technologies related to operational oceanography and marine meteorology.
- To assess the economic and social benefits from operational oceanography.

The Black Sea Strategic Research and Innovation Agenda (http://connect2blacksea.org/) offers a list of older Black Sea Projects that can be found in: http://connect2blacksea.org/black-sea-projects/. One can take part in the National Consultative Online Seminar on Black Sea Strategic Research and Innovation Agenda (BS SRIA), within the framework of the Black Sea Connect project funded by the EU, which provides solving number of tasks in the following areas:

- Addressing fundamental Black Sea research challenges.
- Developing products, solutions and clusters underpinning Black Sea Blue Growth.
- Building of critical support systems and research infrastructures for the benefit of Black Sea communities.
- Education and capacity building.

The SeaDataNet infrastructure links already more than 110 national oceanographic data centres and marine data centres from 35 countries riparian to all European seas. The data centres manage large sets of marine and ocean data, originating from their own institutes and from other parties in their country, in a variety of data management systems and configurations. Major objective and challenge in SeaDataNet are to provide an integrated and harmonised overview and access to these data resources, using a distributed network approach. This is achieved by developing, implementing, and operating the Common Data Index (CDI; https://cdi.seadatanet.org/search; Figure 1.5-4) service that gives users a highly detailed insight in the availability and geographical spreading of marine data across the different data centres across Europe. The CDI provides an ISO19115 - ISO19139 based index (meta-database) to individual data sets (such as samples, timeseries, profiles, trajectories, etc) and it provides a unique interface to online data access. Data sets are available in ODV (Ocean Data View) and NetCDF (CF) SeaDataNet formats that can be imported to ODV software, which includes the Data Interpolating Variational Analysis software tool (DIVA).

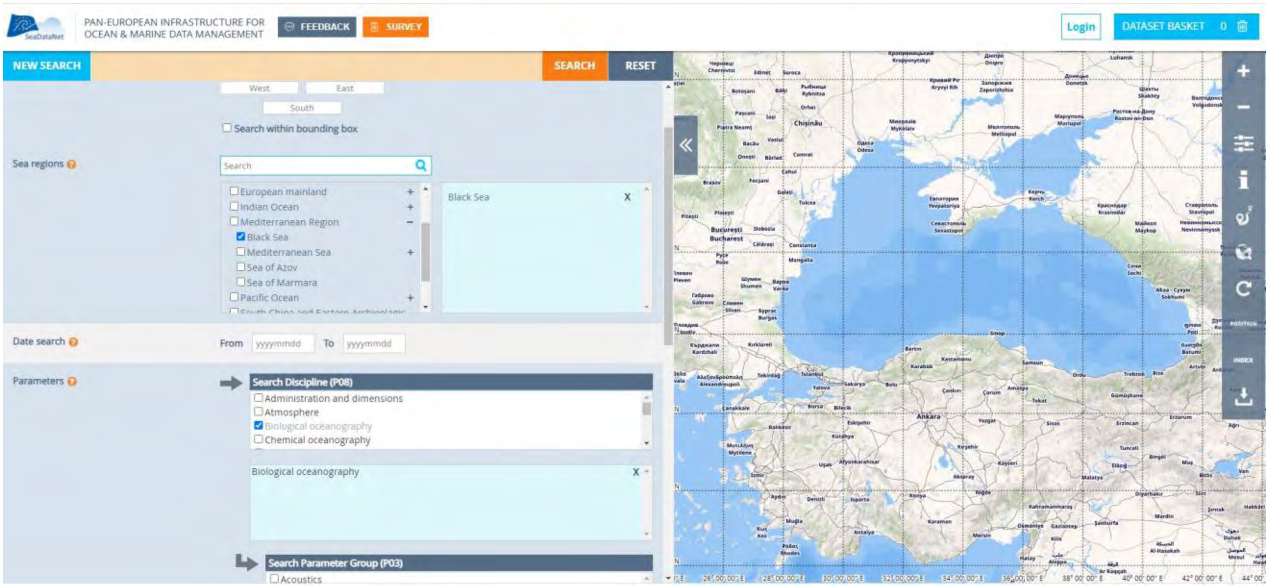


Figure 1.5-4 SeaDataNet portal environment for the Black Sea Basin available datasets.

OBIS is a global open-access data and information clearing house on marine biodiversity for science, conservation, and sustainable development. Specifically, for the Black Sea Basin the link is: https://obis.org/node/bdb3b59b-7dad-4c06-a2d6-3e576158cc4c. It provides statistics records for occurrence, species level, species numbers, classification and counting of Taxa, identification of datasets, covering time ranges from 1992 to 2017 (Figure 1.5-5).

Figure 1.5-5 OBIS post-processed datasets provided via the Black Sea Basin biodiversity portal (accessed via https://obis.org/node/bdb3b59b-7dad-4c06-a2d6-3e576158cc4c).

There is a Black Sea GIS system developed in MHI complementing it with a model bank. The software for data access and visualization was developed using client server architecture. A map service based on MapServer and MySQL data management system were chosen for the Black Sea GIS. Php-modules and python-scripts are used to provide data access, processing, and exchange between the client application and the server. According to the basic data types, the module structure of GIS was developed. Each type of data is matched to a module which allows selection and visualization of the data. The results are shown on the map as a separate layer. It is possible to display measured parameters as graphs and tables (Figure 1.5-6).

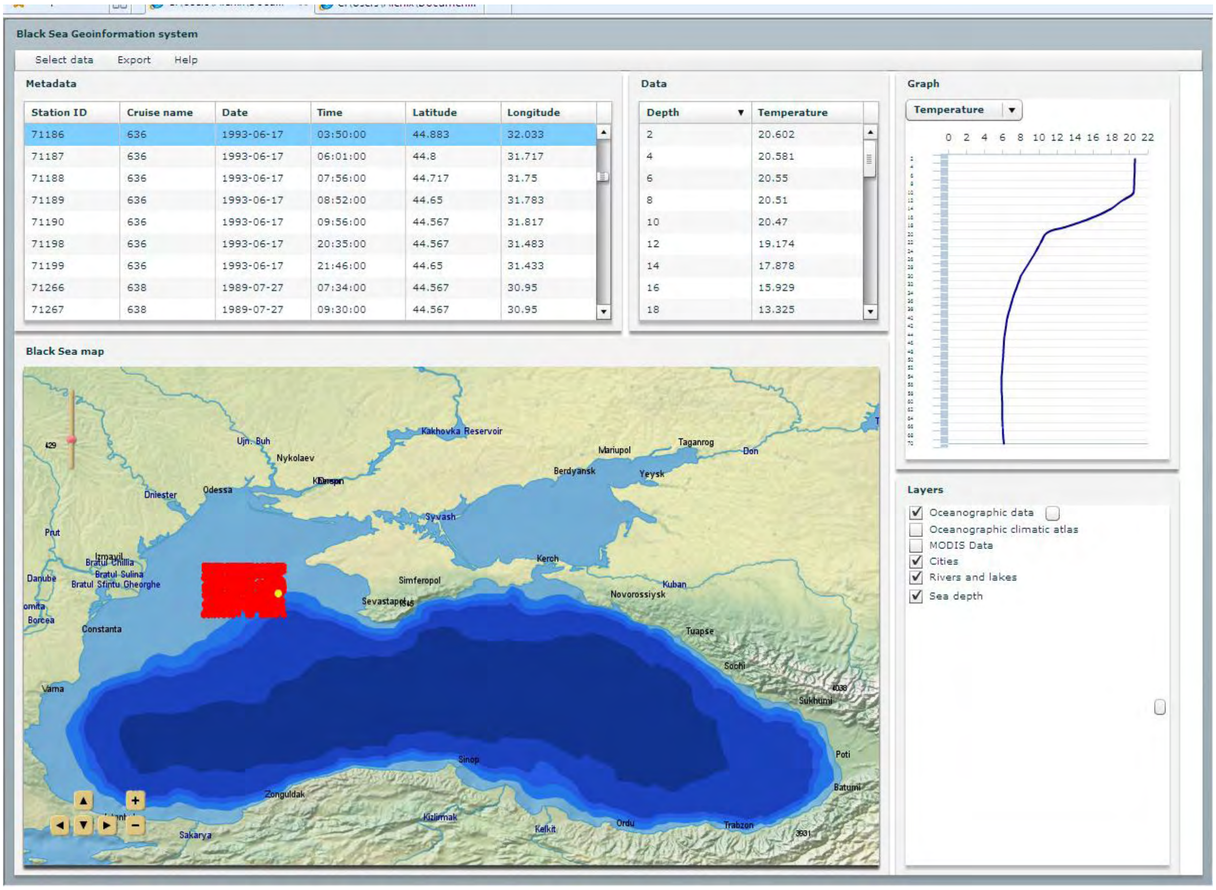


Figure 1.5-6 Display example of the selected result of oceanographic data by MHI.

Palazov et al. (2019) report on the Black Sea Observing System, whose goal are end-user-oriented products with high scientific quality. Beneficiaries are the governmental services, coast and offshore based enterprises and research institutions that make use of the products generated by operational oceanography. Direct users are coastal managers, shipping, search and rescue, oil spill combat, offshore industry, ports, fishing, tourism, and recreation industry. Indirect beneficiaries, through climate forecasting based on ocean observations, are food, energy, water, and medical suppliers. Availability of updated information on the actual state as well as forecast of marine environment is essential for the success and safety of maritime operations in the offshore industry. Various systems for the collection and presentation of marine data for the needs of different users have been developed and put in operation in the Black Sea. The systems are located both along the coast and in the open sea and the information they provide is used by both the maritime industry and the widest range of users. The Black Sea Monitoring and Forecasting Center in the frame of the Copernicus Marine Service is providing regular and systematic information about the physical state of the ocean, marine ecosystem, and wave conditions in the Black Sea area, assimilating observations, keeping efficient operations, advanced technology, and high-quality modelling products. Combining and optimizing *in situ*, remote sensing, modelling, and forecasting into a Black Sea observing system is a task that must be solved, and that will allow to get a completer and more comprehensive picture of the state of the marine environment as well as to forecast future changes of physical and biogeochemical state of the Black Sea and the Black Sea ecosystem.

European Union

The EOOS framework (www.eoos-ocean.eu) is driven by the European community to better coordinate Europe's ocean observing capacity. EOOS will help linking the disparate components of the ocean observing system and promote shared strategies, infrastructure development, data standardization, open access, and capacity building.

Ocean observing data and information are required to meet many societal challenges, from food security, to climate change, ecosystem health, or water management. Yet, the European in situ ocean observing capacity is still fragmented and broadly unsustained. While the space-borne ocean observations are funded through the Copernicus programme, in situ observations are supported through numerous short-term projects, with no guarantee of a long-term sustainability (Figure 1.5-7).

Figure 1.5-7 EOOS-EUROGOOS initiative schematics of objectives and strategies.

Building on the existing initiatives, EOOS fosters a better integration and a stronger engagement across the different ocean observing sectors. EOOS will gather information on the infrastructure status and monitoring plans and discuss technology breakthroughs and funding priorities, helping to inform national and pan-European research programming. Critical to the EOOS success will be an open dialogue between ocean observing funders, implementers, and users – for a truly fit-for-purpose European ocean observing capability.

EuroGOOS, the European Global Ocean Observing System identifies priorities, enhances cooperation, and promotes the benefits of operational oceanography to ensure sustained observations are made in Europe's seas underpinning a suite of fit-for-purpose products and services for marine and maritime end-users. EuroGOOS is the European component of the Global Ocean Observing System of the Intergovernmental Oceanographic Commission of UNESCO (IOC GOOS). EuroGOOS Secretariat is located in Brussels, serving 44 members, and supporting five regional systems in Europe. EuroGOOS working groups, networks of observing platforms (task teams), and regional systems (ROOS), provide fora for cooperation, unlock quality marine data, and deliver common strategies, priorities, and standards. These many EuroGOOS networks work towards integrated, sustained and fit-for-purpose European ocean observing, underpinning the EOOS framework. EuroGOOS, together with the European Marine Board and many other partners, is strongly engaged in building the EOOS framework. EuroGOOS co-chairs the EOOS steering group, provides an EOOS secretariat, manages EOOS communications, and ensures the link to the global operational oceanography systems and GOOS.

Data Management, Exchange, and Quality WG is offered via the EuroGOOS DATAMEQ working group, which helps improving harmonization and integration of European marine data. DATAMEQ WG works hand in hand with Copernicus Marine Service (CMEMS), SeaDataNet, EMODnet, JERICO Next and AtlantOS. The working group fosters links between real-time and historical data streams and works closely with EuroGOOS Task Teams (https://eurogoos.eu/data-management-exchange-quality-working-group-data-meq/).

Worldwide Applications

Bean et al. (2017) reviewed the tools used for marine monitoring in the UK, by combining historic and contemporary methods with modelling and socioeconomics to fulfil legislative needs and scientific ambitions. The seas around the UK are currently monitored by targeted, impact-driven, programmes (e.g., fishery or pollution-based monitoring) often using traditional techniques, many of which have not changed significantly since the early 1900s. The advent of a new wave of automated technology, in combination with changing political and economic circumstances, means that there is currently a strong drive to move toward a more refined, efficient, and effective way of monitoring. We describe the policy and scientific rationale for monitoring our seas, alongside a comprehensive description of the types of equipment and methodology currently used and the technologies that are likely to be used in the future. We contextualize the way new technologies and methodologies may impact monitoring and discuss how whole ecosystems models can give an integrated, comprehensive approach to impact assessment. Furthermore, they discuss how an understanding of the value of each data point is crucial to assess the true costs and benefits to society of a marine monitoring programme.

The Coastal Ocean Observing System (COOS) named SECOORA (https://secoora.org/education-outreach/coastal-ocean-observing-system/) is a combination of many components - from hardware to humans -used to gather information and turn it into useful products that support human populations, coastal economies and a healthy, sustainable environment for the southeastern US. The following are the major types of platforms used in (https://portal.secoora.org/#map).

Moorings, often called buoys, include a number of technologies that are anchored, i.e. moored, to the ocean floor with a floating surface structure. Buoys can be for a single purpose such as waves or include a variety of sensors mounted both above and below the water surface. Most buoys relay data back to shore in real-time. Profiling buoys include sensor packages that regularly move up and down the mooring rope providing a comprehensive look at the water quality. Buoys can be outfitted with sensors for wind, waves, currents, salinity, chlorophyll-a, and other ocean chemistry and biology parameters.

Shores stations are installed on coastal beaches, islands, on piers and offshore platforms to measure wind speed, gust and direction, air temperature, relative humidity, barometric pressure, solar radiation, rainfall, water temperature data and more. These basic measurements provide important real time information on storms and help predict changes to the weather. When measurements are collected over a long time period, they can also help predict changes in the climate.

Gliders are autonomous, unmanned underwater vehicles that can be equipped with sensors that can measure ocean properties such as water temperature, chlorophyll a, salinity, and fish acoustics. They sawtooth up and down the water column following a GPS path set by the researcher. Every few hours the glider surfaces to call home, transmits data and awaits further instructions. Gliders are flexible platforms that can be used for continuous monitoring or deployed in the event of an oil spill or harmful algae bloom or other major events.

Ships have been used to collect ocean information since the days of Captain Cook. Research and fisheries vessels carry a variety of sensors to gather physical, chemical, and biological information on ocean conditions along the cruise route. Some sensors are mounted on the ship and take regular measurements of water and atmospheric conditions. Scientists also deploy instruments into the ocean and Great Lakes to gather information on conditions throughout the water column.

Land-based High Frequency radar (HFR) provide real-time information on the speed and direction of surface currents over a large coverage area. This information can be useful in tracking oil or other hazardous materials such as harmful algal blooms. Because of the large coverage area, HFR data also are valuable input for ocean models and for assisting with search and rescue operations at sea. SECOORA operates the Southeast HFR network to provide data to the Coast Guard and NOAA for use in search and rescue and spill response.

Observations from satellites are an essential component of SECOORA. Earth observing satellites orbit the Earth at an altitude of 500 to over 20,000 miles and collect imagery that allows us to measure ocean conditions including sea surface temperature, ocean color, and sea surface height. Satellite data can be used to identify ocean fronts, harmful algae blooms, oil spills, hurricanes, and polar ice distributions.

Data management is key to the success of SECOORA (Figure 1.5-8). The goal of the SECOORA data strategy is to ensure that users have seamless access to quality and timely data, in a format they can access and understand. SECOORA data management uses state-of-the art information technology (IT) techniques to integrate data from multiple Federal and non-Federal sources, making both current real time and historical data available.

Figure 1.5-8 SECOORA data portal.

SECOORA engages with various user communities to understand their information needs – how they use the data, how often, in what format and for what purposes – in order to transform raw data into useful information (Figure 1.5-9). Websites are the primary way users access the information they need but at user requests, data is also made available through smart phone apps and on marine radio reports. Example products include real-time information on sea state conditions for mariners, early warning for flooding or harmful algae blooms, water quality information for shellfish growers, beach goers and more.

Statistical and numerical models are powerful tools that can forecast ocean and Great Lake conditions. SECOORA observation data is incorporated into computer models that simulate the coastal environment. Models can be used to forecast circulation patterns, flooding, the movement of harmful algae, fish larvae or pollutants through the ecosystem and more.

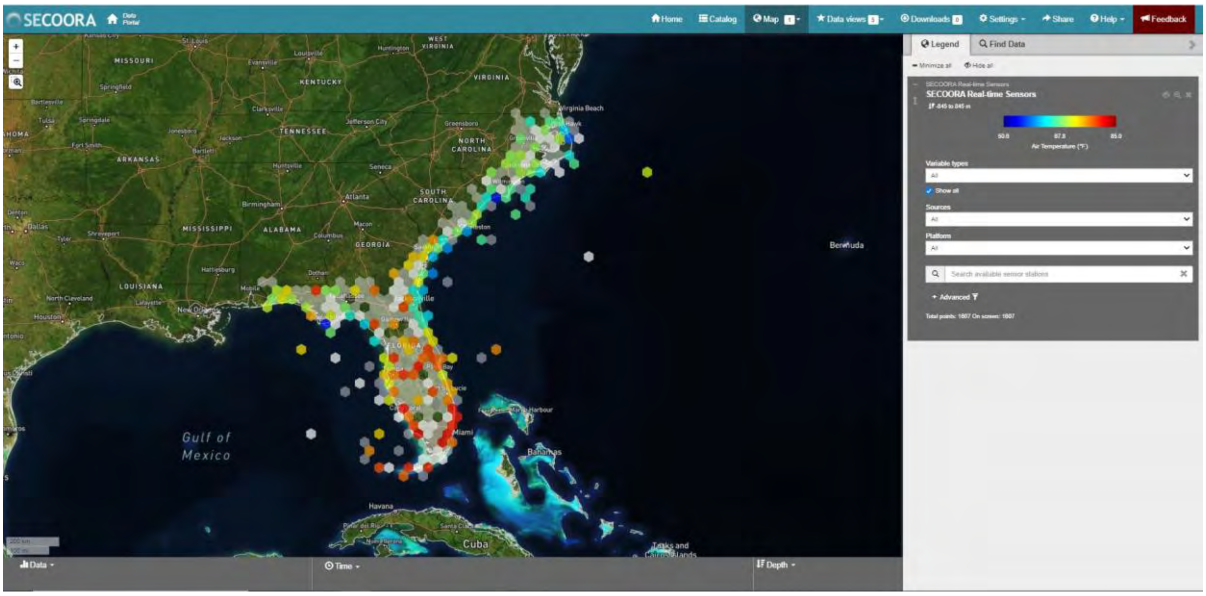


Figure 1.5-9 SECOORA data portal map tool.

The Copernicus platform described in Subsection 1.3 provides versatile datasets of near real-time (NRT) *in situ* quality-controlled observations for the Black Sea, hourly updated and distributed by INSTAC within 24-48 hours from acquisition in average. Selected parameters include the following (Figure 1.5-10):

- Sea water temperature (T)
- Sea water practical salinity (S)
- Water surface height above reference datum (SSH)
- Sea water speed (UV)
- Direction of sea water velocity (UV)
- Mass concentration of chlorophyll-a in sea water (CHL)
- Moles of oxygen per unit mass in sea water (O_2)
- Sea surface wave significant height (SWH)
- Sea surface wave mean period (MWP)
- Sea surface wave from direction (VMDR)

The Black Sea *In Situ* Near Real Time Observations metadata are provided by the CMEMS application (Figure 1.5-11).

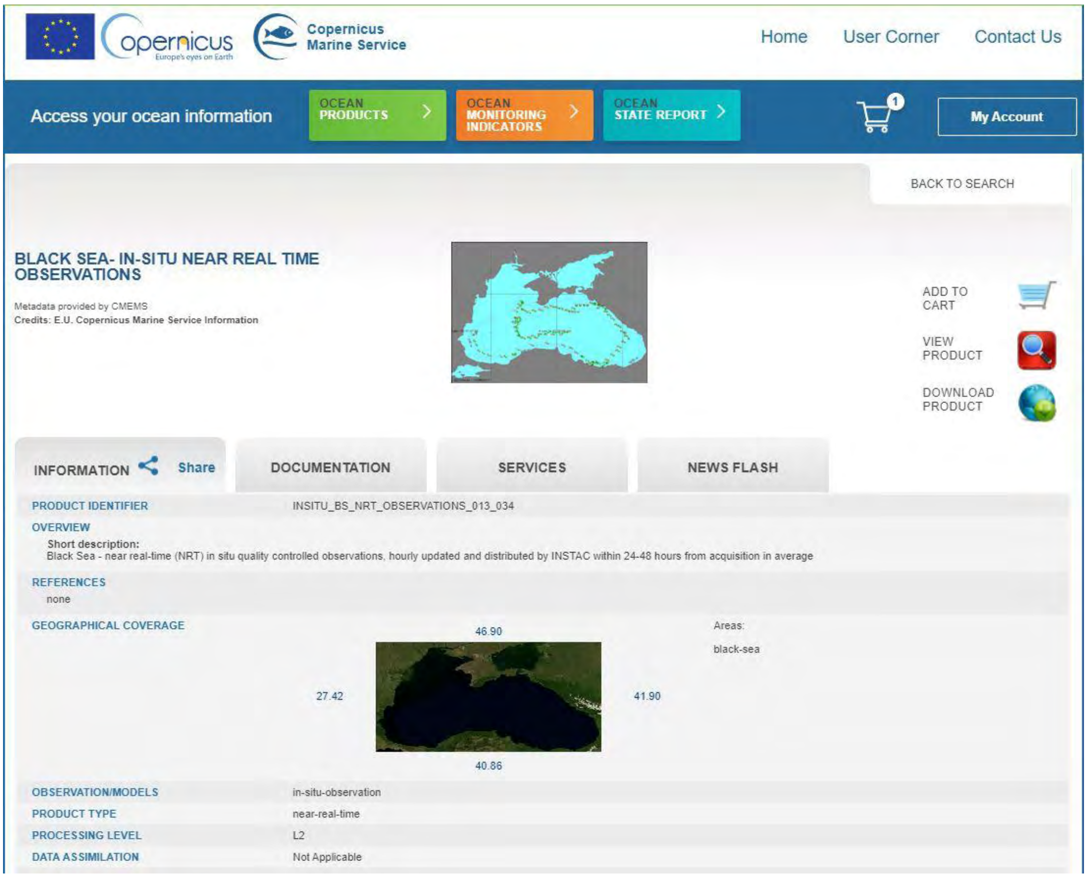


Figure 1.5-10 CMEMS data portal web-GIS tool for parameter choice and downloading within the Copernicus platform.

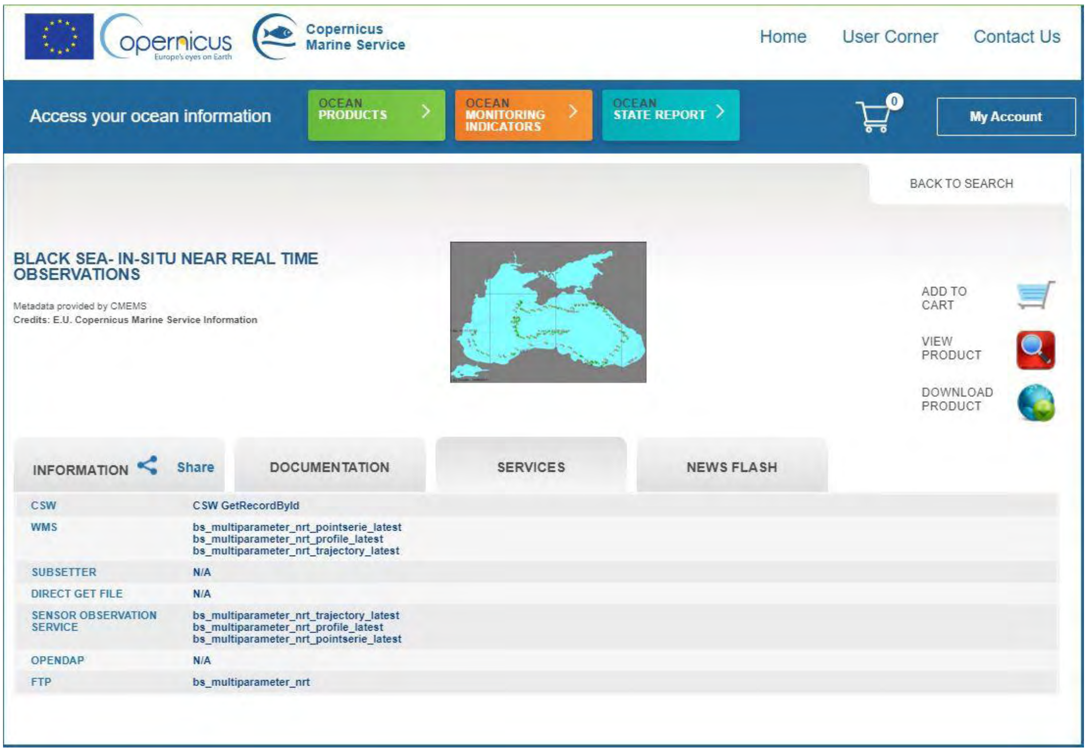


Figure 1.5-11 CMEMS web-GIS tool for in situ near real time observations of the Copernicus platform

The Global Ocean Observing System (GOOS) for Climate, which contributes to the global *in situ* component of the US Integrated Ocean Observing System (IOOS), has now achieved about 61% of its initial design goal. While this observing system, implemented cooperatively by over seventy countries worldwide, serves multiple applications, it is designed primarily to address climate requirements defined by the international Global Climate Observing System (GCOS). The US contribution to the system, described here, is implemented as an interdependent set of observational subsystems that constitute about half of the over 8,000 observing platforms deployed by the world community. While designed to provide information that is critical to NOAA's climate and weather forecast missions, global ocean observations also support:

- Coastal ocean applications
- Marine hazard warning systems (e.g., tsunami warnings)
- Transportation
- Marine environment and ecosystem monitoring
- Naval and other applications
- Global Ocean Observing System for Climate

This system strives to deliver continuous instrumental records and global analyses of the following phenomena, which serve as scientific drivers of the observing system:

- Sea Surface Temperature and Surface Currents, to identify significant patterns of climate variability.
- Ocean Heat Content and Transport, to better understand the extent to which the ocean sequesters heat, to identify where heat enters the ocean and where it emerges to interact with the atmosphere, and to identify changes in thermohaline circulation and monitor for indications of possible abrupt climate change.
- Air-Sea Exchanges of Heat, Momentum, and Freshwater, to identify changes in forcing functions driving ocean and atmospheric conditions, and to elucidate oceanic influences on the global water cycle.
- Sea Level, to identify changes resulting from trends and variability in climate.
- Ocean Carbon Uptake and Content, to better understand the extent to which the ocean sequesters CO2 and how cycling among ocean-land-atmosphere carbon reservoirs varies on seasonal-to-decadal time scales.
- Sea Ice Thickness and Extent, to elucidate climate variability and rapidly changing climate at high latitudes.

The U.N. Intergovernmental Oceanographic Commission (IOC) collaborates with dozens of international programs and organizations to coordinate global scale efforts transitioning oceanography science to operational oceanographic services and products providing societal benefits and protecting the environment. The Global Ocean Observing System, GOOS, is the overarching coordination tool for these observation systems (Figure 1.5-12). GOOS is a system of programs, each of which is working on different and complementary aspects of establishing an operational ocean observation capability for all of the world's nations. International cooperation is always the first priority of GOOS. GOOS is designed and being implemented to embrace the oceans as a single entity, to provide a global view of the ocean system. It is a permanent global system for observations, modeling, and analysis of marine and ocean variables to support operational ocean services worldwide. GOOS provides accurate descriptions of the present state of the oceans, including living resources, continuous forecasts of the future conditions of the sea for as far ahead as possible, and the basis for forecasts of climate change. GOOS is designed to monitor, understand, and predict weather and climate; describe and forecast the state of the ocean, including living resources; improve management of marine and coastal ecosystems and resources; mitigate damage from natural hazards and pollution; protect life and property on coasts and at sea; and enable scientific research. GOOS is implemented by member states via their government agencies, navies and oceanographic research institutions working together in a wide range of thematic panels and regional alliances.

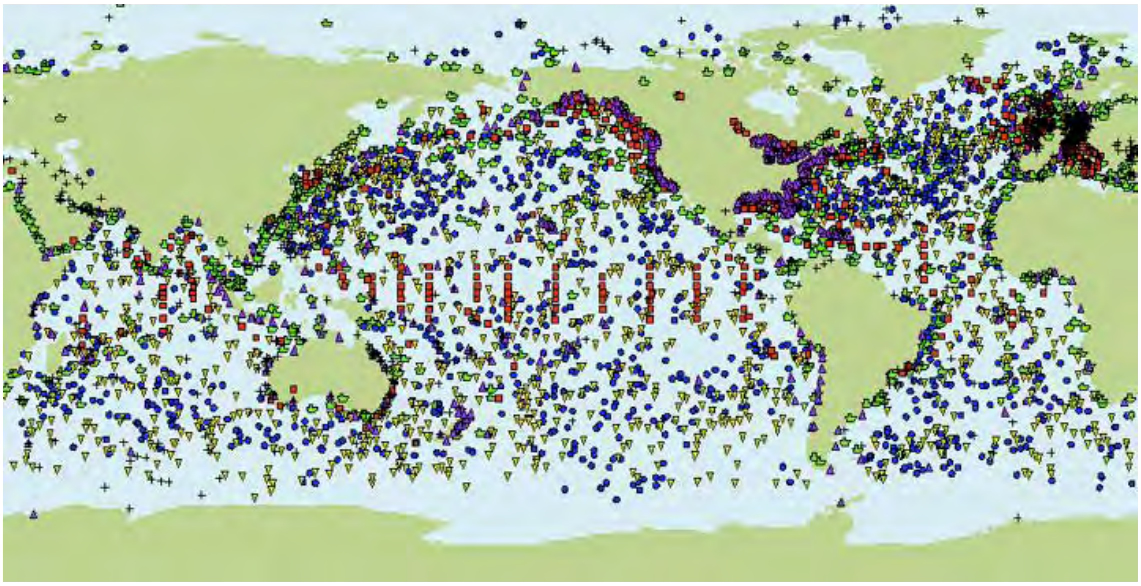


Figure 1.5-12 GOOS global web-GIS tool for in situ observations.

1.5.1 Cloud technologies for data handling and web-based applications

Recent advances in ocean observations and models mean increasing flows of data, integrating observations between disciplines over spatial scales from regional to global presents challenges. Running ocean models and managing the results, along with processing and managing observational data are computationally demanding procedures. Cloud computing and its related technologies gradually alter many traditional approaches. Such changes are more evident in the recent developments made in shared data processing workflows utilizing common, adaptable software to handle data ingest and storage, and an associated framework to manage and execute downstream modeling.

The use of such systems is becoming more and more widespread in the everyday work of researchers. Cloud platforms and the services/APIs they provide offer new ways for scientists to observe and predict the ocean's state. High-performance mass storage of observational data, coupled with on-demand computing to run model simulations in close proximity to the data, tools to manage workflows, and a framework to share and collaborate, enables a more flexible and adaptable observation and prediction computing architecture. Model outputs are stored in the cloud and researchers either download subsets for their interest/area or feed them into their own simulations without leaving the cloud. Expanded storage and computing capabilities make it easier to create, analyze, and distribute products derived from long-term datasets.

Currently there are many ways to view how cloud computing alters the researchers' and scientists' materials and methods, as well as their workflows. According to Butler and Merati (2016), one can identify six patterns of cloud use:

- Cloud based scientific data and its acquisition by scientists
- Storing and management of scientific data in the Cloud

- Cloud computing infrastructure for scientific research. This can take the form of SaaS (Software as a Service), PaaS (Platform as a Service), IaaS (Infrastructure as a Service).
- Analysis in the Cloud on large datasets from different sources as opposed to analysis on local systems.
- Visualization using cloud-based tools as well as making the visualizations available through the Cloud.
- Almost Real Time Dissemination of results in scientific and non-scientific audiences by the means of cloud-based platforms and tools.

The patterns above can be identified in the following examples of current uses of Cloud technologies.

The NOAA Big Data Project

The U.S. National Oceanic and Atmospheric Administration's (NOAA) Big Data Project (BDP), (2015-2019), was a collaborative research effort to improve the discoverability, accessibility, and usability of NOAA's data resources. NOAA signed five identical Cooperative Research and Development Agreements (CRADAs) with collaborators: Amazon Web Services (AWS), Google Cloud Platform (GCP), IBM, Microsoft Azure, and the Open Commons Consortium (OCC). The BDP is an experiment to determine to what extent the inherent value in NOAA's weather, ocean, climate, fisheries, ecosystem, and other environmental data can underwrite and offset the costs of commercial cloud storage for access to those data. The project also investigated the extent to which the availability of NOAA's data on collaborators' cloud platforms drives new business opportunities and innovation for U.S. industry.

The BDP facilitates cloud-based access to NOAA data to enhance usability by researchers, academia, private industry, and the public at no net cost to the American taxpayer. Marine datasets include elements of the NOAA Operational Forecast System (OFS). Two OFS related links are the following https://docs.opendata.aws/noaa-ofs-pds/readme.html, https://www.tidesandcurrents.noaa.gov/models.html. In addition, other marine datasets include sea surface temperature, NCEP/NCAR reanalysis data, and some National Marine Fisheries Service (NMFS) Trawl, Observer, and Essential Fish Habitat data. The full list of available datasets can be found at:

https://www.noaa.gov/organization/information-technology/list-of-big-data-program-datasets.

Under the CRADA, collaborators are allowed to charge for the "marginal cost of distribution." To date, however, none of the collaborators has implemented this provision.

The NOAA Big Data Project CRADA phase ended in May 2019, followed by discussions with CRADA participants and NOAA managers, in order to define a sustainable partnership to continue providing cloud-based data access. The result was the initiation of BDP's Operational Phase in September 2019.

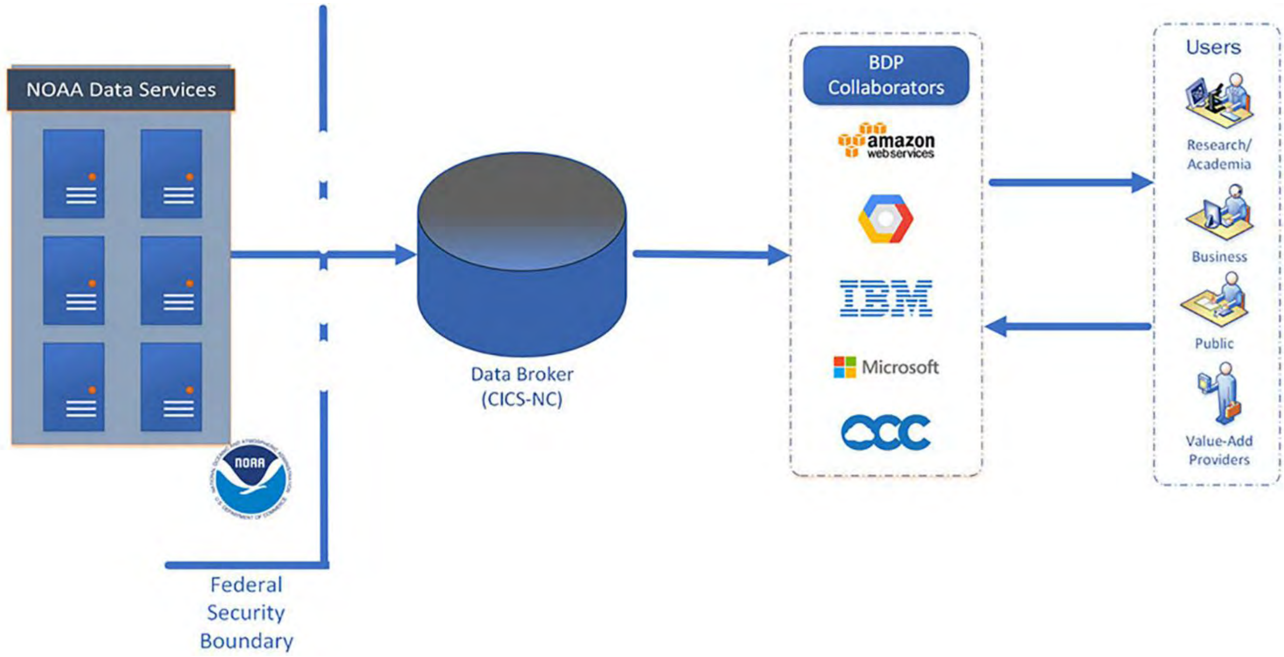


Figure 1.5-13 Data broker architecture diagram for Cloud ingest.

(source: NOAA BDP). CICS-NC: Cooperative Institute for Climate and Satellites – North Carolina.

Cloud Use Within IOOS (USA's Integrated Ocean Observing System)

Many Regional Associations (Ras), members of the Integrated Ocean Observing System (IOOS) have migrated ocean observation data management and distribution services to the cloud. The migration rates vary significantly for each RA. Some have deployed most of their web service infrastructure on the cloud, some others infrastructure to shared data centers with or without cloud components, while a few utilize mostly local infrastructure that may include some cloud backup capability.

The most common use of cloud is for web applications and data access services, including data servers that provide both observation and forecast data to end users. Such well known servers are THREDDS (Thematic Real-time Environmental Distributed Data Services) and ERDDAP (Environmental Research Division's Data Access Program), and GeoServer.

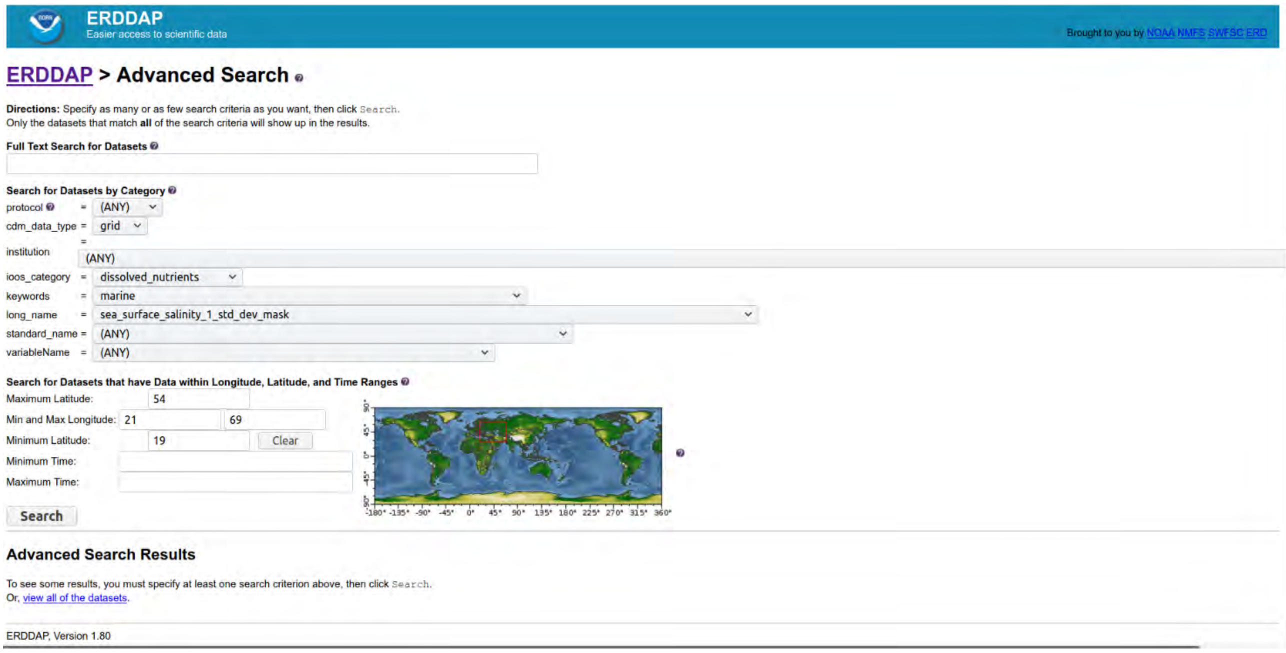


Figure 1.5-14 Figure: ERDDAP Data Search.

https://www.ncei.noaa.gov/erddap/search/advanced.html?page=1&itemsPerPage=1000)

Other services include map-based applications and web pages. THREDDS and ERDDAP servers are deployed using either virtual machine or Docker runtime environments (container technology). The IOOS Environmental Data Server, or EDS (https://eds.ioos.us), a web-mapping platform for oceanographic model visualization, is run on the cloud using the Docker platform. GLOS, the Great Lakes IOOS regional association, uses cloud-based virtual machines to run their buoy portal application and the Great Lakes acoustic telemetry system (https://glbuoys.glos.us , https://glatos.glos.us).

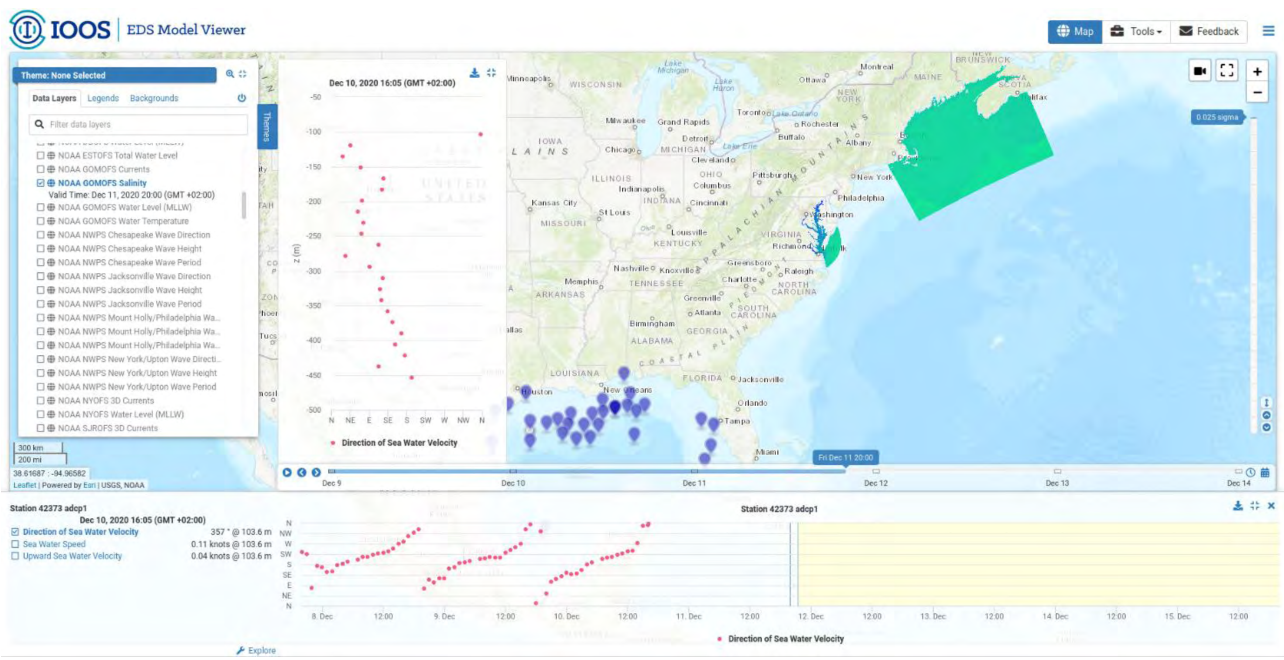


Figure 1.5-15 IOOS EDS Viewer (https://eds.ioos.us).

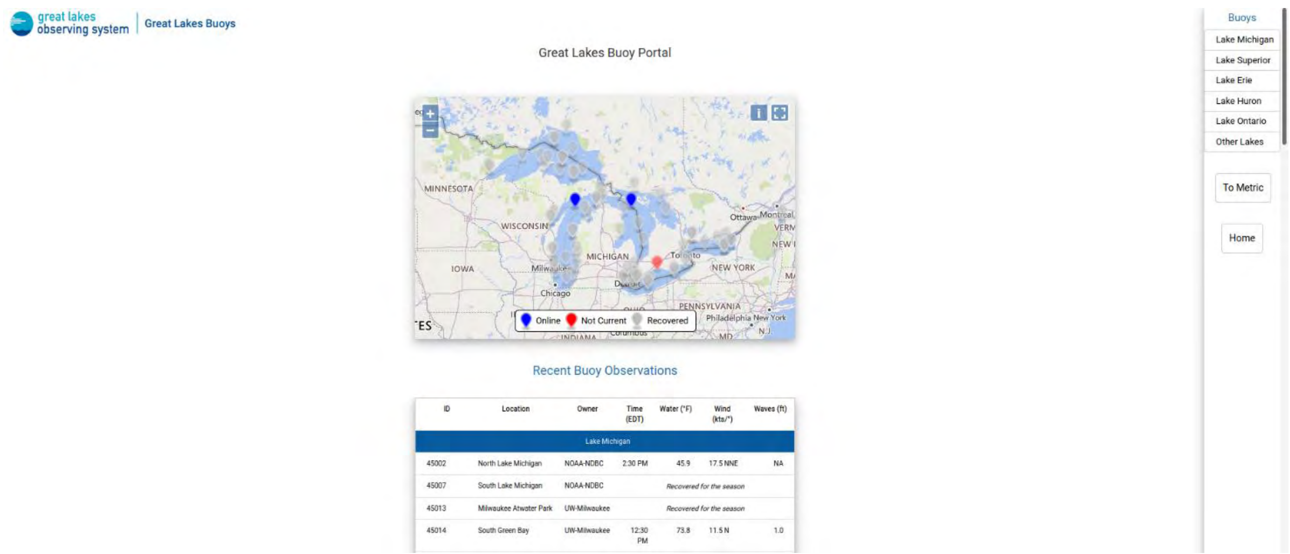


Figure 1.5-16 Great Lakes Buoy Portal (https://glbuoys.glos.us).

Several RAs move towards using the cloud for the ingestion and storage of near-real time observational data. In such a case, data from buoys or other sensors are being telemetered directly to a Cloud-based ingest point. For example, GCOOS (IOOS region for the Gulf of Mexico) and its affiliate Mote Marine Laboratory use a cloud-based instance of Teledyne Webb Research's Dockserver application, that receives data transmitted by a glider through the Iridium communications network and transfers it to the Internet. Mote Marine Laboratory moved its Dockserver on the cloud around 2010. Since them, operational gliders send data packets in real-time via satellite downlink to the server application. One of the benefits of the specific cloud based Dockserver is the more secure operating environment for Mote's glider operations, that is less vulnerable to weather related hazards than previous configurations that included local systems that resided on premises on or near the coast.

CARICOOS (IOOS region for the Caribbean), migrated much of their web presence and associated data services to AWS in 2015, in order to overcome problems caused by insufficient power grid reliability issues at their University of Puerto Rico's Mayaguez facility. The problems included unreliable Internet, data flow, modeling, webpage, and THREDDS server uptimes. Migrating to the cloud resulted in significantly less problems caused by power outages. For example, during the 2017 hurricane season, CARICOOS provided near continuous uptime for their most essential data flows, data services, and web pages for use in planning and executing relief efforts, in spite of widespread power outages and catastrophic damages. CARICOOS' data buoys that remained unharmed by the storms, were able to remain online sending data to the cloud-based infrastructure.

Another interesting perspective is the migration of High-Performance Computing (HPC) numerical models in the cloud. In order to further mitigate problems caused by hurricanes, CARICOOS are planning on moving part of their modelling infrastructure in the cloud, on AWS. These include a regional high-resolution setup of FVCOM (Finite Volume Community Ocean Model), their Weather Research Forecast (WRF) implementations, Simulating Waves Nearshore (SWAN) forecasts, as well as an updated Regional Ocean Modeling System (ROMS) implementation. These models currently run on local servers. CARICOOS aims to increase the reliability of their operational modeling capability by using a dual local-cloud scheme.

<u>The EU's Copernicus Earth Observation Program in the Cloud. Copernicus, Google Cloud and Google Earth Engine combination.</u>

Copernicus is the European Union's Earth Observation Program, offering free and open information based on satellite and in situ data. The provided data cover land, ocean and atmospheric observations and also include modeling output and forecasts. Several aspects of the latter have been presented in previous chapter.

Copernicus' main components are: Space, in situ, and Services. "Space," includes the European Space Agency's (ESA) Sentinels and contributions by missions operated by national and international organizations. One way of accessing Sentinel data is through the Copernicus Open Access Hub. Processing is possible by the means of the Sentinel-2 and Sentinel-3 Toolboxes. Another way is through the Google Earth Engine (GEE) and Google Cloud (GC), that provide a simplified environment to access and operate data online. Access and management are achieved by a Python API, that interacts with the GEE servers through the GC Datalab. Datalab also allows advanced data analysis and visualization by the means of virtual machines within the Google data centers. Users can achieve high processing speeds of the data by coding with open-source tools and software. Another aspect is Datalab's capability for machine learning modeling, which at the same time opens up very interesting workflows combining different marine in situ and satellite data.

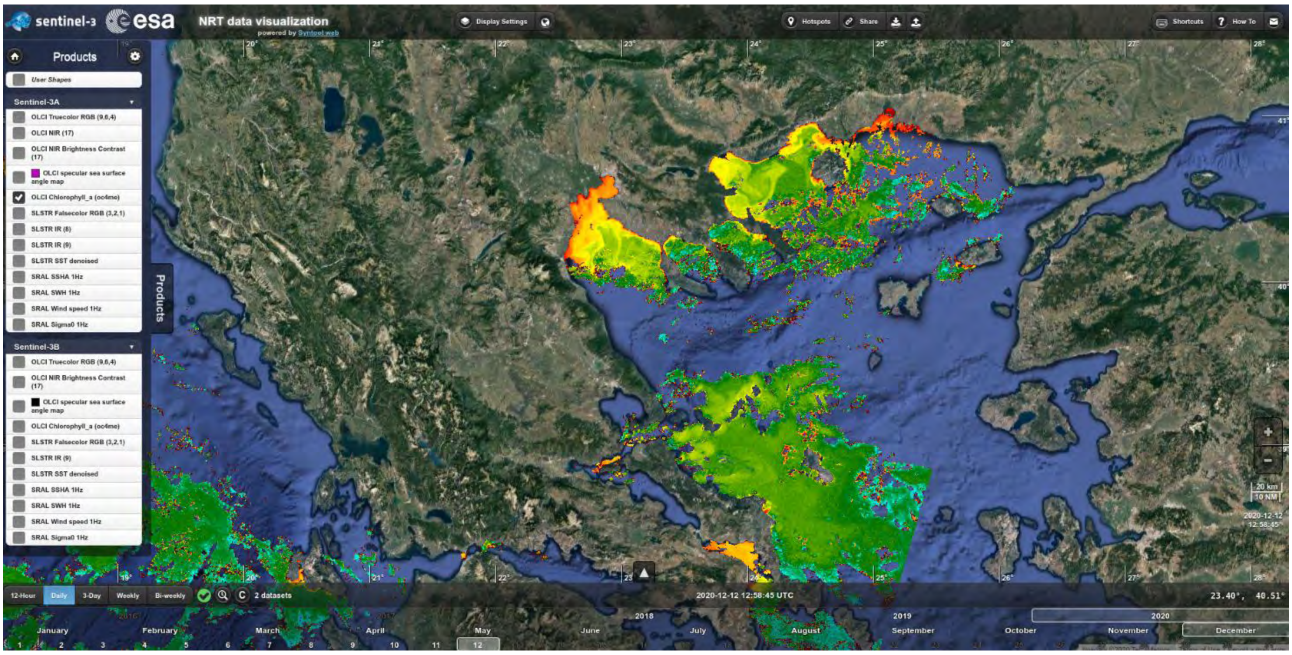


Figure 1.5-17 Sentinel-3 ESA NRT data visualization (OLCI Chlorophyll-a).

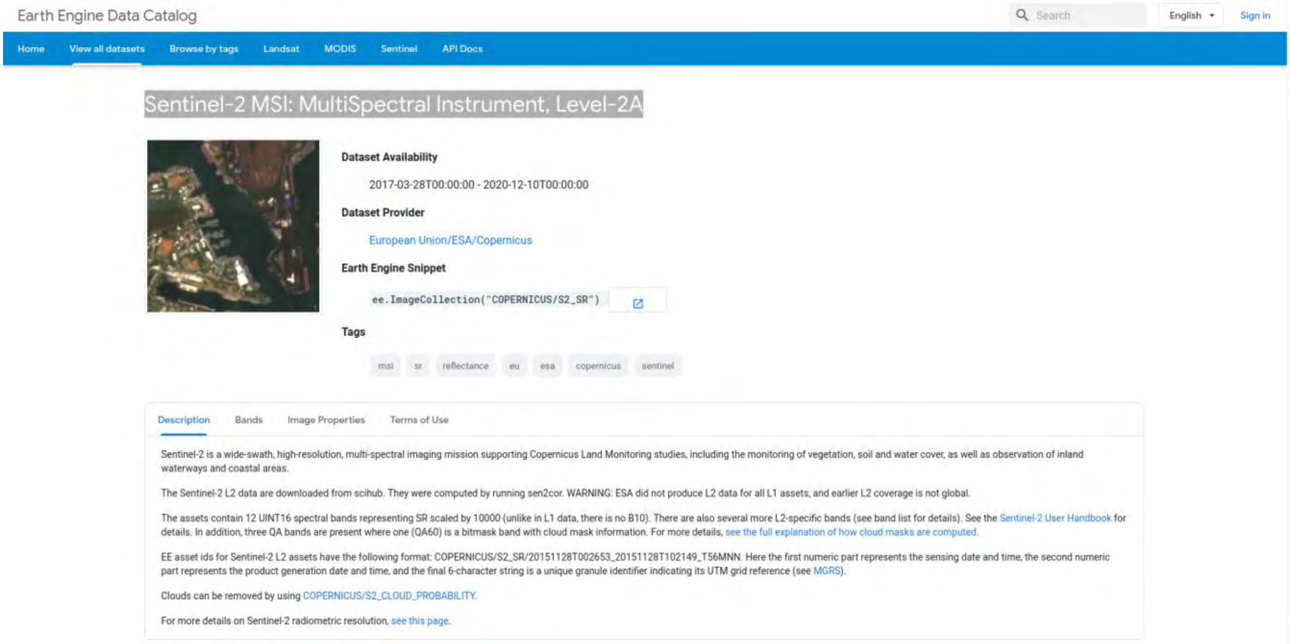


Figure 1.5-18 Google Earth Engine Data Catalog.

In situ information is collected from different monitoring networks around Europe, that include weather stations, ocean buoys, or maps. These data can be accessed through the Copernicus Marine Environment Monitoring Service (CMEMS). CMEMS was established in 2015, succeeding and expanding the previous My Ocean framework. CMEMS provides a catalog of services in four core areas for the marine sector: Maritime Safety, Coastal and Marine Environment, Marine Resources, and Weather, Seasonal Forecasting, and Climate. In situ data are essential to calibrate and validate satellite observations. Moreover, they are quite useful for the extraction of advanced information from the oceans. As presented in a previous chapter, CMEMS also provides a gateway for accessing several marine monitoring and forecast model products.

At the moment, the main limitation of these set of tools is the lack of integration between some data sources and the virtual environment. Satellite data is stored in the cloud, while in situ data is available through CMEMS. The latter process of downloading and accessing data is less straightforward than the Earth observation case. On the other hand, the inclusion of machine learning makes the Google Earth Engine – Google Cloud - Copernicus combination quite a powerful set of tools for ocean observation applications and research.

Apart from the combination mentioned above, Copernicus data can be found in the Cloud via other ways too, such as through AWS or the WMS ingestion of images using appropriate tools.

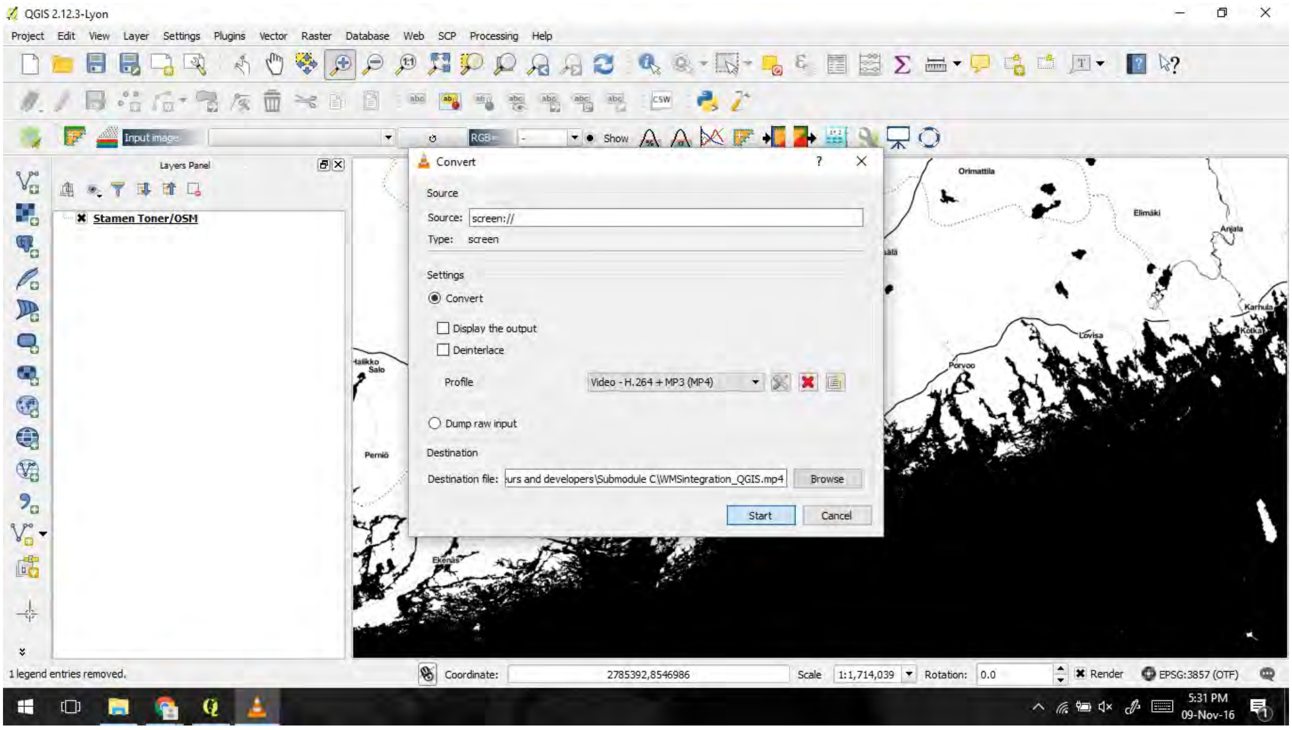


Figure 1.5-19 WMS ingestion of images using desktop QGIS implementation

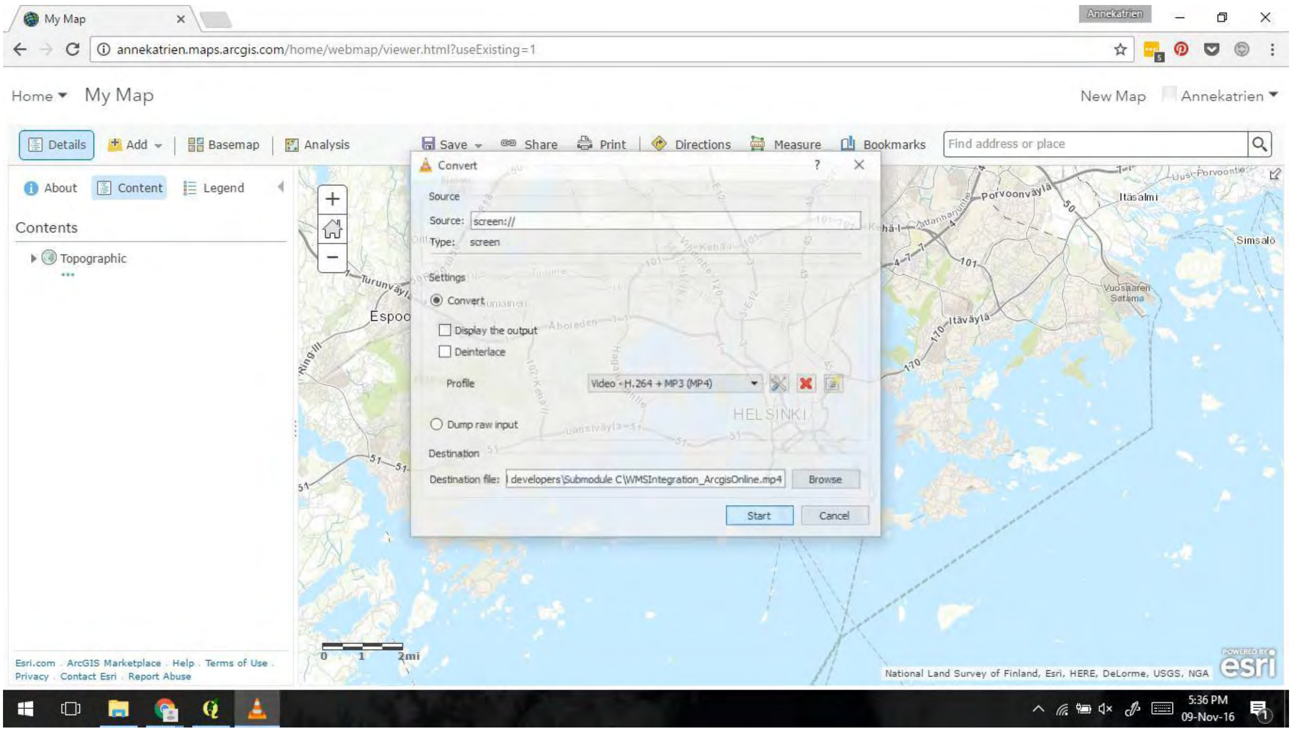


Figure 1.5-20 WMS ingestion of images using web based Arcgis implementation

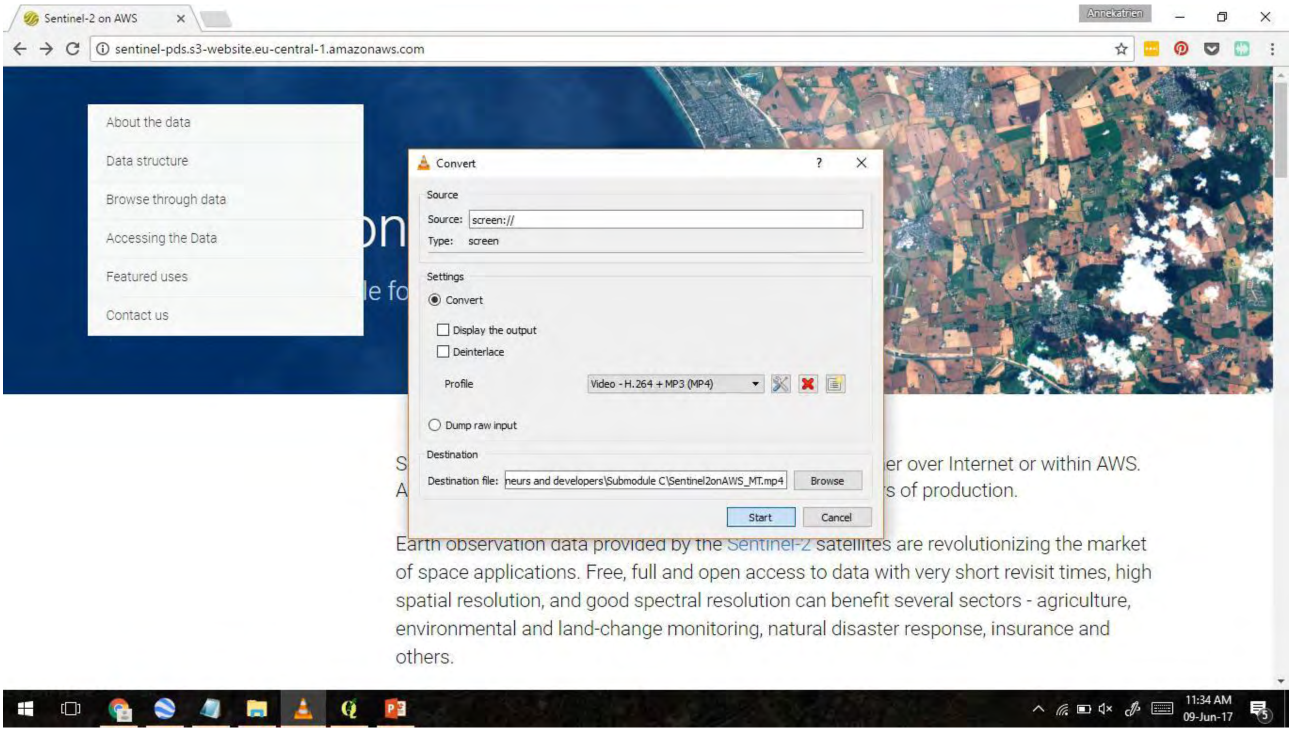


Figure 1.5-21 Sentinel-2 on AWS (Amazon Web Services)

Visualization and analysis of data in the Cloud

As more and more scientific large data sets are being stored in the Cloud, so emerge the needs for adequate methods of visualization. These needs grow beyond the purposes of previewing the datasets prior to downloading and extend to the analysis of data that results in meaningful figures, graphs, and maps. This can be achieved either directly in a web browser or by using a set of tools installed locally for accessing and managing data in the cloud.

An example of the first possibility is the case of using the Pangeo framework (https://pangeo.io/) for accessing and working with various datasets. The framework combines various Python libraries and tools (Jupyter notebooks, Datashader, HOLOVIZ tools, geoviews, cartopy etc.) and online Python coding for data analysis and the production of interactive visualizations.

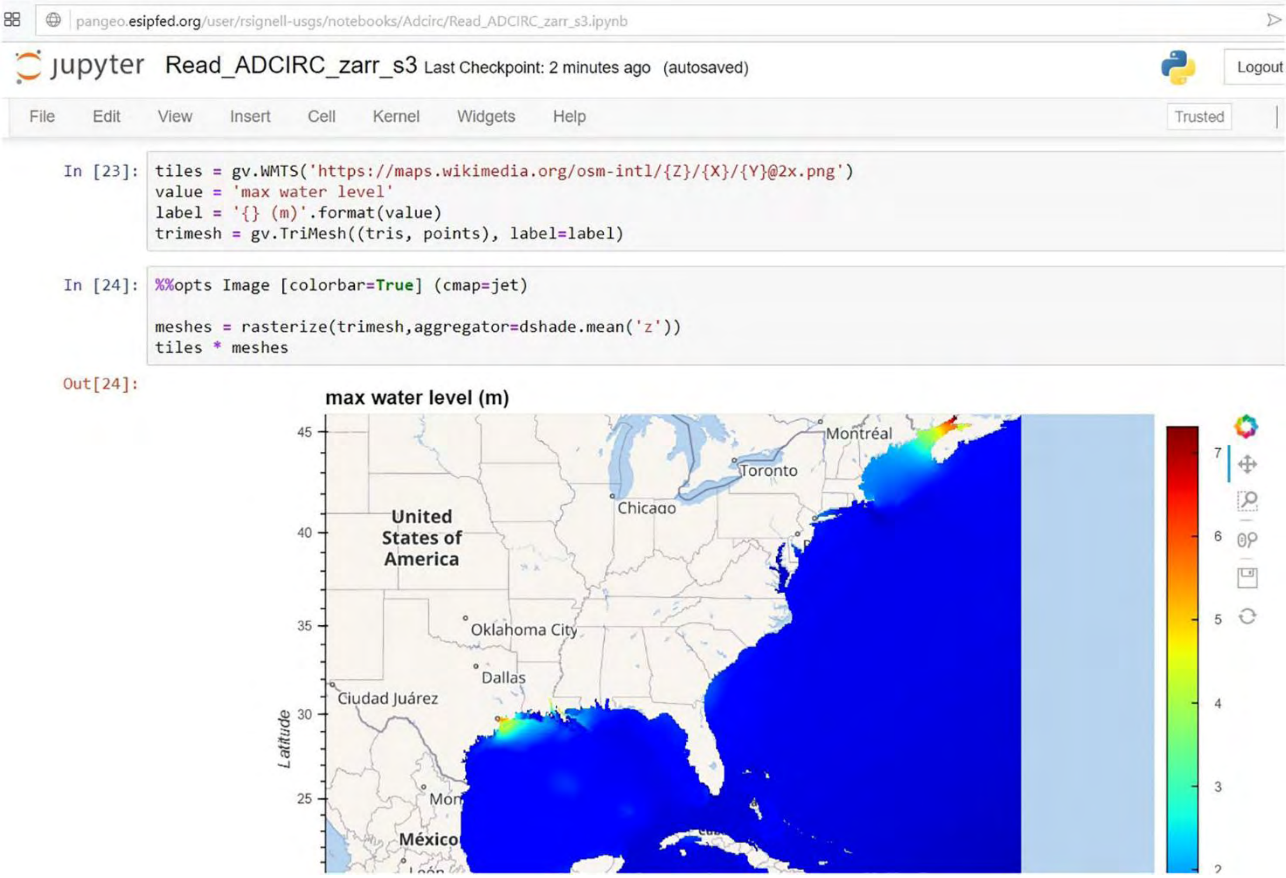


Figure 1.5-22 Figure: Hurricane Ike simulation on a nine million node mesh Visualization using Datashader in a Jupyter Notebook (source: Vance TC et al., (2019) From the Oceans to the Cloud: Opportunities and Challenges for Data, Models, Computation and Workflows. Front. Mar. Sci. 6:211. doi: 10.3389/fmars.2019.00211)

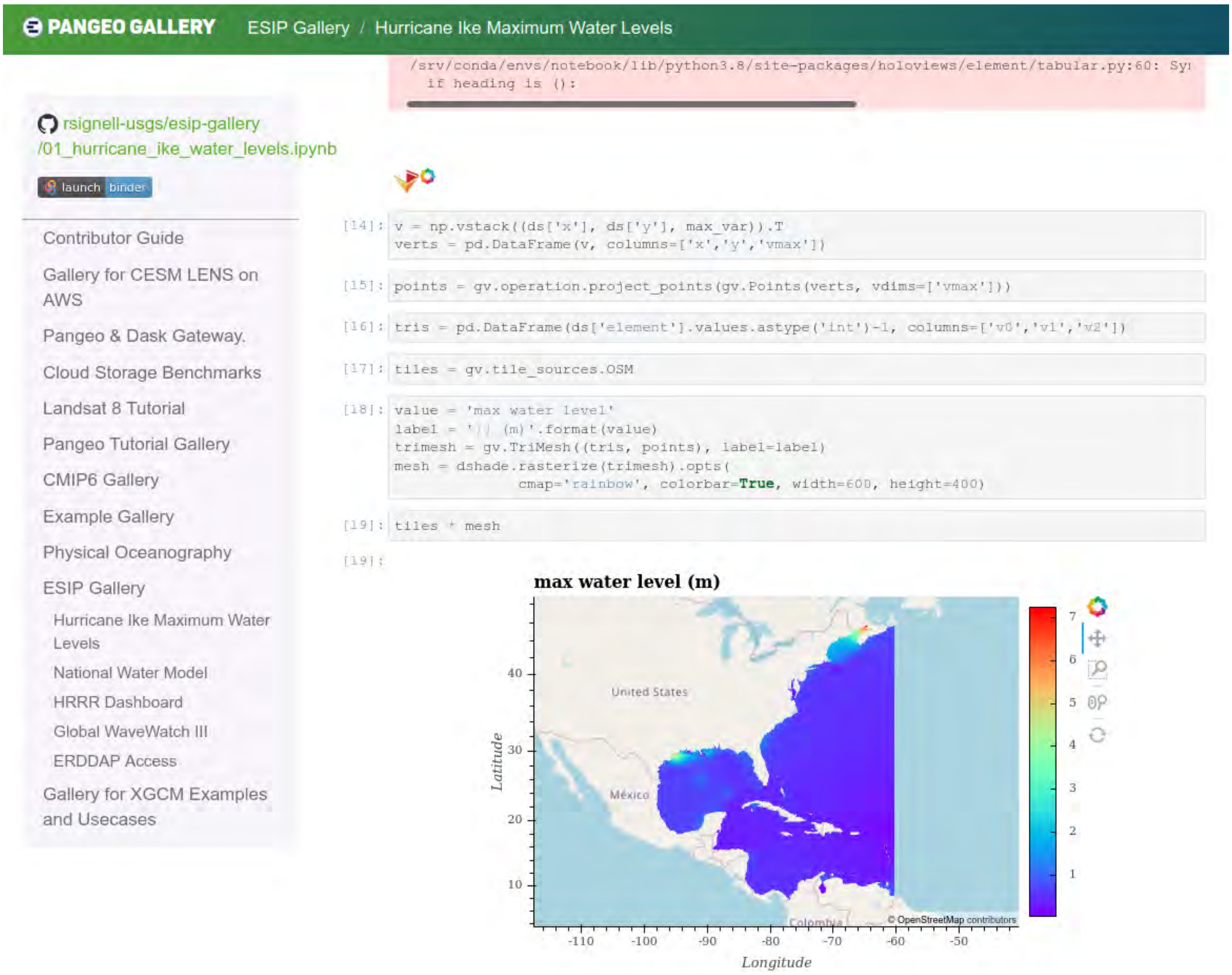


Figure 1.5-23 Hurricane Ike simulation vizualization on Pangeo Gallery

(source:http://gallery.pangeo.io/repos/rsignell-usgs/esip-gallery/01_hurricane_ike_water_levels.html)

An example on local – Cloud configuration is the use of NOAA's THREDDS server by the means of the Python API Siphon (https://www.unidata.ucar.edu/software/siphon/). Siphon is a collection of Python utilities for downloading data from remote data services. Much of Siphon's current functionality focuses on access to data hosted on a THREDDS Data Server, although access to data hosted by other web technologies is being quickly added.

Siphon can be easily integrated into workflows built using the Scientific Python ecosystem, including the Numpy, Scipy, and Matplotlib projects, as well as with Unidata's MetPy library, which is a collection of tools in Python for reading, visualizing, and performing calculations with weather data.

The Siphon project is still in its early stages. Here are a few of its current features:

- reading catalogs from a THREDDS Data Server
- querying the NetCDF Subset Service (NCSS)
- Communicating with the THREDDS Data Server using the CDM Remote protocol
- Clients for downloading data from the University of Wyoming, Iowa State (Iowa Environmental Mesonet), and IGRA2 upper air data archives

1.5.2 Open GIS tools

In the last few decades, field of GIS has witnessed a very high growth rate and is encompassed with various proprietary and open-source GIS software. The adoption of open-source software systems in developing nations, as a means of reducing licensing costs and of promoting indigenous technological development by having access to the source code of these systems (Camara and Onsrud, 2004). Free and open-source software for geospatial applications (FOSS4G) is the annual recurring global event hosted by OSGeo since its inception in 2006 which encourage to open source software and its development. It is general perception that the only distinction between open source and proprietary software is that one is free, and the other is not which is not true at all. They each are based on differing philosophies, methodologies, and business models. Open-source software is, almost by definition, more flexible but requires more effort to use, whereas the opposite is true for proprietary software in general. All open-source software is required to be "licensed". The procedure of implementing "free software licenses" is necessary to protect their users' legal rights and to ensure the freedoms of the software. With open-source software the user can access the source code and redistribute it, as well as modify it to perform specific user intended tasks for analysis and vizualization of geospatial data.

Geographic information system (GIS) software has enabled users to view spatial data on maps, allowing visual interpretation of spatial data. However, commercial GIS software is not accessible for everyone and requires users to spend the time and expenses necessary for use. To address this challenge, open-source web GIS has evolved as a cheaper and easier way of disseminating geospatial data. It does not require users to invest in a resource-intensive machine.

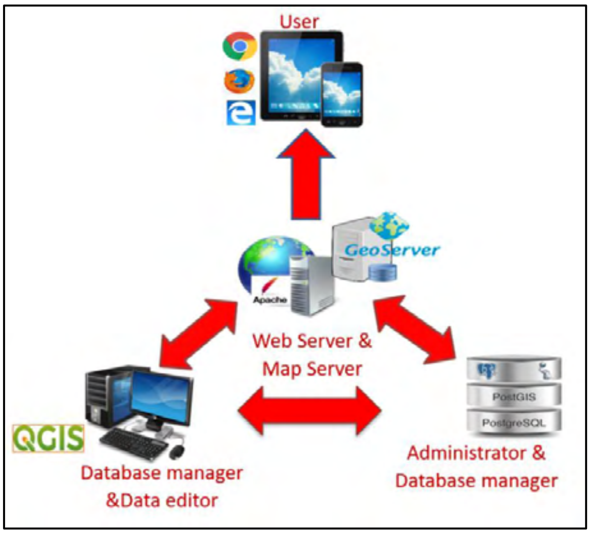


Figure 1.5-24 Application Architecture of a Web based GIS tool

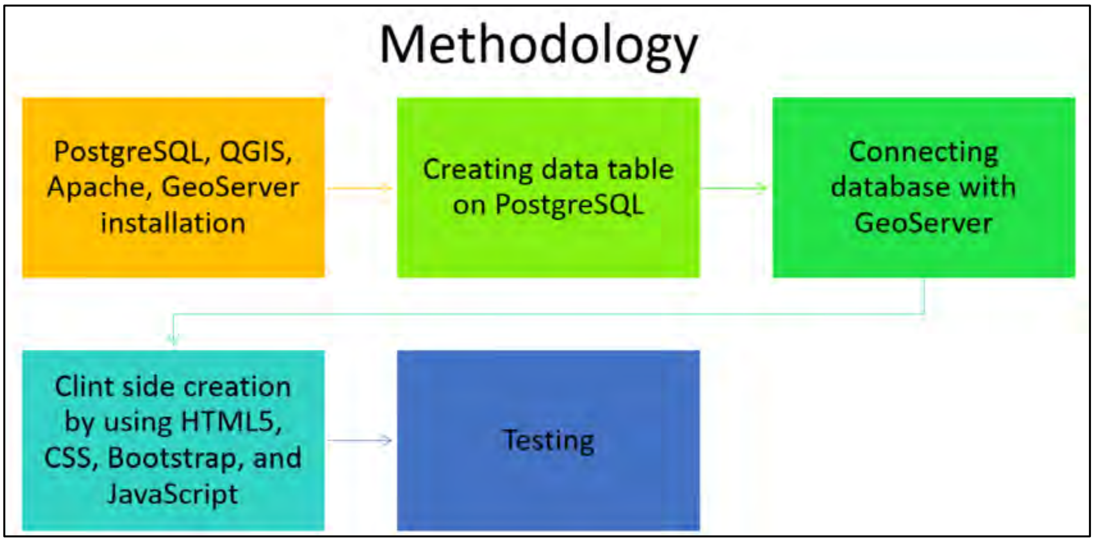


Figure 1.5-25 Methodology of installation – testing of an open GIS platform

Here below a short overview on most popular open GIS tools is presented, in Table 1-7 and figures 1.5-26 to 1.5-28.

GIS Desktop Solution

QGIS is used for a GIS desktop solution. Users can edit and modify data in QGIS and can publish on PostgreSQL by using QGIS database management tool to share with other members.

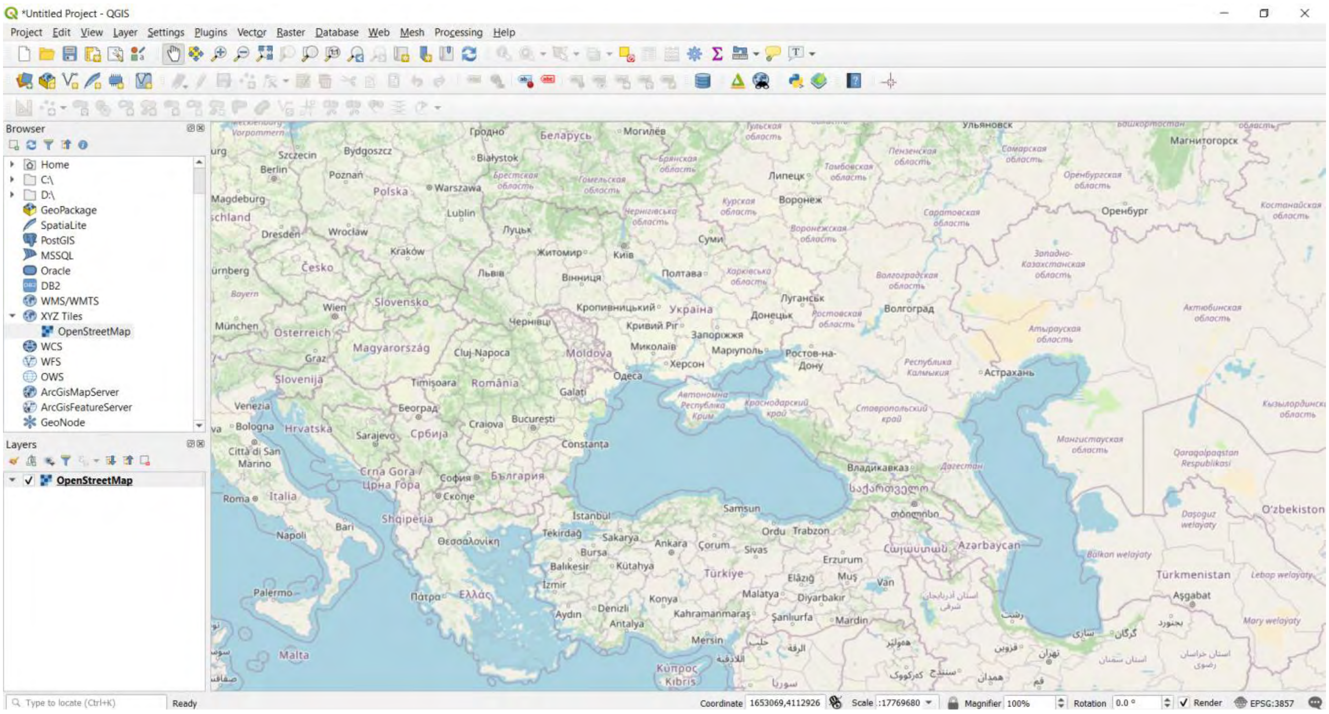


Figure 1.5-26 QGIS Desktop - user interface

Table 1-6 List of open GIS tools

Software, Release Year	***Developed by***	***Target Use***	***Programming Language***	***Software License***
GRASS, 1982	Research Institutes	Analysis and scientific visualization, cartography, modelling	C, Python	GPL
ILWIS, 1985	Universities	Raster analysis	MS Visual C	GPL
FalconView, 1994	Georgia Tech Research Institute	Map display, Overlay analysis	JAVA	LGPL
MapWindow, 1998	Universities	GIS for Decision Support Systems	MS Visual Studio	Mozilla Public License
TerraView, 2001	Brazilian National Institute for Space Research	Vector and raster analysis, Statistics	C++, R	GPL
SAGA, 2001	Universities	Analysis, modelling, vizualization	C++	LGPL
Geoserver, 2001	Open Planning Project	WFS, WMS, WCS, WPS	JAVA	GPL
JUMP, 2002	Universities	Analysis, modelling, vizualization	JAVA	
QGIS, 2002	Universities	Analysis, modelling, vizualization, GRASS-GUI	C++, Python	GPL
SkyJump, 2004	Private company	Military facility management	N/A	GPL
Kosmo, 2005	Private companies	Analysis, modelling, vizualization	JAVA	GPL
Mapserver, 2005	University of Minnesota	Webserver	C	GPL
Geonetwork, 2007	Companies	OGC Web catalogue services	C	GPL
Capeware, 2007	Government	3D terrain mapping	C++	GPL
Kalypso, 2007	Universities	Flood risk mapping	Fortran, Java	LGPL
Whitebox, 2009	University of Guelph	Geospatial Analysis	JavaScript, Python	GPL

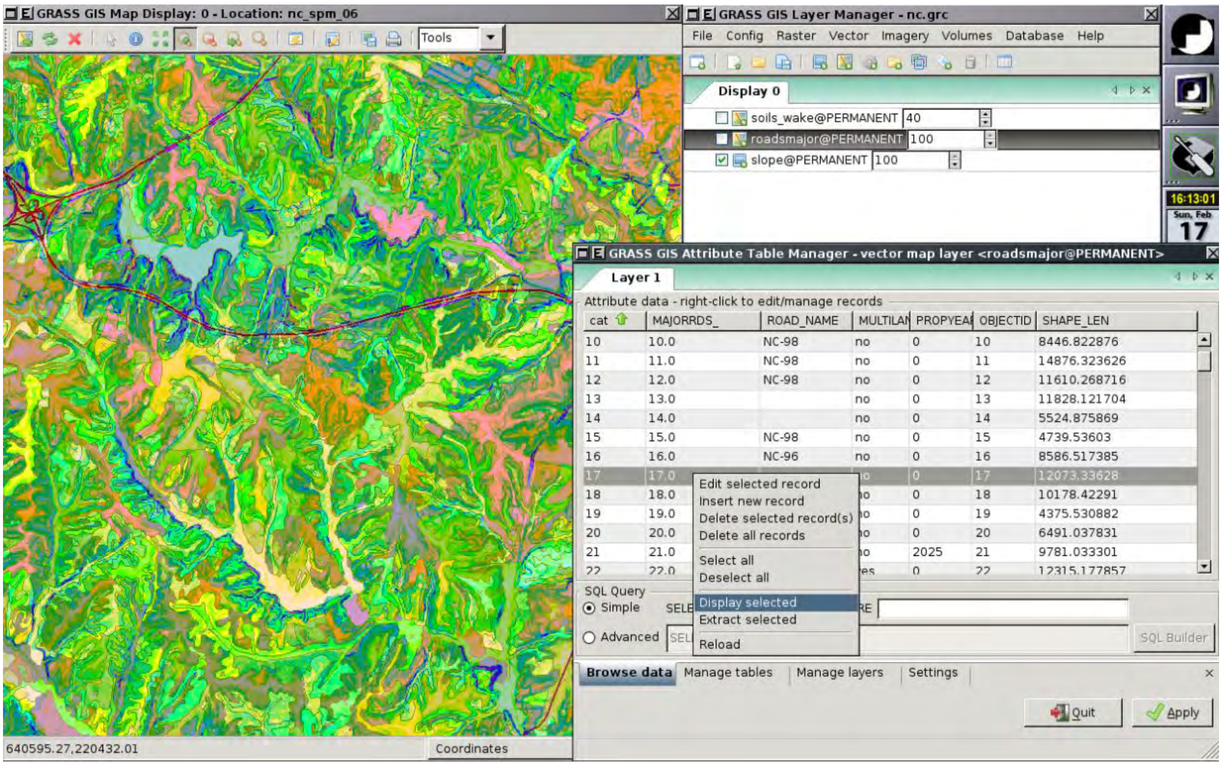


Figure 1.5-27 GRASS GIS - user interface

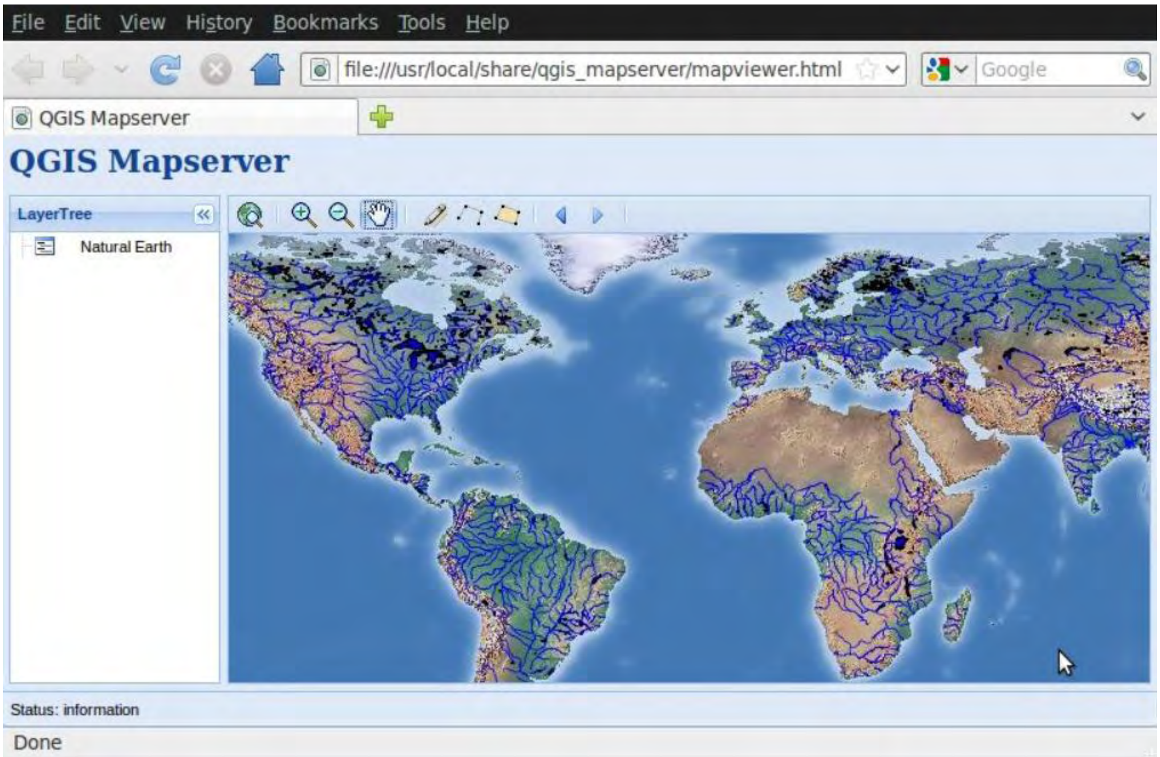


Figure 1.5-28 QGIS Mapserver

1.5.3 <u>Dissemination technologies and alert systems</u>

Dissemination technologies and practices in the water sector, and particularly in marine water quality assessment, are many and diverse. The wide variety of such techniques used either in pilot applications or research studies makes it impossible to list them all, as they mainly depend on the implementation focus and needs of the involved beneficiaries, stakeholders, and target groups. A selected number of rather recent endeavors are reported herein.

With regard to the communication of results, the potential diversity of users should be recognised, and results presented in ways that will be understandable from their perspectives. Scientific and technical jargon should be avoided. As users tend to weigh the information according to their previous knowledge and experience, and in relation to their current views on the issues addressed, a sense of ownership of the research will help adoption of the results.

Dissemination activities should aim to make use of multiple channels of communication – formal and informal. Routes and mechanisms for bringing research results to the attention of users include:

• recognising the availability of information as a first step, better electronic, web-based databases of project reports;

• training, networks and person-embodied knowledge;

• face-to-face meetings enabling users to question researchers;

• policy briefs and science cafes;

• the media; and

• “hands-on” involvement of users in the final research project stages, testing prototypes of databases and models through simulation exercises, etc.

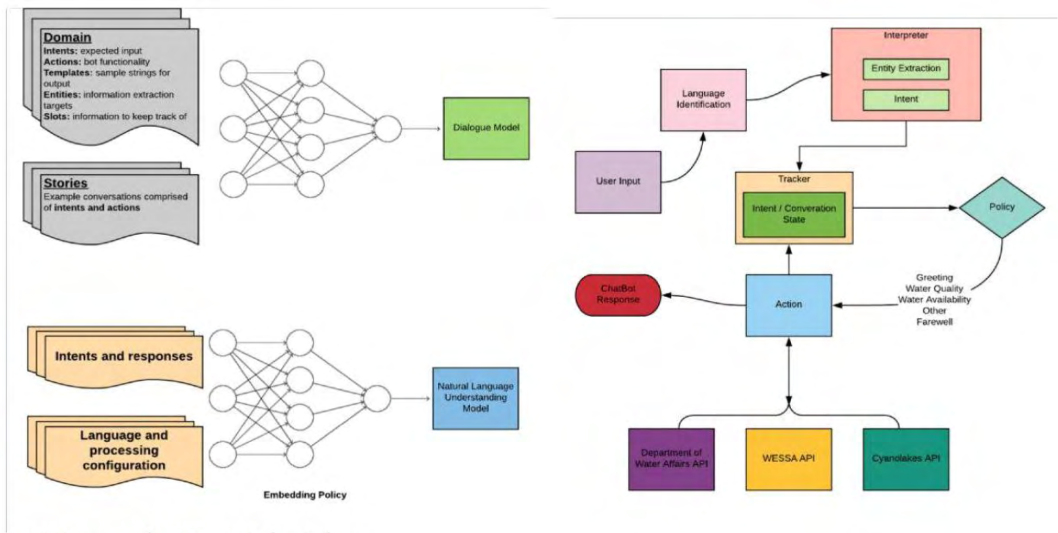
Interpreters and intermediaries are considered to have a key role to play, but this is an under-resourced area and people with the necessary skills are in short supply. As scientists and engineers are frequently not skilled at communicating results in a simplified way across the science and policy gaps, there is a need for interpreters who are familiar with the research and policy terms and are able to bridge between them.

Building networks of researchers, intermediaries and users can also foster communication, creativity, and consensus. The communication of uncertainty in a way which is true to the science while useful to policy makers is also recognised as a major challenge, especially for long-term planning.

Stakeholders need to be made aware of what information is available and how it may be obtained. Scientific information should be translated into suitable forms recognising the diversity of potential audiences. Intermediary organisations, networks and workshops can play a useful role in facilitating interaction between experts, policy makers and the public.

Lourens et al. (2018) present a conversational model to apprise users with limited access to computational resources about water quality and real-time accessibility for a given location. The have used natural language understanding through neural embedding driven approaches. This was integrated with a *chatbot interface* to accept user queries and decide on action output based on entity recognition from such input query and online information from standard databases and governmental and non-governmental resources (Figure 1.5-29). They present results of attempts made for some South African use cases and demonstrate utility for information search and dissemination at a local level, with the scope of presenting an Action-Confusion Matrix as a Decision Support Tool.

They proposed and validated an information dissemination model integrating a machine learning driven language modelling task with an interactive chatbot infrastructure (Figure 1.5-29). The utility was shown for different applications pertinent to water quality in different circumstances and locations, in a user-friendly conversational style. Possible future extensions would look at integrating insights from sentiment analysis of social media mentions, refining the natural language embedding process using seq2seq models and modelling conceptual level information, apart from expanding to different languages and use cases. A direction of research also needs to be explored on the mechanisms for secondary and tertiary information ingestion into the system, such as building and identifying API's for relevant data. It is noted that the overall architecture is lightweight and has a low computational requirement and is amenable to deployment on low-cost smartphones.



a) Dialogue and NLU Model training.

(b) Rasa-adapted chatbot architecture

Figure 1.5-29 a) Natural Language Understanding unit and dialogue module; b) Chatbot overview courtesy of Lourens et al. (2018).

Read et al. (2017) report that in the US water data are still collected by hundreds of research groups and organizations, many of which use nonstandard or inconsistent data descriptions and dissemination, and disparities across different types of water observation systems represent a major challenge for water research. To address this issue, the Water Quality Portal (WQP) was developed by the US Environmental Protection Agency, the US Geological Survey, and the National Water Quality Monitoring Council to be a single point of access for water quality data. The WQP is the largest standardized water quality data set available with more than 290 million records from more than 2.7 million sites in groundwater, inland, and coastal waters. The number of data contributors, data consumers, and third-party application developers making use of the WQP is growing rapidly. Key technological features of the WQP include a community-developed water quality data model, robust web services, and geospatial referencing to the National Hydrography Dataset Plus (NHDPlus) catchments, all of which enable large volumes of water quality data to be integrated with other national-scale data sets relevant to natural resources. These features make discoverable and accessible high-value data from Federal, State, Tribal, and nongovernmental sources, dating back more than a century. Any data provider, including individuals, who meets minimum metadata requirements, may incorporate their data into the system through EPA STORET-WQX, to be used in context with hundreds of millions of water data records. There is a positive feedback loop to community adoption of common data models and data repositories: continued community engagement will further improve the data model, data quantity will increase, and the tools available to users will grow.

Users can access WQP data by two means: a *web interface* and *web services*. The Web interface provides point-and-click discovery of- and access to data, whereas web services allow users to access the WQP programmatically through scripting languages, such as R or Python. Users can filter queries by site parameters (State, county, latitudes and longitudes, HUCs, organization identifier, etc.); sampling parameters (sample media, Substance Registry System water quality characteristic, minimum results per site, date range, etc.); by database (USGS NWIS, EPA STORET_WQX, etc.); and by proximity to stream reach catchments on the NHDPlus, a national geospatial surface water network linking 2.7 million stream reaches across the continental US. WQP user interface guide and web service documentation are available online (https://www.waterqualitydata.us/). The software underlying the web interface and web services are in the public domain, and are publicly accessible in online software repositories (https://github.com/USGS-CIDA/WQP_UI and https://github.com/USGS-CIDA/WQP-WQX-Services). The web interface operates by making calls to the application's web data service and web map service. For any query made, web service calls for sites, results, and web feature services are exposed to users. By clicking the Show web service calls button on the web interface, users can access and share static endpoints (URLs) for specific data queries with collaborators and can easily replicate queries through time to obtain updated data. Although the endpoints are static (i.e., URLs do not change), the data returned may vary, as modification of data is at the discretion of the systems of record (USGS NWIS, etc.). For example, because agencies may add new data as they become available or may modify metadata to improve reuse; these actions and others may result in changes in query results over time.

The ASEAN Marine Water Quality Guidelines issued by the Australian Government make use of a Monitoring Manual developed as a guide, documenting recommended methods for the implementation of marine water quality monitoring programs. Methods for program design, sampling, data analysis and interpretation and reporting and information dissemination have been selected on the basis of their suitability for use in the ASEAN region. The methods described focus on the 19 parameters (18 where nitrate and nitrite are counted as one) included in the initial AMWQC report even though only 17 of these were accepted by the ASEAN ministers in 2002 (noting that zinc and arsenic were originally excluded as needing further studies). One other parameter – chlorophyll– has been included in the methods as it is now realised that this is a critical indicator of nutrient enrichment.

One of the final components of any successful monitoring program is the reporting and dissemination of the data collected and analysed in the program. It is important to work out who will use the information, the timeframes for reporting and in what form the information is best presented. Some users will need to know when a measurement falls outside a particular range, other might not care about an odd outlier but are concerned by trends or regular failure to stay within limits. Information technology should enable delivery of information from monitoring programs in a variety of forms to suit a range of users. The recommended steps on the development of the reporting and information dissemination procedures are shown in Figure 1.5-30.

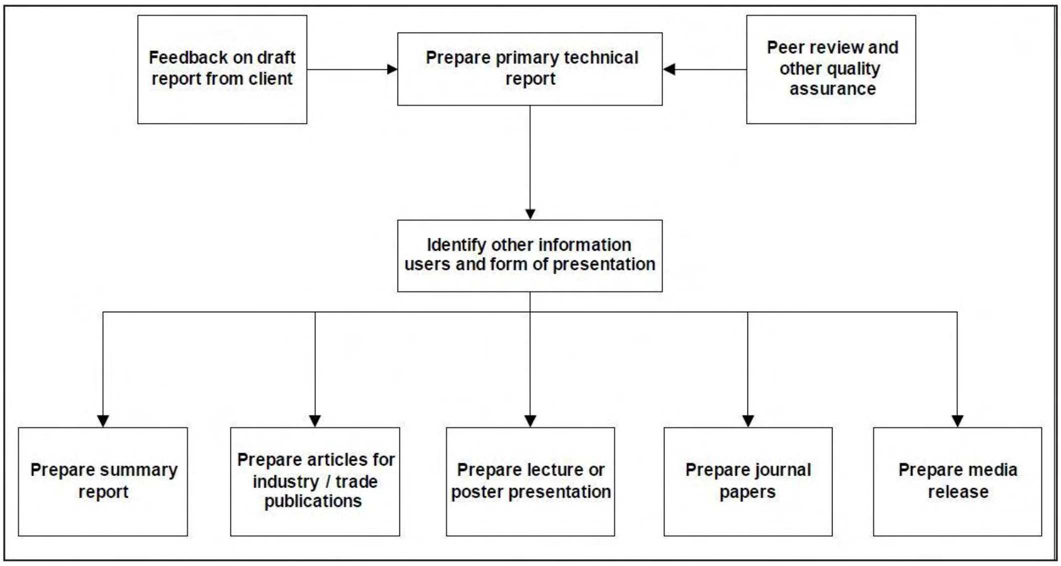


Figure 1.5-30 A framework for designing a reporting system (courtesy of ASEAN MWQ Monitoring Manual, 2008).

Therefore, the classic dissemination options available comprise the following:

- Printed material (brochure, leaflets, flyers, factsheets, pamphlets, posters, newsletters, roll-ups, etc.),
- Digital media (e-newsletters and video commercials on radio, TV, social media, wikis, blogs, logos, banners, templates, visual identity material, etc.),
- Website technologies (GIS, project webpage, databases, communication platforms, etc.)
- Smartphone and tablet apps,
- Patenting (applications, regulations, consortium agreements, recommendations,
- Technical and innovation events (clustering, spreading knowledge, policymaking events, interaction, etc.)
- Outdoor advertising (field training, demonstration activities, exchange visits, press conferences, policy briefings, etc.)
- Experiential learning (sector journals, professional conferences, etc.)
- Events (workshops, conferences, meetings, launch initiatives, sponsorships, summer schools) with the participation of stakeholders (communities, public authorities, local agencies, academia, NGOs, consumers, professionals, general public, etc.).

The internet and web-based dissemination is still the prominent way to educate, inform and/or train the public. The US paradigm is channeled via the *Water Quality Information for Oceans, Lakes, and Rivers by State* application https://www.cdc.gov/healthywater/swimming/water-quality-oceans.html and the Beach Water Quality Monitoring Programs in Coastal States http://www.beachapedia.org/Beach_Water_Quality_Monitoring_Programs_in_Coastal_States.

For the classification of knowledge dissemination techniques Milton (2010) presents a four-way classification of systems for capturing and disseminating lessons learnt from past experience. It can also be applied to classify approaches for knowledge dissemination. Milton's classification uses two dimensions (Figure 1.5-31). The first dimension distinguishes 'collect' approaches (in which knowledge is recorded or written into a repository) and 'connect' approaches (in which knowledge is communicated directly between individuals, whether verbally or through written messages). The second dimension distinguishes 'formal' and 'informal' approaches. By 'formal', Milton means "operating within a defined framework, or set of rules", while 'informal' means "unmanaged and bottom-up". In practical terms, this often means that 'formal' techniques supply knowledge to users in a structured format, while informal techniques supply knowledge in conversational text.

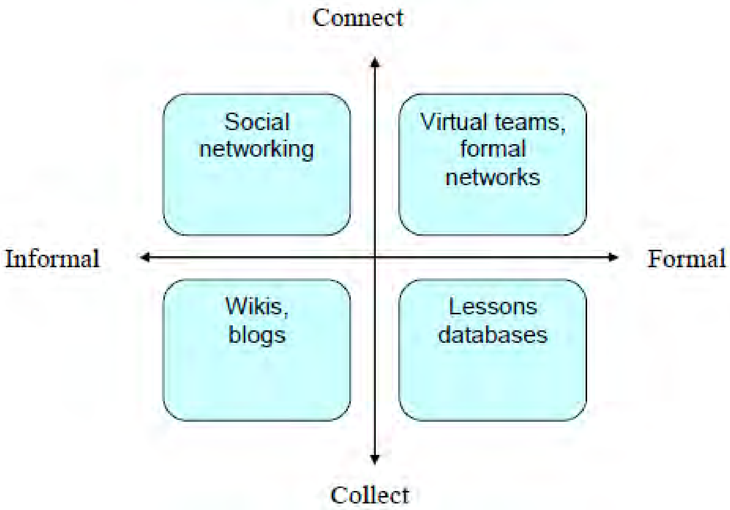


Figure 1.5-31 Milton's classification of 'lessons learnt' approaches (courtesy of Kingston, 2012).

Other characteristic dissemination applications comprise toolboxes, such as the *Aquaculture Toolbox* (https://toolbox-tapas.s1.umbraco.io/) which provides tools and guidance to support the planning and licensing of aquaculture in Europe. It can be used by planners to guide the sustainable development of the aquaculture industry in European nations. License applicants in the industry will benefit from modelling tools and guidance that will support their licensing application and guide them in developing their activities to operate within environmental boundaries.

A classic working alert system is the South Australia Beach Alert monitoring application (https://www.epa.sa.gov.au/environmental_info/water_quality/water_quality_monitoring/), providing advice to beachgoers during the summer about suitability of local beaches for swimming and related activities. Coastal water quality at beaches can be impacted by rainfall which flush stormwater into the sea leaving discoloured water especially around drains.

Brochure of informational material advises people about not swimming in discoloured or murky water and through this program beach users have easy access to current information to enable them to make that decision. Beach users can sign up to receive alerts by email or SMS specifically for Grange, Henley, Hallett Cove, Christies Beach, Noarlunga, or Moana, as these are near the mouths of rivers or creeks, or large stormwater outfalls. On days when stormwater is flowing to beaches, the water quality may be poor. Beaches on an interactive map (http://coastalwarning.waterdata.com.au/?AspxAutoDetectCookieSupport=1) can be flagged in real time at locations where stormwater is discharging and potentially impacting on the bathing water quality. To check the water flows at the beaches, the user is allowed to click on links and select the date range one prefers and 'flow' in the parameter box or select raw data. Each monitoring location has a flow rate that might trigger a beach alert.

Prasad et al. (2015) repot on a local scale Smart Water Quality Monitoring System that measures water parameters for analysis, such as Potential Hydrogen (pH), Oxidation and Reduction Potential (ORP), Conductivity and Temperature using Remote Sensing technologies. While monitoring these parameters, it is perceived that one should receive a stable set of results. Therefore, a continuous series of anomalous measurements would indicate the potential introduction of a water pollutant and the user will be notified of this activity with the aid of IoT technology. False positives, such as anomalous readings over a short period of time, will be recorded but not treated as an alert. Hence, with the successful implementation of this monitoring approach, a more reliable water pollution early warning system can be achieved with a fully realized system utilising multiple monitoring stations.

Pandey and Yadav (2017) present an alternative alert system for Ganga river eutrophication using alkaline phosphatase as a level determinant, making it clear that it is necessary to certify and correctly define the local contamination and pollution drivers, hence the target monitoring parameters of regional interest.

Kamaludin and Ismail (2017) suggest an IoT-based Water Quality Monitoring system implementation by embedding the Radio Frequency Identification (RFID) system, Wireless Sensor Network (WSN) platform and Internet Protocol (IP) based communication into a single platform for water quality monitoring (WQM) purpose. All the WSN nodes are deployed in a real environment at the lake in the campus area of Universiti Sains Malaysia (USM) for performance evaluation. Instead of using 2.4GHz ZigBee protocol, the 920MHz Digi Mesh protocol is proposed to be implemented for water quality monitoring in vegetation area due to its ability to surpass the signal attenuation. This novel proposed system prototype was evaluated in a real environment to ensure that the main functionality on pH measuring process is following the design requirements. This proposed network gateway is connected to the internet connection by using the IoT module; Arduino Ethernet Shield. It will utilize the available internet bandwidth through the internet Access Point (AP). The obtained data from sensor node can be pushed to the cloud storage by using the integrated IoT module onboard the network gateway. This IoT module communicates with cloud storage infrastructure through TCP/IP communication by requesting the HTTP Get command. Once the TCP/IP communication established, the cloud database will store all the received data from the network gateway of the proposed system.

As the mobile platform provides portability, they have proposed a mobile application to enable online monitoring tool with alert triggering system. The proposed mobile application is developed based on an Android OS platform (Figure 1.5-32). The GUI of this mobile application is developed by using the mobile hybrid programming technique. On the other hand, the algorithm of alert triggering system is written in PHP programming language to detect the certain pre-determined pH threshold value and then produces the beeping alert sound at the user's mobile device.

Figure 1.5-32 The Proposed Mobile Application GUI (courtesy of Kamaludin and Ismail, 2017).

Shin et al. (2016) have presented the design of an alert system for water-blooms (green-tide) dynamics of algae in Daecheong Reservoir, Korea, with the schematics of practical alarm triggering by identification of alert levels of combined algae cells and chlorophyll-a given in Figure 1.5-33.

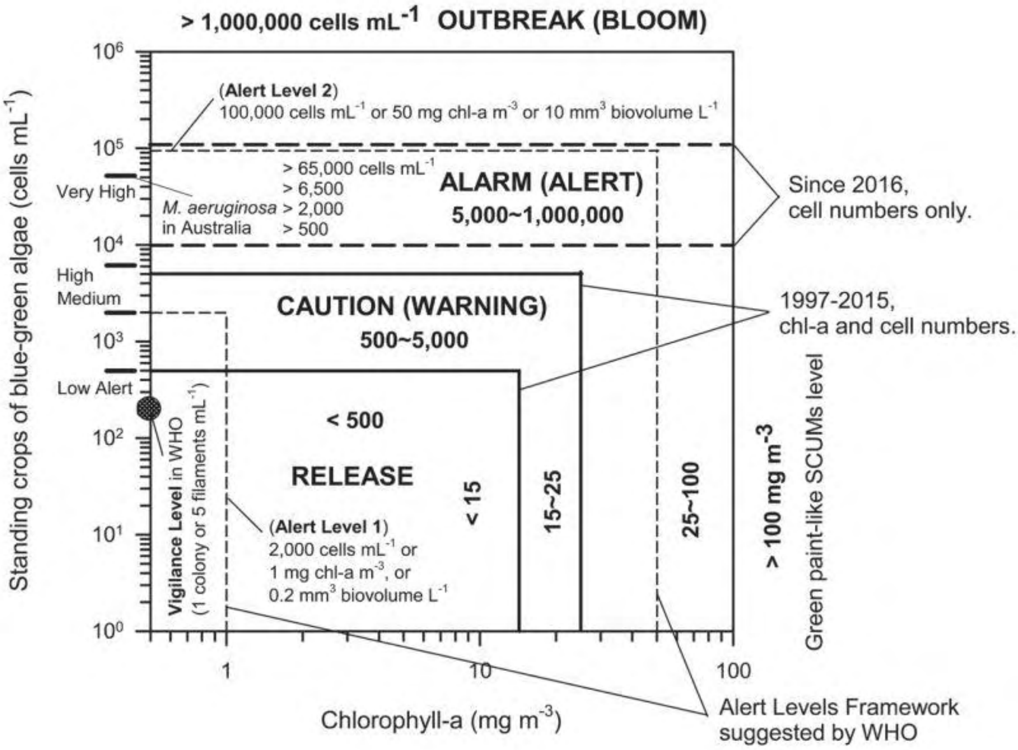


Figure 1.5-33 Alert triggering criteria of chlorophyll-a concentration and standing crops of blue-green algae used in algae alert system of Daecheong Reservoir (courtesy of Shin et al., 2016).

2. REVIEW ON GOOD PRACTICES WITH POTENTIAL FOR REPLICATION IN BLACK SEA

2.1 Water Quality monitoring, Ecosystem forecasts.

2.1.1 *Ecosystem Monitoring for Mediterranean Sea (Poseidon system), HCMR, Greece*

The Greek paradigm of HCMR's efforts of field monitoring in the Mediterranean basin has engaged the good practices of deploying and operating autonomous marine platforms, raising constant concerns in the responsible scientific and technical teams for their safety and operational status. Thus, a web-based alerting service has been developed by the POSEIDON's I/T team, which provides combined information regarding the positioning and the communication status of the moored buoys and the Argo profilers. The implemented service provides a visualization of the fixed platforms position during the recent period along with a drift calculation from the location of the initial deployment (Figure 2.1-1). In another instance, an array of the latest metrics is provided, which contains the latest transmission date together with the relevant position and the drifting from the initial deployment location. An additional instance is also available for the Argo profilers, consists of the latest profiler's transmission date and position together with the maximum recorded depth reported by the profiler. The following metrics are regularly checked with automated procedures and an alert is raised whenever they exceed a predefined threshold:

- The latency of the transmitted measurements which is dependent on the type of the platform. Anything greater than the expected latency may imply an issue to the platform, to the communication system or to the hosted sensors.
- The drifting of a fixed mooring compared to the initial position of deployment. This metric may indicate a serious threat to the station's safety, such as a detaching of its anchoring system. Actions need to be taken as fast as possible in such cases to avoid any further damages to the station and its ability to carry instruments as well as to prevent any maritime accidents.
- The maximum depth of recording. This metric applies only to the Argo profilers, and while this metric is too small, it possibly indicates that the profiler may have shifted close to the coast and an imminent stop of transmission must be expected. Based on the last transmitted geographical location, the POSEIDON team decides if a recovery of the profiler is possible.

Since 2015, POSEIDON system also joined the ocean glider community through the acquisition of two SeaExplorer gliders, which are autonomous underwater vehicles that can be controlled and piloted remotely. Through satellite communication, the pilot can download data, check the functionality of the vehicle and its sensors, tune some of its operation settings, correct or redefine its trajectory and handle any emergency situations. Apart from the communication software that allows the interaction of the pilot with the glider, an additional, dedicated inspection tool has been developed. The trajectory of the glider's mission is provided on a map along with the instant display of the most important communication metadata, while all the transmitted navigation and scientific information are available for visualization by the pilots. The plots can provide additional information such as minimum and maximum boundaries, safety bands of operation, combinations of data series and derived parameters, that should be calculated by the direct measurements received by glider, such as the salinity and the dissolved oxygen.

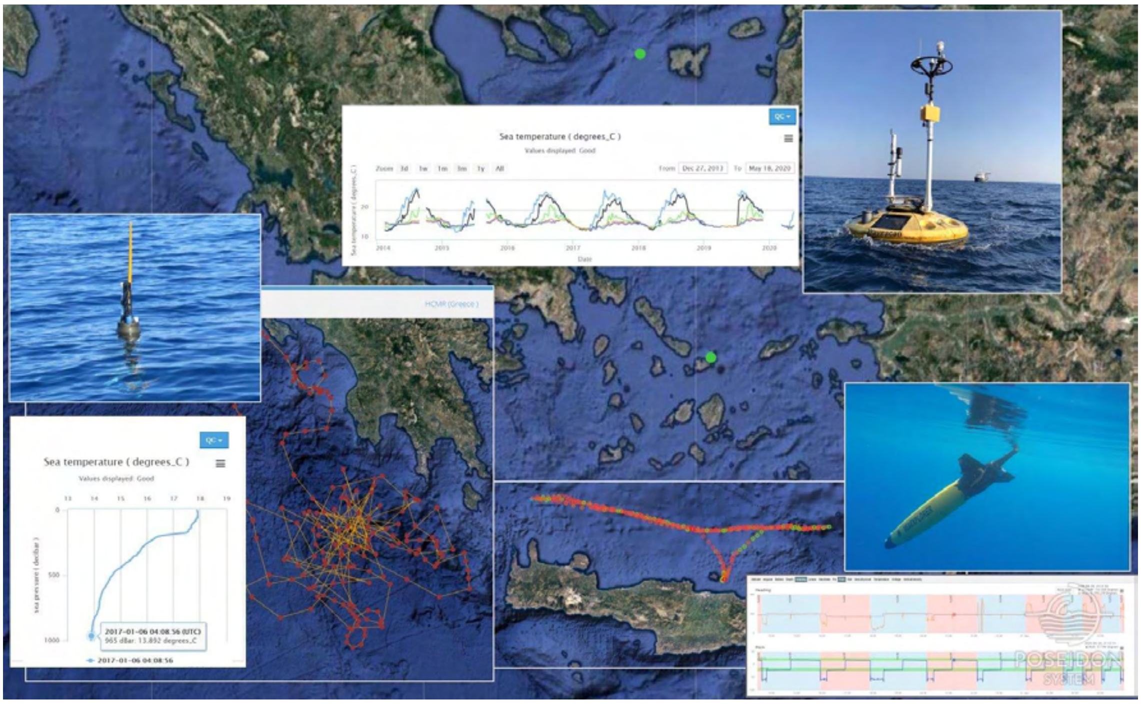


Figure 2.1-1. Ecosystem Monitoring tools for the (east-central) Mediterranean basin (Poseidon system), HCMR, Greece.

The POSEIDON monitoring network consists of a series of different platform types recording in situ data in the vicinity of the Greek seas:

- Fixed mooring stations,
- Tide gauges,
- Argo floats,
- Gliders,
- CTDs,
- Sampling bottles,
- Ferrybox,
- HF radar system and
- Cabled seabed observatory

Each platform hosts several different sensors recording a variety of parameters (oceanographic, biochemical, meteographic, etc.) with different temporal and spatial coverage. Depending on the type of the platform, the collected data can be:

- time series with specific time frequency on certain pressure levels,
- profiles with varying time frequency and multiple pressure levels,
- gridded observations providing a wider spatial coverage,
- sound recordings,
- images.

All the collected datasets are either transmitted in real time to POSEIDON operational data center through satellite and mobile networks or saved into attached data loggers / storage media for later retrieval and processing. The raw data (as provided by the sensors) are undergoing a first level of metadata processing and homogenization following certain naming, units and date format conventions and are then stored into a specifically developed database system. Apart from the instantly recorded parameters, a few derived parameters (salinity, dissolved oxygen, sound velocity, etc.) are also included in the available observations. The conventions and the list of the parameters metadata used in the implementation of all the provided measurements are part of the Copernicus Marine In Situ TAC - physical parameters list (*Figure 2.1-2*).

After the homogenization process is complete, a first level of quality control is applied on the measurements with the use of automated near real time procedures (NRT qc). These procedures provide a first evaluation of the quality of the data by taking into consideration minimum and maximum valid ranges, spikes, and stuck values. The initial values of the datasets are not changed but an additional flag depicting the quality is included as a descriptor to each value. Apart from the automated near real time quality control, a delayed mode quality control is applied using advanced procedures, data comparison and visual inspection conducted by experienced scientists on a later time and at least twice per year. All these procedures are defined by parameter, elaborated in coherence with international agreements, those adopted within SeaDataNet project. Detailed information on the applied procedures can be found in the Relative Documentation on the CMEMS In Situ QC procedure manuals.

As soon as an evaluation phase is complete, the data and metadata are formatted into netCDF (Network Common Data Form) files, following globally used format conventions and standards by OceanSites and Copernicus. Under this format, these files are distributed into some of the most known repositories for marine data such as Copernicus, monGOOS and EMODnet. A description of available tools to open NetCDF files as well as a Python example of working with in-situ datasets can be seen in the Relative Documentation.

Apart from these repositories, the available datasets are publicly accessible through the POSEIDON services as open data. The users can view a brief graphical presentation of the POSEIDON network of observatories and the recorded data, as well as download the datasets of interest. The access to the download services is free but restricted to registered users.

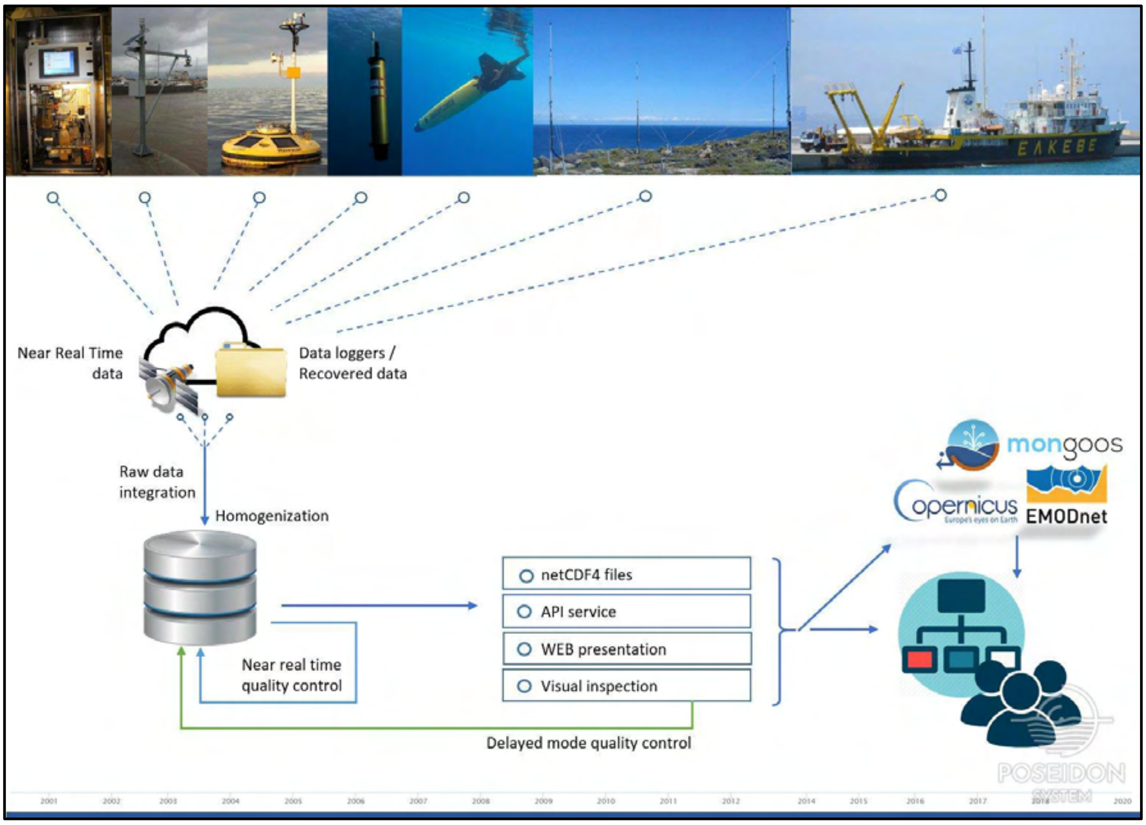


Figure 2.1-2. Data flow of monitoring activities and tools in Poseidon system, HCMR, Greece.

2.1.2 Space Monitoring of coastal Pollution, Russian Sector of Black and Azov Seas

In accordance with the request of the Government of the Russian Federation SRC "Planeta" in cooperation with Hydrometeorological Centre of Russia, Institute of Oceanology RAS, Space Research Institute RAS since 2003 carries out the satellite monitoring of coastal and biogenic pollution of marine environment within the Russian economic zone of the Azov-Black Sea basin. Satellite monitoring is organized with the consideration of international experience in this sphere as well as the specific features of contamination sources and aquatic environment dynamics of the Azov-Black Sea basin.

More than 1100 satellite images in visible, infrared and microwave bands from satellites such as Meteor-M №1, Kanopus-V №1, TERRA, AQUA, NOAA, Jason, Metop-A and Meteosat-10 are received and processed every year within the framework of the project.

A technology that allows interpreting the remote sensing data was developed. With this technology 12-14 types of satellite information data products are issued on a regular basis including maps of oil patches at the sea surface, water mass circulation, phytoplankton and algae distribution, chlorophyll-a concentration, diffuse attenuation coefficient distribution, sea surface temperature, near-water wind speed and sea-level charts, automated water objects recognition maps and water conditions and pollution chart-maps etc.

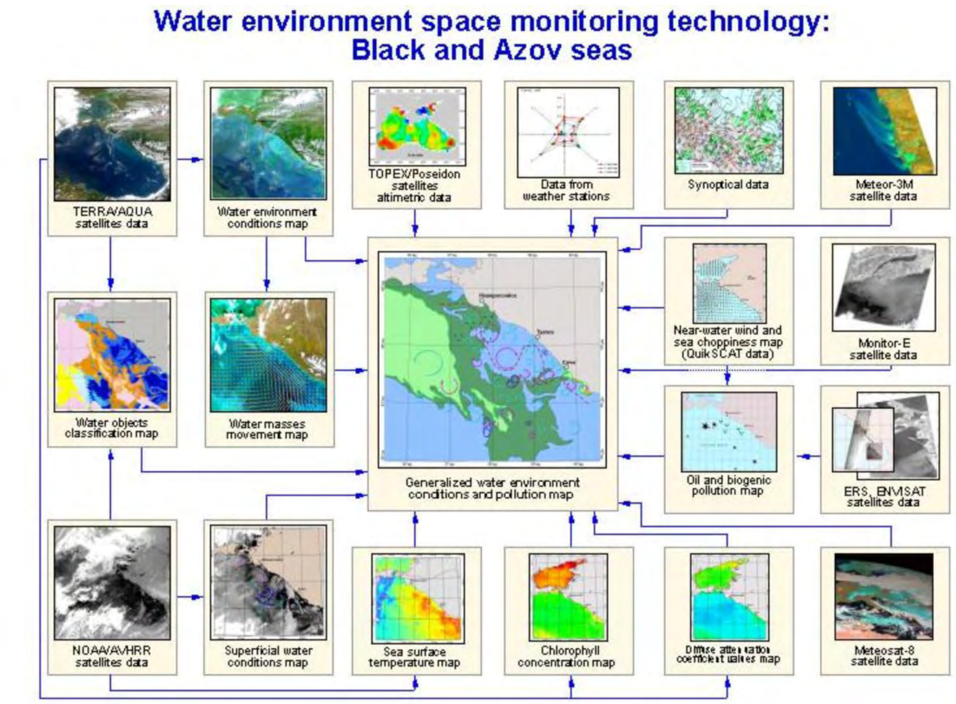


Figure 2.1-3 Space monitoring technology of Black and Azovs seas

Together with satellite data a classification and analysis of ground-based measurements at meteorological stations such as Sochi, Tuapse, Novorossiisk, Kerch, Primorsko-Akhtarsk and Rostov-on-Don, as well as hydrological stations located at the mouths of Don, Kuban and Sochi rivers are performed. This data is used for complex analysis of hydrometeorological and environmental conditions.

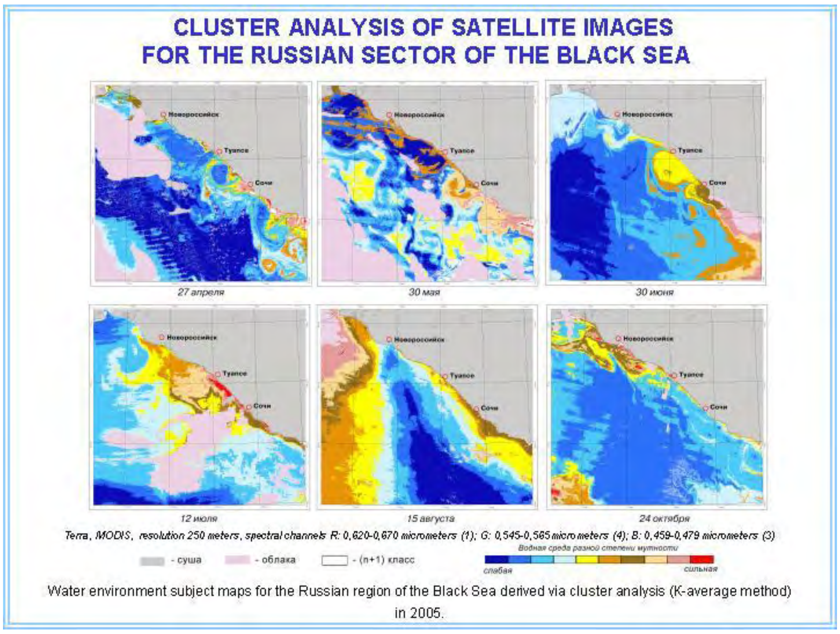


Figure 2.1-4 Cluster analysis of satellite images for the Russian sector of the Black sea

State Research Center SRC "Planeta" is a leading organization in exploiting and development of national satellite Earth observation systems for hydrometeorological, oceanographic, heliogeophysical and environmental purpose and also in receiving and processing data from foreign satellites. SRC "Planeta" works in cooperation with national hydrometeorological services and space agencies of more than 30 countries: USA, European Union, Japan, India, China, South Korea and others.

SRC "Planeta" ground system is one of the largest in the world and the largest in Russian Federation. It receives and processes vast amounts of data (more than 1,4 Terabytes per day) from national and foreign Earth observation satellites, issues more than 550 types of satellite information products, maintains a satellite data archive (that has a status of a Federal Data Fund) and supports more than 560 federal, regional and local level users. The system is the largest in the world in terms of territorial coverage (1/5 of the Earth’s surface).

In Russia this system is unique and is used as a base federal system for supporting federal government with satellite information. It is also used for supporting Russia’s obligations in international satellite data exchange. SRC "Planeta" acts as an operator of on-board hydrometeorological and oceanographical equipment that is mounted on national Earth observation satellites. At present, Russian orbital constellation consists of eleven meteorological and environmental satellites: two geostationary satellites "Elektro-L"№2 and "Elektro-L"№3 and nine polar-orbiting satellites: "Meteor-M"№1, №2, №2-2 "Resurs-P"№1,"Kanopus-V-IK" and "Kanopus-V""№3, №4, №5, and №6.

2.1.3 Buoy Observation System DEKOSIM (METU, Turkey)

Within the scope of DEKOSIM project, two shamanira systems will be established in order to make long-term and continuous measurements in the Black Sea and the Mediterranean. One of the buoy systems will be installed in front of Sinop in the Black Sea and the other in the Mediterranean, in front of the METU Institute of Marine Sciences campus in Mersin. There are sensors that will measure the surface at 10, 20, 30, 50, 75 and 100 meters on the system, which will be installed 5 miles off the coast, at a water depth of about 100 meters. All sensors measure temperature and conductivity (salinity). Receptors at 50 and 100 meters on the surface can measure dissolved oxygen. In addition, chlorophyll and turbidity measurements will be made on the surface.

The cable carrying the float system is also used to transmit data from the sensors carrying inductive modem to the float on the surface. On the float Meteorological measuring devices will be installed in accordance with the protocol signed with the General Directorate of Meteorology. Meteorological data will be published in real time on the D-OMGI website.

The products obtained from oceanographic data will be published on http://dekosim.ims.metu.edu.tr.

Figure 2.1-5 Buoy observation system DEKOSIM, Turkey

2.1.4 Innovative monitoring of marine environment and waste on beaches, IO-BAS Bulgaria

Innovative equipment is collecting data on the marine environment and waste on the beaches of the Bulgarian Black Sea coast. The activities are part of the project "MARine Litter, Eutrophication and Noise assessment tools (MARLEN)", funded by BG02 "Integrated management of marine and inland waters" priority BG 02.03: "Improved monitoring of marine waters" co-financed by the Financial Mechanism of the European Economic Area (EEA FM) 2009-2014. The main objective of the project is to build systems for assessment of the status of marine environment through application of new technologies, innovations and best practices for data collection for marine litter, eutrophication of surface waters and underwater noise.

Four ships owned by different companies were equipped with modern systems for collecting data of seawater properties. Each system has sensors that monitor the following parameters: Oxygen level; Sea water temperature; Turbidity; Conductivity; Chlorophyll; Dissolved oxygen. Sailing on their routes, they transmit real time data which is public available http://eugrant.io-bas.bg/marlen.html.

For examining underwater noise within MARLEN project four hydrophones were purchased equipped with up to date underwater microphones which record sounds in the sea at depths of 20-40 meters.

Figure 2.1-6 Black Sea marine monitoring, MARLEN project, IO-BAS Bulgaria

Figure 2.1-7 Underwater noise measurement, IO-BAS Bulgaria

IO-BAS introduced an innovative technology using an unmanned aerial vehicle with a multispectral camera for monitoring waste on beaches and the sea surface. With its help, vast and hard-to-reach areas, and water areas along the Bulgarian Ernomor coast can be observed.

This equipment was delivered within the project "Mapping and monitoring of depositional areas along the North Bulgarian Black Sea coast using Unmanned Aerial Vehicles", financed by National Science Fund of Bulgaria, contract No. KP-06-COST-12

Figure 2.1-8 Flying drone used by IO-BAS, Bulgaria

2.1.5 Photogrammetric & instrumental measurement of physico-chemical and biological parameters, DiNiMar, Bulgaria

An autonomous multiparameter probe and SPAR irradiance data logger with with a Flat LI-Cor sensor were delivered within the project “Development of an innovative method for underwater digital photogrammetric sea bottom capture in combination with instrumental measurement of physico-chemical and biological parameters of the aquatic environment” by the marine research company DiNiMar MPX. The two new facilities successfully took part in the water quality control, environmental and aquafarms monitoring.

SPAR enables to measure and record active radiation for photosynthesis in fresh and salt waters (radiation with wavelengths between 400nm and 700nm).

MPx enables to measure and record up to 7 physicochemical parameters: Temperature; Pressure (depth); Conductivity (salinity); Turbidity; Dissolved oxygen; Fluorescence (Chlorophyll a, Phycocianine, Phycoerythrin); pH.

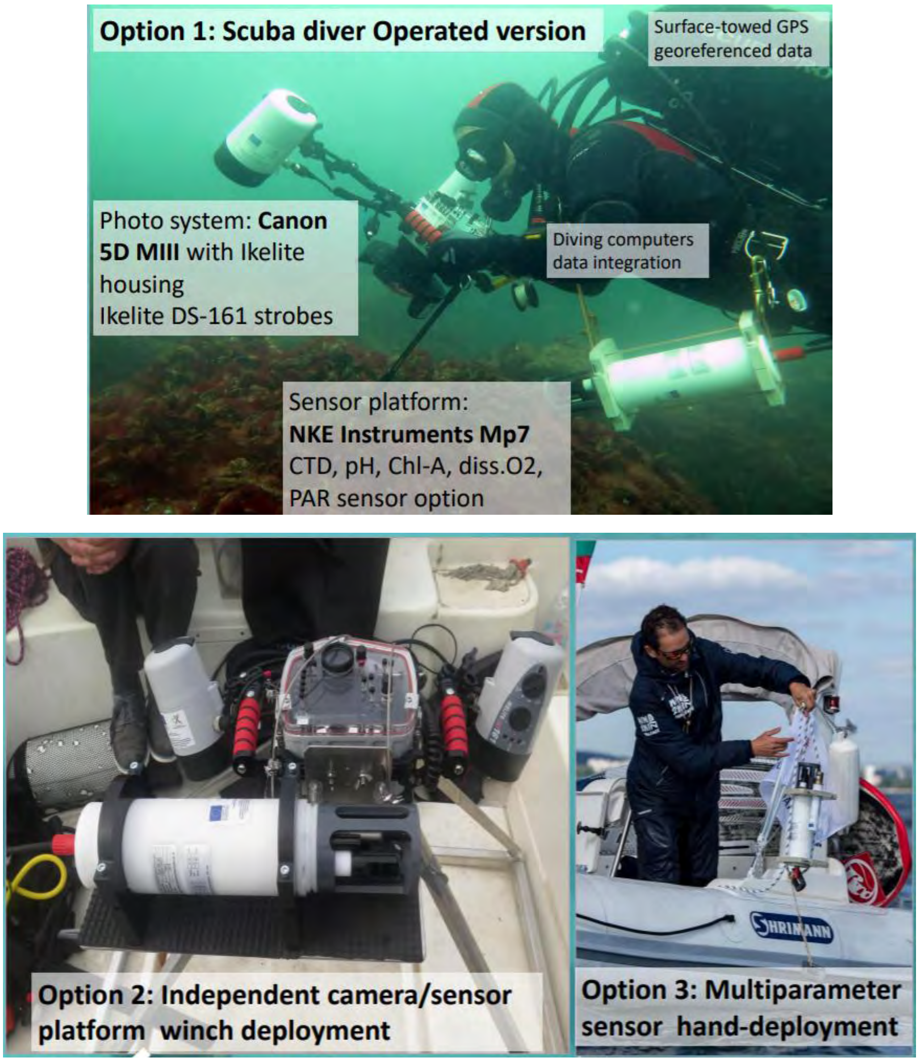


Figure 2.1-9 Photogrammetric & instrumental measurement of physico-chemical and biological parameters
(source: http://www.dinimar.com/bg/%d0%bf%d1%80%d0%be%d0%b5%d0%ba%d1%82%d0%b8/)

2.2 Fish Stock Assessment. Non-fish (shellfish) resource assessment.

2.2.1 *Innovative methodology for the stock assessment and forecast of shellfish species (IFR, Varna)*

An innovative methodology for the stock assessment and forecast of shellfish species has been demonstrated by the INSTITUTE OF FISH RESOURCES, Varna, Bulgaria. This methodology was developed within the framework of the project ECRAMON. Funded within the National Operational programme BG02 "Integrated management of marine and inland waters".

The main goal of the ECRAMON was to assess the stocks, biological parameters, and distribution of economically important shellfish species - Mediterranean black mussel (Mytilus galloprovicialis) and veined rapa whelk (Rapana venosa) in the Bulgarian Black Sea waters. In addition, three different scenarios - intensive fishing, black mussel restocking and designation of fish ban areas - have been developed in order to forecast the development of the shellfish species under different hydrological and ecological conditions in the Black Sea by using MIKE 21 FM and EcoLab software packages.

The monitoring along the Bulgarian Black Sea waters included both hydrobiological and hydrochemical parameters, together with bottom trawling to collect the necessary samples. This allowed the development of the statistical relationships that describe the changes in the ratio of the shellfish species and eventually form the stock assessments. All data has been processed and used for the eco-hydraulic numerical modelling.

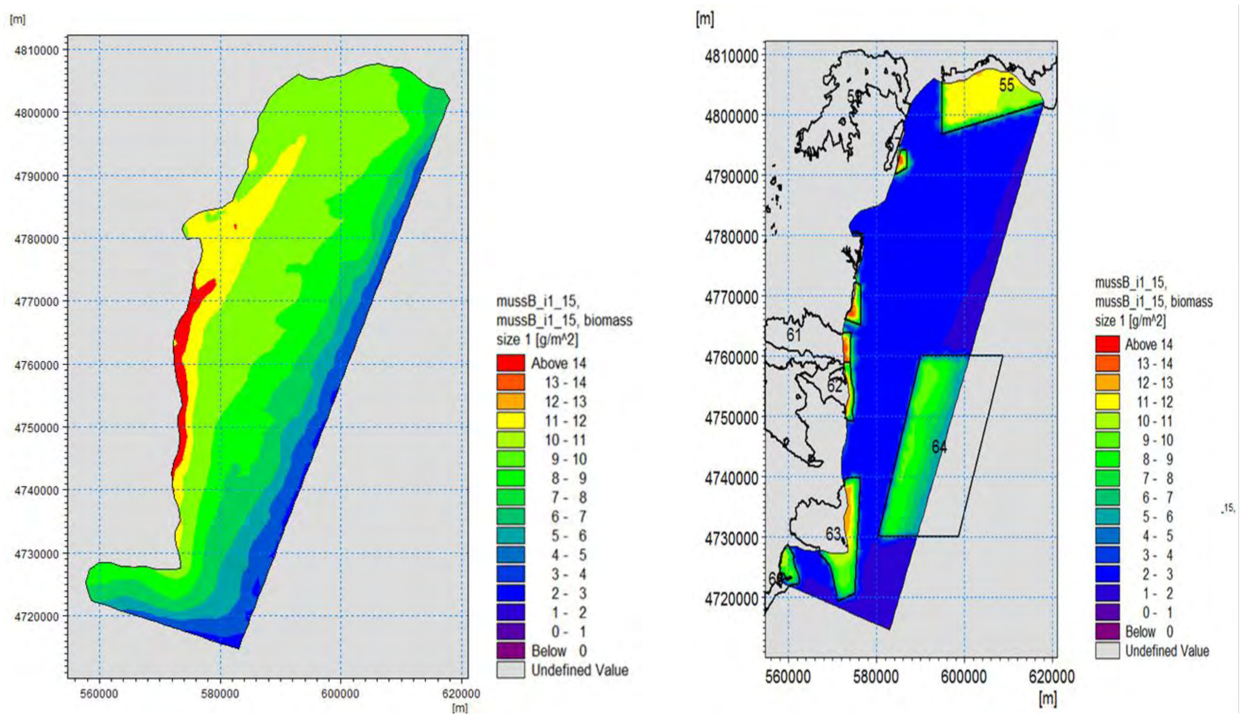


Figure 2.2-1 Simulation of the black mussel's biomass (gDW/m^2) with designated "fish ban" areas

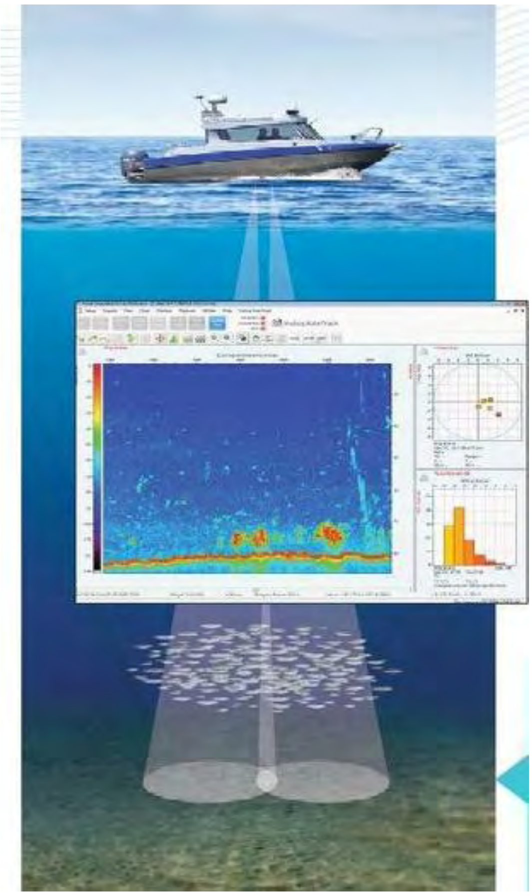
The complex numerical modelling allowed the simulation of the recovery of the black mussels through the designation of "fish ban" areas for a period of 3 years, with the possibility to manage the areas after that period to assure optimal resources exploitation without compromising the stocks.

The project results would be beneficial for a wide range of stakeholders in the fisheries sector - governmental agencies, fisheries associations, NGOs, educational and scientific institutions. At international level, the results would be of practical importance for the Commission on the Protection of the Black Sea (Istanbul, Turkey) and the General Fisheries Commission of the Mediterranean and the Black Sea (GFCM) and might form a platform to advance international collaboration on protection of the shellfish resources.

2.2.2 *Assessment of commercial fish stocks by hydro-acoustic system, NEA, Georgia*

To improve the assessment of commercial fish stocks LEPL NEA (Georgia) has purchased modern equipment, multibeam echosounder BioSonics. With the kind support of FAO and GFCM, the launch of the hydro-acoustic survey for anchovy (Engraulis encrasicolus ponticus) in the Georgian Black Sea territorial waters is planned this year.

BioSonics scientific echo-sounders for fisheries and aquatic habitat assessment include necessary features to explore aquatic ecosystems using hydroacoustics. Proven single and split-beam sonar echosounder systems are versatile, optimized for flexibility, reliability, and ease of operation, and include the data acquisition, real-time analysis, data visualization, and post-processing software you need to get results.



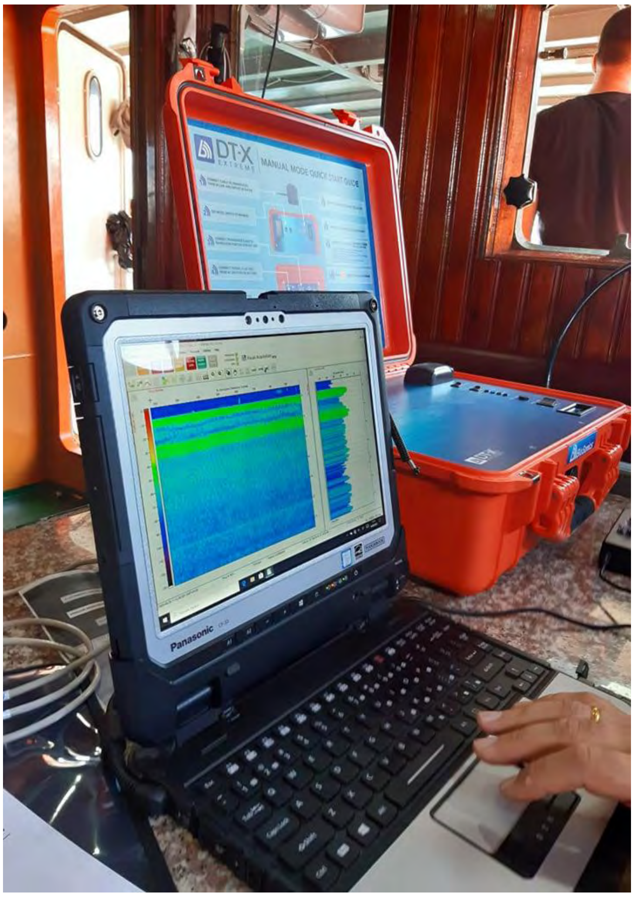


Figure 2.2-2 Hydro-acoustic system (BioSonics scientific echo-sounders) for stock assessment

Mobile Survey Applications[1]

- Scientific Fisheries Echosounder

[1] https://www.biosonicsinc.com/products/dt-x-extreme/

- Fish Stock Assessment
- Population Estimates
- Size Distribution
- Total Biomass Estimates
- Vertical and Horizontal Distribution
- Behavioral Studies
- Plankton Biomass / Vertical Migration
- Predator / Prey Relationships
- Fish Schools, Individual Fish (all size classes), Marine Mammals
- Plankton mapping
- Physical Oceanographic Measurements; Boundary, Mixing and Coherent Structure Detection
- Autonomous Surface Vehicles (ASV), Autonomous Underwater Vehicles (AUV), ships of opportunity, unattended fish stock assessment mobile surveys, and reporting

2.2.3 Fish Stock Assessment from Mediterranean

Colloca et al. (2017) review the recent data on Mediterranean fishing fleets and landings, results from stock assessments and ecosystem models to provide an overview of the multiple impacts of fishing exploitation in the different Mediterranean geographical sub-areas (GSAs). They found that overall landings of fish, crustaceans, and cephalopods, after peaking during mid 90s at about one million tons, declined at about 700,000 tons in 2013. However, while landings are declining in EU countries since the 90s, in non-EU countries a decreasing trend was observed only in the last 5–10 years. The current levels of fishing effort determine a general overexploitation status of commercial stocks with more than 90% of the stock assessed out of safe biological limits. Indicators obtained from available ecosystem models were used to assess the sustainability of the fisheries. They included primary production required to sustain fisheries (PPR), mean trophic level of the catch (mTLc), the loss in secondary production index (L index), and the probability of the ecosystem to be sustainably exploited (psust).

In areas exploited more sustainably (e.g., Gulf of Gabes, Eastern Ionian, and Aegean Sea) fishing pressure was characterized by either low number of vessels per unit of shelf area or the large prevalence of artisanal/small scale fisheries. Conversely, GSAs in Western Mediterranean and Adriatic showed very low ecosystem sustainability of fisheries that can be easily related with the high fishing pressure and the large proportion of overfished stocks obtained from single species assessments (Figure 2.2-3).

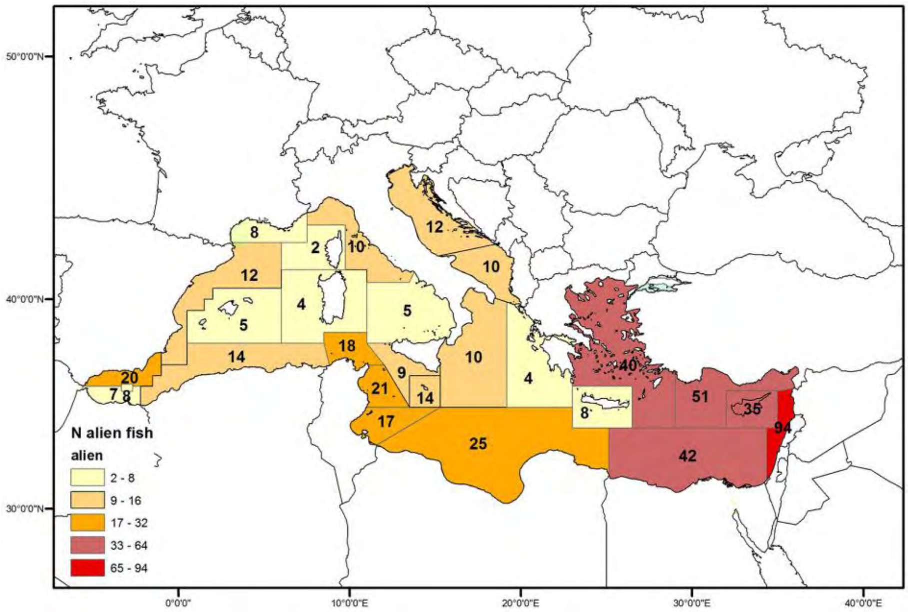


Figure 2.2-3 Number of non-indigenous species by GSA. Data from the CIESM Atlas of Exotic Species in the Mediterranean (http://www.ciesm.org/online/atlas/).

Neofitou et al. (2019) introduced a novel GIS application for environmental monitoring and assessment of fish farming impacts on nutrients of Pagasitikos Gulf (Greece), Eastern Mediterranean. The spatial and temporal effect of fish farming on the water column of Pagasitikos Gulf was examined by means of a GIS tool. For this purpose, a horizontal and a vertical transect of 11 sampling stations was settled. The General Linear Model (GLM) analysis showed significant spatial and temporal differences for DO, chl-a and nutrients, except for NH_4 and NO_3 that were not revealed temporal variation. DO and NH_4 distribution revealed a specific pattern of impact from the fish farm operation. However, concentration of nutrients does not exceed the permitted limits for eutrophication or affect the welfare of cultivated organisms. Moreover, GIS considered to be a very useful tool for the investigation and presentation of the fish farming effects in the aquatic environment, forming a unique system which enables one to estimate the values of the un-sampled points within the study area gaining valuable money and time. Further studies are set as a future goal in order to improve the efficiency of the GIS tool at the disposal of the aquaculture sector in the Mediterranean Sea.

Raicevich et al. (2017) comment on the critical inconsistencies in early implementations of the Marine Strategy Framework Directive (MSFD) and Common Fisheries Policy (CFP) objectives hamper policy synergies in fostering the sustainable exploitation of Mediterranean fisheries resources. The MSFD aims to achieve “Good Environmental Status” (GES) in EU marine waters by 2020. This initiative started its first phase of implementation in 2012, when each member state defined the GES and environmental targets in relation to 11 descriptors and related indicators for 2020. In 2013, the EU Commission launched the reformed CFP, which aims to achieve biomass levels capable of producing maximum sustainable yield (MSY) for all commercial stocks exploited in EU waters by 2020, as well as contribute to the achievement of GES. These two pieces of legislation are aligned since according to Descriptor 3 (commercial fish and shellfish), the MSFD requires reaching a healthy stock status with fishing mortality (F) and spawning stock biomass (SSB) compatible with the respective MSY reference limits for all commercial species by 2020. The authors investigated whether the two policies are effectively aligned in the Mediterranean Sea, an ecosystem where the vast majority of stocks show unsustainable exploitation. For this purpose, they assessed and compared by cluster analysis the number and typology of stocks considered by the member states when assessing GES in relation to data on stocks potentially available according to the EU Data Collection Framework (DCF) and the proportion of landings they represented (Figure 2.2-4). The number of stocks considered by the member states per assessment area was uneven, ranging between 7 and 43, while the share of landings corresponding to the selected stocks ranged from 23 to 95%. A lack of coherence between GES definitions among the member states was also revealed, and environmental targets were less ambitious than MSFD and CFP requirements. This could possibly reduce the likelihood of achieving fishery sustainability in the Mediterranean by 2020. These conditions limited the envisaged synergies between the two policies and are discussed in consideration of the recent Commission Decision on criteria and methodological standards for GES.

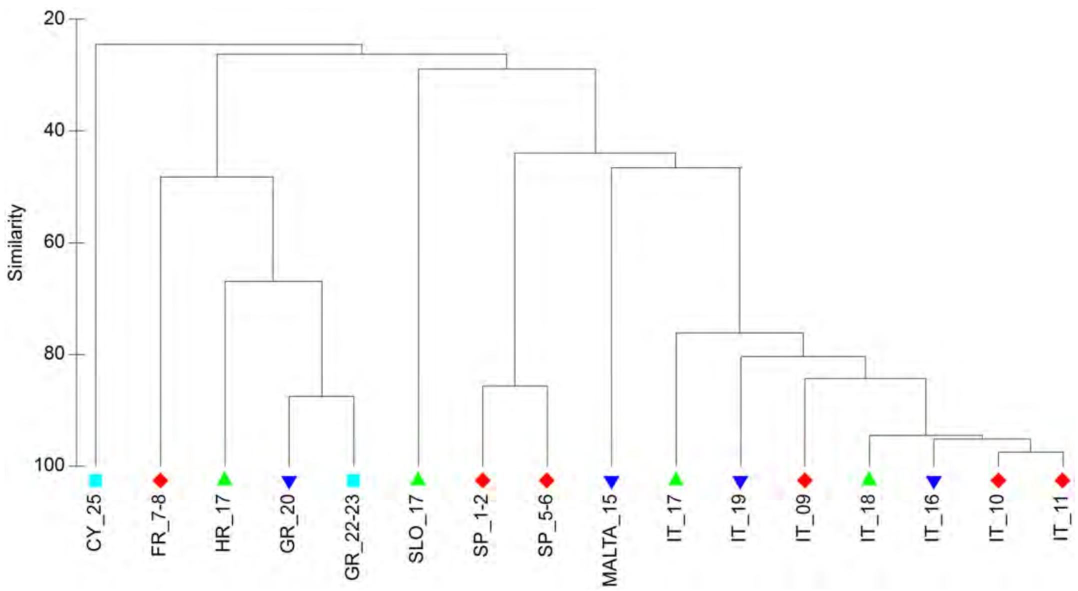


Figure 2.2-4 Cluster analysis (group average, based on Bray-Curtis similarity matrix) of stocks selected per assessment areas (presence/absence data) within the MSFD Initial Assessment in the Mediterranean Region.

2.2.4 SKYFISH - Service for Water Quality Monitoring for Sustainable Fishing and Aquaculture in the Romanian Coastal Area

The SkyFISH platform, developed as a CMEMS downstream service, is a dedicated web-based service that can be used by the end-users as a decision support tool for finding the most favorable fishing zones or analyze the suitability of specific areas for aquaculture activities and monitoring of the existing ones. The area of interest covered by the service is the Romanian coastal zone.

SkyFISH takes advantage of the wealth of data delivered under the Copernicus program (CMEMS) and other data sources. It makes use of advanced Earth Observation data analysis and web-mapping technologies in order to offer access to a wide variety of physical ocean parameters. Users can retrieve, in a simple and user-friendly way, information regarding both essential water-related variables (i.e., temperature, salinity, turbidity etc) and other contextual information (i.e., lighthouses location, bathymetry, meteorological conditions etc).

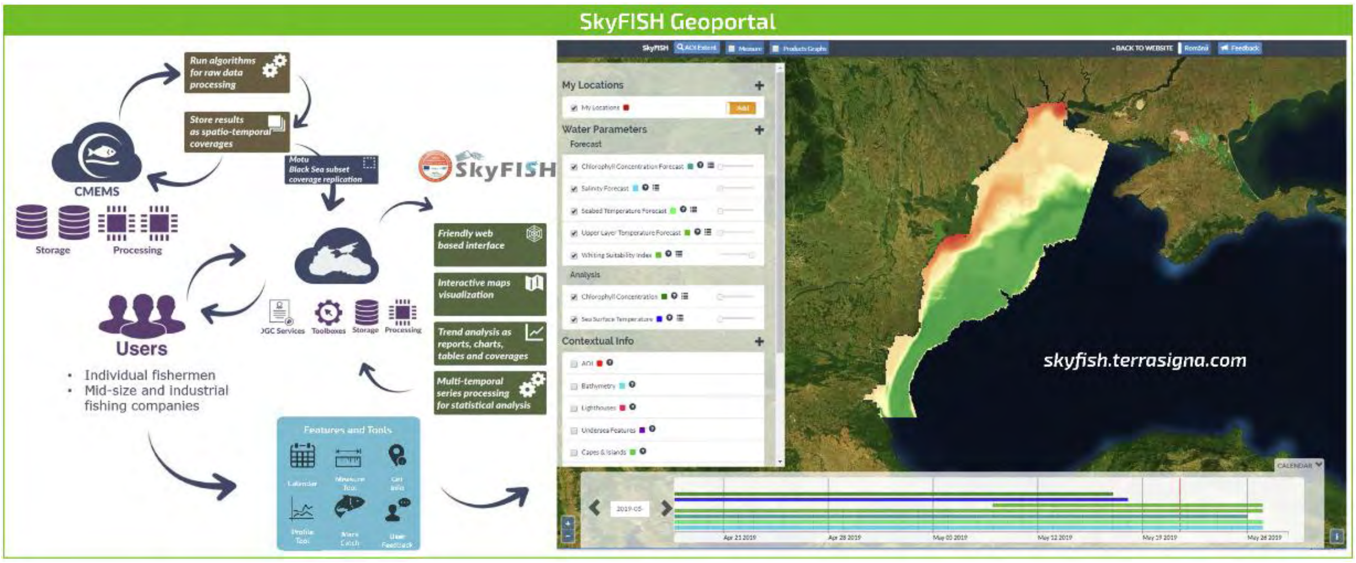


Figure 2.2-5 SkyFISH web-based service geoportal architecture

(from Şerban et al., 2019, http://skyfish.terrasigna.com/)

The main added-value products derived based on these datasets are <u>the suitability indices for fishing and aquaculture activities</u> (Generated using E.U. Copernicus Marine Service Information). The service directly addresses multiple categories of stakeholders, from individual fishermen, to mid-size and industrial fishing companies.

Table 2-1 Datasets from Copernicus Marine Service currently integrated into SkyFISH

Black Sea Physics Analysis and Forecast	BLKSEA_ANALYSIS_FORECAST_PHYS_007_001
Black Sea Physics Reanalysis	BLKSEA_REANALYSIS_PHYS_007_004
Black Sea Monthly and 8-days Reprocessed Surface Chlorophyll Concentration from Multi Satellite Observations + SeaWiFS Daily Climatology	OCEANCOLOUR_BS_CHL_L4_REP_OBSERVATIONS_009_079
Global Ocean NRRS, BBP, CDM, KD, ZSD, SPM (Copernicus-GlobColour) from Satellite Observations: Monthly, 8-days, Daily-Interpolated (Reprocessed from 1997)	OCEANCOLOUR_GLO_OPTICS_L4_REP_OBSERVATIONS_009_081
Black Sea High Resolution and Ultra High Resolution Sea Surface Temperature	SST_BS_SST_L4_NRT_OBSERVATIONS_010_006
Black Sea Monthly, 8-Days and Daily Interpolated Surface Chlorophyll Concentration from Multi Satellite and Sentinel-3 OLCI observations	OCEANCOLOUR_BS_CHL_L4_NRT_OBSERVATIONS_009_045

2.2.5 *ESPOSS: Big Data Infrastructure for the Black Sea region*

ESPOSS is a web based EO data access and processing application for the Black Sea, developed by the Advanced Studies and Research Center (ASRC), in response of the users' demands for simple interfaces to inspect, download, process and analyze marine application data. The application incorporates geospatial data from various sources (satellite images, in-situ data, model outputs) and serves as a working tool for the scientific community and the relevant decision makers. One of the main challenges to be overcame by the ESPOSS platform is the very large quantity of EO and other type of data that is required to be accessed and fast analyzed in order to provide meaningful insight upon various environmental aspects related to the Black Sea basin. The volume of data manipulated by ESPOSS (especially EO data) is significant. However, ESPOSS will not replicate those datasets that can be accessed online through standard network services. To keep the rest of the data in a manageable size, ESPOSS will use special file formats with lossless compression mechanism. The main risk of relaying on third-party services is the lack of guarantee that the service will be always accessible. In order to manage such risks ESPOSS shall address as much as possible data coming from reliable services, such as the ones developed by ESA. The most important example would be MyOcean, the Copernicus service for marine monitoring thematic area. Another main challenge in developing such a web portal is finding the best solution for representing and processing together data coming from various sources. Each piece of information is characterized by different formats, coordinate reference systems, spatial and temporal resolution etc. Coping with all these variables can prove to be not an easy task. Other challenges in developing ESPOSS might refer to: application design and interoperability, accessibility and creating a single-entry point for all datasets and functionalities.

ESPOSS offers services based on Open Geospatial Consortium (OGC) standards for data retrieval (WMS [1], WCS [2], WFS [3]) and server-side processing (WPS) [4]. The services were built upon open-source solutions such as: GeoServer, OpenLayers, GeoExt, PostgreSQL, GDAL, GRASS GIS. The application is composed of several software modules/services. The modules are split into two categories: server-side modules/services (Data storage and access module, Data transformation, harmonization and routing service, Catalogue/Discovery service, Gazetteer service, Data portrayal/view service, Data download service, Data processing/invoke service, Coordinate transformation service, Access control service) and client side modules - responsible for interaction with the user (User module, Webmapping module, Chart viewer module, Profile viewer module, Notification module).

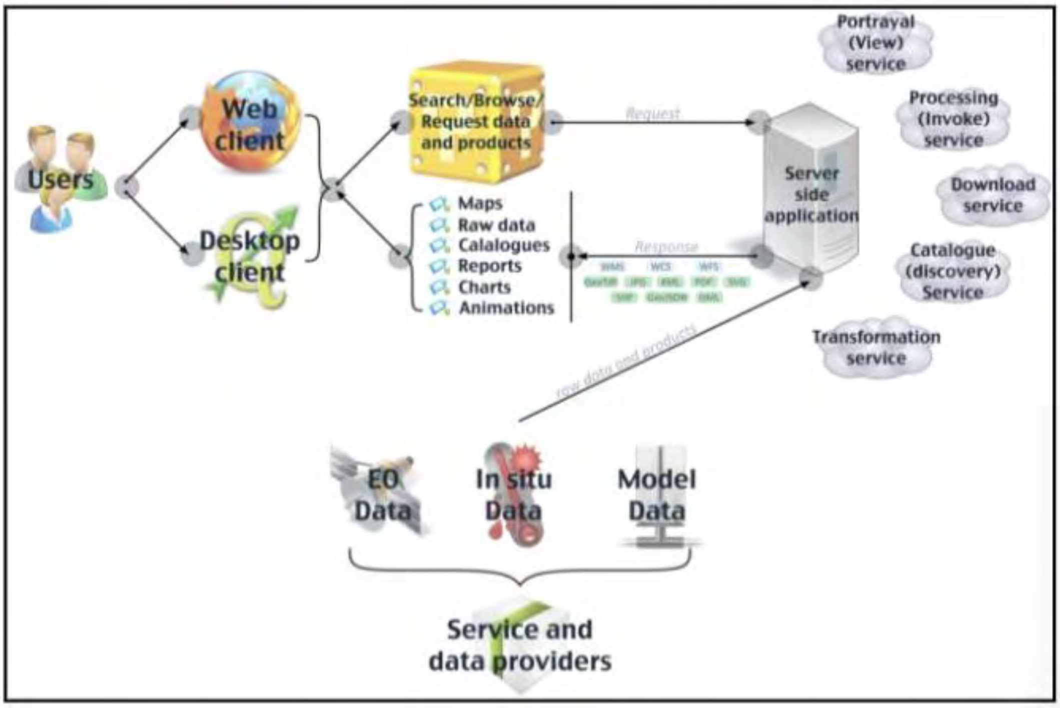


Figure 2.2-6 Architecture of the ESPOSS big data infrastructure
(from Șerban et al., 2014)

2.2.6 *Collecting water quality data by EMSO - EUXINUS / GeoEcoMar*

In 2017 "EMSO - EUXINUS" has been included as a landmark research infrastructure. The roadmap was prepared by the Romanian Committee for Research Infrastructures (CRIC), following a process of evaluating the proposals received from the scientific community. The evaluation was performed with the support of external evaluators.

Through its subsystems, the Center is top position in the Black Sea area, regarding the monitoring of the water column and security at natural marine hazards. The above-mentioned center, due to the uniqueness of the Black Sea, (the Black Sea is the largest anoxic marine basin on the planet, with a weak connection to the World Ocean) since 2016 has become a Node of Pan-European Research Infrastructure - EMSO (European Multidisciplinary Seafloor and water column Observatory) -ERIC, this being the only structure of this kind at national level that is part of a European Consortium for Research Infrastructures (ERIC). Also, starting with 2020, IOSIN "EMSO - EUXINUS" became a member of the European Consortium for Research Infrastructures (ERIC), namely EPOS ERIC (European Plate Observing System).

The three offshore observatories located in the Romanian continental shelf, EuxRO 1, EuxRO 2 and EuxRO 3, one Coastal gauge located near Mangalia and the GNSS Geopontica network, sends data in real time to the National Warning and Observatory Center to Marine Natural Hazards EMSO-EUXINUS.

The surface relay buoys of the observatories EUXRo01, EUXRo03, and CG, are equipped with a weather station continuously measuring the following parameters: wind speed and direction, temperature, pressure. The instrument also integrates a heading sensor, which allows the automatic correction of the wind direction for the buoy rotation. The SRB of each observatory is also equipped with an environmental monitoring instrument pack, mounted on the buoy pole at 5 m water depth. The instrument pack includes:

- a Doppler current meter
- classic CTD sensors (conductivity, temperature, pressure)
- sensors for measuring dissolved oxygen concentration, turbidity, and chlorophyll-a concentration

Auxiliary equipment of the SRBs include a communication box with GPS receiver, radio link allowing full control of the buoy from a nearby ship, iridium bilateral link with antenna for satellite data transmission to the coordination centres and reprogramming of the sensors, active and passive radar reflectors, IALA signalling light and four solar panel for recharging the batteries. A second instrument pack is mounted on the mooring line of each observatory, at 20 m above the bottom of the sea. This pack consists in a Doppler current meter and classic CTD sensors. The tsunamis underwater module, located on the sea bottom, is equipped with a high-resolution pressure sensor and temperature sensor, mounted in titanium housing with pressure port at sea. Each underwater instrument pack has an acoustic communication system for transmitting the data to the SRB. From SRB the data are retransmitted via satellite Iridium bilateral link to two interlinked coordination centres, located in Constanta (Romania) and Varna (Bulgaria).

Figure 2.2-7 EMSO - EUXINUS surface relay buoys
(source: https://eeris.eu/ERIF-2000-000T-0110)

2.2.7 Offshore hydro-meteo buoy at Danube delta, Sulina branch, AFDJ Galati RA

AFDJ Galati RA is a Romanian company whose activity includes the assurance of navigation conditions on Danube by means of dredging works, topo-hydrographical survey, coast and floating signalization, piloting on the maritime Danube sector between Sulina roadstead and Braila and in the Danube maritime ports, special transport on the river and maritime Danube, internal and international tugging as well. The company is operating an offshore buoy located in the Black Sea, at the entry point of the Sulina branch.

Figure 2.2-8 AFDJ off-shore hydro-meteorological buoy in front of Danube delta

The buoy is a hydrometeorological buoy of a 2.0 m diameter, with a couple of sensors and instruments installed on it.

The measured parameters are wind (speed, direction), temperature, wave height and current speed and direction at 3 different depths. The buoy also has installed a radar deflector, AIS/ATON and all data are transmitted remotely via a data-logger with a GPRS modem. The data are received and viewed on a server located at the customer headquarter with options for graphics, table view and also history.

Using this buoy and the data provided, the user, AFDJ GALATI RA can decide if the navigation is possible or not on the Sulina branch, decisions that can be taken from the headquarter in time periods of every 15 minutes.

2.3 Sensor-Carrying Platforms

2.3.1 *Underwater ROV "Max Rover", NCMR, Greece*

Figure 2.3-1 ROV Max Rover Equipment

Greek HCMR's ROV Max Rover Mark II model (**Error! Reference source not found.**) is equipped with 3 video cameras and digital still camera Scanning and side-scan sonarCompass, compass, altitude, and depth sensors, a Trackpoint II USBL positioning system georeferenced through Hypack Max software system, a robotic arm with 5 axes of movement. It is manufactured by Deep Sea Systems International Inc. The ROV's maximum operating (dive) depth is 2000 m with unlimited operating time. Its total weight is 750 kg with dimensions, Length: 2.2 m, Width: 0.9 m, Height: 1.2 m, giving a payload of 68 kg. Max Rover floats by syntactic foam equipment and carries a hydraulic winch 380V (3 phases), 25hp, with slip ring assembly and typical dimensions 2x2x2 m, for a 4.5 tonnes weight. It can reach an underwater speed of 2.5 knots (fwd/rev), 1.5 knots (vert/lat) with bollard pull capacity of 160 kg. It also uses 2 sonars: Tritech Dual Frequency Scanning Sonar (675/1200 KHz) & Tritech Side Scan Sonar (910 KHz) and 4 cameras: Colour CCD video camera (wide angle, on pan & tilt), Colour CCD video camera (wide angle), Colour CCD video camera (macro-zoom on pan & tilt), digital Still Camera (3.2 Mpixel, 1Gb) with 4 green lasers. It is manipulated by Hydrolek electro-hydraulic 5 function.

2.3.2 *Application of a flying drone to marine research, IO-BAS Bulgaria*

IO-BAS introduced an innovative technology using an unmanned aerial vehicle with a multispectral camera for monitoring waste on beaches and the sea surface. With its help, vast and hard-to-reach areas, and water areas along the Bulgarian Ernomor coast can be observed.

This equipment was delivered within the project "Mapping and monitoring of depositional areas along the North Bulgarian Black Sea coast using Unmanned Aerial Vehicles", financed by National Science Fund of Bulgaria, contract No. KP-06-COST-12

Figure 2.3-2 Flying drone IO-BAS Bulgaria

2.3.3 Unmanned surface vehicle (USV) drone, CORES Bulgaria

CORES-A1 is a solar powered USV for hydrographic surveys, provided with navigation & measurement equipment; managed remotely from the shore and transmitting data in real time. This USV provides several advantages compared to traditional survey boats, and cuts substantially the costs of eco-monitoring at sea, or at inland waters (Figure 2.3-3)

Figure 2.3-3 Unmanned surface vehicle (USV) - Aquatic drone / CORES Bulgaria

(http://coresbg.eu)

Main features of the CORES-A1 boat:

- Replaces survey motorboats saves money, saves the environment, brings security!

- Easy-to-transport, easy-to-use: operated by 1 person from the land + autopilot (self-steering)
- Navigation / GPS
- electronic SELF-STEERING (AUTOPILOT) system, follows a predefined route;
- Sensors: echo sounder; ground velocity; current velocity, turbidity, salinity, pH
- Water sampling (remote operated)
- on-board computer, 24 Digital I/O, for connecting measuring devices);
- 2.4 GHz radiotelemetry data transfer system, range 1000 m
- Onboard camera; underwater camera
- Designed to access hard-to-reach locations (e.g., shallow water, dangerous sites)
- Perfect balance of power consumption, manoeuvrability, stability, and pay-load
- Zero emissions: electric engines, enhanced solar power, smart battery charge

Selected as “Product of the month” by Water Inn EU, February 2017 (www.MarketPlace.WaterInnEU.org).

2.4 ICT Tools

2.4.1 The POSEIDON forecasting system for the Mediterranean basin (HCMR, Greece)

The POSEIDON system is HCMR's operational forecast system in the Mediterranean Sea basin, presented analytically in Section 3.9 of D.T1.1.1 (Figure 2.4-1). POSEIDON's infrastructure refers to the Mediterranean basin, for the ocean model forecasting of the marine environment, supporting the efforts of the international and local community and replying to the needs and gaps of science, technology, and society in the EU and globally.

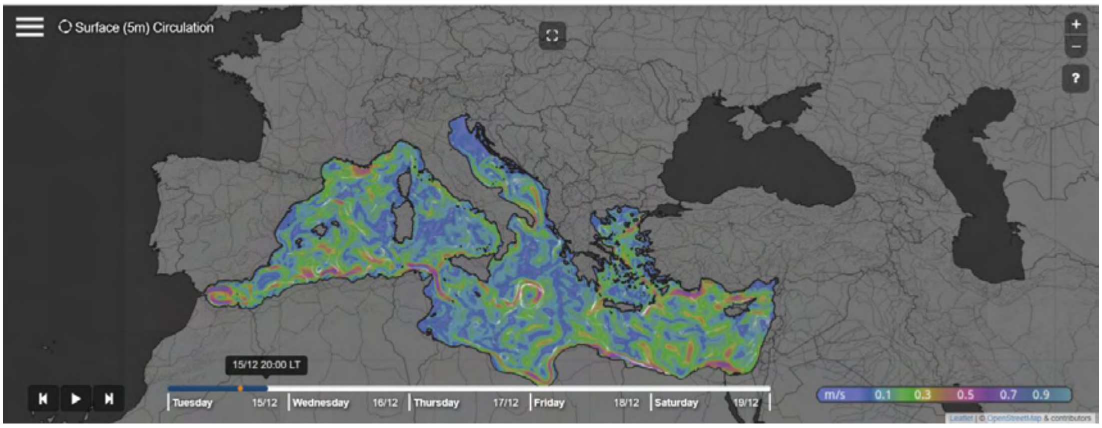


Figure 2.4-1 POSEIDON forecasting system of Mediterranean ocean circulation.

The POSEIDON forecast system consists by a suite of numerical models that provide atmospheric, wave, hydrodynamic and ecosystem forecasts for the next five days in daily basis (Figure 2.4-2). It also cooperates with HCMR's data management and dissemination unit, which collects and process the data from the monitoring network and distributes the observing and forecasting products to the linked European Infrastructures and to the public.

The Mediterranean Sea ocean forecasting system is composed of a 1/10° resolution – 24 sigma layers Mediterranean implementation of POM model (Korres et al., 2008) and a data assimilation scheme based on the Singular Evolutive Extended Kalman (SEEK) filter (Pham et al., 1998; Hoteit et al., 2005). SEEK is an error subspace extended Kalman filter that operates with low-rank error covariance matrices as a way to reduce the computational burden. The filter uses covariance localization and partial evolution of the correction directions (Korres et al., 2008). The assimilation scheme corrects the forecast state of the model on a weekly basis. The assimilated observational data set is multivariate including AVISO sea level height, AVHRR sea surface temperature, MEDARGO floats T and S profiles and XBT data.

The Mediterranean hydrodynamic model is forced with hourly momentum, heat and freshwater fluxes derived from the POSEIDON weather prediction system based on a 1/20° ETA regional non-hydrostatic atmospheric model. The Mediterranean model provides 5-days forecasts and additionally initial and open boundary conditions to the 1/30° POM model of the Aegean Sea. The Aegean Sea hydrodynamic model is based on the Princeton Ocean model (POM) and was initially developed as part of the Poseidon-I system (Nittis et al., 2006; Korres et al., 2002). POM is a primitive equations free surface ocean model which operates under the hydrostatic and Boussinesq approximations. The model equations are written in sigma-coordinates and discretized using the centered second-order finite differences approximation in a staggered "Arakawa C-grid" with a numerical scheme that conserves mass and energy.

The model domain covers the geographical area 19.5°E – 30°E and 30.4°N – 41°N with a horizontal resolution of 1/30° and 24 sigma layers along the vertical with a logarithmic distribution near the surface and the bottom. The model includes parameterization of the main

Greek rivers (Axios, Aliakmonas, Nestos, Evros) while the inflow/outflow at the Dardanelles is treated with open boundary techniques. The Aegean Sea model is forced with hourly surface fluxes of momentum, heat and water provided by the Poseidon - ETA high resolution (1/20°) regional atmospheric model issuing forecasts for 5 days ahead (*Figure 2.4-2*).

For the computational simulation nesting procedures, the boundary conditions at the western and eastern open boundaries of the Aegean Sea hydrodynamic model are provided by:

1) The HCMR Mediterranean model with a resolution of 1/10° and 24 sigma layers in the vertical on an hourly basis for VERSION-I of the forecasting system.

2) the Mediterranean Ocean Forecasting System model (MFS, GNOO-INGV) covering the whole Mediterranean Sea with a resolution of 1/16° and 72 levels in the vertical on a daily basis (daily averaged fields) for VERSION-II of the forecasting system.

The nesting between the two models involves the zonal/meridional external (barotropic) and internal velocity components, the temperature/salinity profiles and the free surface elevation following the nesting procedures described in Korres and Lascaratos (2003). Additionally, volume conservation constraints between the two models are applied at both open boundaries of the Aegean Sea model.

The Aegean Sea model is re-initialized from the HCMR Mediterranean model (Version-I) or MFS OGCM (Version-II) analysis once every week. In order to filter out spurious oscillations that may occur during the re-initialization procedure, the VIFOP optimization tool has been implemented (Auclair et al., 2000) in the forecasting system. VIFOP is a variational initialization technique based on the minimization of a cost function involving data constraints as well as a dynamical penalty involving the tangent linear model.

Basic system attributes are summarized in the following:

Version name	VI/VII
Type	3D primitive equation, finite difference, free surface (based on POM code)
Model region	Aegean Sea(19.5°E -30°E; 30.4°N-41°N)
Coordinate system	Type Orthogonal curvilinear – WGS84 geographical projection
Grid spacing	1/30°×1/30° One way nested with the Mediterranean SYS2b model
Vertical coordinates	Sigma coordinates
Vertical Grid spacing	25 levels with logarithmic distribution near surface and bottom

Initialization procedure of new forecast cycle is based on:

Source	HCMR MED/MFS MED
Initialization method	Variational initialization method (VIFOP)

Surface forcing is based on:

Source	POSEIDON non-hydrostatic atmospheric model
Grid spacing	1/20° × 1/20°
Parameters	Wind speed at 10 m, air temperature at 2 m, relative humidity, net shortwave radiation, downward longwave radiation, precipitation
Frequency	Every 1 hour

River runoff:

Source	Climatological runoff data for the major Greek rivers.
Frequency	Monthly

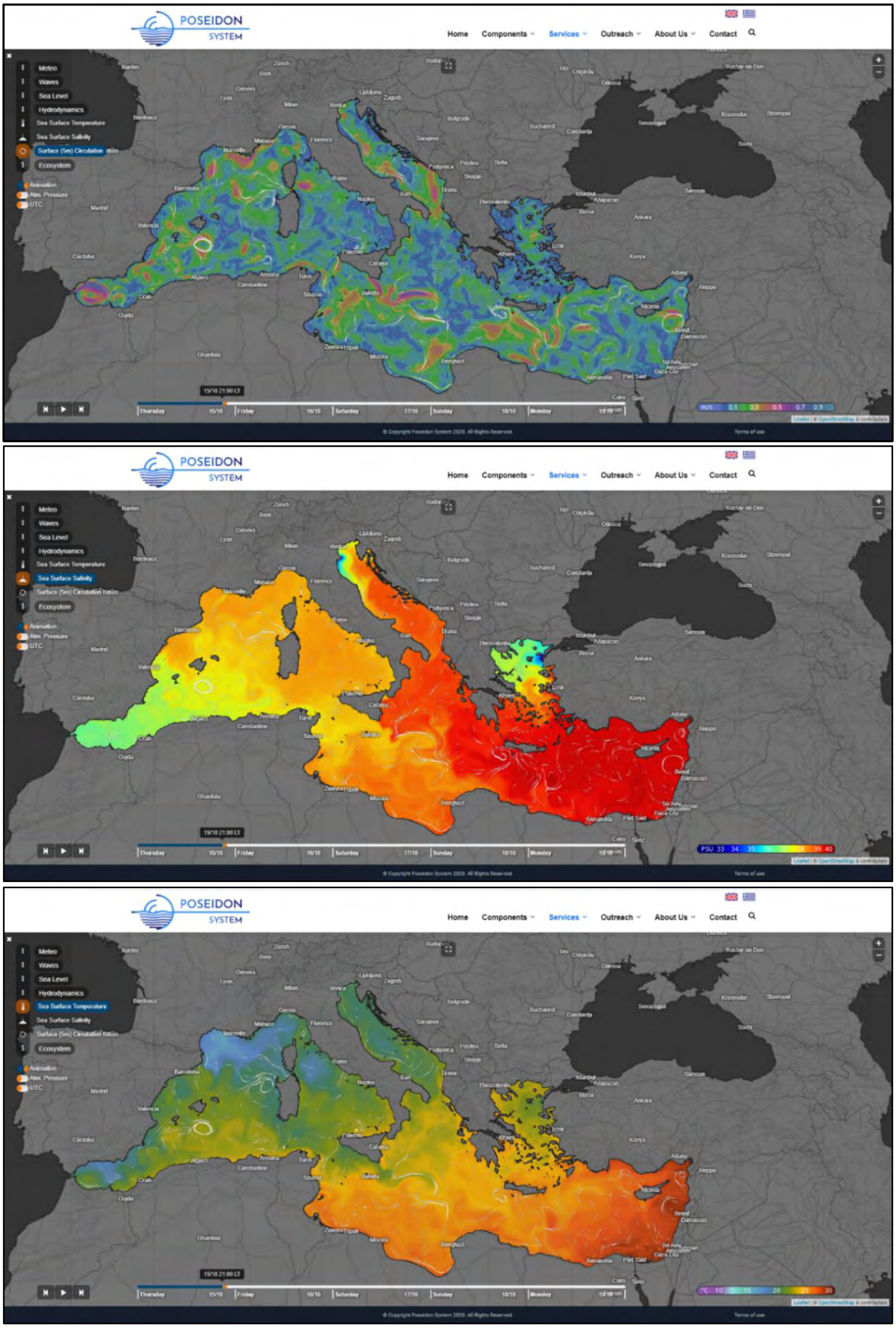


Figure 2.4-2 Online data sharing tool of marine forecast data by the POSEIDON System in the Mediterranean Sea;
Ocean Forecast Parameters: sea surface current (circulation; in m/s); sea surface salinity; sea surface temperature (in °C).

The POSEIDON platform uses the *Leaflet* software technology (https://leafletjs.com/), which is the leading open-source JavaScript library for mobile-friendly interactive maps. Weighing just about 39 KB of JS, it has all the mapping features most developers ever need. Leaflet is designed with simplicity, performance, and usability in mind. It works efficiently across all major desktop and mobile platforms, can be extended with lots of plugins, has a beautiful, easy to use and well-documented API and a simple, readable source code that is a joy to contribute to. ©OpenStreetMap is also a contributor to the platform. One can easily create a map in the 'map' div, add tiles of choice, and then add a marker with some text in a popup. A set of comprehensive, concise yet inclusive tutorials can be found via the link: https://leafletjs.com/examples.html.

2.4.2 ICT tool for Smart Water monitoring (WIDEST project)

The WIDEST Project (Water Innovation through Dissemination Exploitation of Smart Technologies), initiated within the Horizon2020 Program, presents a Smart Water Grid topical roadmap that will tackle the importance of the deployment and inclusion of ICT technologies for the development of infrastructures analogous to the Smart Energy Grids focusing on the key ICT elements that can be relevant for its development in Water Sector. The main outcomes are specific analyses and recommendations for policy makers and relevant water stakeholders that can foster ICT for the Smart Water Grid. The vision of WIDEST is to establish and support a thriving and interconnected ICT for the Water Community with the main objective of promoting the dissemination and exploitation of the results of EU-funded activities in this area (Figure 2.4-3).

One ICT application is the Water Observatory (IWO). The IWO defines a methodology to collect, analyse and publish in a knowledge base resources from relevant sources of information related to ICT for Water technologies. Three case studies of smart water technology implementation in Malta, Singapore and South Korea are also presented to validate the needs and challenges for successful implementation of Smart Water solutions. Lastly, a set of recommendations on the adoption, implementation, and operating and maintenance of Smart Water Technology and a checklist tool for Smart Water Implementation is provided.

Figure 2.4-3 Figure of Micro-scale, Meso-scale, and Marco-scale in Water Management.

The role of ICT in contributing to the “Smart Technologies EIP Priority” is widely recognised by the scientific community and water business professionals. Despite relevant progress and innovation achieved in this field, several barriers hinder the implementation of Smart Water Technologies such as the fragmentation of the sector, slow adoption, absence of SME development, and no holistic vision of water supply considering its whole life cycle. Moreover, at present a fully integrated Smart Water Network does not exist in Europe or globally. Hence, current lack of knowledge of EU water research and innovation results on industry, policy makers, and citizens is slowing down the widespread application of solutions that can leverage the development of the urban systems and infrastructures of tomorrow. This scenario shows that achieving water-related challenges cannot progress with the sole contribution of research. In this sense, the project has the vision of establishing and supporting a thriving, interconnected ICT for water community to promote the dissemination and exploitation of EU funded activities and results in this area. WIDEST will address its goals through a project-to-project approach and the coordination among relevant stakeholders by means of five objectives that will include, amongst others: Conducting literature reviews of relevant academic and commercial references; Establishing common frameworks such as standards, guidelines, website, video channel; Organizing events including conferences, workshops, special sessions; Producing three Topical Roadmaps and one Overall Roadmap; Producing a Portfolio of effective ICT for water management technologies including the methodology to build, update and execute it. The project is backed by a strong consortium composed by institutions with proven track record and expertise across different facets of ICT for water research, including established connections with key stakeholders.

A characteristic outcome of the WIDEST initiative is the Automated Meter Management (AMM) project launched in Malta. The AMM system, deployed by the Water Services Corporation, today is of the fixed-network type. It makes use of the always-on wireless broadband GPRS network to connect every consumer meter to a centralised water management system. A Meter Interface Unit (MIU) is installed on each meter through a pulser unit, which transmits to a receiver gateway, which communicates to the central system through the GPRS network. The meter reading ends up at the central system where the data is stored, analysed, and used for water management tools. The schematic diagram below shows the basic architecture of an AMM system (Figure 2.4-4).

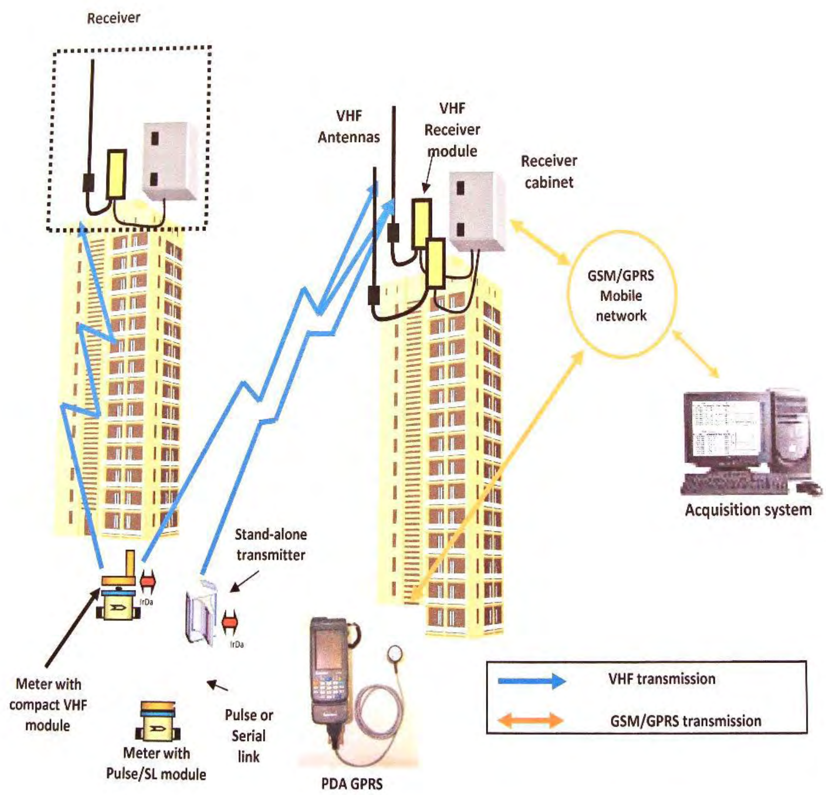


Figure 2.4-4 Schematic diagram below shows the basic architecture of an AMM system.

2.4.3 MARIA-Box ICT tool

The Maria-Box project (*Marine environmental in situ assessment and monitoring toolbox*), co-funded by the European Commission has developed an autonomous, analytical device that exploits novel biosensors to monitor chemical and biological pollutants in seawater. The device has been designed as an instrument suitable for installation on buoys, ships, or free-floating devices. It can also be used as a transportable instrument that fits in the back of a small minivan (http://www.mariabox.net/).

The main, high-level user requirements for the system were for the device to be sensitive, transportable, and capable of repeating measurements over a long period time. The Maria-Box has met those main requirements and delivered an instrument that can monitor marine waters for four categories of algae toxins and four categories of man-made chemicals, without the need for human intervention for up to six months. The device also includes sensors for the measurement of conventional water quality parameters, such as pH, dissolved oxygen, water temperature and salinity. It is also capable of reading additional sensors if this is required in specific scenarios.

One of the main novelties delivered are eight different biosensors for measuring concentrations of: Naphthalene, PFOS/PFOA, Heavy metals, Camphechlor, Saxitoxin, Microcystin, Azaspiracid and Domoic Acid. The Maria-Box biosensors are designed in the form of discs (like a CD). A single disc contains enough biosensor sectors for detecting all 8 targeted analytes and can be used 3 times (usually one measurement per day is enough for most use cases). The incubation of water samples and the analysis process is implemented by spinning the disc at different speeds.

Data from the Maria-Box device is wirelessly transmitted to the users through a combination of different wireless technologies. Depending on the specific scenario and location, data can be transmitted through Wi-Fi, 3G or a Satellite link. The Maria-Box system is complemented by a cloud-based, data collection portal, used as a remote user interface to the device and its measurements. The Maria-Box autonomous device and system provide the tools for environmental institutions, agencies, and professionals to acquire precise, almost real-time, independent data on the environmental status of marine water quality. By sharing the data in an open way, Maria-Box also facilitates the implementation of the Marine Strategy Framework Directive (MSFD). The device is compatible with the INSPIRE directive, Copernicus and GOOS initiatives and SeaDataNet as well as the OGC Sensor Observation Service (SOS). The lower target cost of the Maria-Box system, in combination with its 6-month autonomous operation will allow continuous monitoring of the seas for much longer intervals with respect to today's standards. During the last stages of this 48-month project, four replicas of the Maria-Box device were built and used for real-world demonstration of the technology through monitoring campaigns in Cyprus, Spain Ireland (on buoys) and Norway (inside a ferryboat).

Due to growing concerns about the health of the oceans and their capacity to continue to provide resources as well as associated risks to the human health, there is an increasing demand for real-time monitoring of the environmental status of marine water quality and the provision of early warning systems. As commercially available sensors tend to be too large, expensive, and power-hungry for widespread use, reducing the cost for acquisition of data is a key priority in order to implement EU legislations.

Biosensors are defined as compact, analytical devices that incorporate a biological or biologically derived sensing element either integrated within, or intimately associated with a physicochemical transducer. For environmental applications, biosensors must compete with traditional techniques such as immunoassays, chemical test kits and laboratory testing.

Portability and miniaturization are two aspects desirable for environmental biosensors since they could enable field use.

In order to respond to the aforementioned need and challenges, the Maria-Box project has developed an autonomous, analytical device that exploits novel biosensors to monitor chemical and biological pollutants in seawater. The device has been designed as an instrument suitable for installation on buoys, ships, or free-floating devices. It can also be used as a transportable instrument that fits in the back of a small minivan. The project included thirteen partners with complementary profiles: Universities, private companies, and public institutions from six European countries: Cyprus, Italy, Spain, Ireland, UK and Norway. It has been coordinated by CyRIC - Cyprus Research and Innovation Center Ltd.

Main project objectives have been:

• To develop new biosensors to monitor selected chemicals and toxins in seawater.

• To produce a marine pollution-monitoring device, using the new biosensors, implemented as a set of autonomous modules for the analysis of marine pollutants and the assessment of water quality.

• To develop a software platform and smartphone application for the marine monitoring and GOOS/GEOSS data collection and distribution so to be almost real-time available and interfaced to Copernicus.

• To establish a fully inter-operable Maria-Box with existing observing systems and compatible with standard requirements such as the Marine Strategy Framework Directive and the INSPIRE directive. The Maria-Box autonomous device and system provide the tools for environmental institutions, agencies, and professionals to acquire precise, almost real-time, independent data on the environmental status of marine water quality. By sharing the data in an open way, Maria-Box also facilitates the implementation of the Marine Strategy Framework Directive (MSFD). The device is compatible with the INSPIRE directive, Copernicus and GOOS initiatives and SeaDataNet as well as the OGC Sensor Observation Service (SOS).

• To design and develop the Maria-Box automatic calibration procedure and sensor replacement mechanism to ensure long term autonomous deployment.

• To prove the validity of the system in real and varying conditions in Norway, Cyprus, Ireland and Spain.

• To contribute to the development of new environmental monitoring standards. The increased spatio-temporal data availability, in combination with the longer operation period of Maria-Box (with respect to currently available systems) will promote the development of new, stricter, environmental monitoring standards.

• To create a cost-effective system, suitable for large-scale production and exploitable as a commercially viable set of products.

Maria-Box has delivered different Scientific and Technical (S/T) results, throughout its four years of operations. All of those are significant and build the base for the post-project exploitation of Maria-Box.

- The Maria-Box-COMM: The Maria-Box communication module is responsible for sending the data from the Maria-Box device to the data management software platform (-NET). The communication module uses Wi-Fi, 3G/GPRS technology, and satellite data transmission technology for remote locations where the cell phone network option is not available. The Maria-Box-COMM module is composed of a Wi-Fi router, a 3G/4G router, a 3G/4G USB modem and an Inmarsat EXPLORE 510 SATCOM terminal. It is housed inside a waterproof enclosure. The communication module has been developed including a set of plug & play components to provide flexible/extendable communication links for all demo sites. It can be seen an external module to the main Maria-Box device, thus increasing the flexibility and modularity of the design.

One of the most interesting results was the Maria-Box-NET: The Maria-Box portal (also referred to as Maria-Box-NET) makes near real-time Maria-Box sensor data from the various Maria-Box devices deployed available to the Maria-Box team and other possible users. Data is transmitted from the Maria-Box devices and, more specifically from the Maria-Box-CORE of each device and made available to the Maria-Box-NET via TCP/IP ports. The data is then processed, stored, and made available to the user by the Maria-Box-NET platform. Linux-based systems are utilised to acquire, transmit, process, and validate the data before it is stored in a Cassandra database. Erddap and ASP.Net web-based applications make this data available to the users. A web-based sensor observation service is also utilised to make data available to users in an interoperable format. The applications also permit selected users to send configuration and control commands to the Maria-Box-CORE. Users can access the portal and Erddap via a graphical user interface. The web applications and all associated middleware systems are hosted in Microsoft Azure. Erddap is used to make Maria-Box data available is a variety of formats e.g., json, mat, kml, csv, html.

Another is the Maria-Box-MOB: The Maria-Box-MOB is the mobile application developed to communicate with the Maria-Box device when the user is in proximity of the device for maintenance purposes or in case of failure of the communication between the Maria-Box Communication module (-COMM) and Maria-Box-NET online platform. The Maria-Box tablet application is the physical user interface of the system and covers a broad range of end-users' requirements. The application interfaces with the transmission module of the Maria-Box-CORE and allows end-users to monitor and to modify various configuration parameters. The Maria-Box-MOB application is based on the Android mobile operating system.

Regarding the exploitation of the project results, a business plan (confidential) has been prepared. The main exploitable results of the project are presented below:

1. Maria-Box device/ instrumentation hardware design, including mechanical design of sub-modules
2. Maria-Box-CORE and related electronics
3. Maria-Box-POW and Maria-Box-COMM
4. Maria-Box-NET
5. Maria-Box-MOB
6. New buoy used in Spanish and Cypriot pilots
7. Several types of Biosensors

3. FUTURE AND EMERGING TECHNOLOGIES

3.1 Artificial Intelligence and Machine Learning applications for the marine environment

Machine Learning (ML) algorithms and applications are a subset of the Artificial Intelligence approaches and related technologies. Adoption of such methodologies promotes decision making based on collected data. Through Artificial Intelligence, ML capabilities can be integrated into data driven modeling systems. ML algorithms can be a powerful tool used for accurate and efficient analysis of oceanographic and climate data. It also spans on a wide spectrum of real time applications in oceanography and Earth sciences.

The initial implementation of ML algorithms needs large amount of data, separated in two sets: the training set and the testing set. These can be collected by scientific instruments or by the vast number of datasets in the cloud. ML algorithms first need to be trained by this data, in order to build correct and high accuracy models. The model's various parameters are optimized based on sample data during the training/learning step of the procedure. If the training phase of the algorithm ends successfully, the model can be used for making predictions. In this phase, the previously optimized model parameters are used to infer results on data previously "unseen" by the algorithm.

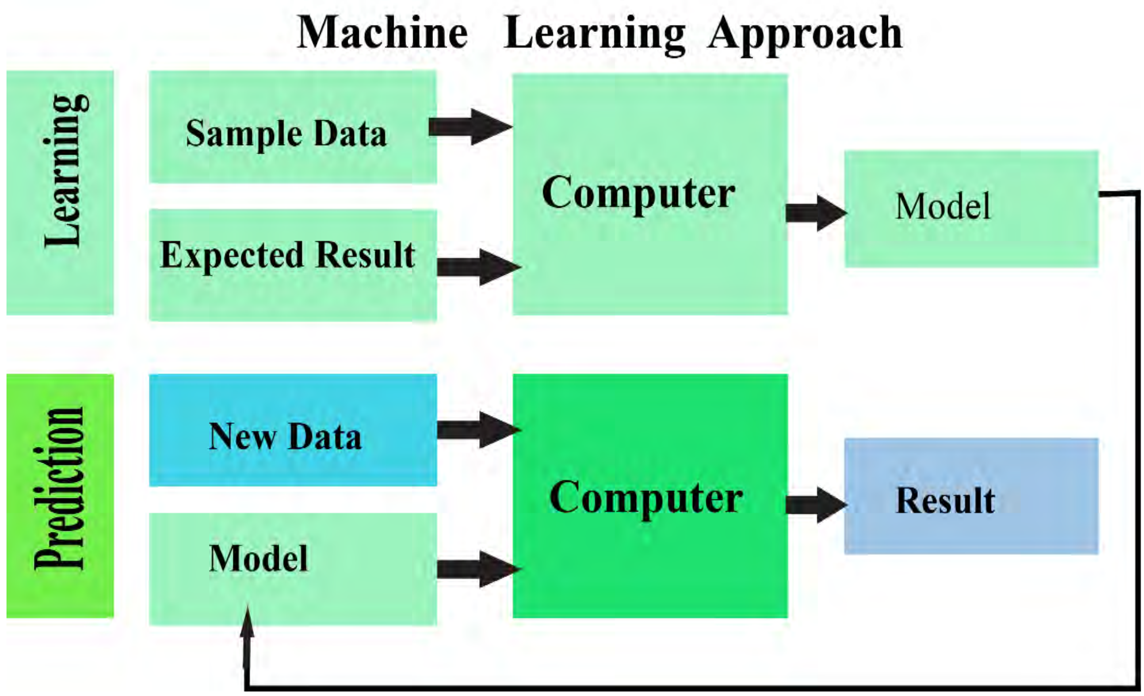


Figure 3.1-1 Simple Machine Learning approach.
(Ahmad, H. (2019). Machine learning applications in oceanography. Aquatic Research, 2(3), 161-169. https://doi.org/10.3153/AR19014)

ML comprises of multiple algorithms, techniques and methodologies employed to build models. These fall into three main categories: Supervised Learning (SL), UnSupervised Learning (USL), Reinforced Learning (RL) and Deep Learning (DL). The specific use of each main category may give name to specific applications, e.g., Deep Vision.

SL uses labelled data for the training phase. Subsequently, the model is presented to a new set of data so that the algorithm may analyse the training data and produces a correct outcome based on the labelled data. SL algorithms try to model the relationship between the inputs and their corresponding outputs. This means that in the prediction phase, the model has to be able to make predictions based on its prior “discoveries” of the relationships between the training datasets. The two main categories of SL algorithms are classification and regression.

On the other side of the spectrum, USL training uses data that is neither classified nor labelled. The algorithm tries unguided to group unsorted data based on the similarities, patterns, and differences. USL methods can be classified into clustering, dimensionality reduction and anomaly detection.

RL methods take a slightly different path compared SL or USL. Similar to an empirical approach, an RL agent learns how to behave in its environment by performing actions, seeing the results, and drawing intuitions.

DL algorithms aim to imitate the structure and function of a living brain’s neurons forming Artificial Neural Networks. In general, an Artificial Neural Network is an interconnected group of nodes, where each circular node represents an artificial neuron, and an arrow represents a connection from the output of one artificial neuron to the input of another. Models comprise of synaptic links, that allow inputs (x_1 x_2, ... x_n to be measured by applying weights (w_1, w_2, ... w_n). The continuous scientific research on Artificial Neural Networks has given rise to several types of such methods, such as convolutional neural networks, feed forward neural networks and their descendants recurrent neural networks.

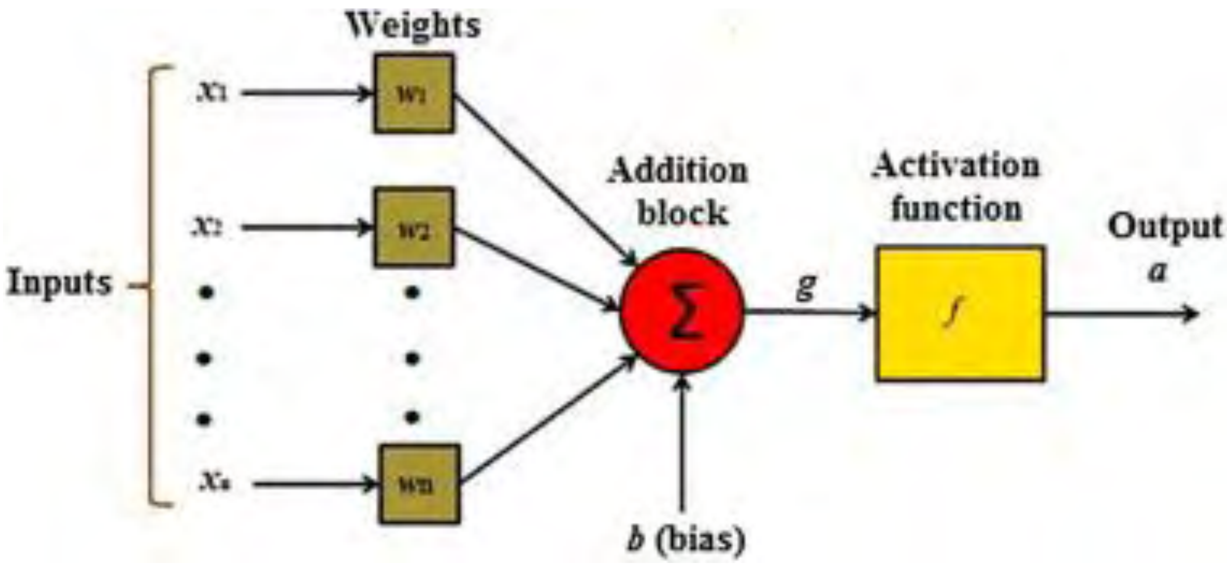


Figure 3.1-2 Simple artificial neural network.
(Burkitt, 2006; Oja, 1982; Turkson et al., 2016)

The ocean is a vast, dynamic, and complex system. As scientific research and knowledge progresses, datasets concerning the ocean become larger and more complex. As a result, traditional methods of data analysis can become more time consuming and expensive. Moreover, there are still cases, due to a lack of full understanding of some processes, where traditional analysis may not lead to concrete conclusions. Nevertheless, decisions based on gathered data still need to be and ML techniques provide a robust, fast and accurate framework built for such a purpose. Some of the common oceanography related fields, where ML techniques that are currently applied include: ocean weather and climate predictions, habitat modeling and distribution, species identification, coastal water monitoring, marine resources management, detection of oil spill and pollution and wave modelling.

ML methods have been used to predict rainy and non-rainy days (Haupt, 2009), to forecast coastal sea level fluctuations (Cox et al., 2002). Horstmann et al. (2003) used MultiLayer Perceptron (MLP) NN models to retrieve wind speeds globally at about 30 m resolution using SAR data (Horstmann et al., 2003). ML was used to study El Niño, sea surface temperature anomalies, and monsoon models (Cavasos et al., 2002; Hsieh, 2009; Krasnopolsky, 2009; Thessen, 2016). Wu et al. (2006) developed an MLP NN model to forecast the sea surface temperature (SST) of the entire tropical Pacific Ocean. Even though ocean circulation models are the standard method used for ocean dynamic process analysis, it is possible to improve the prediction of ocean currents using historical data and ML methods (Hollinger et al., 2012). Another example is a neural networks application used to build Reynolds average turbulent models (Bolton and Zanna, 2019) for sub-grid parameterization of ocean circulation models.

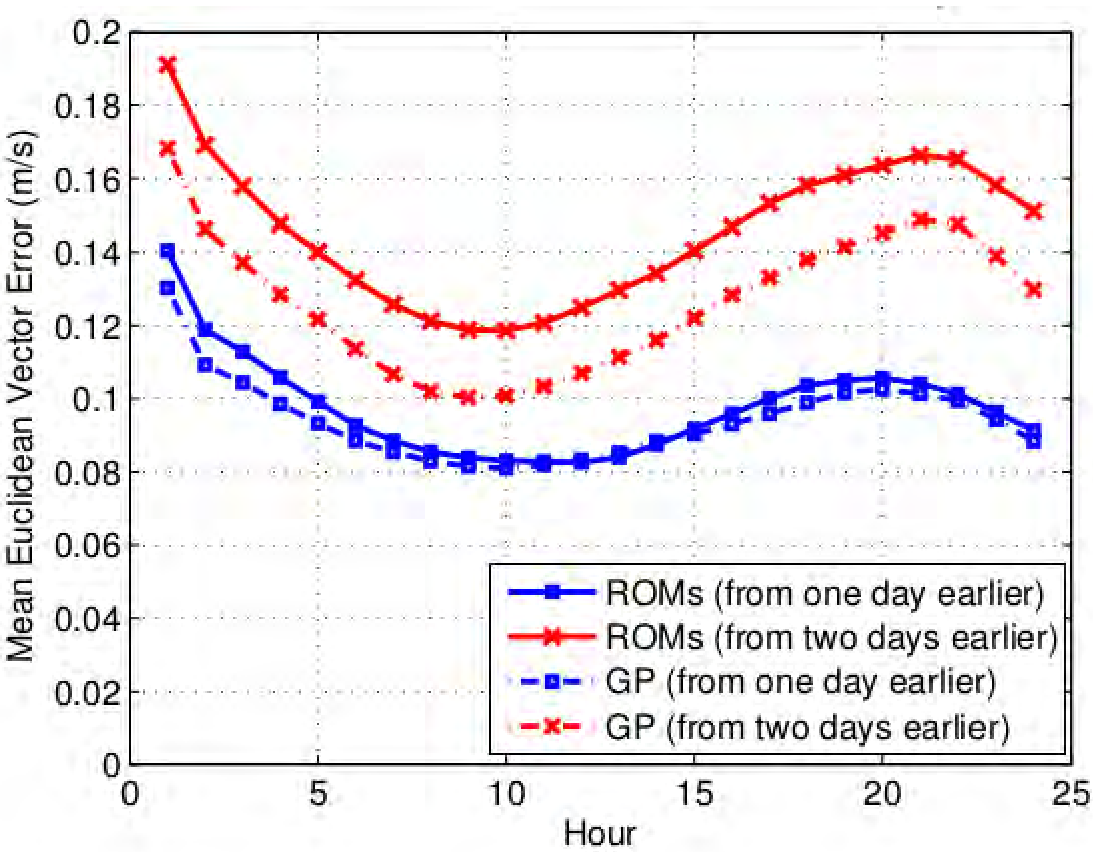


Figure 3.1-3 Typical Error for one-day and two-day predictions of surface currents using ROMS and GP ML method

Hollinger et al., (2012)

The learning method achieves on average 3.8% improvement for the one-day prediction and 13.0% improvement for the two-day prediction. (source: Hollinger et al., 2012)

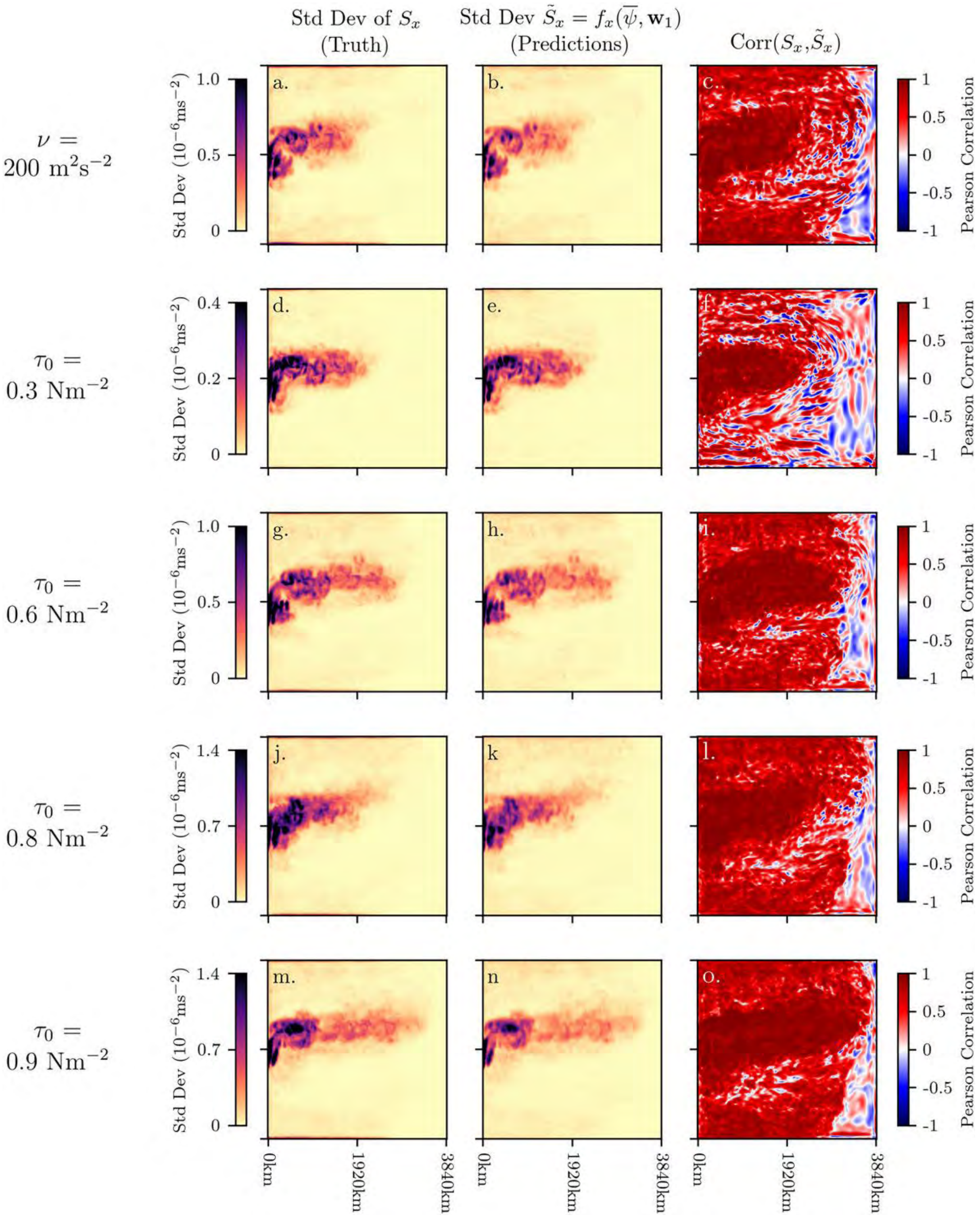


Figure 3.1-4 Examination of the ML model's ability in building Reynolds average turbulent models
to generalize to new regimes using the trained neural network (Bolton and Zanna, 2019)

Ocean wave modelling for forecast purposes can be sped up by applying ML methods, replacing in certain occasions computationally intensive physics based numerical models. Such gains can be important when optimizing shipping in order to avoid rough sea states and thereby reduce transportation times. Wave condition forecasts can be accomplished by straightforward multiplication of an input vector by mapping matrices resulting from the trained machine learning models (James et al., 2018). The same reasons for fast and accurate wave condition forecasts apply for many marine based industries, where knowing in advance wave heights and directions is considered a resource (O'Donncha, 2017).

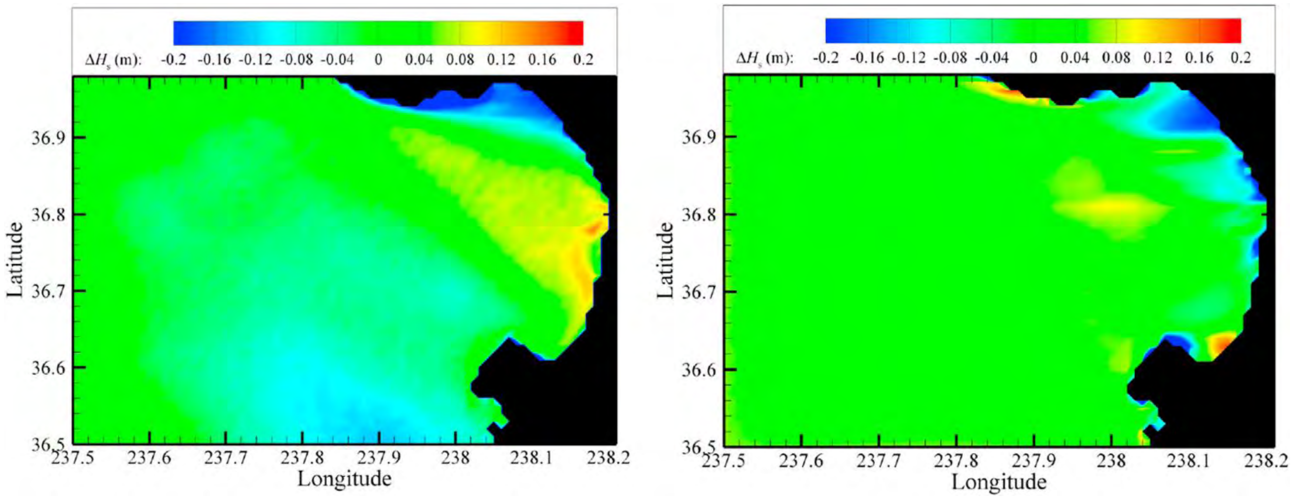


Figure 3.1-5 Two representative heat maps of the differences between SWAN and machine-learning-simulated Hs

Hs -significant wave height. The above maps are selected from the 11,078 SWAN model runs. The wave height-differences snapshot on the left shows some trends of local discrepancy (in this image, RMSE is 6 cm) not evident in the right figure, which actually has a higher RMSE (14 cm in this image). Nevertheless, most of the domain has near-zero RMSE with local deviations nearer the shoreline where secondary effects are most prominent (source: James et al., 2018).

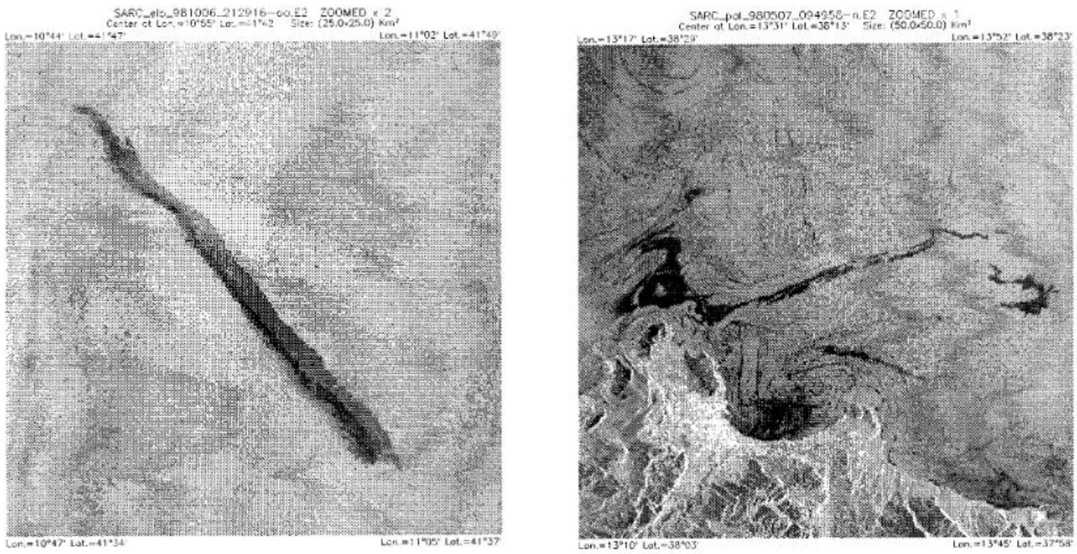


Figure 3.1-6 Images of verified oil spills detected by the MLP NN model (source: Del Frate et al. 2000).

ML can also be used for the detection of ocean pollution such as oil spills, plastics pollution, algal bloom etc., using satellite and radar images. Del Frate et al. (2000) used MLP NN models to detect oil spill on the ocean surface from synthetic aperture radar (SAR) images, replacing the previous need of a highly trained human operator to assess distinct satellite and radar images.

AI can be used for habitat modelling and species distribution. Large datasets can be used for training algorithms in matching environmental variables to taxon abundance or presence/absence data. A well trained and tested algorithm, can make predictions about what taxa may be present at a given location, based on environmental variables from a different location. This technique has been used to identify current suitable habitat for specific taxa, model future species distributions including predicting invasive and rare species presence, and predict biodiversity of an area (Thessen, 2016).

Along the same lines, ML can be used for improved species identification with the development of automatic identification techniques. ML algorithms are trained on images, videos, sounds and other types of data labeled with taxon names, in order to automatically annotate new data. These methods have been used to identify plankton, shellfish larvae from images, bacteria from gene sequences, cetacean from audio, fish, and algae from acoustic and optical characteristics (Simmonds and Armstrong, 1996; Boddy, 1999; Olson and Sosik 2007; Jennings et al., 2008; Goodwin and North 2014).

Figure 3.1-7 Imagery from the HabCam survey operations
with an example of skate detections using the VIAME/YOLO v2 open source software
(source: Michaels, W. L., N. O. Handegard, K. Malde, and H. Hammersland-White (eds.). 2019. Machine learning to improve marine science for the sustainability of living ocean resources: Report from the 2019 Norway - U.S. Workshop. NOAA Tech. Memo. NMFS-F/SPO-199,99p.)

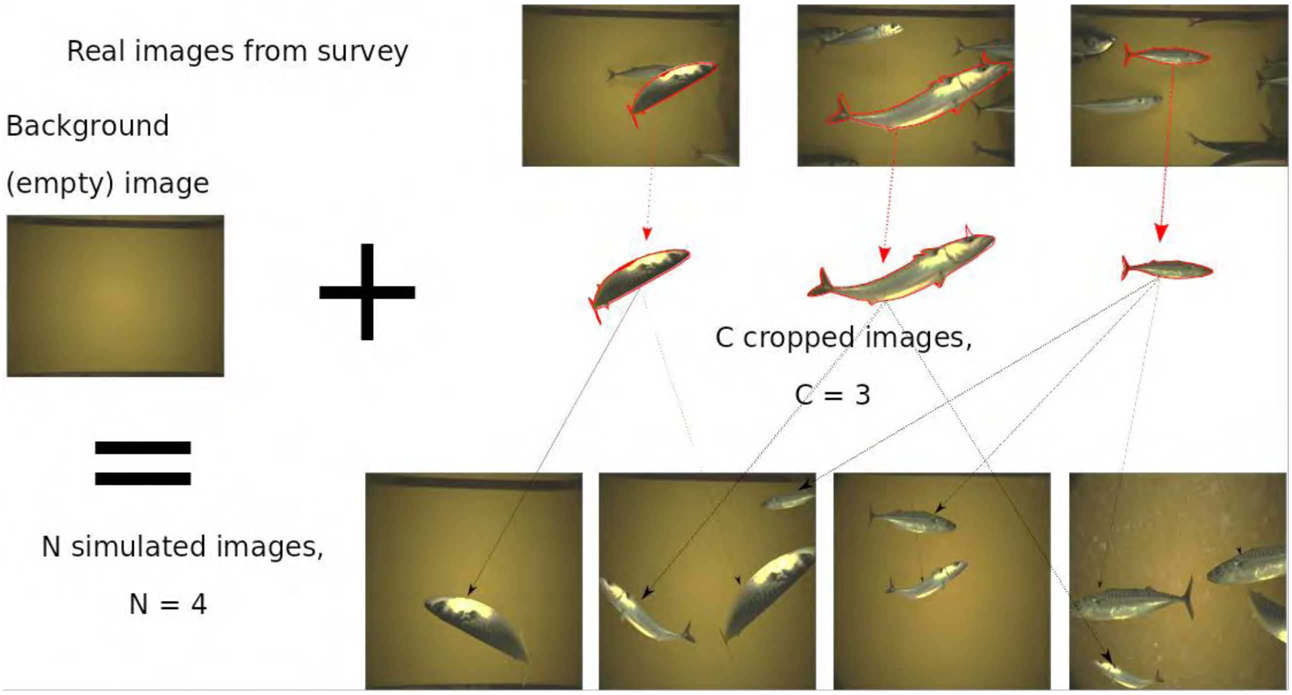


Figure 3.1-8 Generating synthetic images from fish crops for training

(source: Michaels W.L. et al., 2019, Machine learning to improve marine science for the sustainability of living ocean resources: Report from the 2019 Norway - U.S. Workshop. NOAA Tech. Memo. NMFS-F/SPO-199,99p.)

Some interesting information about AI and ML applications for the marine environment are included in the Technical Report of the Norway - U.S. Workshop entitled "Machine Learning to Improve Marine Science for the Sustainability of Living Ocean Resources" was held in Bergen, Norway on 23-25 April 2019. The goal of the workshop was to exchange information on the current state of development, progress, and applications of computer vision and machine learning (ML) analytics. The three-day workshop was held at the Institute of Marine Research (IMR), with sponsorship by IMR, National Ocean and Atmospheric Administration (NOAA), and Scantrol Deep Vision AS. Invited contributions provided diverse overviews and case studies on the application of computer vision and ML classifiers for imagery and acoustic data collected from underwater and aerial surveys, including detection-classification of plankton, fish, and marine mammals. ML applications involved data collections from traditional survey platforms, autonomous platforms, monitoring-classification systems of fisher trawl operations to reduce bycatch, and electronic monitoring of fishing vessel operations and catch. The final phase of the workshop provided hands-on training on GitHub and the open-source Video and Image Analytics for Marine Environments (VIAME) toolbox that utilizes computer vision and machine learning analytics.

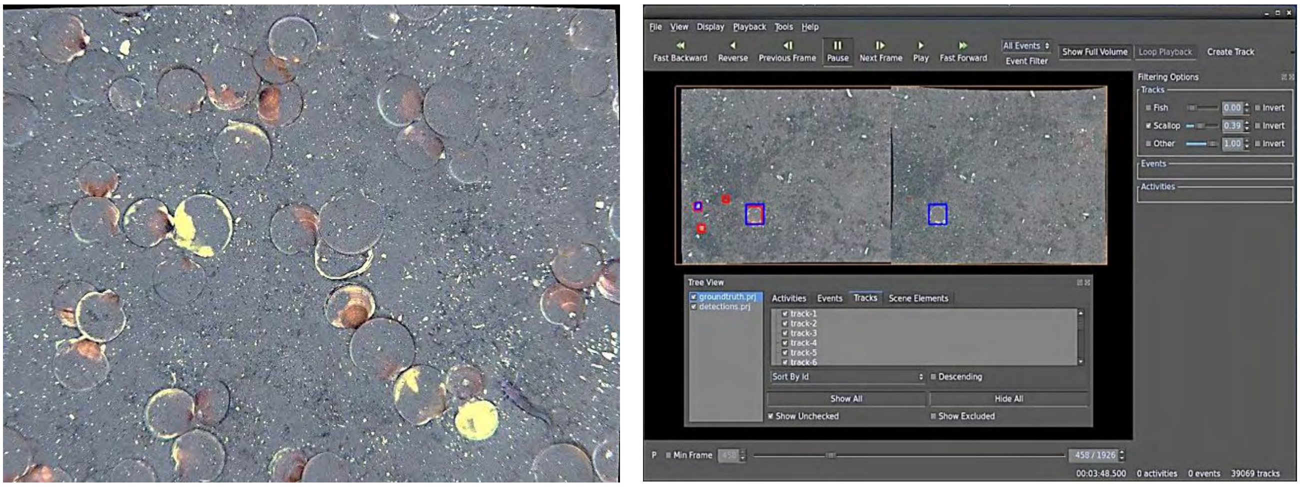


Figure 3.1-9 VIAME used for automated scallop detection and measures to provide accurate and timely assessment for fishery management
(source: Michaels, W.L. et al., 2019. Machine learning to improve marine science for the sustainability of living ocean resources: Report from the 2019 Norway - U.S. Workshop. NOAA Tech. Memo. NMFS-F/SPO-199,99p.)

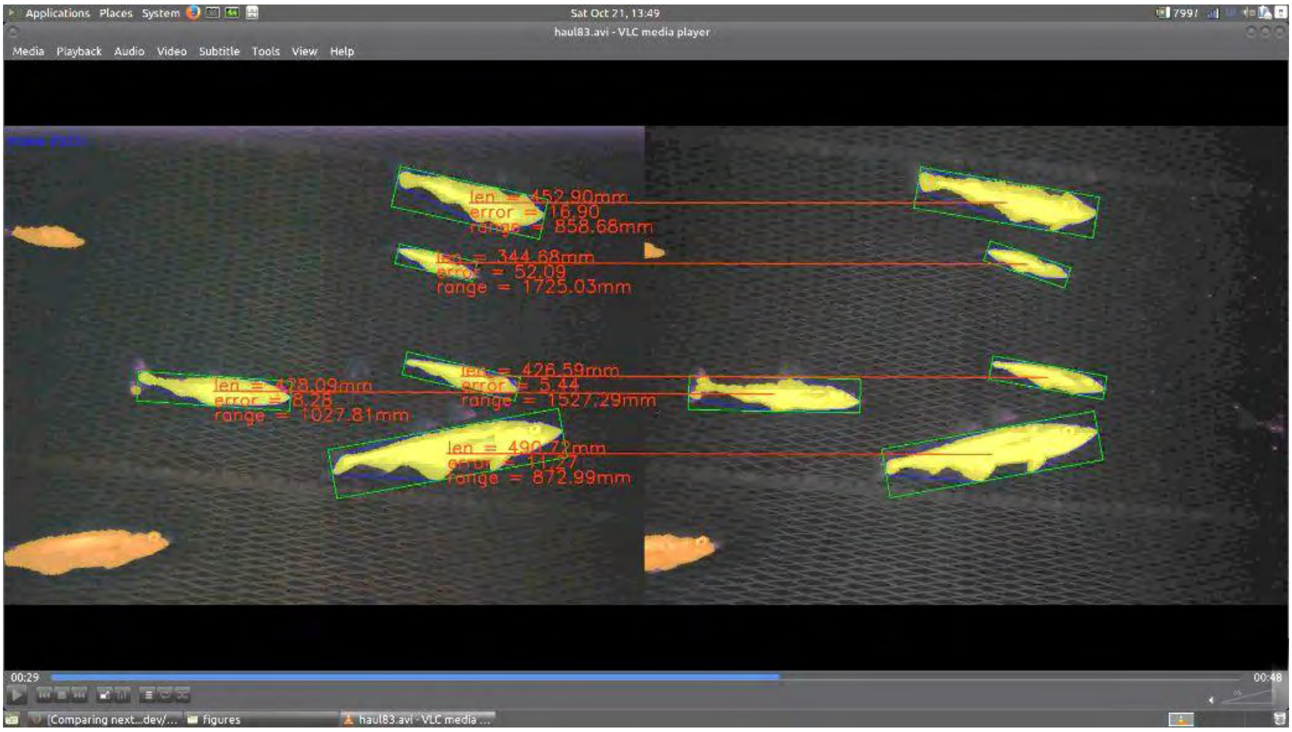


Figure 3.1-10 VIAME used for automating the processing of stereo imagery collected during the Bering Sea pollock survey
resulting in improved automation of species identification with accurate length measurements for stock assessments. (source: Michaels, W.L. et al., 2019. Machine learning to improve marine science for the sustainability of living ocean resources: Report from the 2019 Norway - U.S. Workshop. NOAA Tech. Memo. NMFS-F/SPO-199,99p.)

During the workshop, NORCE (Norwegian Research Centre), demonstrated its accomplishments in utilizing ML and AI applications designed for the marine environment. NORCE has also used

ML for automatic fish detection, lice counting, and the prediction of fish growth and health of farmed salmon. For marine stock assessment and research, they have developed the Large-Scale Survey System (LSSS) has been in collaboration with IMR. LSSS has been in use since 2007. It consists of two parts: a pre-processor (e.g., noise reduction, bottom detection, school detection, species identification, plankton analysis) and an interactive interpretation module.

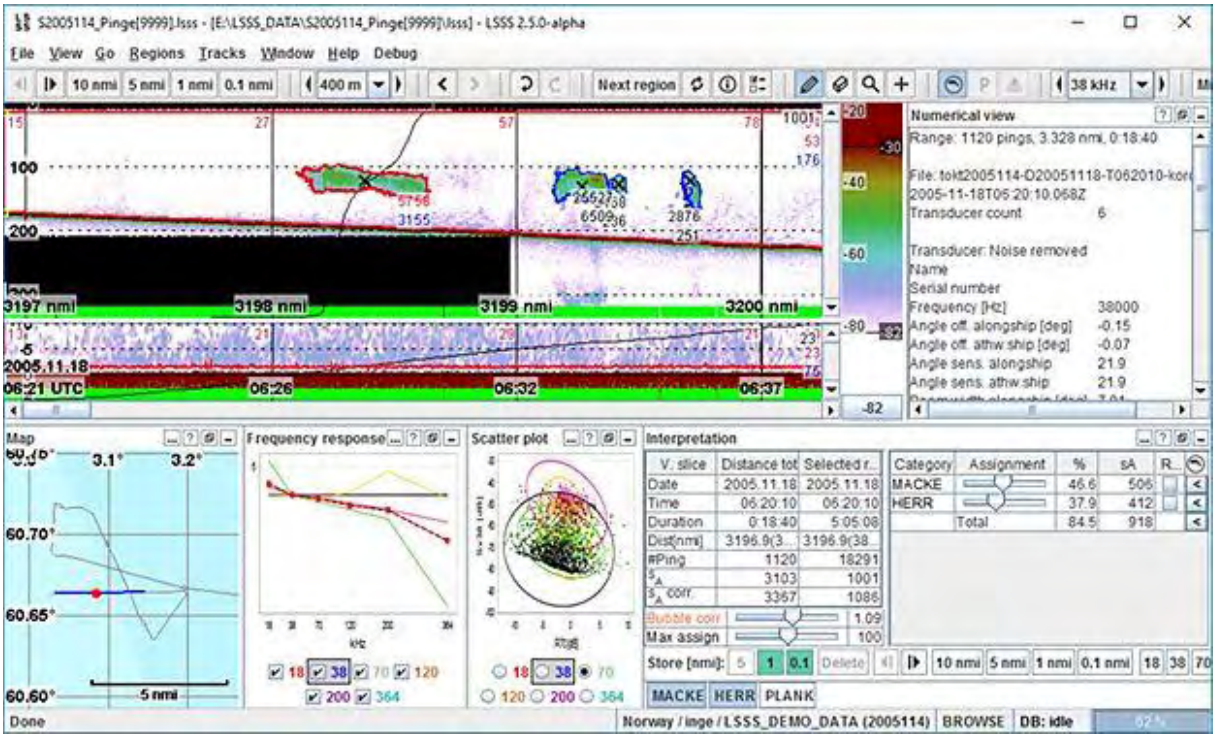


Figure 3.1-11 A Large-Scale Survey System (LSSS) screenshot

(source: Michaels W.L. et al., 2019. Machine learning to improve marine science for the sustainability of living ocean resources: Report from the 2019 Norway - U.S. Workshop. NOAA Tech. Memo. NMFS-F/SPO-199,99p.)

Figure 3.1-12 NORCE ML for automatic fish detection

(source: Michaels W.L. et al., 2019. Machine learning to improve marine science for the sustainability of living ocean resources: Report from the 2019 Norway - U.S. Workshop. NOAA Tech. Memo. NMFS-F/SPO-199,99p.)

In addition, NORCE has developed their own decision support, Nlive, for their drones, and are investigating using ML to make the operation of the drones more autonomous. NORCE is the supplier for the European Maritime Safety Agency for using drones to detect oil spills and improve operations. Their Sail Buoy was the first Unmanned Surface Vehicle that completed an Atlantic crossing. It can be equipped with a large number of sensors, can be used as a communication relay station, and was recently used for doing a krill survey in the Antarctic.

Figure 3.1-13 NORCE's Sail Buoy

(source: Michaels W.L. et al., 2019. Machine learning to improve marine science for the sustainability of living ocean resources: Report from the 2019 Norway - U.S. Workshop. NOAA Tech. Memo. NMFS-F/SPO-199,99p.)

Marine and coastal resources management can also benefit from the implementation of AI and ML techniques. ML models can capture complex, nonlinear relationships in the input data. Said relationships are the crucial building blocks for the implementation of ecosystem-based fisheries management. Making the right decisions about marine conservation and management can be very difficult. Lack sufficient data may raise uncertainty issues, with potentially disastrous consequences. ML methods, especially those that incorporate Bayesian probabilistic approaches can help in resolving such issues (Thessen, 2016). To that end, Bayesian ML networks and GIS tools are being used for marine spatial planning (Lewis et al., 2001).

3.2 Autonomous Research Ships with Artificial Intelligence

Artificial Intelligence in Autonomous Ships

Another example of recent (September 2020) hi-tech advancement in this area is the Mayflower Autonomous Ship, a Robot research ship developed by ProMare and IBM. ProMare is co-ordinating the scientific studies working with IBM Research and a number of leading scientific organizations (Fig.3.2-1).

Designed to provide a safe, flexible and cost-effective way of gathering data about the ocean, the new-generation Mayflower promises to transform oceanography by working in tandem with scientists and other autonomous vessels to help understand critical issues such as global warming, micro-plastic pollution and marine mammal conservation.

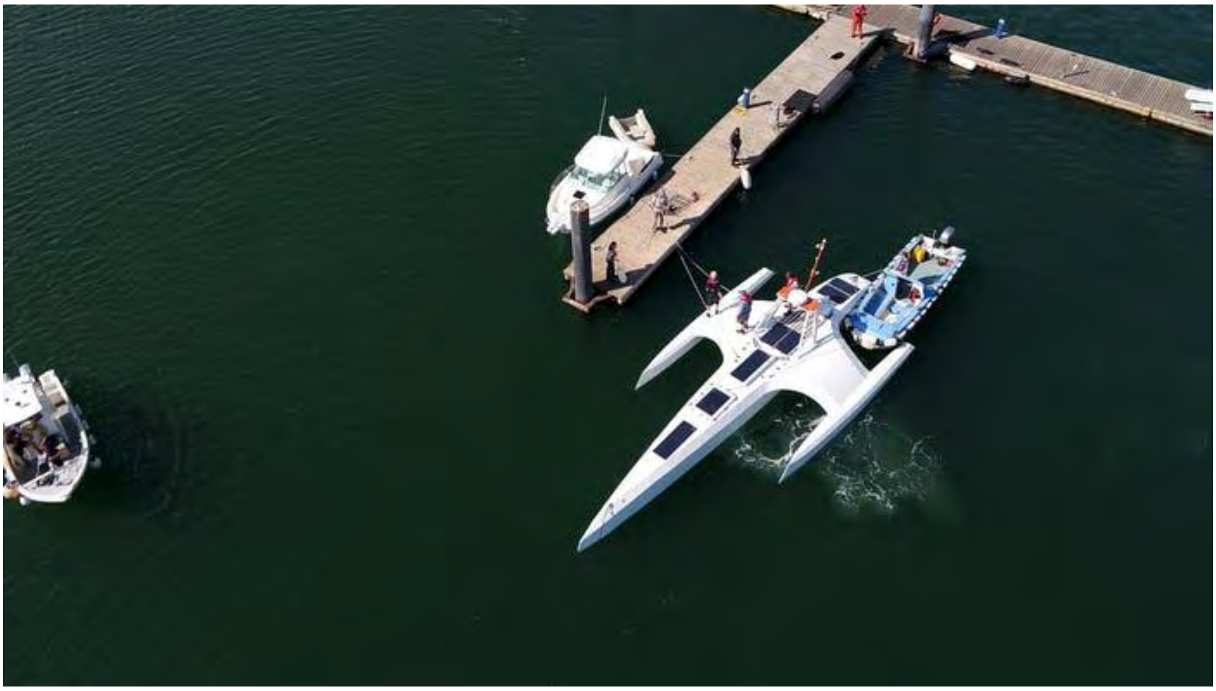


Figure 3.2-1 Mayflower Autonomous Ship (ProMare & IBM Research)
https://mas400.com/.

The ship's "AI Captain" (artificial intelligence) performs a similar role to a human captain. Assimilating data from a number of sources, it constantly assesses its route, status and mission, and makes decisions about what to do next. Cameras and computer vision systems scan the horizon for hazards, and streams of meteorological data reveal potentially dangerous storms. Machine learning and automation software ensure that decisions are safe and in-line with collision regulations.

Aquarius USV™ Powered by Renewable Energy (*Under Development*)
https://www.ecomarinepower.com/en/aquarius-usv

The Aquarius USV™ (Figure 3.2-2) is being developed as a cost-effective Unmanned Surface Vessel (USV) or Autonomous Surface Vehicle (ASV) that will incorporate a number of innovative technologies. These technologies include the patented Aquarius MRE and EnergySail plus high performance marine batteries & lightweight flexible marine solar panels.

The Aquarius USV will be powered by a solar-electric hybrid marine power (HMP) solution which will also feature a solar panel array. On-board batteries will be re-charged via the solar-panel array or via ship or shore power using rapid battery re-charging technology.

The vessel will also be fitted with a sensor pack including several unique sensors developed by EMP. These sensors will be able to collect data from above and below the waterline and this data can either be stored on-board the vessel and/or transmitted back to a ship or shore office. Data transmission will be possible via Wi-Fi, mobile phone or satellite connections.

The Aquarius USV's shallow draft and low height will allow it to operate on urban waterways, rivers, bays and lakes in addition to being suitable for coastal waters and missions at sea. If needed, the masts can also be lowered (optional) to give the vessel a stealth capability.

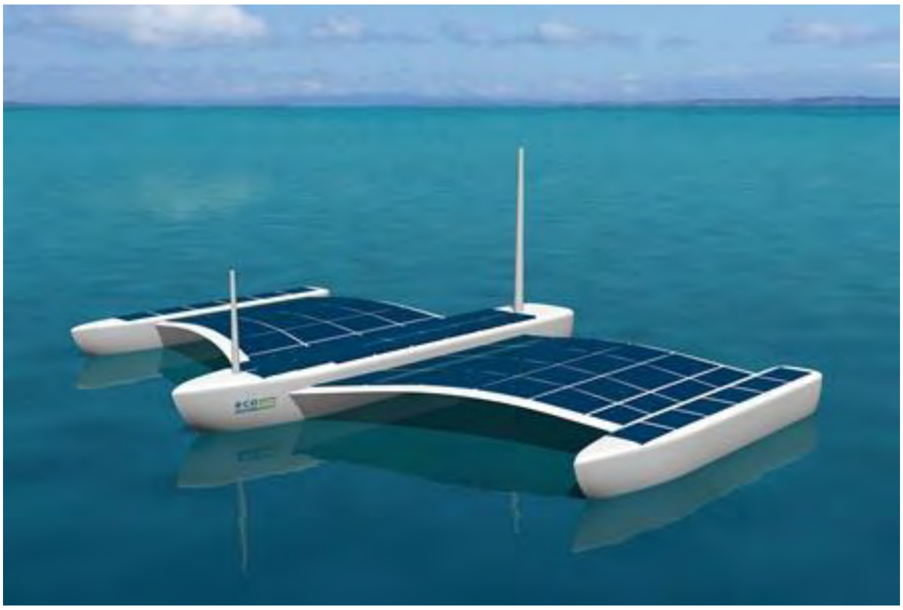


Figure 3.2-2 Solar Powered Aquarius USV by Eco Marine Power
https://www.ecomarinepower.com/en/aquarius-usv

Typical missions for the Aquarius USV could include monitoring harbour pollution, oceanographic surveys, maritime park surveillance, port security, coastal border patrols, marine data collection and anti-submarine warfare (ASW).

3.3 Photonics and Hyper-Spectral Imaging (HSI) techniques

Photonics, i.e., the applied science of harnessing light and analyzing physicochemical properties of matter, is a promising innovative technology for either *in situ* or remote sensing, that appeals to successful applications in the industrial sector (e.g., manufacturing and production within the food, drink, tobacco, metal, and chemical industries, etc.) as well as in safety and security services. However, photonics science and technological applications in environment monitoring and marine water sector are still limited (Figure 3.3-1). Field observations of Water Quality (WQ) parameters, including the concentration of harmful pollutants, are the established way of regulatory sanitary environmental inspections, followed by classic detailed laboratory analyses, yet these are arduous, time-consuming and transfer the action of monitoring away from the *in situ* field set. New, innovative, emerging, and paradigm-shifting seawater monitoring technologies include Hyper-Spectral Imaging (HSI) sensors for the detection of water pollution phenomena such as harmful algal blooms (HABs), eutrophication, fecal contamination, chemical pollution etc. for field-based identification and hopefully early warning systemization. The last years, the new generation HIS devices have become rather easy-to-use and affordable, demonstrating novel pollution detection capabilities, based on heterogeneous data integration, deep learning data processing for chemometrics, etc.

The new HSI systems usually comprise: i) portable prototype optic devices, e.g. adapted/mounted cameras and measuring chambers (Figure 3.3-2), ii) the communications' system, e.g. smart phone devices or other online gateways for raw data transmission to web-based services via easy-access user interfaces, and iii) cloud and/or web services for chemometric processing, including deep learning algorithms for the detection and classification of pollution phenomena, based on interaction with Big Data repositories, chemometric datasets and libraries, similar *in situ* physicochemical data from environmental monitoring networks, remote sensing datasets, etc. New practices reveal that hand-held HIS devices will be mostly used for phytoplankton, chlorophyll-a, green algae, and turbidity detection, while alternative setups of Hyper-Spectral Microscopy Imaging (HMI) are expected to be employed mainly for bacteria detection from seawater samples, in the near future. Of course, HSI minicameras should be backed up by a laptop and via a wireless or USB connection to smartphones for field testing and post-processing. Aqua samples are used for on-site analysis while parts of them are usually analyzed in the laboratory with classic methodologies for referencing, fine-tuning, and calibration of pollution detection algorithms. The main process followed is spectroscopic analysis of water samples by good mixing and active illumination.

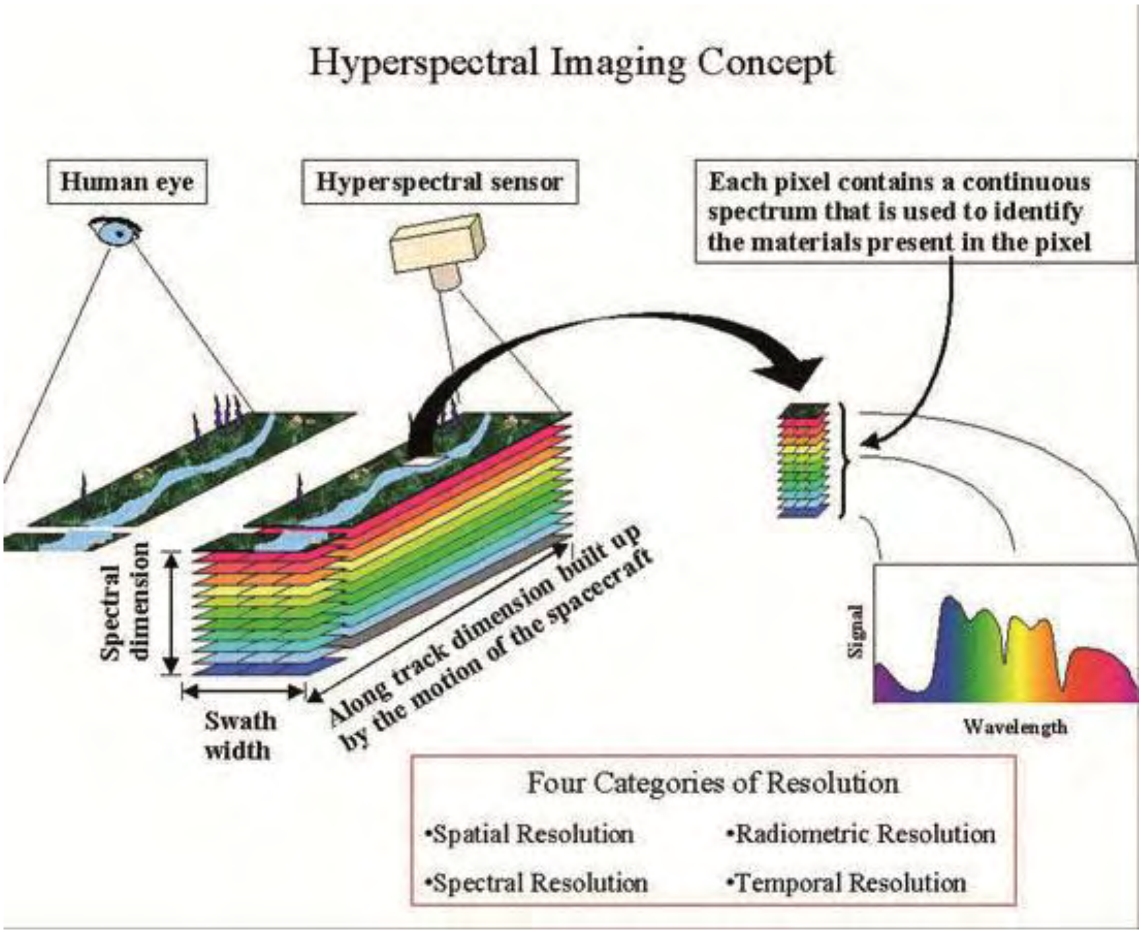


Figure 3.3-1 Hyper-Spectral Imaging conceptual schematics in environmental water management and monitoring.

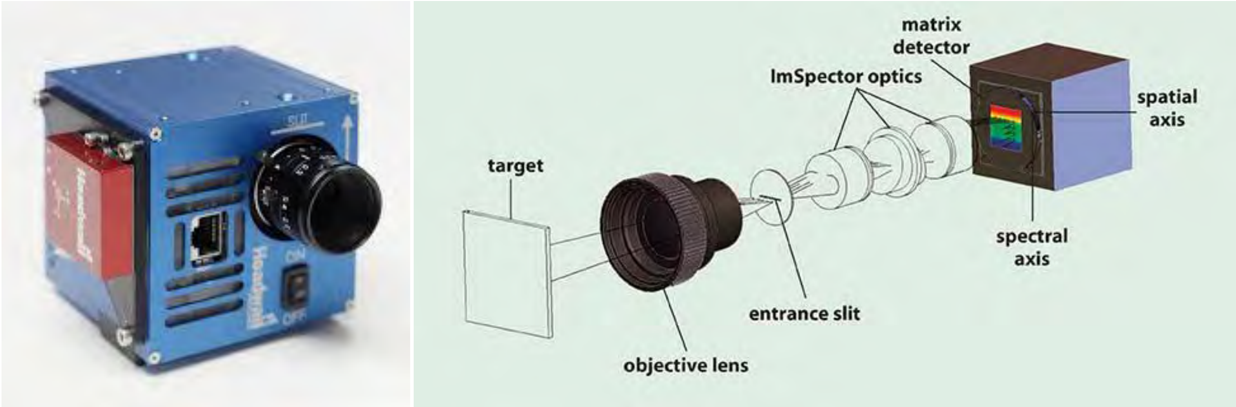


Figure 3.3-2 Hyper-Spectral Imaging optic device (camera).

HSI processing receives 3-D information, 2 spatial x-, y- and 1 spectral λ-dimension. The result is a spectral image dataset referred to as a data cube (x, y, λ), which offers a significantly enhanced amount of information, when compared to traditional RGB imaging (Figure 3.3-3). In RGB imaging the dimensionality of the spectral axis is triple, whereas HIS can employ hundreds of levels. Typically, HSI systems are based on reflectance measurements carried out under broadband illumination in Ultraviolet Visible Spectroscopy (UV-Vis), Near-Infrared and Mid-Infrared (NIR and MIR) spectral ranges (Figure 3.3-4).

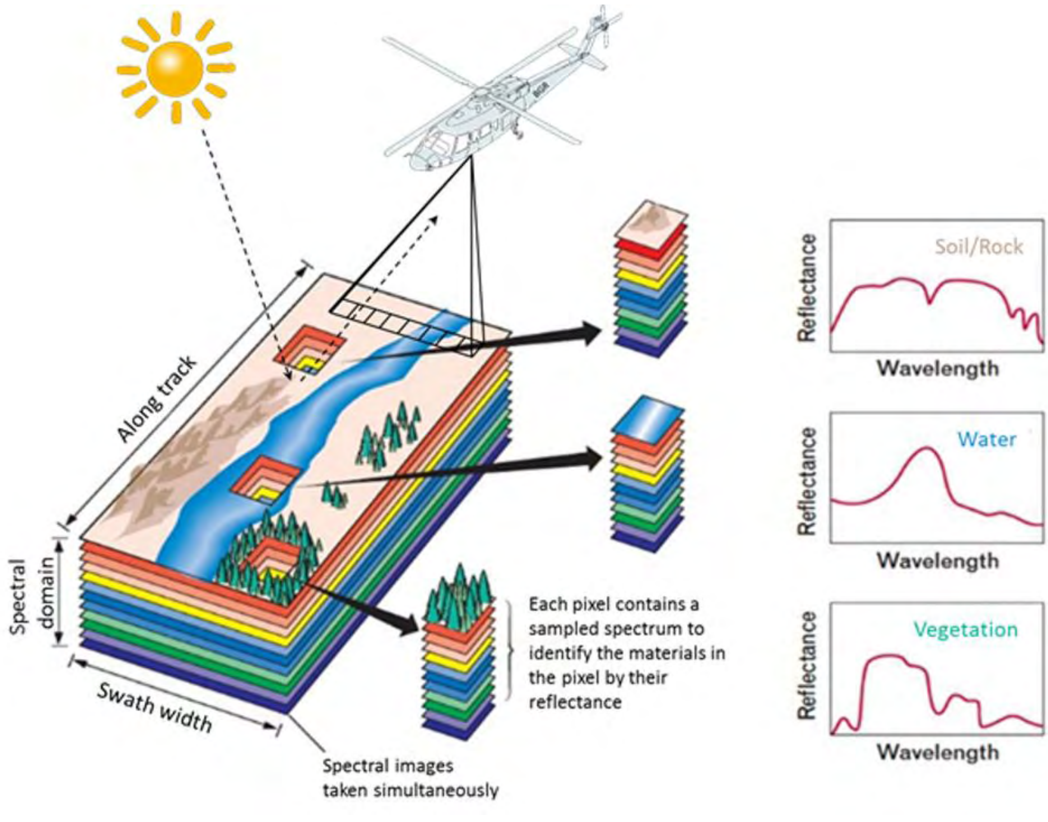


Figure 3.3-3 Hyper-Spectral Imaging processing technique of 3-D level information.

The four techniques in spectral imaging refer to point-scanning, wavelength-scanning, snapshot, and push broom imaging. Thus, from each taken image pixel, a spectrum can be recorded/reproduced (Figure 3.3-5). Point-scanning measures spectral information (λ) of one point followed by scanning across all spatial locations (x, y) to create a data cube. The push broom technique utilizes a 2-D detector array to collect one (y, λ) slice of the data cube at a time, so that only one spatial (x) dimension subsequently needs to be scanned. Although this type of line-scan imaging is very commonly used in HSI systems, there are some disadvantages including low light throughput due to slit, non-uniform efficiency and limited spectral range due to the grating order superposition. The snapshot technique acquires the entire 3-D data cube in a single exposure without the need for scanning. It is a quick scanning method but limited in the number of wavelengths one device can scan and is typically more multispectral than a hyperspectral imager. The fourth technique, referred to as wavelength-scanning, captures one (x, y) spatial image of the data cube at a time, and then scans across all wavelengths (λ). A wavelength-scanning imager is implemented using either a filter wheel, linear variable filter, variable interference filter (VIF) or tunable filter, which is placed either in front of the broadband light source or in front of the matrix detector of a monochrome camera. The sample is then imaged sequentially at different wavelength bands with varying filter settings. Therefore, the wavelength scanning technique enables the tuning of the number of spectral bands acquired to the needs of the specific application it is used for.

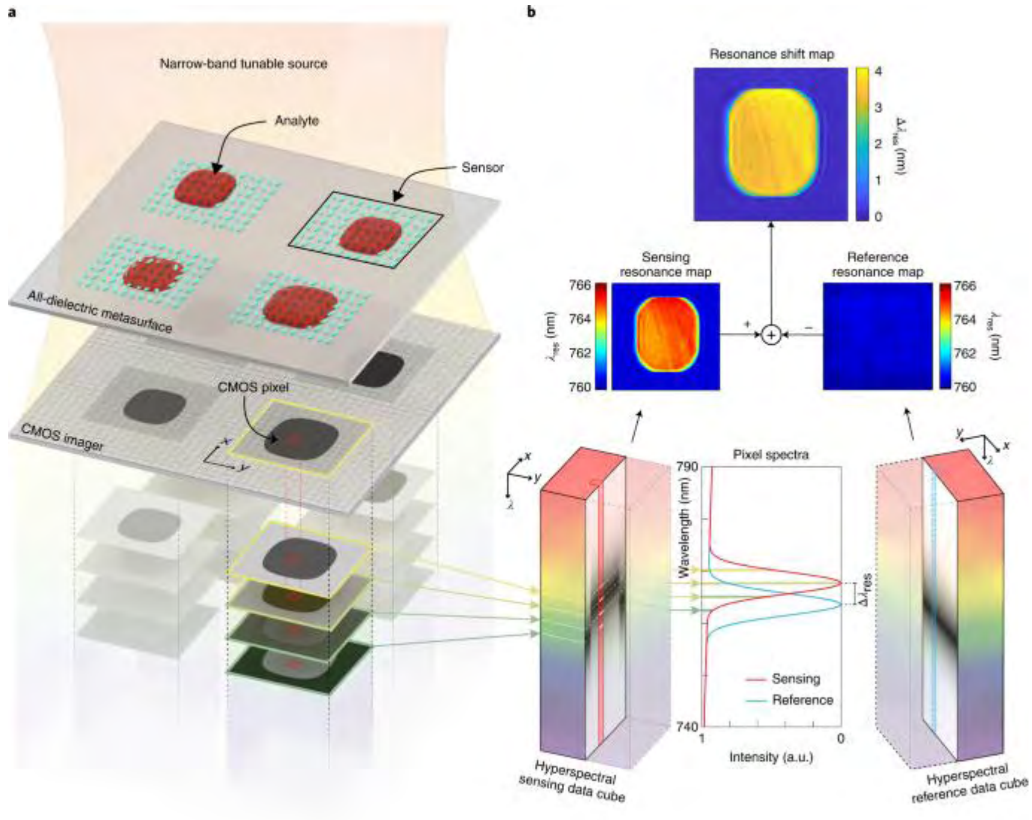


Figure 3.3-4 Hyper-Spectral Imaging processing technique of 3-D level information.

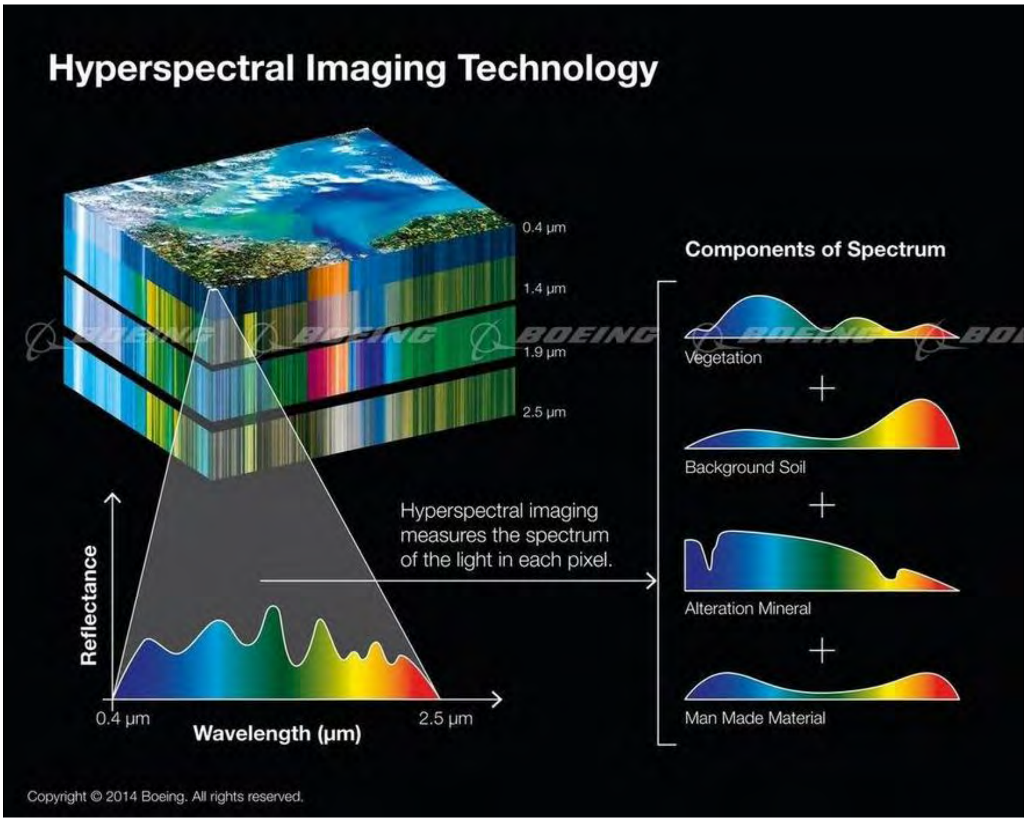


Figure 3.3-5 Hyper-Spectral Imaging technology for spectroscopic analysis.

Over the past two decades, HSI has been growing in prominence and utility, presenting advantages over standard machine vision imaging techniques, which use light only from the visible spectrum. However, the benefits of HSI, e.g. in agricultural land monitoring, are followed by increased complexity of the camera imaging systems in terms of lighting, filtering, and optical designs, while their ever-decreasing sizes allow their attaching on UAVs and drones for extended HSI environmental field inspection (Figure 3.3-6).

Figure 3.3-6 Hyper-Spectral Imaging cameras mounted on drones used in agriculture

to monitor the health of fields across a broad range of the electromagnetic spectrum.

In typical machine vision applications, the illumination used and captured by the sensor is from roughly 400 nm (violet) to 700 nm (dark red) (Figure 3.3-7). The light is often collected with imaging lens assemblies and sensors that have peak spectral sensitivities around 550 nm. The quantum efficiency of most camera sensors, or the ability to convert photons into an electric signal, decreases significantly when extended into the UV or the NIR.

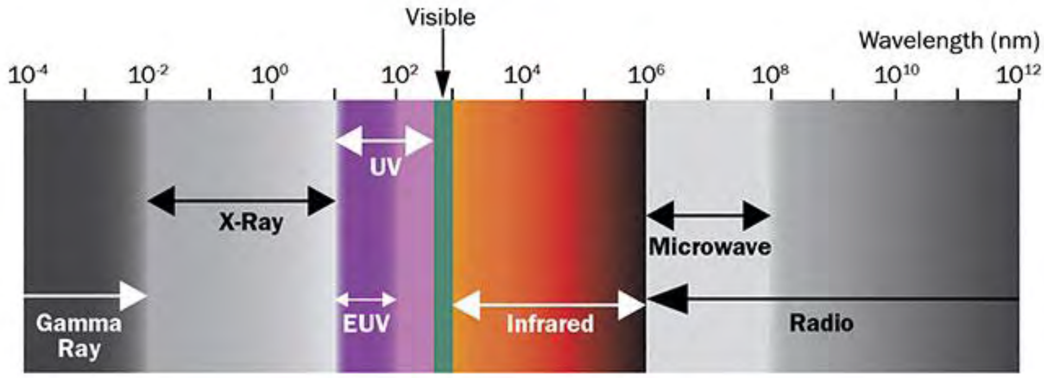


Figure 3.3-7 Wavelength regions outside of the visible spectrum used in HSI.

HSI, in simplest terms, captures images that contain information from a broader portion of the electromagnetic spectrum. This range can start with UV light, extend through the visible spectrum, and end in the NIR or shortwave MIR. The extended wavelength range can reveal properties of material composition that are not otherwise apparent. A sensor used in machine vision will output an array of grayscale values that result in a 2-D image of some object within a viewing area. The functional utility of this is generally feature recognition for the purposes of sorting, measuring, or locating objects. Unless optical filtering is used, the vision system is unaware of the wavelengths that are being used for illumination. This is obviously not true for sensors that have a Bayer filter pattern (RGB), but even then, each pixel is restricted to accepting light from a narrow band of wavelengths, and the camera software assigns color after the fact. In a truly hyperspectral image, each pixel corresponds to coordinates, signal intensity, and wavelength information. For this reason, HSI is often referred to as imaging spectroscopy. As a quick aside, spectrometers collect wavelength information as well as relative intensity information for the various wavelengths detected. These devices typically collect light from a singular source or location on a sample. They can be used to detect the presence of substances that scatter and reflect specific wavelengths, or material composition based on fluorescent or phosphorescent emissions. An HSI system takes this technology to the next level by assigning positional data to the collected light spectrums. A hyperspectral system does not output a 2-D image, but instead a hyperspectral data cube or image cube in the four aforementioned image acquisition modes. HSI is best suited for applications that are sensitive to subtle differences in signal along a continuous spectrum. These small signals could be missed by a system that is sampling larger wavebands. However, some systems require that significant portions of the electromagnetic spectrum be blocked, and that light be only selectively captured. The other wavelengths could present significant noise that could potentially ruin measurements and observations. Also, if less spectral information is included in the data cube, the image capture, processing, and analysis can happen more quickly.

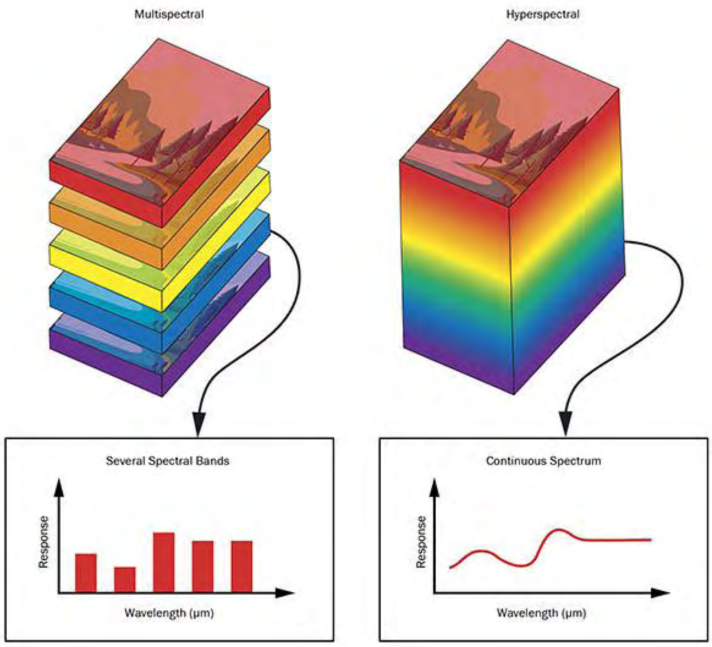


Figure 3.3-8 HSI image stacks, spectrum and wavelength analysis compared to Multi-Spectral Imaging (MSI).

The number of applications that require HSI will continue to grow in the 21st century. These technologies have large footprints in the life sciences and remote sensing. More specific markets include agriculture, food quality and safety, pharmaceuticals, health care, environmental monitoring, spatial planning, hydrogeology, marine technology, etc. The last decade, HSI has been a crucial component of remote sensing, which involves aerial imaging of Earth's surface with the use of UAVs and satellites. Spectral photography can penetrate through Earth's atmosphere and various types of cloud cover for an unobscured view of the ground below. Remote sensing can be used to monitor changes in population and observe geological transformations among other tasks. These imaging techniques have become increasingly critical in the study of the environment. They enable data to be collected on deforestation, ecosystem degradation, carbon recycling, erratic weather patterns, and lately water quality inspection. Marine researchers could potentially use the gathered information to create predictive models of aquatic ecology in coastal areas. The systems are significantly more expensive when compared to other machine vision components for the time being, as sensors are more complex, have broader spectral sensitivity, and must be precisely calibrated. The sensor chips often require the use of substrates other than silicon, which is sensitive only from approximately 200 to 1000 nm. The materials indium arsenide (InAs), gallium arsenide (GaAs), and indium gallium arsenide (InGaAs) are used for collecting light up to 2600 nm. If the requirement is to image from the NIR through the MWIR, a mercury cadmium tellurium (MCT, or HgCdTe) sensor is required. The sensors and pixels used in these systems will also need to be larger than many machine vision sensors to attain the required sensitivity and spatial resolution. These are applicability and accessibility issues for the scientific community to combat in the near future.

Another challenge exists in pairing these high-end sensors with the proper optical components. Bandpass filters, diffractive optics such as prisms or gratings, and even liquid crystal or acousto-optic tunable filters are required to separate light of differing wavelengths so the spectral data can be recorded. Additionally, the lenses used for these cameras must be designed to work optimally across vast wavelength ranges and temperature fluctuations. The need for more optical elements in the designs increases system cost and weight. These elements will also need to have different refractive indices and dispersive properties for broadband color correction. With differing glass types comes varied thermal and mechanical properties as well. After selecting glasses that have the appropriate internal transmission spectra, broadband multilayer antireflection coatings must be applied to each lens to ensure maximum light throughput. The multitude of unique requirements in these circumstances makes for a tedious process of lens design for HSI, and such design requires great skill. Certain application spaces also necessitate that the lens assemblies are athermal to ensure that a system will function the same whether used on the ground or in the upper atmosphere.

The goals of future development include making HSI systems more compact, affordable, and user-friendly. Improvements in these areas will encourage new markets to use the technology and will advance the markets that already do. This way HSI techniques for environmental evaluation can become a key method for nondestructive, remote evaluation of coastal areas and lakes. The most well-known application is in remote sensing of the Earth using either air- or satellite-borne systems. Such monitoring has been used to study agricultural effects, monitor the distributions of phytoplankton and chlorophyll-a in lakes, and detect and map invasive species in wetlands, swamps, and prairies. Coastal sites are to be included in the near future. HSI systems would be incomplete without the use of data analysis software to extract from the hyperspectral data the key information about the process or samples being monitored. A typical workflow is described in Figure 3.3-9.

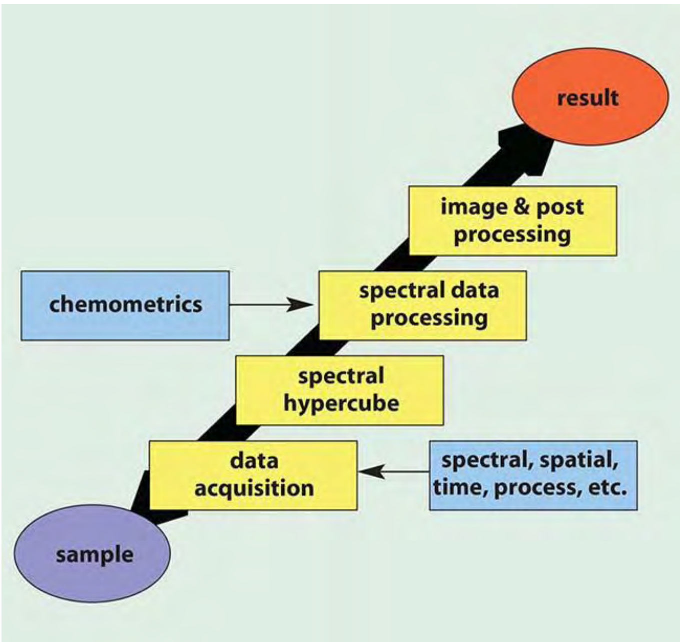


Figure 3.3-9 Typical HSI workflow.

The wealth of additional information available and the application benefits that HSI produce are almost without limit. Since its early use in satellite remote sensing, both the technique and optical instrumentation have developed to support applications that require real-time process monitoring, control, inspection, quantification, and identifications. The use of transmission-grating imaging spectrographs has allowed these systems to be compact and robust and to possess excellent spatial and spectral performances at a cost level not easily matched by comparable instrumentation. It can be expected that the growth in HSI will continue in chemical monitoring, whether it is the life sciences, oceanography, hydrography, environmental management, forensics, homeland security, pharmaceuticals, or any other application where the spectral information provides a dramatic contrast improvement in sample conditions and features compared with conventional imaging systems.

3.4 Internet of Things (IoT) technologies

The **Internet of Things (IoT) technologies** refers to a vast number of "things" that are connected to the internet so they can share data with other things – IoT applications, connected devices, industrial machines and more. Internet-connected devices use built-in sensors to collect data and, in some cases, act on it. IoT connected devices and machines can improve how we work and live. Real-world Internet of Things examples range from a smart home that automatically adjusts heating and lighting to a smart factory that monitors industrial machines to look for problems, then automatically adjusts to avoid failures.

https://www.sas.com/en_us/explore/resources/aiot.html;

Artificial intelligence can multiply the value of IoT by using all the data from smart devices to promote learning and collective intelligence.

The term Internet of Things (IoT) first came to attention when the Auto-ID Center launched their initial vision of the EPC (event-driven process chain network) for automatically identifying and tracing the flow of goods in supply-chains, in Chicago in September 2003 (Uckelmann et al., 2011). Whereas the first mention of 'Internet of Things' appears in an Auto-ID Center paper about the Electronic Product Code by David Brock in 2001 (Brock 2001), increasing numbers of researchers have followed this innovative perception, as it is appearing in numerous books, research papers, conferences and symposia having Internet of Things in their titles.

Internet of Things is an area based on the technological concepts of cyber-physical systems, which enables the emergence of what is called smart factories, smart manufacturing, Industry 4.0, and factories of the future (Haddara and Elragal 2015).

IoT architectures refer to the connectivity of physical objects connected to the Internet that support sense capabilities. These objects can be accessed through unique addressing schemes with interaction and cooperation features. IoT architectures incorporate numerous types of devices, such as microcontrollers, sensors, actuators, smartphones, and wearables. Furthermore, open-source platforms, hardware, and enhanced software solutions for data analytics, consulting, management, and storage are required to design and develop IoT architectures. IoT architectures involve people who use these IoT devices and should contribute and cooperate with IoT systems synergistically. Therefore, IoT architectures must be aware of the human context and consider people as an essential part of the system (Marques, Pitarma et al., 2019).

The IoT technology has multiple layers: data, devices, connectivity, and the technology users. The first layer represents the data that is collected, processed, stored, sent, and analysed and presented in the context of that is created for. The device layer is represented by sensors, different hardware and software components, actuators and gateways that connects and interacts with a network.

These layers can provide extensive datasets that may give insights through advanced analytics, which can optimize operational efficiency and potentially accelerate productivity. The analytics' outcomes can be reduced unplanned downtime and more optimized productivity (Haddara and Elragal, 2015).

Currently, there are numerous open-source platforms and operating systems that aim to provide support for different systems, data confidentially, safety, fusion, and dissemination (figure 3.4-1).

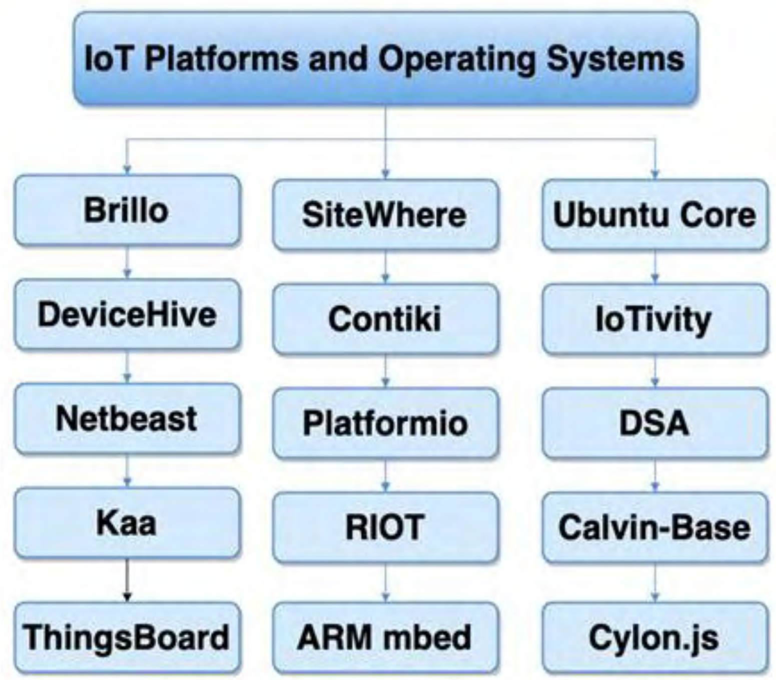


Figure 3.4-1 IoT platforms and operating systems
(source: Marques, Pitarma et al. 2019)

Through IoT, industries can achieve better visibility and gain enhanced insights into their operations and assets through the integration of machine sensors, middleware, software, and back-end cloud computing and storage infrastructure (Haddara and Elragal 2015, Vollen and Haddara 2019).

Applications for Fisheries Sector

Internet of Things (IoT) technologies are changing several industries and providing standards and infrastructures to connect physical objects, applications, machines, and devices. IoT has the potential to make industries more efficient and create new business opportunities. The most prominent areas include smart homes, energy, healthcare, manufacturing, supply chains, sustainability, among others. Smart Industry or industry 4.0 is the core of IoT and smart manufacturing.

A schematic representation of the Internet of Things of exploitation of coasts, seas and oceans is given on Figure 3.4-2.

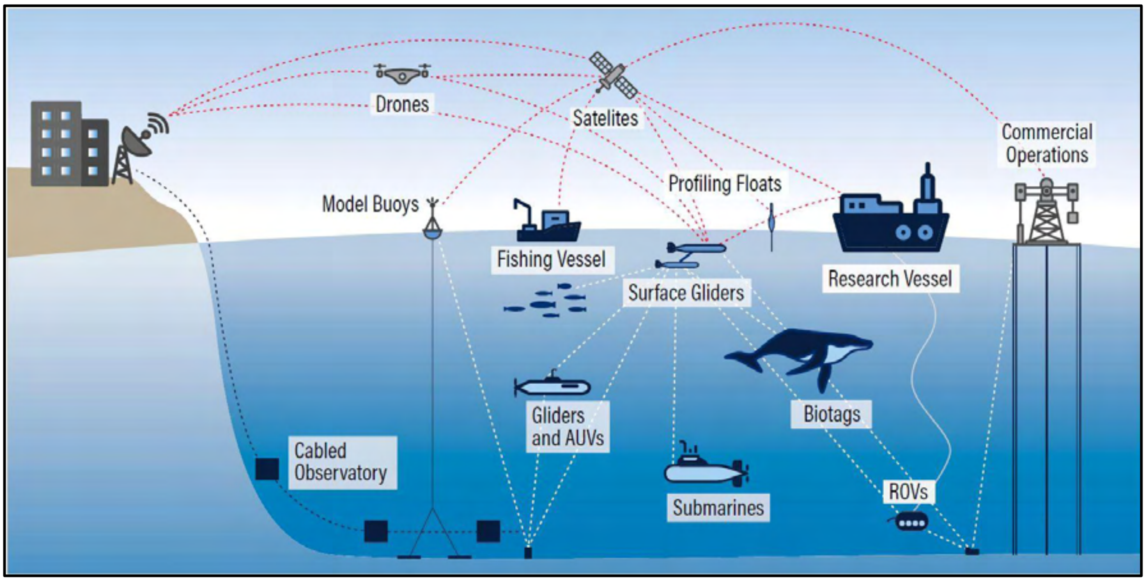


Figure 3.4-2 Schematic representation of the Ocean Internet of Things (source: Leape et al., 2020, Technology, Data and New Models for Sustainably Managing Ocean Resources, HIGH LEVEL PANEL for a Sustainable Ocean Economy; oceanpanel.org

Vessel Monitoring Systems (VMS) have greatly increased the efficiency of monitoring, control, and surveillance of fishing vessels. In the last few years, several countries have mandated the use of VMS to monitor fishing vessel activity and to ensure these vessels actively report on catches to the fisheries management authority.

IUU (Illegal Unregulated Unreported) fishing is a global issue that threatens the sustainability of the industry and environment. With IoT, however, organizations can better monitor fishing operations and combat IUU fishing activities.

- VMS compliance: With satellite services integrated with VMS systems, fishery agencies can collect information relating to the position, speed, course, and identification of connected vessels on a regular basis. The VMS can generate alerts for operations in non-authorized areas.
- Electronic logbooks: Fishing vessels are replacing traditional paper logbooks with electronic logbooks. Crew use their Wi-Fi enabled phones or tablets to record catches, transhipments, landings, and sales, and they transmit this information over satellite to the appropriate authorities based on policy.
- Personal crew communications: Provide personal communication services to crew, augmenting other mandated systems. This also enables the fisheries to send weather alerts, environmental conditions, and maritime traffic information to crew.

Another application of IoT in fisheries is related to fishing gear monitoring (figure x). Currently, fishing boats have become larger and use advanced fishing methods. Therefore, fishing gear management laws, monitoring systems, closed seasons, and resource management efforts have been considered (Sangmin and Dongsoo, 2017).

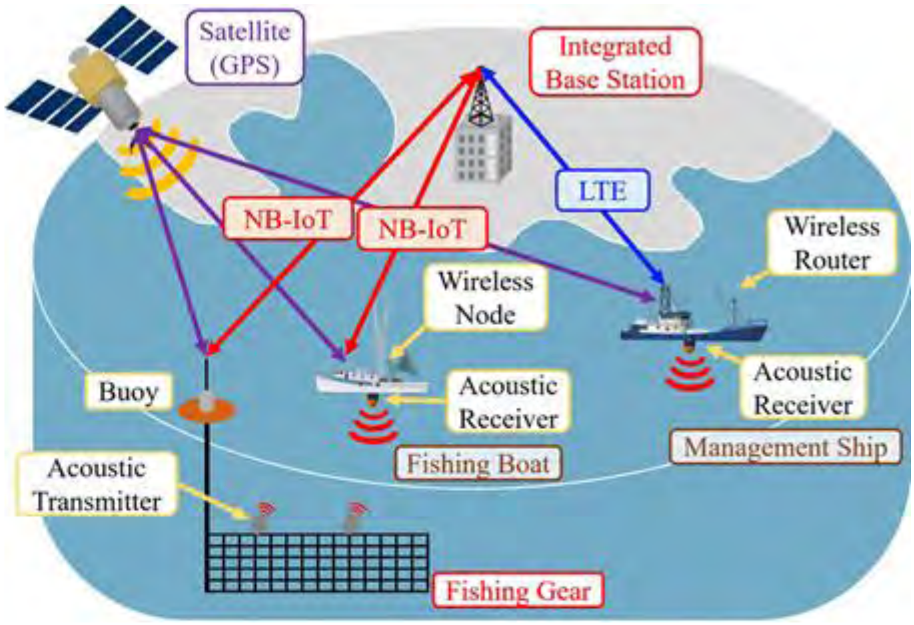


Figure 3.4-3 The automatic identification monitoring system for fishing gear based on NB-IoT – Narrow Band – Internet of Things
(from: Sangmin and Dongsoo, 2017)

The automatic identification monitoring system as a new system developed by the governments/countries, attempts to prevent lost and derelict fishing gear from causing harm to marine environments while also maintaining a safe environment for fishermen by attempting to prevent marine accidents which are caused by the derelict fishing gear, among other tasks.

The governments/countries want to successfully manage fishing gear near the shore and in offshore areas. The monitoring system can always track the positions of fishing gear and judge whether these items are lost. Furthermore, the real-name fishing gear system serves to prohibit the overuse of fishing gear and to control fish catches. Above all, these measures motivate fishermen to maintain control over their fishing gear.

The adoption of IoT technology for communication between fishing gear and the base station, between the base station and management ships, and between the base station and fishing boats is the key aspect of this monitoring system. The monitoring system utilizes NB-IoT communication technology, broadcasting on empty bandwidth segments of the licensed LTE frequency domain. The automatic identification monitoring system for fishing gear based on NB-IoT consists of satellites, buoys, fishing gear, base stations, integrated base station on land, management ships, and fishing boats (Sangmin and Dongsoo, 2017).

3.5 Do-It-Yourself (DIY) low-cost technologies and open-source hardware and software in monitoring

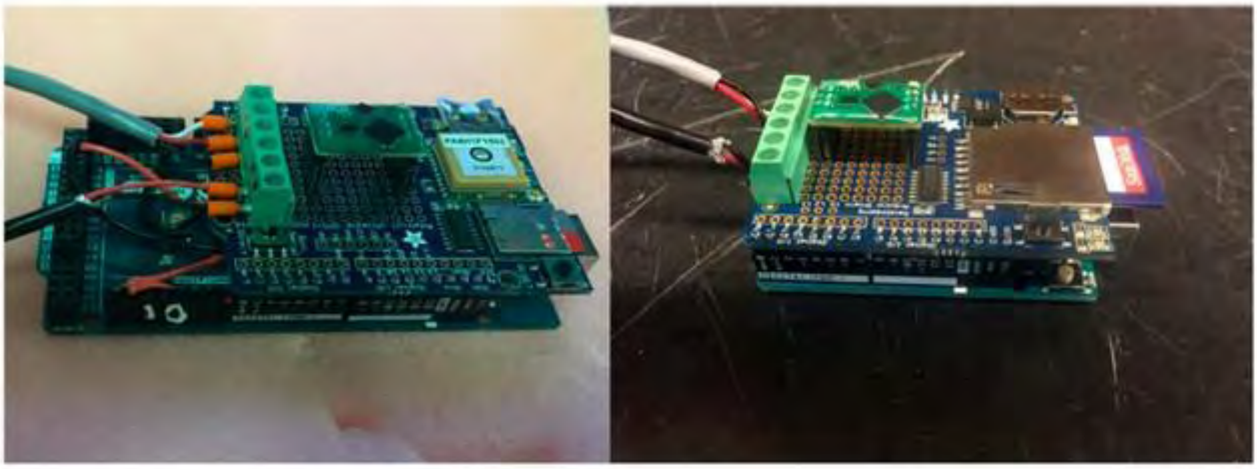
(e.g., Arduino, Raspberry Pi, small micro-controllers, single-board computers)

Low-Cost Arduino implementations for the measurement of seawater parameters

Lockridge et al. (2016) addressed the need for an expansion in the monitoring of marine environments by the means of a low cost, robust, user friendly sonde, using the open-source software and hardware of the Arduino framework. The proposed sonde was built on two Arduino platforms, Arduino Mega 2560 and Arduino Uno. Lockridge et al. (2016), provide a relatively detailed description of the implementation and state it can be accomplished without specialized tools or training. Furthermore, it can be easily modified to meet individual application requirements. The Arduino platform was chosen over similar alternatives (i.e., Raspberry Pi, Gumstix) because of its lower price and the extensive online support network. Additionally, the Arduino was found to be capable of withstanding a large amount of physical abuse, making it the ideal option for deployment in harsh marine environments.

The utility of the Arduino based microcontroller is clearly evident and viable, with examples of their incorporation ranging from automated sterilization of laboratory equipment (Arizaga, J. et al., 2012) to in situ measurements of phytoplankton florescence (Leeuw, T. et al., 2013). While generally reported as successful, insufficient resolution is the most commonly noted limitation of these electronics (Leeuw, T et al., 2013; Barnard, H. et al. 2014; Fisher, D. et al., 2012).

However, the resolution limits, while not ideal for all applications, are sufficient for many efforts, namely, environmental monitoring or educational endeavors, where the low cost and the ability to manufacture and customize multiple units take precedence over higher precision data collection. Other similar efforts have utilized Raspberry Pi and Gumstix platforms successfully (Fisher, D. et al., 2012), and while they have more powerful processors, and can interface with a wider range of sensors and instruments, they require more expertise and are less cost effective than the specific Arduino by Lockridge et al. The platform allows for internal logging of multiple parameters of which conductivity, temperature, and GPS position are demonstrated. Two design configurations for different coastal hydrographic applications are highlighted to show the robust and versatile nature of this sensor platform. The first one was intended for use as a Lagrangian style surface drifter, while the second was for deployment, moored to permanent structures.



(a) (b)

Figure 3.5-1 Figure: Assembled Arduino based sonde for (a) the drifter application and (b) the moored application

(source: Lockridge et al.,2016).

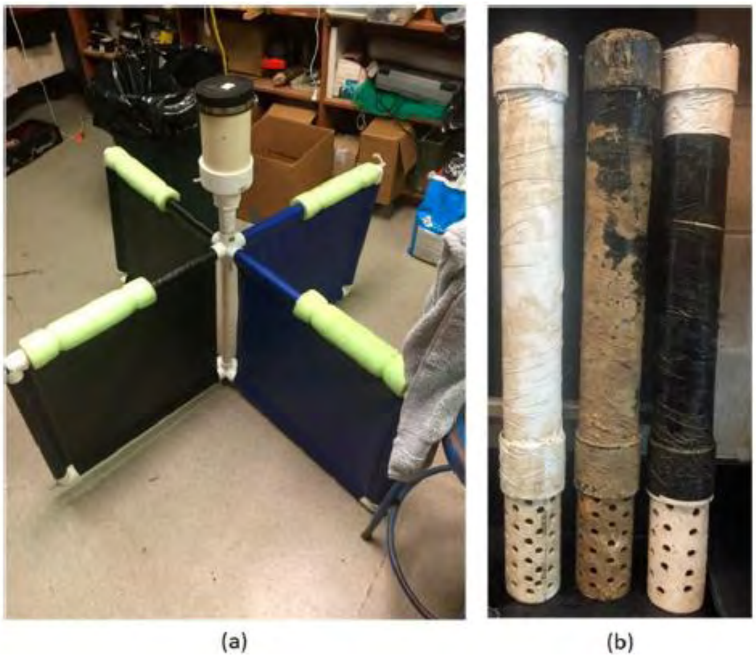


Figure 3.5-2 Figure: Picture of the deployment housing for (a) the drifter application and (b) the moored application
(source: Lockridge et al.,2016).

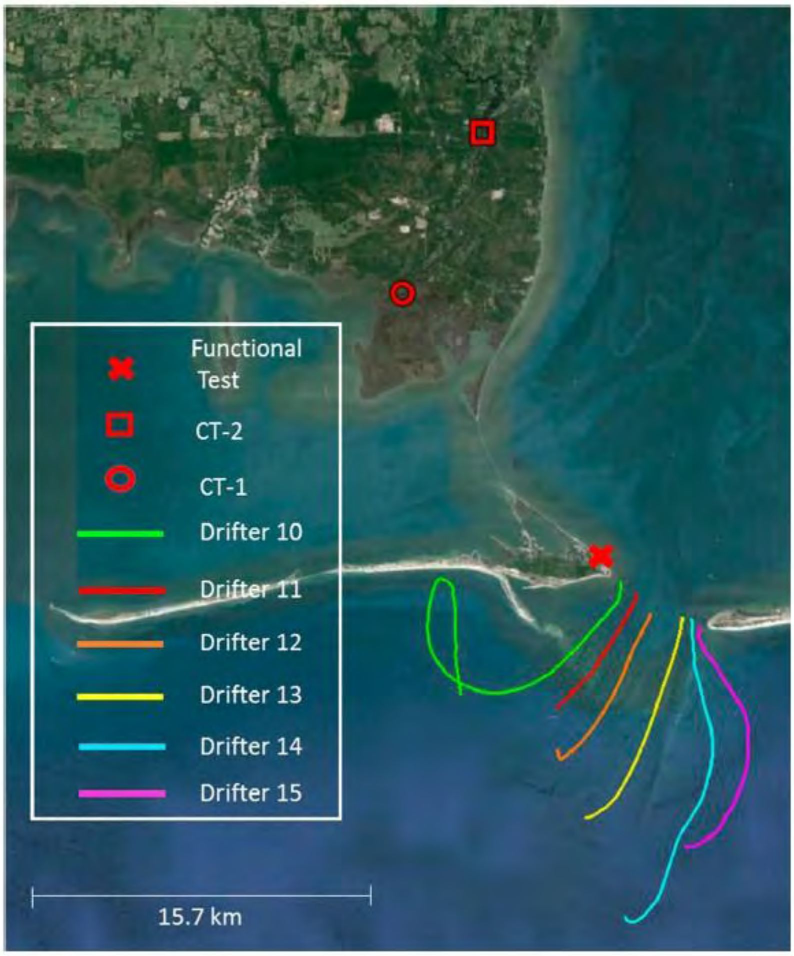


Figure 3.5-3 Plots of the recorded GPS tracks from drifters
(source: Lockridge et al.,2016)

Plots of the recorded GPS tracks from drifters the drifter application are represented by colored lines. The location of the functional testing is a red X. The red square and circle identify the locations of the moored application deployments (source: Lockridge et al.,2016).

The drifter configuration was designed in order to record measurements of temperature; salinity; and position for a deployment duration of less than 24 hours. Functional testing of the sensor consisted of a 55 hour comparison with a regularly maintained water quality sensor (i.e., YSI 6600 sonde) in Mobile Bay, AL. The temperature and salinity data were highly correlated and had acceptable RMS errors of 0.154 oC and 1.35 psu for the environmental conditions.

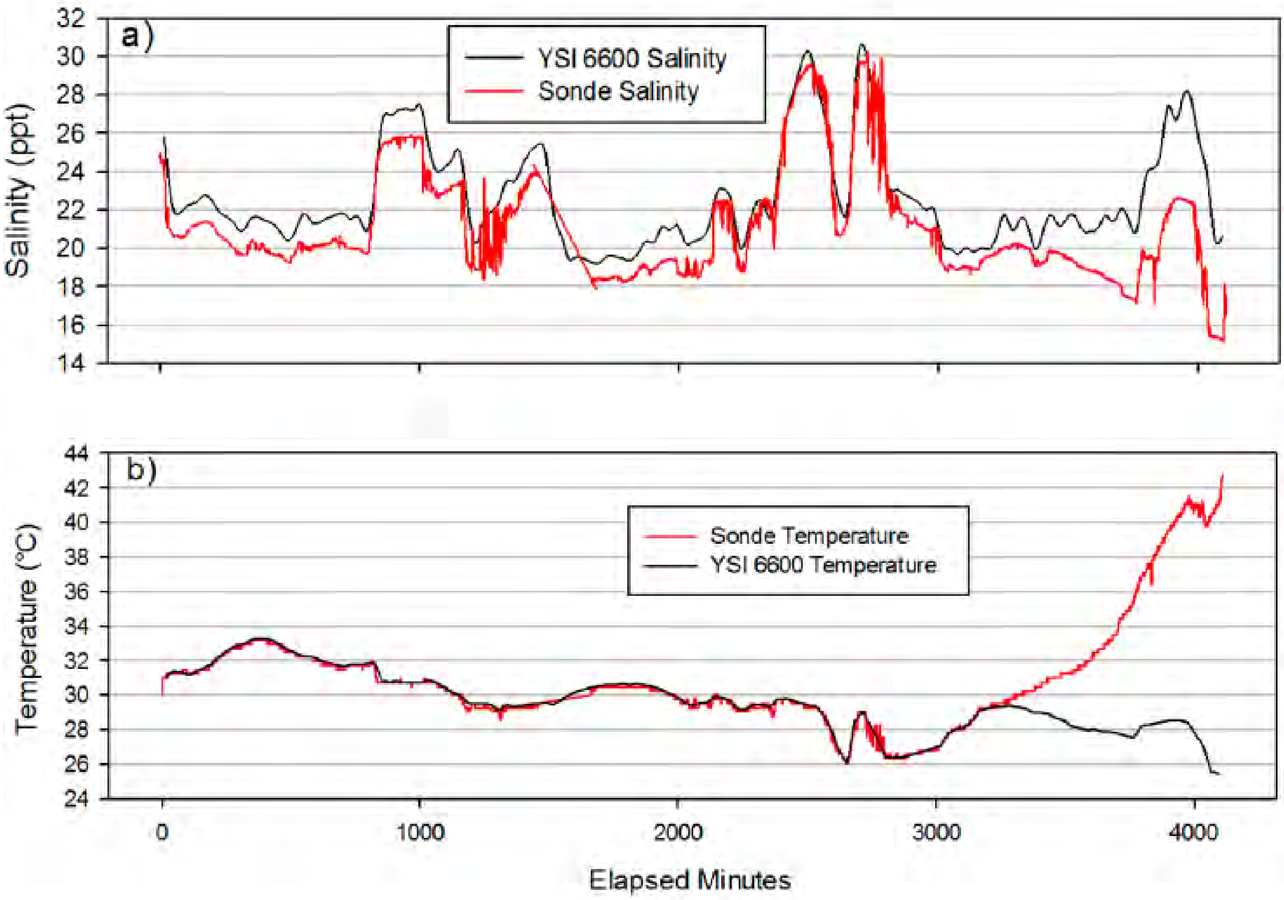


Figure 3.5-4 Comparison of salinity (a) and temperature (b) between the drifter configuration of the sonde and the Dauphin Island Sea Lab (DISL) Weather Station YSI 6600 from 1546 GMT August 24th, 2015 to 1146 GMT August 27th, 2015 (source: Lockridge et al., 2016).

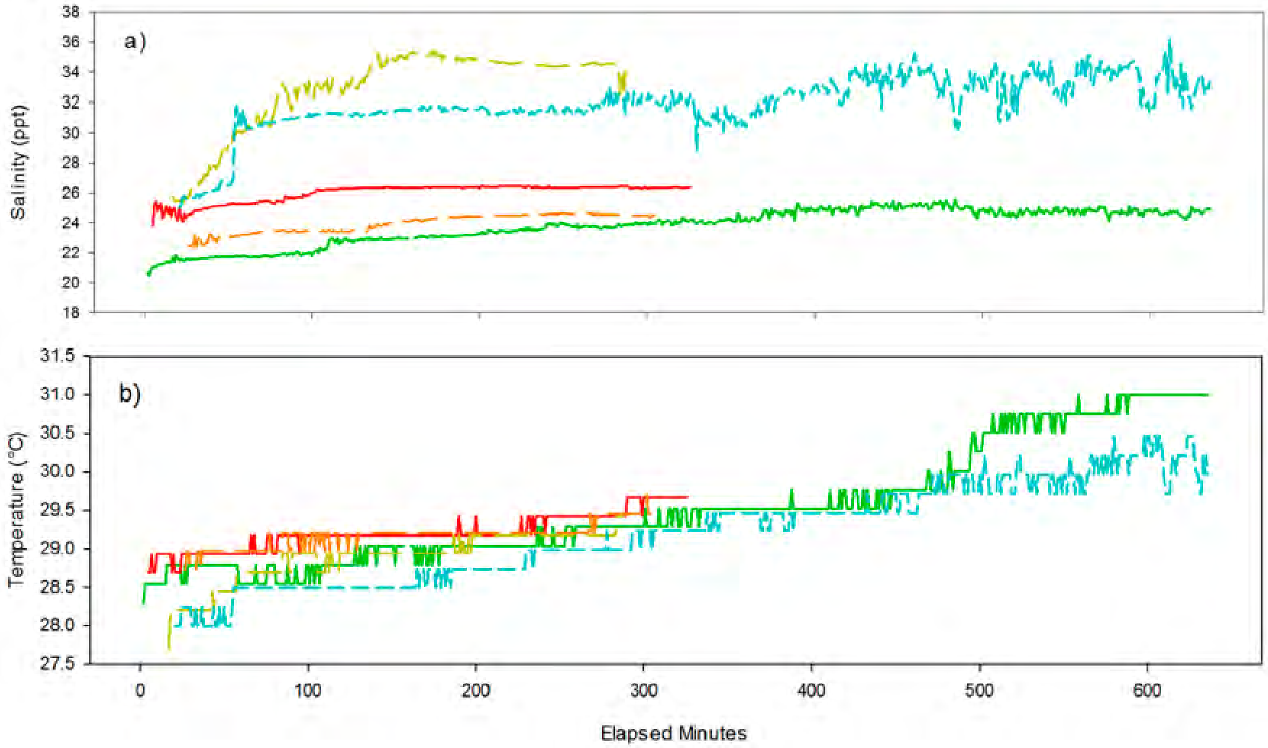


Figure 3.5-5 Salinity (a) and temperature (b) readings from drifters 10–14 during deployment on September 4th, 2015 across the mouth of Mobile Bay, Alabama

(source: Lockridge et al.,2016).

The second application using the sonde platform was designed for longer duration (~3–4 weeks); subsurface (1.5–4.0 m depths) deployment, moored to permanent structures. Design alterations reflected an emphasis on minimizing power consumption, which included the elimination of the GPS capabilities, increased battery capacity, and power-saving software modifications. Two conductivity and temperature data loggers (CT) using the moored application design were deployed for a total of 24 days from 13 November 2015 to 7 December 2015. CT-1 was deployed in West Fowl River (30_21.742 N, 88_10.434 W), while CT-2 was deployed at Bellingrath Gardens (30_25.716 N, 88_8.138 W). The locations can be seen in Figure above.

Salinity and temperature measurements were taken every 30 min and the results can be viewed in the following Figure.

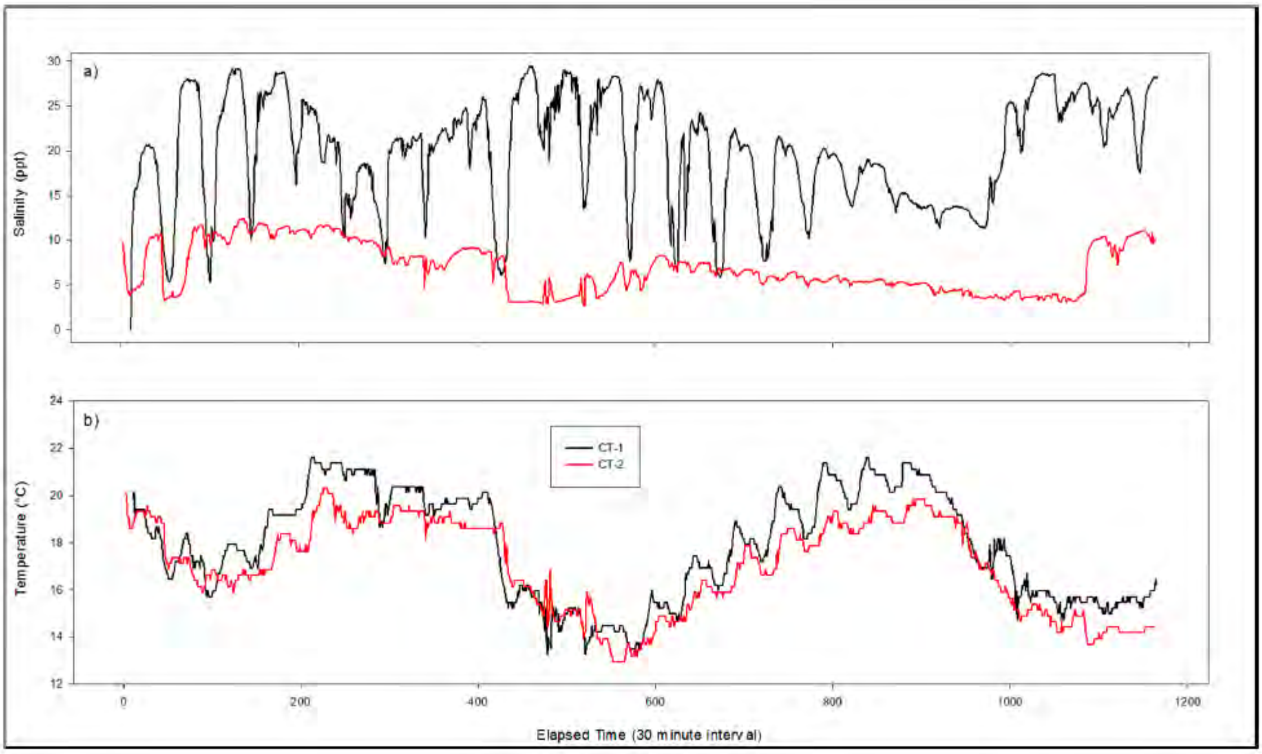


Figure 3.5-6 Salinity (a) and temperature (b) measurements taken with the moored application design from sites CT-1 and CT-2

during deployment of 13 November to 7 December 2015 (source: Lockridge et al., 2016).

Results from the extended deployment period produced expected trends were consistent with expectations. The temperature and salinity measurements during this test deployment fluctuated diurnally with tidal cycles. The tidal influence on salinity is noticeably less defined at CT-2 when compared to CT-1 as a result of the geographic location of each site. CT-1, located at the mouth of a tributary leading into Mississippi Sound, experienced large fluctuations with each tidal cycle because of its proximity to the mouth of Mobile Bay where large salinity gradients are expected. In contrast, CT-2, located farther from sources of large salinity gradients, experienced lower overall salinities with less dramatic changes as a result of tidal advection.

According to Lockridge et al., the Arduino platform proved to be an exceptional tool for environmental monitoring, because of its surprising durability, low cost, and most importantly, the outstanding network of free online support. While not as reliable and precise as top-of-the-line instruments with designated user interfaces, software packages and technical support, the designs they presented seem to have a valid place in observational and functional ocean science as well as resource management. The authors argue that utilization of these low-cost platforms provides the means for new and innovative research by creating opportunities, where historically, few have existed. Furthermore, in coastal environments, where large changes in salinity can affect commercial important marine resources these sonde designs provide a low-cost option for state and local governments to develop or expand management capacity.

The authors also supply tables that contain the individual costs of each component, as well as the total cost of each configuration. Even though the costs are in US dollars and refer to 2016, they remain highly indicative of the cost-effectiveness that can be achieved by using such platforms and designs.

Table 3-1 Individual and total component for drifter sonde design

Drifter Application			
Component	Manufacturer	Supplier	Cost (US $)
Arduino Mega 2560	Arduino	Arduino.cc	45.95
Ultimate GPS Logger Shield	Adafruit	Adafruit.com	49.95
EZO-EC Microchip	Atlas Scientific	Atlas-Scientific.com	58.00
Conductivity K 1.0 Probe	Atlas Scientific	Atlas-Scientific.com	126.00
ENV-TMP Probe	Atlas Scientific	Atlas-Scientific.com	25.00
PCB mount 3 pin 5.08 mm terminal	Uxcell	Amazon.com	1.90
		TOTAL COST	306.80

Table 3-2 Individual and total component for moored sonde design

Moored Application			
Component	Manufacturer	Supplier	Cost (US $)
Arduino UNO	Arduino	Arduino.cc	24.95
Adafruit Data Logging Shield	Adafruit	Adafruit.com	19.95
EZO-EC Microchip	Atlas Scientific	Atlas-Scientific.com	58.00
Conductivity K 1.0 Probe	Atlas Scientific	Atlas-Scientific.com	126.00
ENV-TMP Probe	Atlas Scientific	Atlas-Scientific.com	25.00
PCB mount 3 pin 5.08 mm terminal	Uxcell	Amazon.com	1.90
		TOTAL COST	255.80

The software of each sonde design is available on the popular Github platform, where numerous open-source software projects are hosted in.

Another Arduino based application was developed by Croatian researchers from the University of Split's Faculty of Civil Engineering. Their application concerned the implementation of open-source software and hardware for the measurement of surface water properties in an estuary. The research team selected river Jadro, Croatia as their case study.

They designed their device with the aim to measure position, temperature, and electrical conductivity in multiple realizations. The device consisted of a floating container equipped with the following components: an Arduino Mega development board, a power management module, an SD card logging module, a Bluetooth module, a temperature measuring module, a global positioning satellite (GPS) position module, and a newly developed module for measuring electrical conductivity (EC).

All the tools they used are open-source and greatly supported by the worldwide community. The authors state that the materials used for the single measurement probe at the time of building amounted to approximately 105 EUR, and required up to 20 engineering hours, therefore presenting a low-cost alternative to commercially available options. If additional costs generated by more complex calibration procedures are considered, the aforementioned unit price may increase up to an estimated value of 130 EUR when a batch of ten is produced.

As is well known, Arduino development boards support microprocessors with all the necessary passive and active electronic components, while the Arduino integrated development environment (IDE) provides easy coding for microprocessor operations in a common programming language, C. In addition to Arduino development boards, the research team used multiple modules to perform specific activities of the measurement platform.

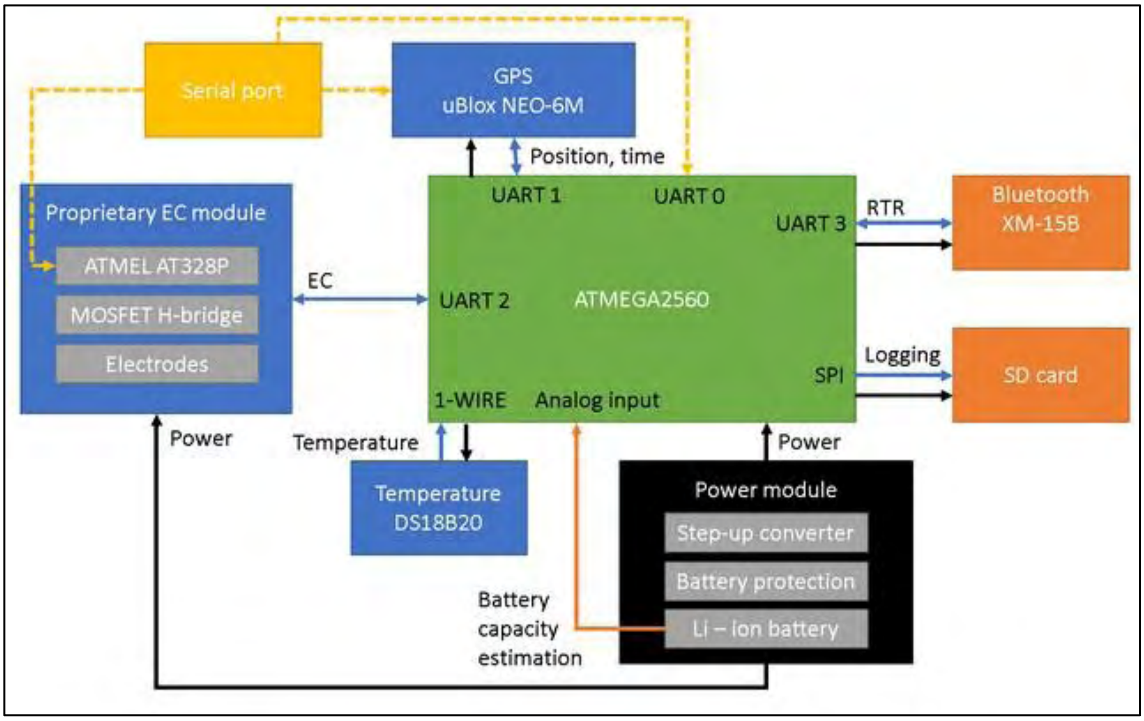


Figure 3.5-7 Schematic representation of the Arduino based probe system (source: Divic et al., 2020)

Figure 3.5-8 An example of a probe with exposed electrodes below the plastic container (left); and the calibration procedure in laboratory with the industrial probe (right) (source: Divic et al., 2020).

Figure 3.5-9 The probes released on river Jadro, Croatia (source: Divic et al., 2020).

In Divic et al. (2020), the authors describe in detail the design and the components of the device, the computational procedure of the associated software that leads to the results of the measured parameters and a thorough overview of the device's calibration process. The probes were tested during a field campaign conducted at the estuary of River Jadro near Split (Croatia). Nine of them were released at the river mouth and their position, temperature, and electric conductivity (EC) were monitored and recorded during the experiment, which ended when the probes stopped, due to the river plume attenuation. The same experiment was repeated three times. All of the probes recorded consistent temperature data, while the EC data show more variable behavior, due to the higher sensitivity of the corresponding sensor. This was expected as a part of the natural process in the estuary. The measured data were additionally used to parameterize an analytical model for mean flow velocity and salinity as a proxy concentration. This showed a good match between the experimental results and the theoretical framework.

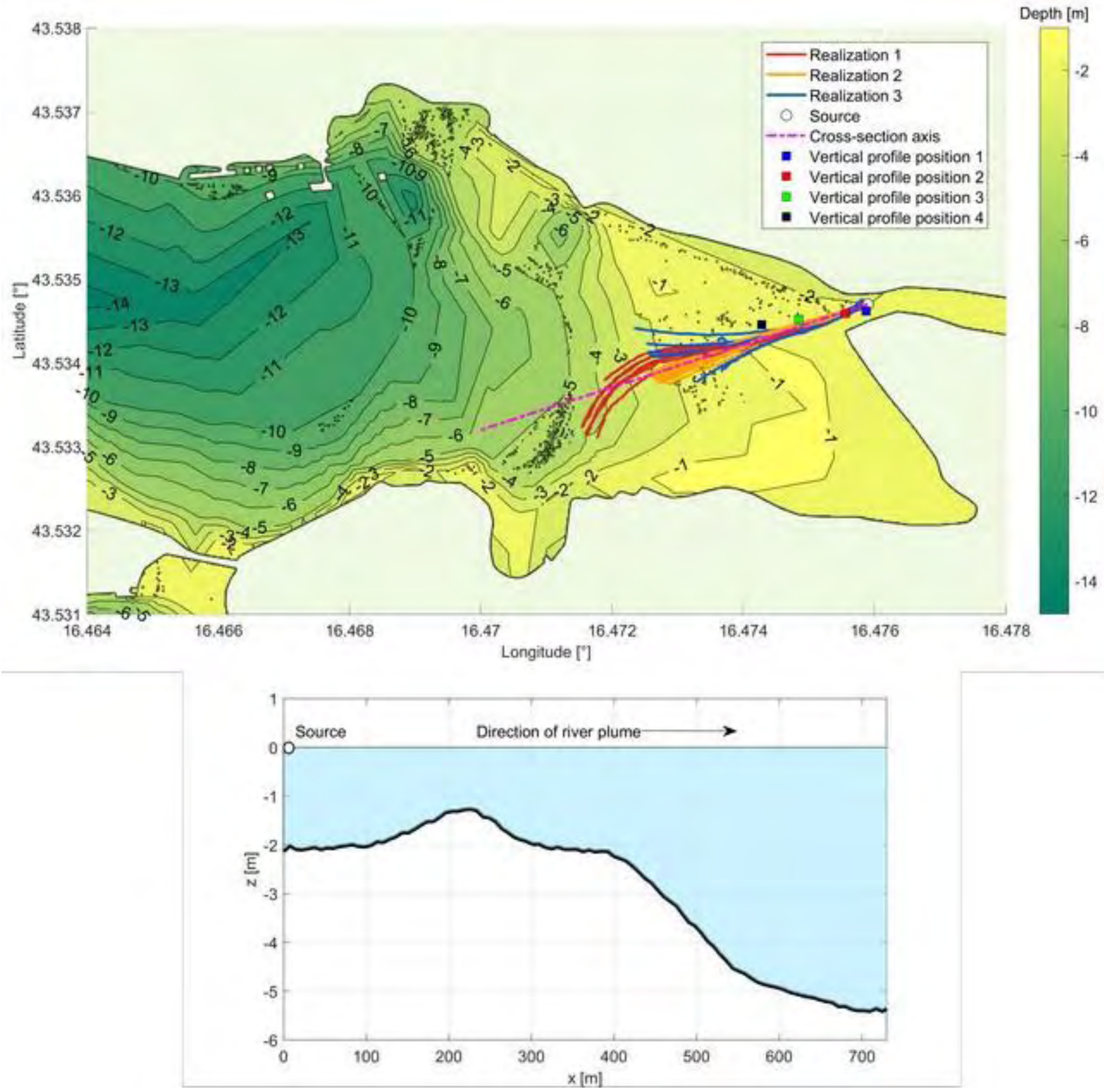


Figure 3.5-10 Planar view of the study area with annotated trajectories of probes and vertical profiles positions (top); and longitudinal cross section (bottom)
(source: Divic et al., 2020).

The figures that follow depict several measured surface water parameters, showing the capabilities and potential use of the probes.

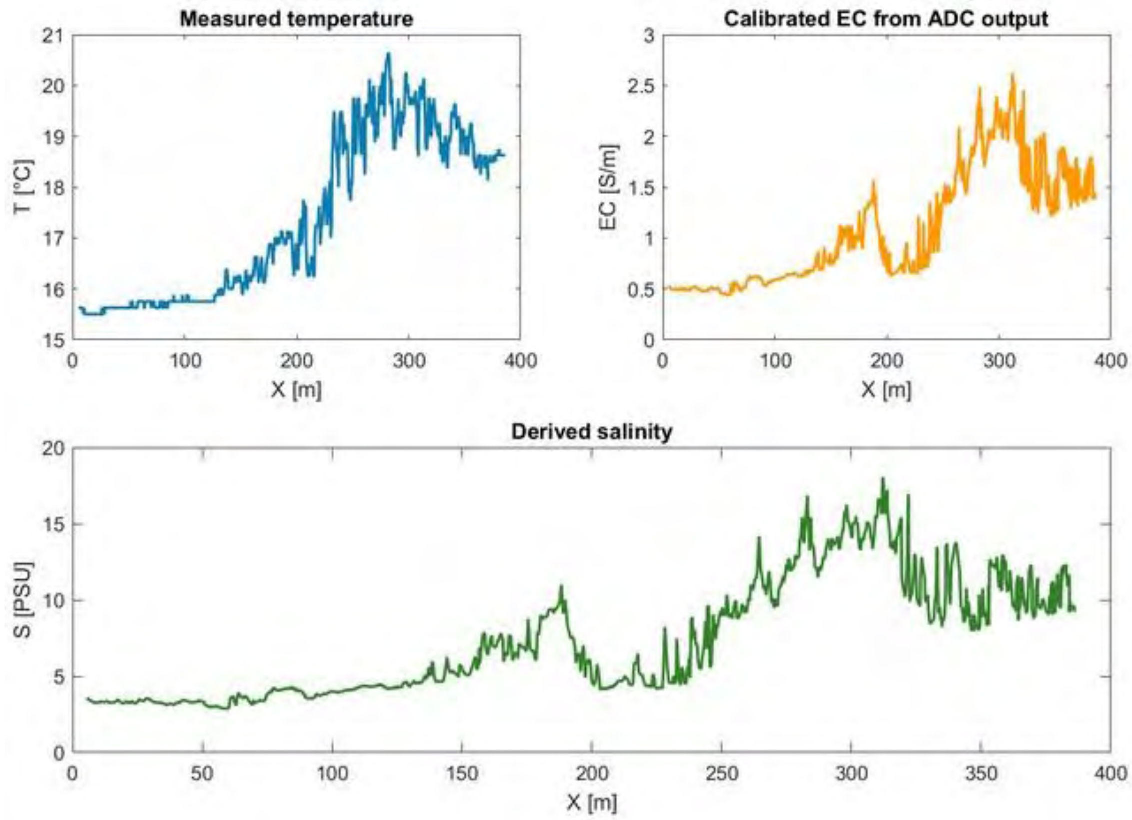


Figure 3.5-11 Derived salinity for Probe 9, Realization 1
(source: Divic V. et al, 2020).

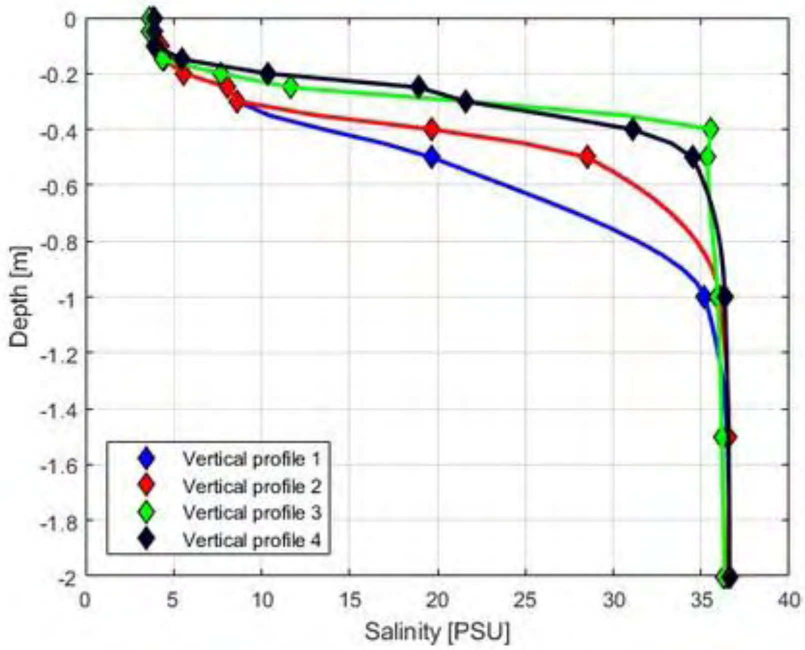


Figure 3.5-12 Vertical salinity profiles indicating the presence of the salt wedge stratification (source: Divic et al., 2020)

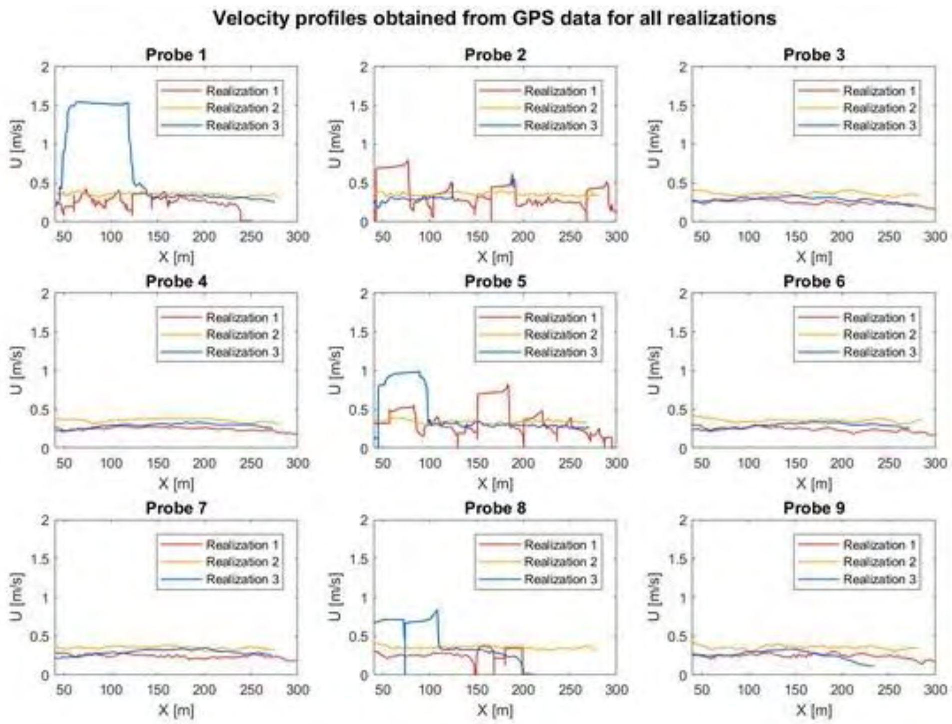


Figure 3.5-13 Velocities obtained by GPS data (source: Divic et al., 2020).

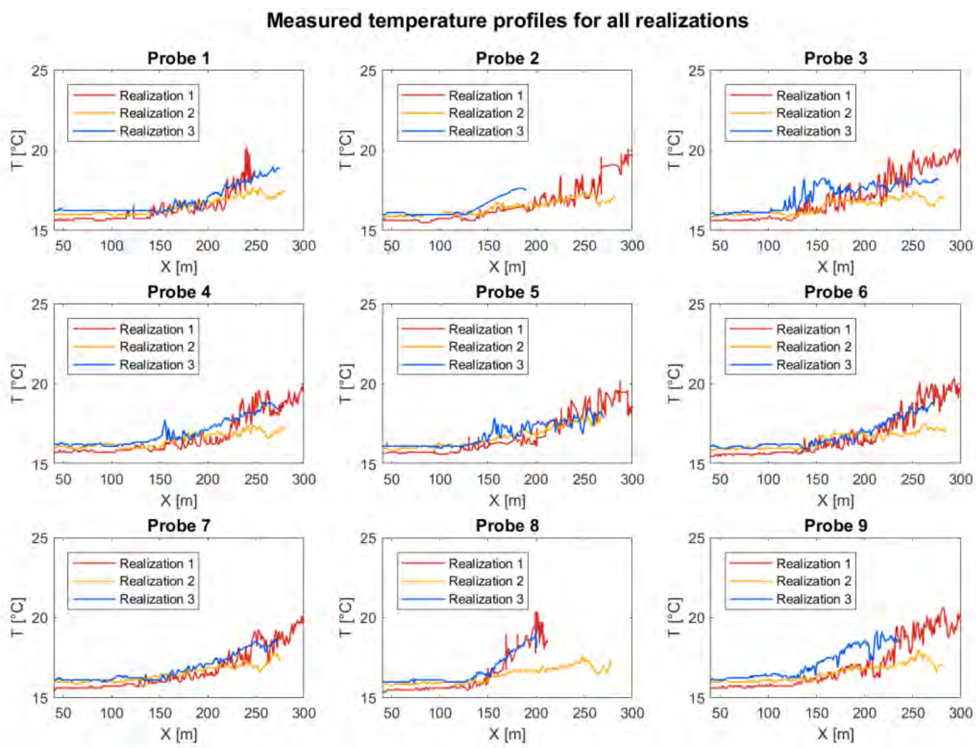


Figure 3.5-14 Measured temperature (source: Divic et al., 2020).

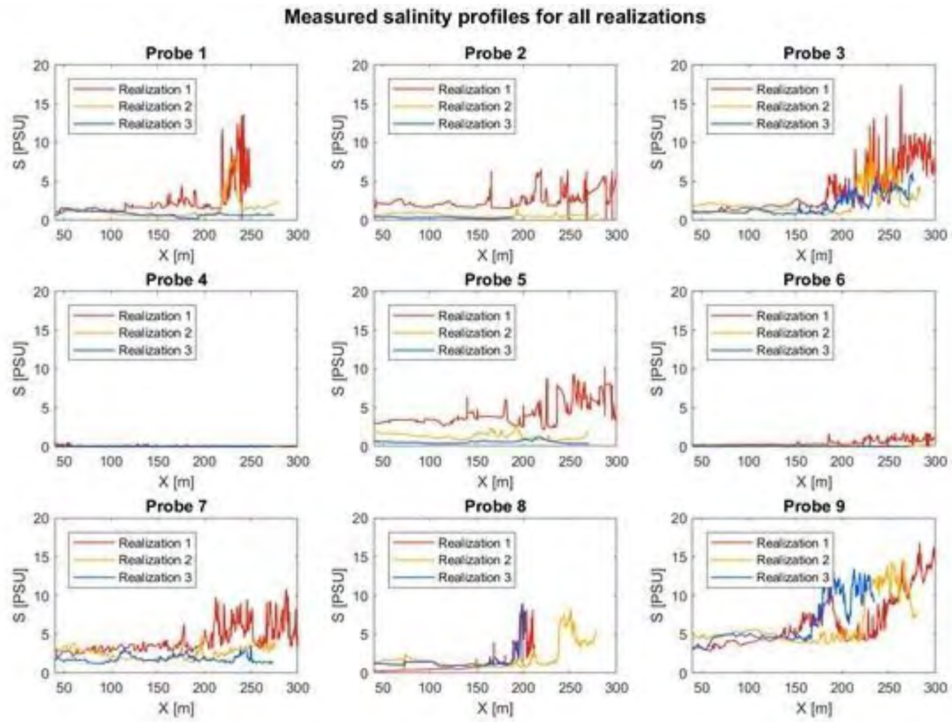


Figure 3.5-15 Measured salinity in practical salinity units (PSU) (source: Divic et al., 2020).

According to the authors, the obtained results deliver promising functionality for surface salinity data, downstream surface velocities, and surface temperature. They also state, that for more detailed and depth-related information on salinity, researchers would need different equipment. Thanks to the multiple probe-releasing option, the velocity field is rather easily obtained from GPS data. The measured velocity agrees with the attenuation model proposed by Galešić et al. (2016). Moreover, one may obtain the velocity attenuation coefficient in this way with only one realization by averaging the velocity profiles of all probes. Divic et al. (2020) also underline the detection of several expected problems while testing their prototype probes. For example, they concluded, that their newly developed electrical conductivity sensor should be made more range oriented, i.e., if salinity is expected to appear out of the range 2–25 PSU, the corresponding electrodes should have multiple sensitivity real-time switchable settings.

Among other findings they suggest that the kind of free probe-release they tested is best applied to steady and calm surface conditions. Sudden waves resulting from passing boats, birds, or wind may interfere with the data acquisition. Such stabilization problems can be quite common in DIY solutions. But can be solved by further developing the probe's hull shape, and differently designed keel shaping or/and by adding some additional weight. As far as power efficiency is concerned, the Lithium-ion batteries used by the research team proved to be an effective solution for short term measurements of up to 8 hours. Such a time span was within the duration of occurrence of the relatively steady conditions, for which the probes were designed. While processing GPS data to obtain velocity, the researchers observed that it is possible to include inertial measurement units (IMU) on the Arduino board, such as accelerometers, gyrometers, and magnetometers. Such additions may offer to have more quality and control over the gathered GPS data.

This prototype drifter/probe system was specifically developed to simultaneously obtain data on surface salinity concentrations in multiple points, in order to improve the validation of analytical models for conservative solute transport by both Galešić et al. (2016) and Andričević and Galešić (2018). However, during the development and testing stages it became apparent, that the system can be further developed towards more complex monitoring applications, suitable for larger sets of varied conditions. With that in mind, the authors' undergoing research includes the analysis of data with the probes fixed on chosen stream-wise or cross-stream profiles, obtaining datasets at multiple points. The goal of such a configuration is to test point defined statistics (i.e., probability density functions and their moments) and spatially integrated statistics (expected mass fraction and spatially integrated moments) of the measured parameters against the results of analytical models.

3.6 Social media mining for environmental monitoring

Social Media has been grown rapidly as a type of online communication tool wherever users make comments, shares, and put videos, photos and posts on social network at a remarkable rate. Environmental issues are progressively getting to be concern of the worldwide. Contribution of media generally and social media particularly in the raising environmental awareness in the target group is important because of produce greater environmental influence on growth of world population and standards for high lifestyle of our communities.

Since people are becoming more environmentally aware, several trends are spreading worldwide, especially in the digital world. Social networks allow us to defend our ideas and actions freely and share them with our community. People get more and more involved in real life but even more on social media. We are seeing more and more companies and celebrities sharing their ideas and defending their causes via Twitter, Instagram or Youtube. With social media we have the opportunity to relay information faster and to a broader audience than before and we can see a bigger impact.

Facebook, QQ, WhatApp, QZone, WeChat, Linkedln, Skype, Google+, Instagram, Twitter, Snapchat – all these names are very much known in present days. These are top rated social media networks that are bonding people globally. Every social networking sites have their own format own style own attraction and applications. Overall, all these social networking platforms are doing excellent work in the promotion and action on various issues of environment. From global warming, climate change to solid waste management, renewable energy news and environmental monitoring, these social media are very much active with participation of a large number of people especially the youth or young generation *(Robelia, Greenhow & Burton, 2011)*.

Technology has given people the ability to change some of their behaviours and conduct clean and green business but still people are not keeping up with the pace of the environmental changes happening locally and globally because of indiscriminate utilization of natural resources. Social media has become an important tool for providing a space and means for the public to participate in influencing or disallowing environmental decisions made by governments and corporations that affect all. This has developed a mode for people to get connected with local environmental challenges and interpretations to larger-scale stories that will affect the global community *(Warner, Eames & Irving, 2014)*.

Social media has rapidly become an essential marketing and communication tool for Govt., private, public, and non-governmental organisations, institutes, and autonomous bodies across the world to promote their organizational mission, vision, action, publications, events and initiatives. Common people use social media to post or share real time photos on a variety of environmental issues such as air, water, noise, soil, solid waste pollution, forest fires, chemical or oil spills in waterways, illegal dumping, plastic menace, affected plants or animals. This simple, yet effective action can result in prompt awareness of an environmental incident and timely response from various agencies responsible for the environment *(Roshandel Arbatani, Labafi & Robati, 2016)*.

Social Media Platforms

The most common kinds of web-based social media are the social networks. One of the most popular social networking sites in the world todays is Facebook; according to different sources, the active users of Facebook are more than 1.5 billion. Other social media involves You Tube over 1.0 billion users, Instagram 400 million users, and Twitter 320 million users.

In order to understand social media importance, it is necessary to describe some of the most relevant social media platforms that are currently in the market and revolutionizing the world:

- **FACEBOOK**

According to its website, Facebook was launched in 2004 by Mark Zuckerberg, who was 23 years old at the time. The site gets income from advertising while being free for users to use. People sign up by giving some personal information, completing a profile, and uploading photos of themselves. They can also share information, thoughts, news, videos, and links to different kinds of interesting topics or media that can be found on the internet. People create an online network with old friends, family, co-workers, or new people they are interested in connecting with. Facebook allows you to keep in touch with people from all around the world. Distance is no longer a problem and Facebook allows others to get closer with just one click.

Why did Facebook become so successful?

By understanding why Facebook is so successful, people can understand a little bit more about how social media works and its impact in our societies. The Social Advisors website argues that Facebook provides connection within friends and family, transforming this social media into a value service that entertains and informs. In comparison with other social streams, “Facebook encourages users to act, to like, to share, to participate all in a subtle way” (The Social Advisors). Facebook can help ordinary people form a deeper connection with others that have fame or status, for example, official artist accounts or important political profiles. Facebook can also gather people with the common interests and offer social interactions that may have been impossible outside of the digital world. Another feature that can be considered for Facebook’s success is its easy-to-use design that allows people to read information, keep track of friends, and upload photos in a very simple way.

- **INSTAGRAM.**

The official Instagram website defines it as a “fun, quirky way to share people’s lives with friends and others through a series of images or pictures”. The user has the option to snap a photo with a cell phone and choose from different filters to make it better. It is a way of sharing people‘s daily life in a more visual way. Instagram website says that “they are building Instagram to allow you to experience moments in your friends” lives through pictures as they happen. We imagine a world more connected through photos.

Instagram was launched on October 6, 2010 and originally only able on iPhones due to the good quality of their cameras. It surpassed 25 million users in early March 2012.

How does Instagram work?

Instagram allows people to take photos within the app or use old photos from your phone album and share a photo moment of your daily life. Users can give a title to it, use hash tags and the photos can be shared with others, not only through Instagram but also in other social platforms like Facebook or Twitter. Initially photos are publicly shared with anybody, but people can choose to keep them private. The foundation of Instagram, as a social network, is to share photos with friends and people who can “like” and comment on them. With this, people share their daily lives in a dynamic visual way. A special feature of Instagram is hash tags, which allow users to find photos of some specific interest. It is like a filter that helps people to search specific photos in an easy way. It’s considered that this kind of social network can help to impact peoples’ minds and opinions by showing information through a strong image. For example, environmental problems around the world can be perceived better in this way. Companies like NatGeo are implementing this social media for the use of different social campaigns and to encourage photojournalism.

- **TWITTER**

Kwak, Haewoon in her “What is Twitter, a social network or a news media?” presentation to the 19th international conference on World wide web, New York, USA, 2010, describes Twitter as a micro blogging service where users tweet about any topic within a 140-character limit and follow others in order to read and receive their tweets, that unlike the other social networks, does not need the reciprocation in following someone back.

“Common practice of responding to a tweet has evolved into well-defined mark-up culture: RT stands for retweet, ‘@’ followed by a user identifier address, and ‘#’ followed by a word represents a hash tag. This well-defined mark-up vocabulary combined with the strict limit of characters conveniences users with brevity in expression. The retweet mechanism empowers users to spread information of their choice beyond the reach of the original tweet’s followers” (Kwak, 2010).

Twitter uses the hash tags to find "trending topics" which are the most common phrases or words people use in this platform during the day or latest hours. With this, Twitter tries to encourage people into discussion. Kwak (2010) also claims that the trending topics are a good representation, if not complete, of issues that reflect societies in their public spheres. Twitter is written in tweets, which are the limited sentences the users write in their personal profiles. Tweets usually express an idea or an opinion. It can also be a critic toward something or just a random thought.

People, who have Twitter, can follow a specific topic, person, or news from all around the world in a very easy way and can also participate in chats that are made through the hash tags. If someone wants to know what the general opinion is about something, someone, or a certain happening, then Twitter is the tool. Some people claim that Twitter is more a news media tool than a social network, but again it all depends how it is used.

Websites like https://interactive.twitter.com/ gathers some Twitter data and makes it available for everybody.

- **YOUTUBE**

YouTube was launched in May 2005 and was created by Steve Chen, Chad Hurley, and Jawed Karim. YouTube official website describes it as “a space that allows billions of people to discover watch and share originally-created videos. It provides a forum for people to connect, inform and inspire others across the globe. It acts as a distribution platform for original content creators and advertisers, both large and small".

The main purpose of YouTube is to share videos online. Everybody can create their own video and upload it in this platform. Videos can be commented, rated, and shared by others. The phenomena of video blogs emerged from this social media, where people record themselves talking about certain topic. This video blog format became something big within the users of YouTube and as a result has created a new community and a new form of business. It became an empirical production for entertainment, information, and interaction. Daniel Margolis (2008) writes in its article "Analysing the Societal Effects of YouTube on the website Certification Magazine" that "YouTube provides ordinary users a way to expose their content to millions of eyeballs immediately".

Margolis also says in its article "Analysing the Societal Effects of YouTube on the website Certification Magazine" that Andrew Perrin, associate professor of sociology at the University of North Carolina at Chapel Hill, says that "He couldn't think of any other medium throughout history that would have been so immediate in its effect. The self-production aspect of YouTube, combined with its broadcast reach, that is a unique form… I'm sure there are lots of estranged spouses throughout history who would like the opportunity to have done that".

Citizen participation in environmental monitoring is not a new idea. However, recent developments in Information and Communication Technologies (ICT), such as the social web and the miniaturization of sensors, have created new opportunities to promote citizen participation in environmental monitoring. The analysis of existing citizen initiatives that use ICT tools, identified the need for a framework conceptualizing way to increase the contribution of volunteered geographic data in environmental monitoring. Environmental Collaborative Monitoring Networks (ECMN) may be used as a framework that combines the concepts of traditional environmental monitoring networks with the ideals of the open-source movement. Such framework can guide the creation of fixed and mobile monitoring networks and may be organized based on three building blocks: (1) Motivated Citizens; (2) Sensing Devices; and (3) Back-End Information Infrastructure (*Cristina Gouveia & Alexandra Fonseca*).

According to *V. Jovanovic, and D. Vukelic from Singidunum University, Belgrade, Serbia*, marine environment monitoring is an indispensable number of systematic process and activities, which take place to observe and characterise the contemporary effects of sea terrestrials on the environment and the natural order. It has attracted an increasingly great deal of research and development attention due to its essentiality and issues which have not yet been resolved. During the past decade, various marine environment monitoring systems have been developed. However, most of the environment monitoring systems still continue to possess two disadvantageous aspects, which are expensiveness and time-consumption and has low responses both in time and space, with very limited or sometimes no presence to the general public.

With the appearance of Web 2.0, ubiquitous computing and corresponding technological advancements social networks have become massively popular, especially during the last decade. The term social networks refers to a different spectrum of digital interaction and information platforms. It includes blogs (e.g., Twitter, Blogger, WordPress,), digital social services (e.g., Facebook, Google+) and multimedia content sharing services (YouTube). Although they are distinguish-able, these social media services share the common goal of enabling the general public to contribute, disseminate and exchange information. At the same time, social media content is rapidly increasing. Facebook announced in 2012 that its system deals with petabyte scale data as it processes 2.5 billion content elements and over 500 TB of data daily.

Social media data provide an unprecedented wealth of information on people's perceptions, attitudes, and behaviors at fine spatial and temporal scales and over broad extents. Social media data produce insight into relationships between people and the environment at scales that are generally prohibited by the spatial and temporal mismatch between traditional social and environmental data. These data thus have great potential for use in socio-environmental systems (SES) research. However, biases in who uses social media platforms, and what they use them for, create uncertainty in the potential insights from these data.

While analysis of social media data will never replace traditional research methods, there are several advantages to the use of social media data for SES research that make it a useful compliment. The unsolicited nature of social media is akin to revealed rather than stated preferences in economics and may make it more appropriate than traditional surveys for uncovering new social phenomena, capturing rapidly changing situations, and understanding people's true views on certain topics. In addition, many studies have shown the utility of social media for accurate social and environmental monitoring in areas where authoritative data are lacking. Insights from social media will likely only increase in the future, as will strategies to account for the particularities of the data to draw robust conclusions. The social media may be used to scale up from existing in-depth, small-scale studies (using authoritative data at the smaller scale to ground-truth findings) and quantify individual behaviors for parameterizing and validating complex systems models. In many cases, social media analysis may be used as an exploratory tool, documenting a new phenomenon, particularly in locations and populations where data from traditional sources are lacking. Recognizing the exploratory nature of such studies and following up with more targeted studies, including those using more traditional methods, is necessary to test whether the phenomenon is real *(Bianca E. Lopez, Nicholas R. Magliocca and Andrew T. Crooks*).

3.7 Data Management (Data streaming citizen science; Data scraping from open-data sources and repositories)

Data scraping:

Open data refers to data that are freely available without restrictions from copyright, patents, or other mechanisms of control (UNICEF Data). In this context, it is not enough to just share data publicly in hard copy reports. For data to be considered fully open, it must follow certain principles that maximizes its utility:

- to be structured using classifications accepted internationally;
- to use non-proprietary file formats (such as JSON or CSV);
- to be available via standards-compliant communication interfaces (such as SDMX-JSON);
- and have appropriate metadata describing it.

Open data is part of a larger set of movements, that includes also open-source software, open educational resources, open access, open science, open government and other.

For environmental sciences:

- BCO-DMO, Marine Biology data, listed with Marine Sciences repositories.
- DataONE, KNB, and PANGAEA, listed under Multidisciplinary repositories.
- British Atmospheric Data Centre (BADC). From the Natural Environment Research Council (NERC). Many datasets are openly accessible, but some are restricted.
- Climate Change Data Portal. From the Environment Department of the World Bank.
- Climate Data. A section within the Comprehensive Knowledge Archive Network of the Open Knowledge Foundation (OKF). A joint project of the OKF, Climate Code and Real Climate.
- Consortium of Universities for the Advancement of Hydrologic Science, Inc HIS stands for Hydrologic Information System. CUAHSI's HIS is an internet - based system to support the sharing of hydrologic data. It consists of databases connected using the internet through web services as well as software for data discovery, access, and publication.
- EDI Data Portal(perma.cc). The EDI Data Portal contains environmental and ecological data packages contributed by a number of participating organizations.
- The Marine Geoscience Data System (MGDS)(perma.cc). The Marine Geoscience Data System (MGDS) provides access to data portals for the NSF-supported Ridge 2000 and MARGINS programs, the Antarctic and Southern Ocean Data Synthesis, the Global Multi-Resolution Topography Synthesis, and Seismic Reflection Field Data Portal.
- National Snow and Ice Data Center (NSIDC) Cryospheric datasets from ground field research and satellites.
- National Ecological Observatory Network (NEON). A joint project of 50+ US universities and laboratories.
- NERC Data Centers(perma.cc). NERC has a network of environmental data centres that provide a focal point for NERC's scientific data and information. These centres hold data from environmental scientists working in the UK and around the world.
- Socioeconomic Data and Applications Center (SEDAC) specializes in spatial data and services in support of human-environment research and applications, in the context of NASA’s Earth science mission and the overall U.S. Global Change Research Program.

Geosciences and geospatial data:

- Also see DataONE and PANGAEA, listed under Multidisciplinary repositories.
- Commons of Geographic Data. "This site is intended for any data in any format that can be referenced to location on the earth." From the University of Maine.
- EarthChem Library(perma.cc). The EarthChem Library is a data repository that archives, publishes and makes accessible data and other digital content from geoscience research (analytical data, data syntheses, models, technical reports, etc).
- GeoCommons. From FortiusOne.
- Geodata Repository. From the Open-Source Geospatial Foundation.
- GeoGratis. From Natural Resources Canada.
- GeoNames. A database of placenames, under a CC-BY license. Founded by Marc Wick.
- The Geosciences Network (GEON) project is a collaboration among a dozen PI institutions and a number of other partner projects, institutions, and agencies to develop cyberinfrastructure in support of an environment for integrative geoscience research. GEON is funded by the NSF Information Technology Research (ITR) program.
- Magnetics Information Consortium (MagIC)(perma.cc). Improves research capacity in the Earth and Ocean sciences by maintaining an open community digital data archive for rock and paleomagnetic data with portals that allow users access to archive, search, visualize, download, and combine these versioned datasets.
- National Geographic Data Center Archive of national and international marine environmental and ecosystem datasets.
- National Space Science Data Center serves as the permanent archive for NASA space science mission data. "Space science" means astronomy and astrophysics, solar and

space plasma physics, and planetary and lunar science. As permanent archive, NSSDC teams with NASA's discipline-specific space science "active archives" which provide access to data to researchers and, in some cases, to the general public.

- OpenTopography(perma.cc). OpenTopography facilitates community access to high-resolution, Earth science-oriented, topography data, and related tools and resources.
- Polar Data Catalogue A primarily Canadian archive of free RADARSAT imagery as well as Arctic, Antarctic, and other cryospheric data sets covering a range of disciplines, from natural sciences and policy to health and social sciences.
- ShareGeo. Integrating the older GRADE (Geospatial Repository for Academic Deposit and Extraction) repository. From EDINA. (Repository discontinued.)

Marine sciences:

- DataONE and PANGAEA, listed under Multidisciplinary repositories.
- BCO-DMO. The Biological and Chemical Oceanography Data Management Office provides access to data sets contributed by investigators funded by the Biological and Chemical Oceanography sections of the US National Science Foundation (NSF).
- Naval Oceanography Portal Data Services. From the United States Naval Observatory (USNO).
- SeaDataNet. Funded by the EU and coordinated by Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER).
- SEAONE - Sea Open Scientific Data Publication(perma.cc). SEANOE (SEA scieNtific Open data Edition) is a publisher of scientific data in the field of marine sciences. Data published by SEANOE are available free. They can be used in accordance with the terms of the Creative Commons license selected by the author of data.
- Ocean Tool for Public Understanding and Science (perma.cc). OcToPUS relies on established free and open-source geospatial technology to provide interactive access to dynamically updated, multi-dimensional data on the marine environment.
- Ocean Action Hub: https://www.oceanactionhub.org/ocean-data-sources
- Sea Around us: http://www.seaaroundus.org/

Citizen science

Public participation in scientific research is a growing trend in our increasingly crowdsourced world. Citizen science, as it is called, typically involves data collection by members of the public who pass their information along to researchers trying to answer real-world questions.

Volunteer monitoring has contributed for many years to diverse fields ranging from astronomy to medicine and computer science to natural resource management. Volunteers benefit from opportunities for informal education, while contributing to outreach efforts that promote public understanding of scientific issues.

Ways to contribute to citizen science:

- Monitor Marine Debris: Record the type and amount of debris on your beach to help scientists tackle the challenge of marine debris.
- Watch for Dolphins: Share your whale sightings so scientists can track their population trends.
- Fight Harmful Algal Blooms: Collect water quality data that helps researchers to respond to harmful algal blooms.
- Geocache for a Good Cause: Gather field notes, photos, and GPS data at benchmarks for location and height data.
- Be a Sanctuary Steward: Pitch in at a local marine sanctuary or estuarine research reserve.

Contribution from RECM

Growing numbers of private individuals worldwide are collecting and reporting scientific information and observations about their surroundings. They are participating in thousands of citizen science initiatives that can produce valuable data about the environment and a rich set of other benefits (e.g., awareness-raising and empowerment), enabling communication, trust-building and behavioral change. However, in spite of their massive potential, the acknowledgement and use of these data by policymakers and their uptake in monitoring and implementation remain limited. European Commission published in 2020 a working document ***"Best Practices in Citizen Science for Environmental Monitoring"***. The best practices in this document aim to demonstrate how citizen science and policymaking can be of mutual benefit, to strengthen the link between them and to facilitate and enhance the use of citizen science in the EU's environment policymaking. Building on a study of the European environmental citizen science landscape, past experience and ongoing projects and initiatives, it was identified the opportunities and challenges of citizen science in EU environment policy and highlighted good practice and lessons learnt. The document presents a series of recommendations for specific actions to improve the uptake of citizen science in environment policy. Particular attention is given to the uptake and use of citizen generated data as a complementary, value-adding element in monitoring and reporting; other relevant areas of environment policy are considered to a limited extent. The resulting enhanced environmental monitoring might serve different purposes, such as policy development, official environmental reporting, and the formulation of environment policy indicators.

The recommendations in Chapter 5 and Annex II constitute tools and a basis for further reflection for the key actors in citizen science and environmental monitoring, including:

- ✓ EU authorities – policymakers in EU institutions (e.g. the Commission) and other EU bodies (e.g. the European Environment Agency (EEA));
- ✓ public authorities in the Member States – national, regional and local governmental bodies, including environmental protection agencies (EPAs) and statistical offices;
- ✓ citizen science associations and networks (including civil society organisations (CSOs) and other partners) – formal organisations, usually national or regional networks promoting citizen science;
- ✓ citizen science communities – groups of people leading or participating in citizen science initiatives. These can be informal, grassroots groups of volunteers or organised groups taking part in projects (possibly including professionals leading or advising the initiative); and
- ✓ researchers – researchers in academia and in other research organisations.

Since citizen science is by nature based on cooperation, most of the actions do not address a single group of stakeholders, but rather target partnerships involving practitioners, researchers, and public authorities across different levels of administration. The stakeholders have been consulted on several occasions and their valuable input and feedback have contributed to the development of the document and the recommendations in particular.

What is citizen science?

Citizen science can be defined as the non-professional involvement of volunteers in the scientific process, commonly in data collection, but also in other phases, such as quality assurance, data analysis and interpretation, problem definition and the dissemination of results. Other definitions exist and are under debate in the scientific community. The level of expertise or qualifications required of the volunteers depends on the nature of the initiative.

For activities such as reporting litter, none are required. Under other initiatives (e.g., FreshWater Watch), volunteers may receive instruction or training. For initiatives in highly specialised areas (e.g., identifying lichen species), volunteers may need specific knowledge (not necessarily from professional training) in order to be able to make observations.

Citizen science is well developed in the environmental domain, where it offers a unique opportunity to expand the knowledge base by mobilising lay and local knowledge, and to promote public awareness and involvement. In particular, it has been recognised that citizen science plays a critical role in advancing knowledge on biodiversity, by monitoring trends in the occurrence, distribution, and status of species. The vast volume of data that can be collected in a cost-efficient manner by such a large number of volunteers dwarfs the capacity for professional monitoring. This is especially true for biodiversity monitoring over a wide area (e.g., the European continent) or timespan (e.g., several decades).

There are many different types of environmental citizen science initiatives. According to a recent study, the majority are 'contributory', i.e., designed by academics/research organisations, but entailing the collection of monitoring data by volunteers. However, initiatives with greater public involvement in the scientific process have recently been on the rise, i.e., 'collaborative' projects (designed by researchers, with volunteers contributing data, refining project design, analysing data and/or disseminating findings) and 'co-created' initiatives (volunteers and researchers work together throughout).

The value of citizen science has been widely recognised in the literature and on the ground. Here, we are focusing on its policy value, but its scientific and societal value are equally important:

- **policy value** – citizen science can contribute to various phases of the policy-making cycle, by:
    - ✓ identifying problems or issues, by making valuable, systematic observations and bringing public concerns (with supporting scientific evidence) to the attention of decision-makers;
    - ✓ helping in the formulation of policy, e.g., by contributing to the development of policy options and assessing their potential impacts. Citizen science can facilitate the inclusion of diverse societal perspectives in decision-making;
    - ✓ increasing societal support to policy ('ownership'), by involving people in decision-making and thereby improving understanding of environmental issues, stewardship and public decisions;
    - ✓ helping government agencies and other organisations to implement policies that are meaningful to society, following their legitimisation and public endorsement (see above);
    - ✓ helping to evaluate the impacts of policy decisions through scientific observations and investigations on the ground, thereby contributing to a climate of openness and trust and bringing forward the best practices of transparent, rigorous scientific research;
    - ✓ supporting the monitoring of policy implementation and compliance by contributing to data collection, co-designing measurement methodologies and drawing authorities' attention to emerging issues.
- **scientific value** – policy decisions increasingly rely on the best available scientific evidence, but this does not necessarily come only from peer-reviewed academic publications. Citizen science can complement or even improve on conventional science in

many ways. One of its primary benefits is the collection of data that would otherwise be unavailable, e.g., because of their temporal or local granularity and detail, vast time/spatial coverage, and sheer volume, etc. Key parameters for the scientific value of citizen science data are:

  - ✓ fitness for purpose;
  - ✓ documentation of quality;
  - ✓ precision;
  - ✓ spatial and temporal resolution;
  - ✓ robustness; and
  - ✓ long-term access and re-usability.

Access to and the inclusion of lay, local and traditional knowledge are equally important;

- ➢ **societal value** – citizen science initiatives empower people to draw attention to local issues, provide the evidence base to call for, propose or co-create solutions (e.g., noise abatement) and contribute to increased participation and sustained involvement. Initiatives and their outcomes can also help to:
  - ✓ raise awareness of environmental issues;
  - ✓ support life-long learning; and
  - ✓ prompt behavioral change — especially in relation to issues that are not immediately visible (e.g., air pollution near schools or radiation from radon and longer-term health effects).

Official monitoring alone could never give us (at reasonable cost) the number of observations and geographical and temporal coverage currently provided by thousands of volunteers and required for the above purposes. Examples of good practice are also demonstrating the added value of citizen science in monitoring and policymaking in the areas of air pollution and waste/litter.

There is significant potential for public authorities to make more use of this valuable source of information and for citizen science initiatives to have a greater impact on policy. A growing number of initiatives are generating significant amounts of valuable data and knowledge in a range of environmental domains. The wide availability of mobile internet, dedicated apps, portable sensors, and other devices is facilitating the participation of large numbers of volunteers and the near real-time publication of results. The findings (e.g., on pollution) are attracting public interest and the attention of the media, and people are demanding that local politicians take action.

However, obstacles such as data quality issues and the complexity of data requirements seem to be holding back a wider use of this potentially policy-relevant information.

The need for complementary data was identified in the Commission's 2017 fitness check of reporting and monitoring of EU environment policy. That review concluded that tapping into new sources of data, including data collected by members of the public, could help improve and streamline reporting, and make it more reliable, thereby strengthening the evidence base for environment policy. The companion plan setting out ways of streamlining environmental reporting called for more specific action to promote the wider use of citizen science and, in particular, the development of guidelines and disseminating best practices. Boosting public involvement will help build the environmental knowledge that EU policymakers need (e.g., indicators for monitoring progress on the SDGs and the biodiversity objectives).

Analysis of the challenges, opportunities and examples of good practice has led to the development of recommendations for promoting wider use of citizen science in environmental monitoring and reporting. The recommendations are clustered around four main areas of intervention to support the policy-making cycle:

1. Matchmaking between knowledge needs for environment policy and citizen science activities;
2. Promoting awareness, recognition and trust;
3. Promoting standards for data quality and interoperability, and sharing tools; and
4. Supporting coordination, cooperation, and resources for policy impact.

The High-Level Political Forum (HLPF) 2018, on Sustainable Development, highlights data gaps as a notable challenge, stating 'more and better data are required for national, regional and global monitoring' (HLPF, 2018). In terms of water quality, the recent data drive of 2018 on Sustainable Development Goal (SDG) indicator 6.3.2 (on the 'proportion of bodies of water with good ambient water quality') (UN, 2017) only resulted in available data from about thirty countries (UN Water, 2018). These data were mainly provided from developed countries, with less developed countries experiencing a lack of human and financial resources for gathering, analysing, and sharing data (UN Water, 2018). However, indicator 6.3.2 sets out to estimate the quality of freshwaters through a core set of easily measurable parameters, namely dissolved oxygen, electrical conductivity, total oxidized nitrogen, nitrate, orthophosphate, and pH; and proper measurement of water quality is often the starting point for addressing complex water quality problems through management and governance (Kirschke et al., 2017). The present gap in water quality data is therefore recognized as a key challenge for governments to care for the freshwater of their territories (UN Water, 2018; UNEP, 2016).

To address this data gap efficiently, researchers and practitioners increasingly call for the integration of non-traditional data sources in water quality monitoring, such as data collected by citizens (Quinlivan et al., 2020; HLPF, 2018; UN Water, 2018; Buytaert et al., 2014; Lowry and Fienen, 2013; Conrad and Hilchey, 2011). The idea is that citizens hold immense potential to increase temporal and spatial data availability and therefore could bridge the data gap that the international community faces (Assumpção et al., 2018; Carlson and Cohen, 2018; Ballard et al., 2017; Hulbert, 2016; Walker et al., 2016; Buytaert et al., 2014; Loperfido et al., 2010). However, citizen-derived data may also be selective and biased, calling on the need for identifying design principles for successful citizen science projects (Brouwer et al., 2018; Crall et al., 2011).

Environmental and sustainability research has come up here with numerous studies discussing the role of citizens in scientific data gathering. Prominent fields are astronomy, biodiversity, and medical research, regularly publishing scientific studies based on citizen-derived data (e.g., Fritz et al., 2019; Hecker et al., 2019; Turbé et al., 2019; Irwin, 2018; Domroese and Johnson, 2017; Schröter et al., 2017; Kosmala et al., 2016). Such studies also discuss relevant design principles for successful citizen projects, such as critical motivational factors for initiating and participating in citizen science projects, new digital tools, and a cross-check of citizen-derived data. But while there exists knowledge on designing citizen science in these fields, ***one may not easily transfer such knowledge to the area of water quality monitoring***. First, ***water quality is an invisible subject***, calling for specific equipment whose handling can be particularly challenging. Second, ***water is a basic human need*** with enormous impacts on health and human being, which may also influence the motivation of citizens to monitor its quality. In sum, this calls for a separate analysis of design principles for successful citizen science projects.

Against this background, water research has increasingly dealt with the emergence of citizen science in supporting water quality monitoring. However, comparative analyses of the role of citizen science activities for addressing the water quality data gap are currently unavailable. Similar to the broader citizen science literature, water-related citizen science projects researcher encounter varied factors that improve or hinder the success of citizen science projects. But given the focus on case studies, the researchers report on these factors in a less systematic manner that does not allow for generalization. Primary factors highlighted across such projects involve, but are not limited to, citizens' knowledge, awareness, interest, and capacity (Weeser et al., 2018; Storey et al., 2016; Buytaert et al., 2014; Conrad and Hilchey, 2011). These factors are spoken about separately and scattered across countries, watersheds, temporal monitoring regimes, and individual perceptions of citizens and institutes. As a consequence, different factors (e.g., prior knowledge and experience of citizens) mostly relate to specific regional project settings (e.g., measuring chemical or physical parameters in Europe, Asia, or Africa), but are not generalized for water quality monitoring. Moreover, studies generally focus on individual dimensions of success, such as the amount of reliable data rather than providing a systematic review considering various dimensions of success, such as the amount of data, related scientific outputs, and political problem-solving.

Citizen science is not a new concept, especially in the environmental domain. However, ICT developments in the past decade and growing calls for public involvement and transparent policymaking have created new opportunities and fueled rapid change in approaches and practices. The citizen science community has not only grown, but also become more organised (nationally and internationally). This has attracted increasing interest, including from public authorities at all levels, who themselves are trying to make policy processes more accountable to citizens and more knowledge-based. The Commission’s ambitions under the Green Deal can be expected to increase the need to tap into sources of information that can complement the knowledge base for environment policy development and monitoring. Below we highlight the new opportunities relating to environmental monitoring and reporting, set out the challenges and single out potential benefits in terms of stronger links between citizen science activities and EU environment policy.

New opportunities

The digital revolution has given us new tools for sharing, collecting, and processing large volumes of information. These include the ubiquitous presence of (broadband) internet, the easy availability of mobile tools (such as dedicated apps and smart devices) and big data analytics.

In addition, the rise of social media makes it easier to promote and encourage participation in citizen science initiatives among interested communities (and beyond). Participatory approaches to societal issues easily attract mass attention on social media.

The abundance of scientific information, education, and awareness-raising activities (fairs, youth camps, museum events, TV programmes, etc.) helps to build science literacy, trust, and recognition among the general public. Citizen science initiatives can both benefit from and contribute to science education, and can raise environmental awareness, which in turn can lead to behavioural change.

Many citizen science communities are already active across the EU, often with a local or regional action radius. In some cases, committed volunteers work with professional researchers when designing projects and/or processing data. In some, CSOs provide coordination and support. In others, governmental authorities are directly involved, with a view to improving their own communication with the public and public services. Knowledge exchange is enabled via regional, national, and international associations.

Citizen science activities offer an under-used, cost-efficient additional source of knowledge and feedback in the monitoring of the environment and the implementation of environment policies. This includes non-traditional data sources, analytical capacities, opportunities for engaging with citizens and possibilities for knowledge exchange (learning). With the environmental ambitions under the Green Deal, public authorities will be even more driven to tap into citizen science initiatives, communities, and outputs, to expand their knowledge base in key areas such as biodiversity, pollution, circular economy, climate change and sustainable food.

Challenges and obstacles

The uptake of citizen science in policymaking is still limited. While some initiatives have been massively successful in supporting environmental action, at both EU and Member State levels (e.g., e-Bird for conservation planning, the European bird index for biodiversity and agricultural policies), the evidence points to a gap between the policy relevance and policy uptake. Below are only few challenges and obstacles in up taking citizen science in decision-making:

- ✓ resistance from public authorities – policymakers are not always convinced of the added value of citizen science. Obstacles include doubts as to data quality (see also below), reluctance to embrace change in traditional working methods, and incumbent ownership and responsibilities in reporting processes. Also, an initiative has to stand out in order to reach policymakers and insufficient visibility can be an issue;

- ✓ lack of guidance – a lack of guidance on how to organise citizen science activities can be an issue, as can academic involvement with and support for CSOs that develop activities. All actors need to be prepared to take different supporting roles and share responsibilities in order to exploit the opportunities of citizen science for environmental monitoring and reporting;
- ✓
- ✓ data quality – policymakers often do not trust citizen science data. It is difficult to establish the right balance between ensuring sufficient data quality and not deterring potential participants. Quality assurance requires attention even before an initiative begins, e.g., through the availability and use of good quality guidance, smart project design (co-creation with researchers from academia/research organisations) and training for citizen scientists and project managers. Data quality assurance and validation are crucial if citizen-generated data are to complement data from more traditional sources. Good documentation and communication on quality assurance are key in reassuring potential data users. This also applies where quality concerns are based on prejudice rather than real shortcomings;

- ✓ risk of inconsistency in information acquisition and processing, and thus overall quality – academic data are produced according to a tradition of rigorous accountability, quality control and peer review. Complementing them with non-academic data creates new challenges and new support tools are required to ensure the requisite overall quality. It is important to know the 'pedigree' of data (i.e., to have a standardised description of the mode of production and the anticipated use), in order to ensure consistency when processing and communicating scientific information. It is also difficult to grasp the weight of evidence in citizen science data and the degree of underlying uncertainty;

- ✓ different data policies and data management principles – research has identified a need for guidance and training on the importance of data licences, clear data access and use conditions. This is because data management practices vary widely across citizen science activities and limited use is made of common standard licence schemes providing a clear indication of data ownership and conditions for re-use. It is also unclear whether current standards cover the most important cases of intended re-use;

Expected benefits of up taking citizen science:

- ✓ improved knowledge base – citizen science can generate new data, uncover new issues and add (upwards or downwards) scalability to existing data. In particular, the data can complement existing (government-led) monitoring schemes, with a potential for gap-filling through increased data volume with greater time/spatial coverage and/or higher resolution. A review of best practice suggests that, where a business model for sustained financing is embedded in the governance process, citizen science may represent a long-term data resource;
- ✓ more accountable, informed open society – citizen science leads to a better-informed public and more transparent data. People can see how the data to which they have contributed are used for decision-making and science. In the best cases, they can be involved in the decision-making process. Citizen science raises awareness of environmental issues and can lead to behavioural change, through improved science literacy and information-sharing in networks and communities of interest (e.g. the transfer of species knowledge, where volunteers 'teach' other volunteers about particular species). It also helps to establish working relationships, distribute responsibilities and build trust between stakeholders;
- ✓ timely reaction and pro-active approaches – citizen science makes it possible to identify and solve problems more quickly. It is particularly useful for detecting rare events (e.g. pests, pathogens, invasive species and diseases). The use of mobile sensors and other devices in combination with online data platforms enables the near real-time availability, processing and visualisation of measurements and observations. This can also speed up the detection of changes/trends in environmental indicators (shorter time-lag than with 'conventional' reporting);
- ✓ societal relevance of policy measures – by improving our understanding of people's needs and expectations, citizen science can ensure that policies are more socially relevant. It contributes to the dialogue between policymakers and society (uptake and use in relation to policy);

- ✓ more inclusive and participatory socio-scientific-policy ecosystems – citizen science can help establish a direct connection between real-life actions and policies, and it can open up participation to different stakeholder groups. It can raise policymakers' and stakeholders' awareness of certain environmental issues (e.g. identify new problems) and provide starting points for further investigation, including evidence and established partnerships. It can shift research agendas towards more practical and relevant questions, e.g., in the case of nature conservation;
- ✓ better value for money – arguably, citizen science can provide better value for money than traditional scientific methods. In particular, it allows for the densification of observation networks at lower cost and provides decision-makers with low-cost, high-granularity and timely information, thus helping to innovate public services. At the same time, it also adds value to deliberation, life-long learning, environmental awareness and (possibly) behavioural change. However, its cost-effectiveness compared with other options should not be taken for granted (citizen science can entail costs not associated with other forms of science);
- ✓ empowering people – policy-relevant citizen science rewards volunteers primarily by enabling them to increase their awareness and contribute to something of general importance. They can be empowered through their involvement in solving local problems and can sometimes be the force behind regulatory change. This is particularly important for vulnerable groups in society, who may have a low perception of their agency: by contributing with their actions to the improvement of their conditions, perceived self-efficacy will increase, and the likelihood of exclusion will decrease;
- ✓ creation of networks and partnerships – citizen science may create new communities of interest and improve social connections and the sense of belonging. Most initiatives bring together actors and communities who would never cooperate otherwise. Thereby, they help to establish new paradigms of communication — with or without the use of new technologies; and
- ✓ making evidence-based policy-making more open and transparent – citizen science often goes hand in hand with open data access and data-sharing policies, and brings about more responsible, fairer and more accessible research and policymaking.

3.8 Deep Chemometrics for Spectroscopical Image analysis

Chemometrics is the science of extracting information from chemical systems by data-driven means. Chemometrics is inherently interdisciplinary, using methods frequently employed in core data-analytic disciplines such as multivariate statistics, applied mathematics, and computer science, in order to address problems in chemistry, biochemistry, biology and chemical engineering. Chemometric processing nowadays is set to employ deep learning techniques, e.g., to detect and classify polluted water, based on HSI data. With deep (learning) chemometrics one can extract parametric description of most prevalent pollutants in water bodies through HSI analysis, while training Deep Neural Networks (DNNs). In order to benefit from data augmentation in chemometric model training, the chemometric processing can be improved through time, by adding the online processed HSI data to the training set and re-executing the learning procedure based on the updated data after a specific amount of time, to have a more accurate pollution detector.

In the near future, chemometric processing techniques could lead to classifier models which can detect the most common seawater pollution, based on HSI images. The characteristics of the resultant DNN-based classifier including the network structure, weights, training process, hyperparameters and testing performance could be specified at the end of the processing. Deep chemometrics data processing usually cooperate with other heterogeneous data from *in situ* physicochemical monitoring networks, social media data mining, remote sensing technologies, and weather information, in a holistic learning algorithm framework for reliable pollution detection mechanisms. Data fusion techniques usually support the learning algorithm in integrating all the available information, improving water pollution detection for the delivery of effective results (**Error! Reference source not found.**).

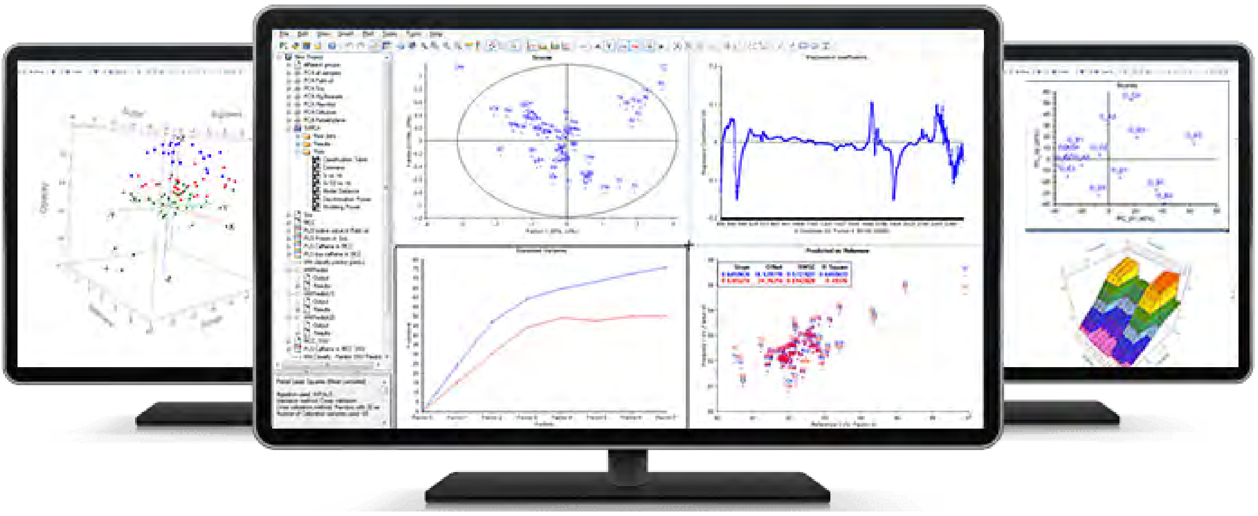


Figure 3.8-1 Typical deep chemometrics software setup for multi-level analysis.

The emerging techniques in the field, comprise:

- Multivariate calibration; The objective is to develop models which can be used to predict properties of interest based on measured properties of the chemical system, such as pressure, flow, temperature, infrared, Raman, NMR spectra and mass spectra. Examples include the development of multivariate models relating 1) multi-wavelength spectral response to analyte concentration, 2) molecular descriptors to biological activity, 3) multivariate process conditions/states to final product attributes. The process requires a calibration or training data set, which includes reference values for the properties of interest for prediction, and the measured attributes believed to correspond to these properties. Multivariate calibration techniques such as Partial-Least Squares Regression (PLSR), or Principal Component Regression (PCR) and many others are then used to construct a mathematical model that relates the multivariate response (spectrum) to the concentration of the analyte of interest, and such a model can be used to efficiently predict the concentrations of new samples. Therefore, fast, cheap, or non-destructive analytical measurements (such as optical spectroscopy) can be used to estimate sample properties which would otherwise require time-consuming, expensive, or destructive testing. Equally important is that multivariate calibration allows for accurate quantitative analysis in the presence of heavy interference by other analytes.

- Classification, pattern recognition, clustering; Supervised multivariate classification techniques are closely related to multivariate calibration techniques in that a calibration or training set is used to develop a mathematical model capable of classifying future samples. The use of rank reduction techniques in conjunction with these conventional classification methods is routine in chemometrics, for example discriminant analysis on principal components or partial least squares scores. A family of techniques, referred to as class-modelling or one-class classifiers, are able to build models for an individual class of interest. Such methods are particularly useful in the case of quality control and authenticity verification of products. Unsupervised classification (also termed cluster analysis) is also commonly used to discover patterns in complex data sets, and again many of the core techniques used in chemometrics are common to other fields such as machine learning and statistical learning.
- Multivariate curve resolution; In chemometric parlance, multivariate curve resolution seeks to deconstruct data sets with limited or absent reference information and system knowledge. These approaches are also called self-modeling mixture analysis, blind source/signal separation, and spectral unmixing. For example, from a data set comprising fluorescence spectra from a series of samples each containing multiple fluorophores, multivariate curve resolution methods can be used to extract the fluorescence spectra of the individual fluorophores, along with their relative concentrations in each of the samples, essentially unmixing the total fluorescence spectrum into the contributions from the individual components. The problem is usually ill-determined due to rotational ambiguity (many possible solutions can equivalently represent the measured data), so the application of additional constraints is common, such as non-negativity, unimodality, or known interrelationships between the individual components (e.g., kinetic or mass-balance constraints).
- Signal processing is also a critical component of almost all chemometric applications, particularly the use of signal pretreatments to condition data prior to calibration or classification. The techniques employed commonly in chemometrics are often closely related to those used in related fields. Signal pre-processing may affect the way in which outcomes of the final data processing can be interpreted.
- Multivariate statistical process control (MSPC), modeling and optimization accounts for a substantial amount of historical chemometric development. Spectroscopy has been used successfully for online monitoring of manufacturing processes for 30 years, and this process data is highly amenable to chemometric modeling. Specifically, in terms of MSPC, multiway modeling of batch and continuous processes is increasingly common in industry and remains an active area of research in chemometrics and chemical engineering. This field is becoming a high priority research area in environmental monitoring for the 21st century with the use of novel applications in established mathematical software (**Error! Reference source not found.**).
- Multiway methods are heavily used in chemometric applications. These are higher-order extensions of more widely used methods. For example, while the analysis of a table (matrix, or 2nd-order array) of data is routine in several fields, multiway methods are applied to data sets that involve 3rd, 4th, or higher orders. Data of this type is very common in chemistry, for example a liquid-chromatography / mass spectrometry (LC-MS) system generates a large matrix of data (elution time versus m/z) for each sample analyzed. The

data across multiple samples thus comprises a data cube. Batch process modeling involves data sets that have time vs. process variables vs. batch number. The multiway mathematical methods applied to these sorts of problems include PARAFAC, trilinear decomposition, and multiway PLS and PCA (Principal Component Analysis) (**Error! Reference source not found.**).

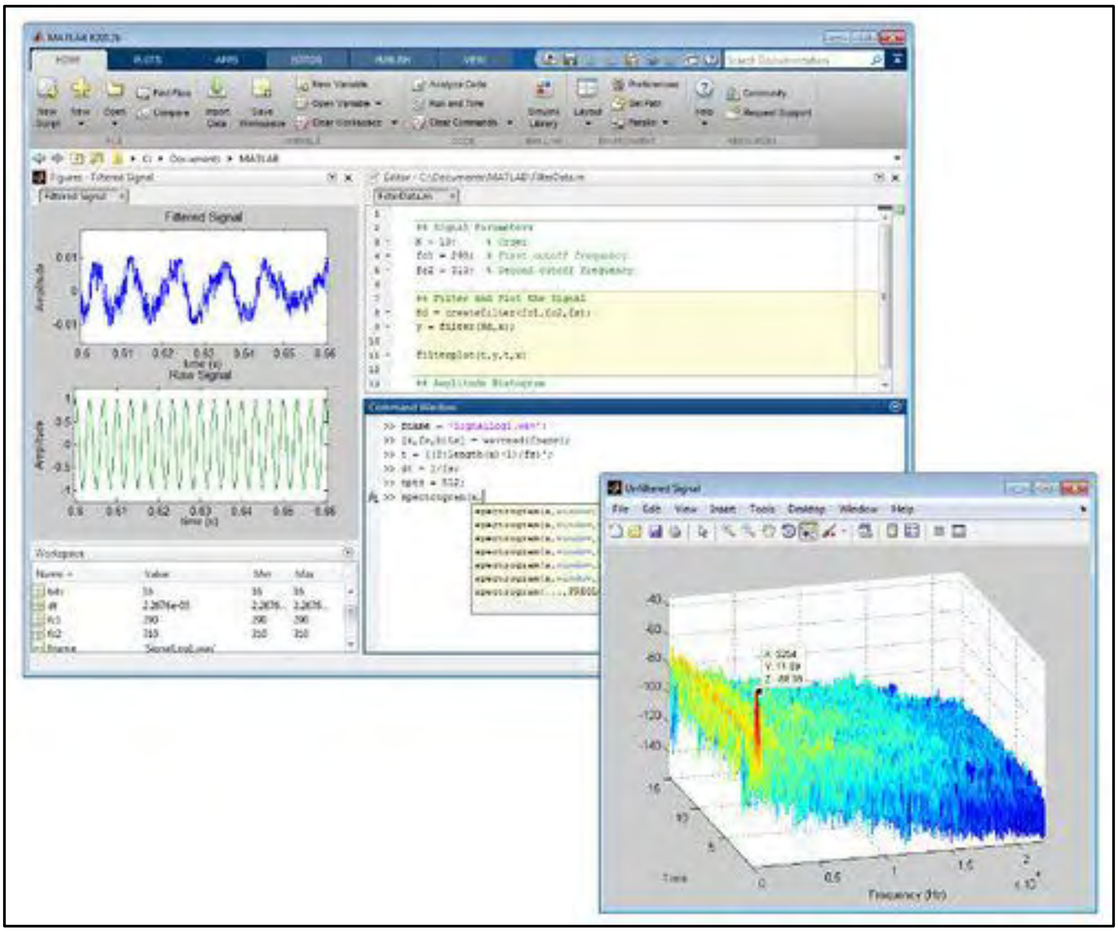


Figure 3.8-2 Typical HSI processing workflow in Matlab applications.

Figure 3.8-3 Typical PLS model software setup and workflow.

Deep chemometrics rely on available Big Data repositories. The efficiency of deep learning algorithms is strictly related to a repository infrastructure oriented towards the Big Data for sensor signal. Indeed, on one hand, a greater amount of data allows for more effective analyses and learning processes; on the other hand, it creates the issue of providing an efficient and scalable solution for its management. In this framework, future research will focus on correctly managing specific problems, schemes of archiving, optimised for managing a large amount of signal sensor data from HSI devices.

Deep Learning is the field of Machine Learning that uses artificial DNNs for performing different tasks such as regression, classification, event detection and many more. These models are non-linear computational tools designed to reproduce some functions of the human brain such as adaptive learning and parallel distributed processing. Deep Learning applications have had success in many fields, however, their application on chemometric problems is relatively recent. Deep Learning has been applied to some chemometrics tasks. Most of them have followed a classical approach by using feed forward neural networks. These approaches have showed good success since they have been able to capture non-lineal features that were not possible to infer by previous lineal models. Nevertheless, on spectroscopical image analysis, Convolutional Neural Networks (CNNs) have been used due to their great success in computer vision tasks (**Error! Reference source not found.**).

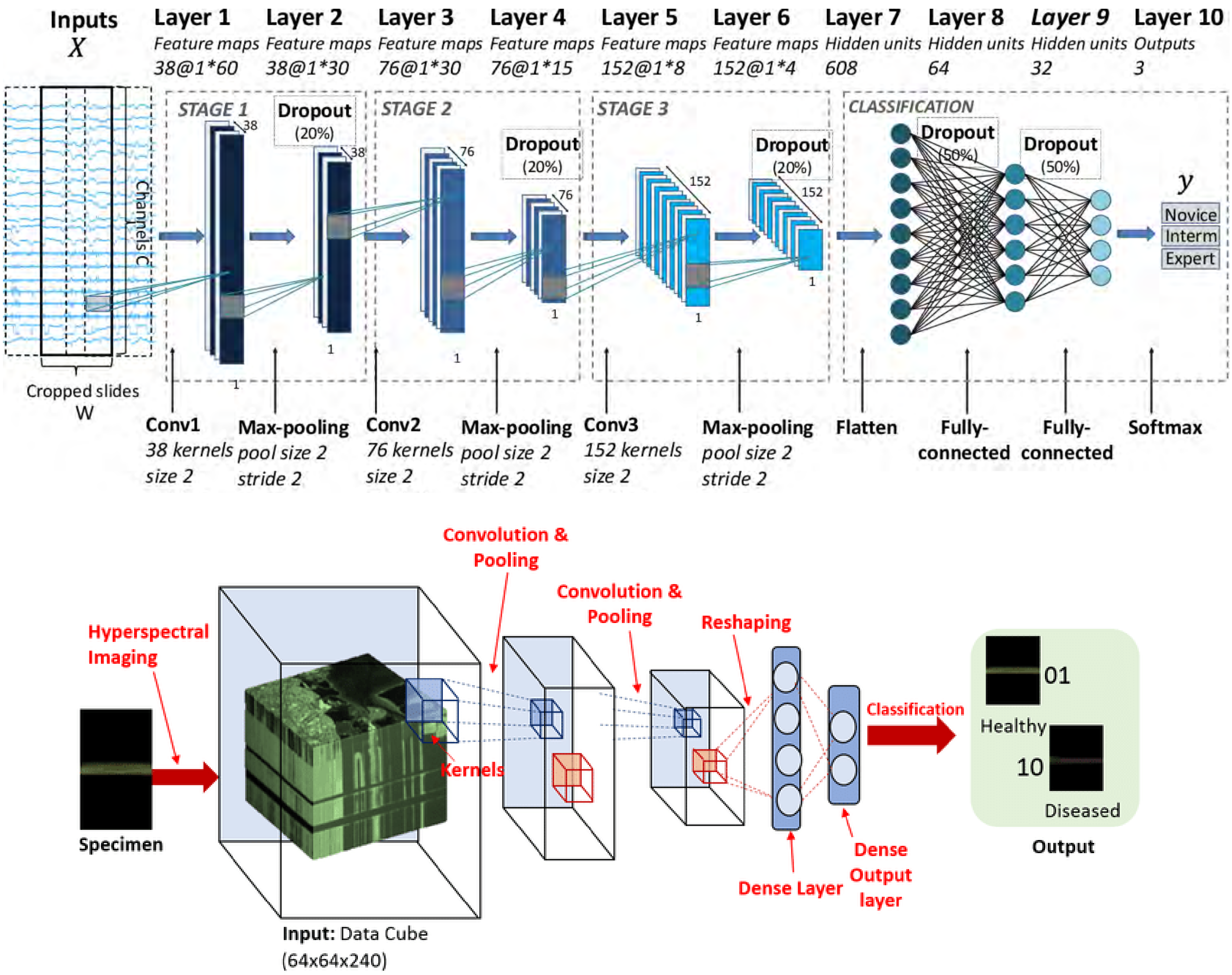


Figure 3.8-4 Examples of architecture of a Convolutional Neural Network combining a group of convolutional and pooling layers with more traditional fully connected feed forward layers.

Deep Learning models require a large amount of data to be trained, making its applications limited and conditioned to data availability. Some data augmentation techniques have been used to surpass this issue by generating new synthetic meaningful data using the real available data samples. In these experiments, neural-based tools significantly outperformed traditional chemometric techniques, confirming the potential of Deep Learning to deal with real-world problems. Future research on this emerging technology in environmental monitoring is set to focus on designing novel algorithms capable of widening the range of topics that DNNs can cope with.

4. CONCLUSIONS AND RECOMMENDATIONS

In accordance with the information and analyses presented here above in this report the following main conclusions can be drawn:

- The present report provides an extensive inventory and comprehensive analysis on advanced innovative environmental monitoring technologies and best practices, as well as an overview of future and emerging technologies for environmental monitoring, and assessment of fish stock and non-fish living resources. Technology innovation is a dynamic area where new achievements appear continuously; therefore, information in this report will be further reviewed and updated in line with latest technological breakthroughs. However, findings and conclusions in this report provide a good basis to rise capacity and improve cooperation between researchers and surveyours in Black Sea region, and further jointly promote and use advanced innovative technologies.
- Findings and conclusions of this report will be circulated to stakeholders and will be further used to contribute to the development of the TIMMOD Innovation Strategy within GA T.4. Finally, results of this activity will help to promote advanced sensors, instruments, and methodologies for environmental monitoring and fish and non-fish stock assessment. This way, it could contribute to data-collection and data-sharing for water quality and biodiversity in the Black Sea - in line with the EU's MSFD, DCF, the Blue Growth Strategy, the Black Sea Common Maritime Agenda.
- Various innovative technology components (sensors, in situ methods, platforms, remote sensing techniques, computational models, data handling and GIS tools, etc.) are presented in Chapter 1, as identified in the study carried out by project team on the application of such technologies in wide geographical areas, including EU seas, and the World Ocean. An essential part of these technologies is still in experimental phase and need further verification before commercialization. These methods/instruments/devices will be further observed (during and after TIMMOD project implementation), and the most successful of them will be promoted among surveyors and researchers in Black Sea region;
- As found in Section 1 of this report, automatic acoustic methods of seafloor mapping are still in their early stage of development, despite the technical progress made in recent years. However, good examples of use of multibeam echosounders (MBES), which deliver bathymetry, as well as co-register and geo-locate backscatter of the seabed, has been already demonstrated, and suggested further application of the spectral features for predictive benthic habitat mapping, including research based on multi-frequency multibeam echosounder datasets. The utilisation of spectral features derived from bathymetry provides an important step towards more accurate maps of benthic habitats and seabed sediments composition.
- Optical methods and non-invasive opto-acoustic technologies have been studied and presented in Section 1. The combined power of acoustics and optics has been already demonstrated in a number of areas, and it can be expected that more combined studies will take place in the future. Two areas combining acoustics and optics can be mentioned as particularly promising:
  - A remotely located camera system (e.g., towed, AUV, ROV) combined with acoustic surveys. In principle, this could provide species identification and information about fish length and orientation needed to estimate target strength while underway. With this information, few, if any, trawls would be needed to support the acoustic survey.

- An adaptive survey for epipelagic species that uses an aerial survey with LiDAR and photography to direct an acoustic survey so that the surface vessel time is concentrated in the most important regions. This technique would provide a survey with lower overall cost and greater precision than an acoustic survey alone.

- Based on the review in Chapter 1 of this report, it is found that applications of satellite and remote sensing technologies are currently evolving very rapidly and are becoming practically very promising for environmental monitoring and management in oceanic and coastal areas. Ocean dynamics and coastal environmental assessment by satellite remote sensing in the Black Sea have allowed developments in this field during the recent past. Applications and research mostly focus on ocean colour satellite imagery from Landsat 8 and Sentinel-2 composites, used for the identification of plume spreading, surface current fields, chlorophyll-a concentration (function of RSS slope) by setup and manipulation of appropriate optical flow algorithms for the determination of in the Black Sea. Other implementations involve multispectral Resurs-P, GeoEye, WorldView, Landsat, Sentinel-2 and other satellite images of seawater coastal areas to investigate the thermohaline structure, transport, and evolution of Black Sea eddies. SAR data have also been used for monitoring of the Black Sea surface pollution by oil spills. Future research and upcoming applications need to focus on computing methodologies, such as MCC, for coastal ocean surface currents from MODIS or VIIRS satellite imagery. Regionally focused visualisation/analysis portals for chl-a mapping of ESA's ocean colour CCI OGC is also imperative, followed by merging of bias-corrected SeaWiFS, Aqua-MODIS, MERIS and VIIRS for image data extraction.

- Drones and UAVs are becoming more and more used in ocean monitoring mostly for pollution tracking (oil spill identification; HABs and green/red tide inspection; micro-plastics tracking) and biodiversity management (coastal habitat environmental monitoring; sea mammal, turtles and marine vertebrates tracking, fish stock assessment). Efficiency of monitoring can be enhanced by ship-launched fixed-wing UAVs, especially in measuring marine/ocean surface processes and fish stock identification (focusing on obtaining estimates of abundance, distribution, and density, or even body condition, movement, and behaviour of individuals). Drone- and UAV-based algal bloom studies are bound to gain critical traction in the 21st century, specifically the use of vehicle fleets, and integration of UAVs with other technologies, such as automation, IoT, AI, high-resolution hyperspectral imaging, etc. Overcoming the purely technical challenges and limitations (battery power autonomy, duration spatial range of UAV flight missions, legal networking and regulations, flight credibility, optical capacity, etc.) will be the main challenges for these technologies.

- Radar applications mainly refer to SAR, HFR and CODAR applications, helping forecast modelling in more reliable predictions of currents by data assimilation with high temporal and spatial resolution. Automatic eddy detection is an upcoming methodology for research, and surface current information can be practically used to provide drift predictions, useful for Search and Rescue operations or environmental protection issues. Overall radar technologies are considered to be the most cost-efficient tool to monitor seawater conditions yet are confined to coastal regions' applications.

- There is a very wide variety of ocean circulation and ecological models currently implemented around the world. The most prominent of them, focusing on coastal applications, are the commercial DHI's MIKE 3 with ECO Lab module for use cases of mainly local or regional focus, with highly user-friendly environment by means of an efficient GUI. Another modular suite, yet free and open-source, is Delft3D with its modules FLOW, WAQ, PART, etc. It is tested mostly in coastal and estuarine physical and chemical process applications, particularly robust in algal bloom forecasting. The Matlab GUI is also quite efficient and cooperation with other commercial suites (e.g., MIKE ECO Lab) relies only on proper translations and transformation of hydrodynamic results feeding the numerics of ecological modelling. The latter is quite efficient as part of EIA or aquaculture optimization.

- When selecting appropriate cost-effective technological innovations, special attention must be put to include as a major criterion the possible associated environmental impact during operation (e.g., producing underwater noise while using a towed side-scan sonar). Any suggested technological upgrade must be thoroughly checked versus environmental sustainability criteria. This principle will also be a basic requirement when carrying out field surveys during the Pilot Demonstration Projects. It will also be a basic guide when drafting the Innovation Strategy within activity GA T.4.
- 18 good practices from the Black Sea region and the Mediterranean basin are presented in this report (Chapter 2). These practices have been already proven as effective for various tasks relevant to environmental monitoring, modelling and assessment of water quality and fish stocks & non-fish resources. These good practices, together with recommended innovative solutions will be discussed during next TIMMOD TTM-2 meeting, where other (newly identified) good practices may be added to the list.
- Selection and promotion of applicable innovative technologies and best practices, will be carried out within TIMMOD Activity 1.3, taking in account environmental impact and cost-benefit analysis, and will be reported in deliverable D.T1.3.1 "*Recommendations on adoption of appropriate technology innovation and best practices for marine environmental monitoring at Black Sea*". In addition, the recommended technology solutions will be discussed by the project consortium and stakeholders at 5 national workshops. Nominated "Best practices" will be published in the internet site of the project, will be showcased, and furthermore promoted for replication in the Black Sea basin.

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