PREVIMER: A CONTRIBUTION TO IN SITU COASTAL OBSERVING SYSTEMS

By G. Charria[(1)], M. Repecaud[(2)], L. Quemener[(2)], A. Ménesguen[(3)], P. Rimmelin-Maury[(4)], S. L'Helguen[(5)], L. Beaumont[(6)], A. Jolivet[(5)], P. Morin[(7)], E. Macé[(7)], P. Lazure[(1)], R. Le Gendre[(8)], F. Jacqueline[(8)], R. Verney[(1)], L. Marié[(9)], P. Jegou[(10)], S. Le Reste[(10)], X. André[(10)], V. Dutreuil[(10)], J.-P. Regnault[(2)], H. Jestin[(1)], H. Lintanf[(10)], P. Pichavant[(10)], M. Retho[(11)], J.-A. Allenou[(11)], J.-Y. Stanisière[(11)], A. Bonnat[(12)], L. Nonnotte[(13)], W. Duros[(13)], S. Tarot[(12)], T. Carval[(14)], P. Le Hir[(1)], F. Dumas[(1)], F. Vandermeirsch[(1)], F. Lecornu[(1)]

[1] IFREMER, ODE/DYNECO/PHYSED, Plouzané, France
[2] IFREMER, REM/RDT/LDCM, Plouzané, France
[3] IFREMER, ODE/DYNECO/BENTHOS, Plouzané, France
[4] IUEM-UBO, UMS CNRS 3113, Technopôle Brest-Iroise, Plouzané, France
[5] IUEM-UBO, UMR CNRS 6539, Technopôle Brest-Iroise, Plouzané, France
[6] CNRS/INSU, Division Technique, Meudon, France
[7] CNRS-UPMC, UMR CNRS 7144, Roscoff, France
[8] IFREMER, ODE/LITTORAL/LERN, Port-en-Bessin, France
[9] IFREMER, ODE/LPO, Plouzané, France
[10] IFREMER, REM/RDT/SI2M, Plouzané, France
[11] IFREMER, ODE/LITTORAL/LERMPL, La Trinité sur Mer, France
[12] IFREMER, IMN/IDM/SISMER, Plouzané, France
[13] ALTRAN, Brest, France
[14] IFREMER, IMN/IDM/ISI, Plouzané, France

Abstract

To design a prototype for an Integrated Ocean Observing System (IOOS), at least three components are mandatory: a modeling platform, an *in situ* observing system and a structure to collect and to disseminate the information (*e.g.* database, website). The PREVIMER project followed this approach and in order to sustain model applications, PREVIMER has developed, funded and organized part of *in situ* observing networks in the Bay of Biscay and the Channel. For a comprehensive system, focus was addressed on fixed platforms (MAREL MOLIT, MAREL Iroise, Island network and D4 for sediment dynamics), ships of opportunity (RECOPESCA program and FerryBoxes), and coastal profilers (ARVOR-C/Cm).
Each system is briefly described and examples of scientific results obtained with corresponding data are highlighted to show how these systems contribute to solve scientific multidisciplinary issues from the coastal ocean dynamics to the biodiversity including pelagic and benthic habitats.

Introduction

The PREVIMER project has been a prototype of an integrated system including coastal ocean modeling systems, associated with *in situ* observing networks, and a data center with associated solutions for data visualization (e.g. web site) and distribution. The present paper aims to introduce how the PREVIMER project sustained coastal *in situ* observing systems in the Channel and the Bay of Biscay. Indeed, the project contributed to the development, deployment and setup of ongoing *in situ* platforms including fixed platforms, coastal profiling systems and programs of opportunity measurements. These three components contribute to an integrated observation of the 4D (longitude, latitude, time, and depth) coastal environment from high frequency time series (at fixed stations or onboard commercial cruises) to the sampling of the whole water column in targeted areas (using coastal profilers) or based on opportunity network (using fishing vessels).
Figure 1 shows the spatial distribution of the observing systems partly or fully funded through the PREVIMER project. These items have to be considered as a component of the French coastal observing system, part of the recent extent to the coastal regions of the Coriolis convention. This new convention is including other coastal observing networks with, for example, the SOERE MOOSE[1] in the Mediterranean Sea.

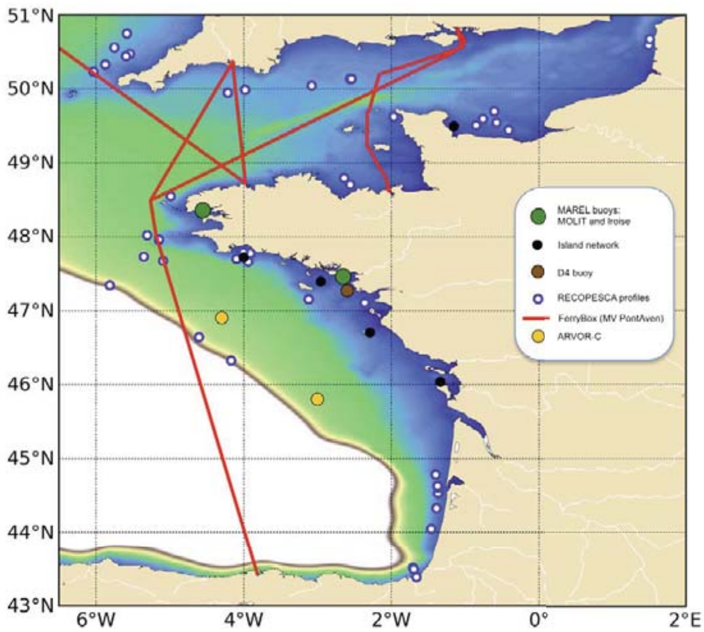


Figure 1: Observing systems in the frame of the PREVIMER project.

[1] SOERE MOOSE: Système d'Observation et d'Expérimentation pour la Recherche en Environnement - Mediterranean Ocean Observing System on Environment (http://www.allenvi.fr/groupes-transversaux/infrastructures-de-recherche/moose)

As fixed platforms, three categories can be described. First, MAREL buoys are complex platforms able to sample a wide range of parameters and to support the development of new sensors (see “Fixed platforms” section). In the PREVIMER project, MAREL MOLIT in the Vilaine Bay and MAREL Iroise in the Bay of Brest have been partly supported. Another network is the island network designed to monitor salinity evolutions near the main river plumes (see “Fixed platforms” section). Finally, a prototype of a fixed platform dedicated to sediment dynamics (called D4) studies has been implemented (see “Fixed platforms” section).
To extend the network of fixed platforms, generally near the coast, two observing systems based on measurements of opportunity have been improved in the frame of the project. The RECOPESCA program aims to acquire hydrological variables with probes implemented on fishing vessels (see “Ships of opportunity” section). This program is initially planed to collect measurements for fishery science. FerryBoxes (see “Ships of opportunity” section) represent the other system of opportunity used in the frame of coastal observing networks. With high spatial resolution measurements, FerryBoxes provide detailed information about the surface ocean.
The last component of the current network is based on coastal profilers called ARVOR-C / ARVOR-Cm (see “Coastal Profilers” section). These platforms, designed as a coastal version of ARGO floats, allow observing the whole water column close to a given geographical point.

In addition to previous systems dedicated to long-term coastal ocean observation, the PREVIMER project also contributed to improve the knowledge of the coastal environment through the investment in sensors and platforms dedicated to scientific cruises (*i.e.* Scanfish - a remotely operated towed vehicle).

In the present paper, we will introduce the different systems through a short description and examples of results obtained exploring the corresponding collected data.

Fixed platforms

The first pillar of coastal high frequency *in situ* observations is based on fixed platforms. MOLIT platform, MAREL Iroise buoy, the island network and the D4 systems are described.

MOLIT platform

The scientific buoy MOLIT (Figure 2) was moored in the Vilaine Bay in October 2007 thanks to the PREVIMER and TROPHIMATIQUE projects:

- PREVIMER relies on Ifremer’s computational cluster, linked to the coastal oceanography data center, which pools observations and stores the model outputs, which are put on-line daily.
- TROPHIMATIQUE project aimed the development of new operational sensors as chemical analyzers or multi parametric probes.

The MOLIT platform is very original regarding its functioning principle: sea water is pumped from two levels (sub surface and bottom) through an umbilical, which is also the mooring device. This means that surface and bottom measurements are performed alternatively by the instrumentation and the system can act as a docking station for the testing of new sensors, analyzers, samplers or measurement protocols.
A special aspect is also the protection of all the pipes, sensors and pumping devices by chlorination (sea water electrolysis).
The water collected is analyzed over the same probe avoiding by the way the possible discrepancy in case of a two probes measurement. MOLIT has a high-capacity instrument payload. It is specially streamlined for use in the open sea. It has sensors to measure nutrients and ammonium, as well as temperature, salinity, dissolved oxygen, chlorophyll and turbidity probes; the data are transmitted to the data center in real time.

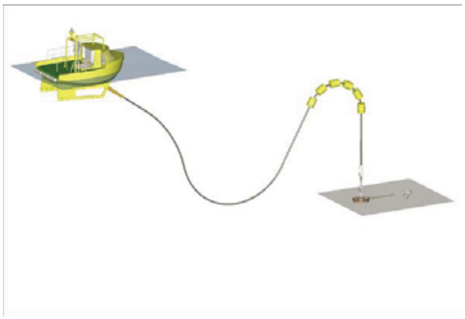



Figure 2: General view of MOLIT scientific buoy.

MOLIT buoy is a key system to observe the dissolved oxygen in the Vilaine Bay.
Indeed, oxygen depletion in the bottom waters is the more dangerous aspect of coastal eutrophication, because of its detrimental effects on the marine life (growth slow-down, increased vulnerability to fishing, reproduction impairment, reduction of the biodiversity) and the ultimate threat of ecosystem death in case of complete anoxia, leading to more and more numerous “dead zones” in the world (Diaz and Rosenberg, 2008). Along the French coast, the only spot where lethal anoxia has been recorded in July 1982 is the Vilaine bay (Merceron, 1988): due to a sudden sunny and calm period following a brief, but strong inflow of nutrient-rich freshwater from the Vilaine watershed, a large phytoplankton bloom developed in the surface layer of the strongly stratified bay, and its decay after sedimentation exhausted the total oxygen content of the bottom water, killing marine invertebrates and fishes (Figure 3). A model of the anoxia event of 1982 (Chapelle et al., 1994) has been recently applied to the whole Bay of Biscay and English Channel, with a zoom on the marine area in front of Vilaine and Loire rivers (Dussauze, 2011). This model reveals that a large part of this area is sensitive to bottom anoxia in summer (not shown). For that reason, in the framework of the PREVIMER and TROPHIMATIQUE projects, the MOLIT buoy has been moored in the northern part of the Vilaine bay to measure every 20 minutes the oxygen concentration in the surface layer as well as in the bottom one. Time-series obtained during the years 2008 to 2013 (Figure 4) show every spring and summer droops of bottom oxygen concentrations, occurring with a small delay after surface oxygen over-saturations (which sign important blooms in the surface layer). A strong effect of tidal regime on the oxygen content of the water column is visible on these records: weak currents during neap tides favour stratification and, hence, surface blooms and bottom decrease of oxygen content, whereas strong currents associated with the spring tides mix again the water column and restore a quasi-

saturation of oxygen in the whole water column. Hypoxia may be more severe near mussel farms, as shown by measurements made in June 2008 by Ifremer/La Trinité. The ecological effects of recurring hypoxias in the Vilaine area are not yet well described, but some seashell (*Mytilus edulis*) and crabs (*Carcinus moenas*) mortalities have been recorded during measured hypoxias in June 2008, and Stanisière et al. (2013) show arguments in favour of a decisive role of acute hypoxia in triggering the mortality of bottom cultivated oysters in the bay of Quiberon, not far from the Vilaine bay. Using the biogeochemical modelling of the decade 2000-2010, they show that in summer 2006, the year of exceptional oyster mortality, 3 abnormal droops of oxygen concentration in the oyster farm areas were simulated in July, August and September, and with a geographical distribution corresponding to the map of recorded mortalities. The fact that the biological response to oxygen deficiency is non-linear, and that lethal, very low, oxygen concentrations are short, impermanent phenomena, occurring mostly during a few hours at the end of the night, militates absolutely for the deployment of automatic sensors, in order to record these dramatic short events.

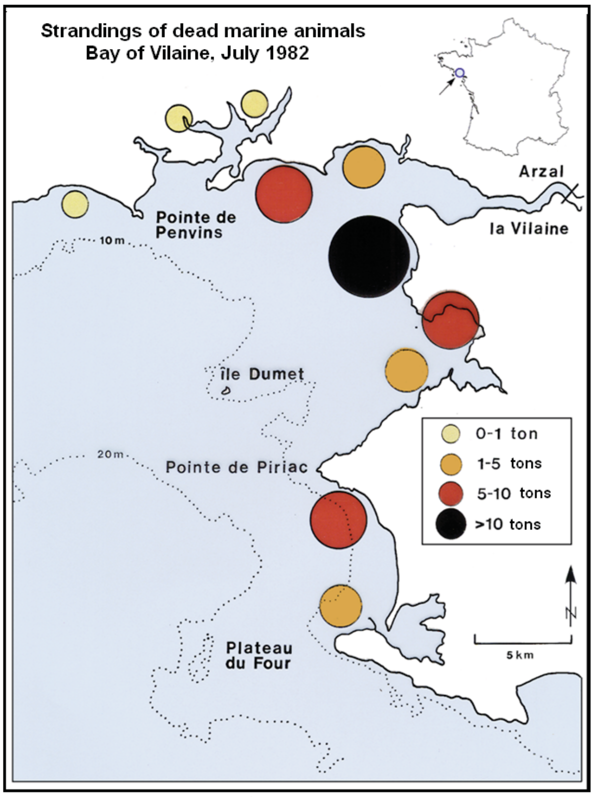


Figure 3: Geographic distribution of dead fish and invertebrates strandings in July 1982.

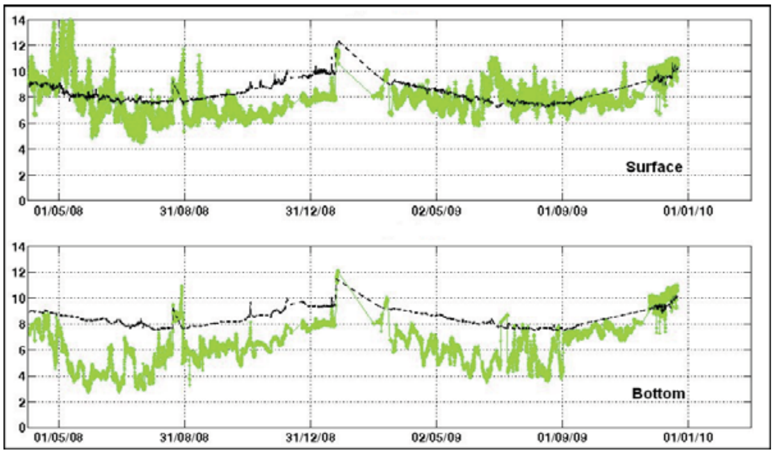


Figure 4: Measured surface and bottom oxygen concentrations (mgO2 L-1) by the MOLIT buoy in the Vilaine bay, during 2008 and 2009 (green: measurements, black: computed oxygen saturation at local temperature and salinity).

Marel Iroise

The MAREL Iroise buoy is a key tool to observe at high frequency the temperate coastal ecosystem of the Bay of Brest, which is impacted by both continental and Iroise Sea inputs. This scientific buoy is property of IUEM (Institut Universitaire Européen de la Mer, http://www-iuem.univ-brest.fr/fr) and Ifremer. It was moored in 2000 at the outlet of the bay (Figure 5) where manual sampling is also performed for the weekly observation network SOMLIT (French coastal monitoring network, http://somlit.epoc.u-bordeaux1.fr/fr/). MAREL Iroise records several parameters at a 20 minutes frequency: temperature (±0.05°C), conductivity (±0.05mS/cm), dissolved oxygen (±5%), in vivo fluorescence (±5%), and turbidity (±5%) of superficial waters. By the mean of two additional sensors, these core parameters are completed by aerial Photosynthetic Activated Radiation (PAR) and pCO_2 (±3ppm). The principle of this automated measurement station is to pump the sea water through a multi parametric probe in order to guaranty the quality of the collected data. Thanks to this method, and to the chlorination of the water circuit, the quality of the collected data is guaranteed over three months without any maintenance. The whole installation is controlled by an autonomous embedded computer, which regulates all functions, including the daily data transmission to an inshore station. The data are available on the website: http://www.ifremer.fr/difMarelstanne/. The computer can be called over a GSM system in order to modify the parameters or transfer the logged data to the shore station. Nutrient concentrations (Nitrate, Ammonium, Silicate and Phosphate) can be also measured for special studies. The MAREL Iroise *in situ* instrumentation has been deployed for 13 years and has produced a data collection with a mean success ratio of 79%. Such data set has already been explored in multidisciplinary studies. Some of them are briefly presented hereby.

Figure 5: The "Marel Iroise" scientific buoy at the outlet of the Bay of Brest

The biological significance of this tool can be illustrated by the study of inter-annual growth variations during the first year of life of the Great scallop (*Pecten maximus*). Since 1987 (EVECOS Series, PI L. Chauvaud), the observing service of IUEM measures daily growth of this animal (Figure 6). How temperature affects the growth of these species in the highly variable environment of the Bay of Brest is analyzed by using the low - frequency records of temperature (1 measurement per week).

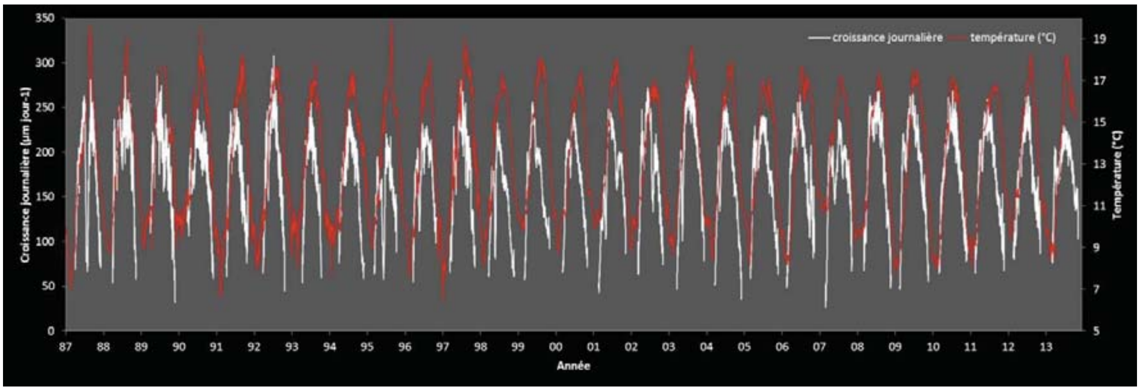


Figure 6: Interannual growth variations of Great scallop Pectenmaximus during their first year of life from 1987 to 2013 (EVECOS, Observing service- IUEM).

The daily formation of the growth striae on the Great scallop valves also provides, by measuring its chemical composition, an access to several proxies. In this context, the use of high - frequency environmental data (1 measure per day) produced by MAREL Iroise allows calibration and subsequent use of these sclerochemical data as environmental proxies.

A more biogeochemical use of MAREL Iroise data has been achieved through the study of high frequency record of pCO_2 (since 2003) in order to investigate the variability and the evolution of CO_2 flux exchanged at the ocean-atmosphere interface (PI Y. Bozec). The authors showed that biological processes like photosynthesis and respiration are the main controller of diurnal and seasonal pCO_2 variations and that diurnal variability can reach 70% of the average seasonal variation (Figure 7). This underlined the need to consider high frequency variation to avoid an 8 to 36% error in the monthly budget estimation. The seven years budget also showed a relatively equilibrated CO_2 emission of 0.4 ± 0.7 $mol.m^{-2} yr^{-1}$ with a low interannual variation so that coastal temperate ecosystem of Bay of Brest seems to act as a buffer interface between estuarine sources and oceanic sinks.

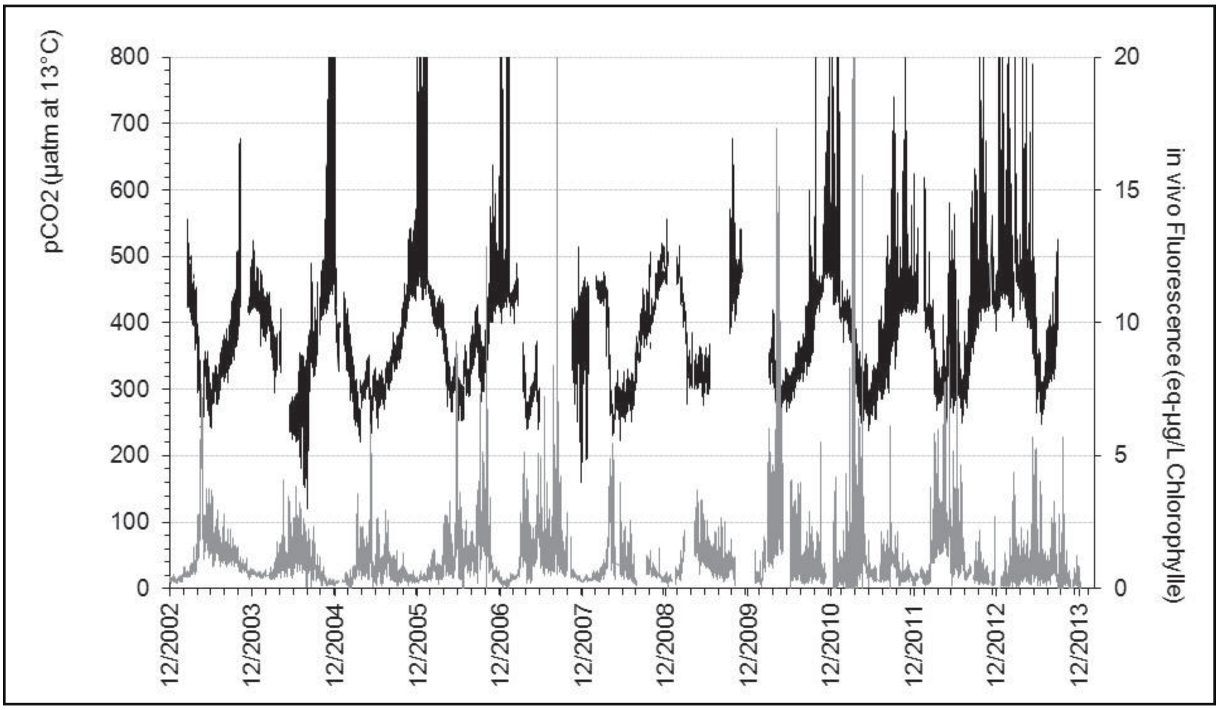


Figure 7: Temporal variation of pCO2 (normalized at 13°C, grey line) and in vivo fluorescence ("Marel Iroise" data, black line).

In a more physico-chemical interest, Tréguer et al. (2013) used the MAREL Iroise data to investigate the temporal variability of physico-chemical features of the Bay of Brest waters during winter in relation with large and local scale weather processes over the 1998-2013 period. These authors examined the relationships between sea surface temperature, sea surface salinity and nutrient concentration, river discharges, precipitation and climatic index data (North Atlantic Oscillation, NAO; East Atlantic Pattern, EAP; Atlantic Ridge, AR). Mainly focused on winter months, the study reveals that the variability in the coastal water characteristics is impacted by both the large-scale North Atlantic atmospheric circulation and local river inputs. While the NAO is strongly correlated to changes in sea surface temperature, the EAP and the AR have a major influence on precipitations, which in turn modulate river discharges that impact sea surface salinity. A future dominance of a positive EAP phase could support an increase in precipitations and therefore, the delivery of high nutrient standing stocks leading to a high new production during the following spring.

These studies highlight the scientific significance of this high frequency *in situ* monitoring, which allows the observation of the long-term evolution of coastal marine ecosystems. They also show that it is essential to continue the high frequency acquisition of physical, chemical and biological parameters in order to predict the responses of coastal systems to climatic changes and anthropogenic forcing.

Island network

The island network was initially designed in 2000 (Lazure et al, 2006) to track the fate of the large river plumes in the Bay of Biscay. The continental shelf is under the influence of two major rivers, the Loire and Gironde with annual mean discharges of 900m^3 s^{-1}. Numerous smaller rivers spread also along the coast and may dramatically affect the local salinity patterns. To avoid these local effects, conductivity probes have been deployed as far as possible from estuaries but not too far to allow regular maintenance operations. To cope with these constraints, probes have been deployed along the coast of several small islands (Glénan, Houat, Yeu and Oléron) and the times series of coastal salinity have been used as validation data for the operational regional MANGA model (Lazure et al, 2009).

Since the end of 2010, the network has been renewed to allow direct time access to the data and better calibration and validation procedures.
The Island network is now formed by a set of four small autonomous small buoys named MAREL SMATCH (Figure 8).

Figure 8: A MAREL SMATCH buoy.

MAREL SMATCH buoy is an operational remote transmission multiparametric probe: temperature (accuracy: 0.02°C), conductivity (accuracy: 0.05mS) and pressure (accuracy: 0.1m). The included principle of local chlorination protects the sensors against bio fouling and therefore guaranties the quality of the measure for a period of three months without any maintenance. An autonomous embedded computer deals with the logging, and transmission of data (GPRS modem) once a day. This small buoy weights only 9 Kilograms and can be easily moored by a rope and a small dead weight for coastal operations. Data can be downloaded from: http://www.coriolis.eu.org/Data-Services-Products/View-Download/Eulerian-networks-fixed-buoys.

A new mooring has been deployed near Saint Marcouf island (Bay of Seine, English Channel), mainly to monitor the fate of freshwater inputs from the Seine river and four secondary watersheds flowing in the Bay of Veys (*i.e.* Vire, Douve, Aure, Taute). The Bay of Seine receives large freshwater inputs, mainly from the Seine River (mean flow around 500 m^3/s) whereas cumulated mean flow from the Bay of Veys does not exceed 40m^3/s. It covers around 3500 km^2, with a tidal range varying from 3 m at neap tide to 7.5 m at spring tide. The mean depth is around 20 m and the bay is striated by a deeper channel corresponding to the paleovalley of the Seine River. Tidal residual circulation in the Bay of Seine have been well described (Ménesguen and Gohin, 2006) and exhibits important meso-scale features such as two anticyclonic gyres, induced by the presence of capes; one offshore of "Barfleur" (49.67°N/-1.25°W) and the second near "Antifer" (49.66°N/0.12°E). Saint Marcouf mooring is located approx 100km west from the Seine mouth, and 15km north from the Bay of Veys. Prevailing wind in this part of the English Channel are usually southwesterlies but intense northeasterly wind sequences frequently occur.

Figure 9 presents salinity data recorded at St Marcouf mooring between the end of August 2010 and April 2012. On black curve, tidal signal has been removed to rub out high frequency variations, and red solid line represents the seasonal component. Solid blue line corresponds to the Seine instantaneous flow whereas dotted line is the Vire flow (x factor 15). Wind barbs (2 days averaged) are shown on the bottom panel (scale 10 knots).

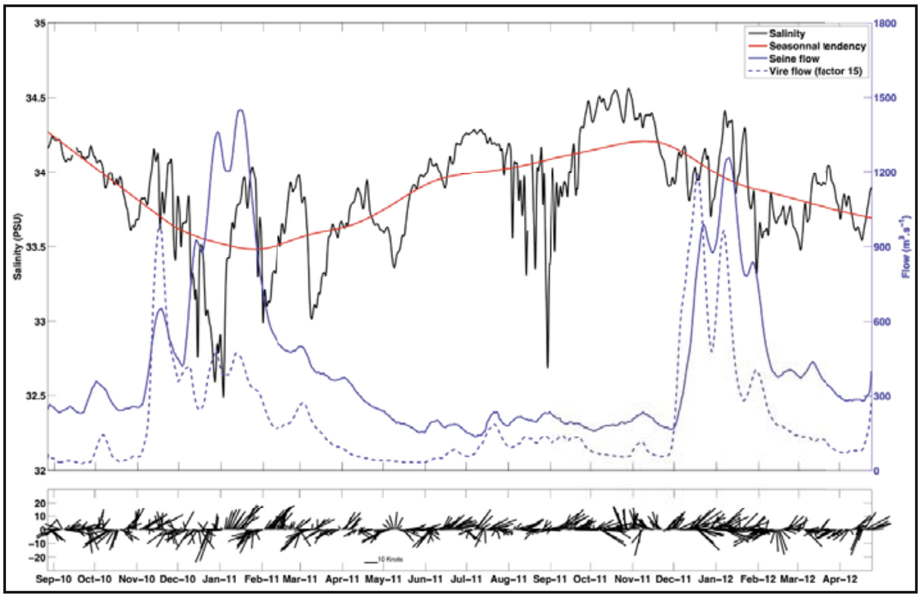


Figure 9: Salinity data recorded at St Marcouf mooring between the end of August 2010 and April 2012 (black). On black curve, tidal signal has been removed to rub out high frequency variations, and red solid line represents the seasonal component. Solid blue line corresponds to the Seine instantaneous flow whereas dotted line is the Vire flow (x factor 15). Wind barbs (2 days averaged) are shown on the bottom panel (scale 10 knots).

Salinity ranges from 32.5 to 34.5 psu. Minimum was recorded at the beginning of winter 2010-2011. This figure exhibits interesting features to help us apprehend the functioning of the bay. We can first note that Seine and Vire flow evolutions are not necessarily concomitant with larger runoffs from the Vire observed few days before peaks in the Seine flow. The salinity decreases, as during winter 2010-2011, occur generally after Northeasterlies sequences resulting in an extension of the Seine freshwater plume to the mooring position. However, in winter 2011-2012, the decrease is less pronounced (until 34 psu instead of 32.5 psu during winter 2010-2011). The different wind regime can partly explain this difference. More generally, the seasonal cycle is also strongly dependent on the wind regimes.

Beyond the use of these data to observe and to explain local processes, the island network measurements are key observations to qualify model simulations contributing to reduce the lack of observations (specifically for salinity and in a near future for turbidity) close to river plumes.

D4 : a platform to quantify suspended sediment concentration in the water column

Context

Suspended sediment in the water column and related turbidity constitute driving parameters of the coastal ecosystems. They are associated to sediment fluxes, sedimentary habitats, and influence the productivity of ecosystems as limiting the euphotic depth and hence the primary production. Quantifying suspended sediment concentration (SSC) in the entire water column in quasi real-time is a challenging issue. It requires operating top research measuring techniques and pre-process, collect and transmit a limited volume of data.

Platform overview

The Previmer-D4 measuring platform (Figure 10) was designed in collaboration with iXSurvey and operated to provide key hydrodynamic and sediment features in the coastal seas, i.e. current and SSC profiles, waves, seabed sediment altimetry and temperature/salinity time series. The system is composed of two non-contact interconnected principal modules. The benthic module consists of an anti-trawl frame receiving a detachable basket containing the following instruments: a 1MHz Nortek® AWAC Doppler acoustic profiler (measuring waves, current/acoustic backscatter signal profiles (0.50m cells), seabed temperature and pressure), a WETLabs® ECO-NTUS pole mounted turbidity sensor, a Tritech® PA500-6 bed millimetric altimeter vertically fitted on a firmly grounded external T-shaped frame, and a Sercel® MATS211 acoustic modem for data transmission from the bed to the surface. At the surface the buoy supports a Sercel® MATS251Z7-MATS231/P acoustic modem, a Hydrolab MS5 multi-sensor probe (temperature, salinity, turbidity), a GPS, a radio modem with UHF antenna, solar panels and batteries, and an embedded micro-PC collecting, buffering and transmitting data from all instruments. Data are sent every half an hour for all parameters except waves each hour through GSM protocol and collected on the CORIOLIS server in Ifremer Brest.

Figure 10: Schematic view of the Previmer-D4 platform (left) and a photography of the real buoy (right).

Measuring SSC profiles

Two optical backscatter sensors are operated on the Previmer-D4 platform, but measurements are only collected at 1.70m below the surface and 1.75m above the bed. Quantifying SSC on the entire water column requires analysing the AWAC acoustic backscatter signals (Thorne and Hanes, 2002). We decided to apply a semi-empirical method to correct the acoustic signals from water attenuation and calculate SSC profiles (Tessier et al., 2008), using the near bed SSC time series (from the calibrated optical turbidity sensor located in the second AWAC cell).

Previmer-D4 observations

The measuring platform was deployed twice in 2007-2008 2nm S/SW off Le Croisic and in 2009-2010 close to Quiberon in the bay. Focusing on the first deployment (November 2007-March 2008), the system successfully recorded several winter storms characterised by 3 to 4m wave height. These wave events resuspended sediments, with SSC up to 100g.l^{-1} close to the bed, and impacted the entire water column. As an example, 30mg.l^{-1} SSC was regularly recorded 10m above the bed while the ambient calm weather concentration is around 5mg.l^{-1} (according to calibration of simultaneous measurements/water samples - Figure 11). The quasi real-time data collection enables to evaluate the coastal sea dynamics, and compare with both satellite ocean colour data and model results.

From this experience several technical improvements would be necessary to lower uncertainties on quantitative SSC measurements. The first issue is related to the calibration of the optical sensors, which requires ground truth water sample on the full signal range. However, operations at sea are mainly conducted with small boats under calm weather for safety and do not allow to collect sample during high turbid (waves) events, hence limiting the calibration range to low SSC. The second limitation is associated to the acoustic signal and its validity close to the surface: the mixing at the air/sea interface contributes to introduce bubbles in the water column, the depth depending on wave intensity. These bubbles are intense scatterers that produce noise in the acoustic signal. In consequence, part of the acoustic signal is discarded, as bubbles/suspended sediment signals cannot be separated. Research works are currently in progress in order to improve the quality of the measurements.

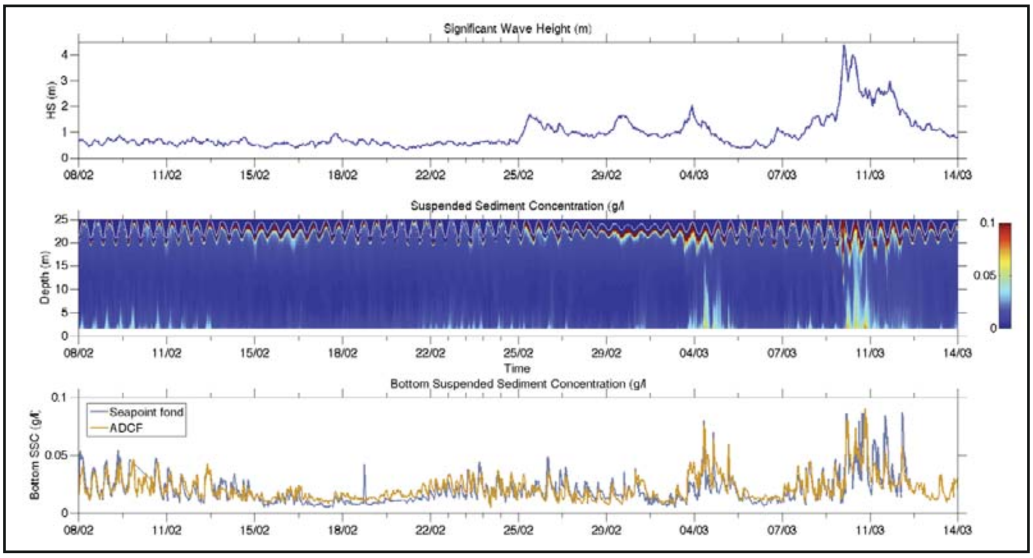


Figure 11: Wave and suspended sediment time series from the 8th February 2008 to the 14th March 2008 at Le Croisic (France).

Ships of opportunity

The second part of coastal observing systems is based on the use of ships of opportunity to collect frequent observations with an optimal cost/quality ratio. In the present manuscript, data collected in the RECOPESCA project and from FerryBox are presented.

RECOPESCA project

The aim of the RECOPESCA project (Leblond et al., 2010) is to achieve accurate spatial distribution (GPS monitoring of boat and timestamp) of catches (weight with anti-rolling weigh-scale), fishing effort (working duration of the fishing gear) and environmental (depth, temperature, salinity, turbidity) characterization of fisheries area required for an ecosystem approach to fisheries. The collected data are available for fishery scientists and physicists who dispose of continental shelf dataset from 2 to 300m depth. The physical data are stored and shared in two data centers (i) The Fisheries Information System of Ifremer and its database *Harmonie* (ii) the *Coriolis* database for operational oceanography. A real time quality control is applied on collected data.

RECOPESCA is a mean based on a participative approach, where the voluntary fishermen team up with fishery scientists. This successful collaboration is possible because we used equipment, which doesn't need interventions of the fisherman team during several months. For this, we developed rugged probes that can be directly fixed on fishing gears (trawl, net, fishing trap…), self-powered, autonomous, with accurate and fast response time sensors for profiling function during way down.

Onboard basic equipment is comprised with:

- A probe with depth (3% full scale precision) and temperature sensor (precision less than 0.05°C in the range 0°C to 20°C) without or with an additional sensor such as conductivity sensor (precision ± 0,05 mS/cm in the range 10 to 60 mS/cm) or turbidity sensor (precision less than 2%). The probe records only during immersion stage and the data are timestamp. The record time frequency is configurable. Typically we use two frequencies. The first is set to 1 second during the way down period (profiling period) and the second set to 2-10 minutes during the fishing gear bottom working period. The probe is equipped with a radio device for transmitting automatically its data to the *concentrator.*
- A receiver on-board hub called *concentrator*, placed outside on the vessel bridge. The *concentrator* is equipped with a GPS 3D patch, a GPRS modem for transferring all the data to the Ifremer data center in Brest, a radio device for bi-directional communication with the probes. The probes are set to time at each data transfer with the *concentrator*. The *concentrator* has 6 months memory capacity.

In addition, specific equipment can be added:

- A turn-counter placed on the gear hauler in order to measure the length of passive gears hauled at each fishing operation. A radio device is present for data transfer to the concentrator.
- An anti-rolling weight-scale recording the catches per species and fishing operation. A radio device is present for data transfer to the concentrator.

At the end of 2013, around 80 vessels are equipped and 28181 profiles have been collected in the Bay of Biscay and the Channel (domain: 43°N/52.5°N - 12°W/2°E). The deployment plan, at the national scale, is in accordance with the diversity and representativeness of the fishing fleets (fishing area, vessel length and work experience).

The geographical distribution of vertical profiles (Figure 12) from 2006 to 2013 translates the preferential areas for fishing activities (in agreement with the fishery science aim of the project). We can notice very well sampled areas as the South of Brittany or the western Channel and undersampled regions as the South of the Bay of Biscay off Landes coast, where profiles (less profiles than in the northern part) are distributed in an area very close to the coast where the hydrology is very sensitive (e.g. upwelling activity) and then profiles are potentially supporting a stronger variability.

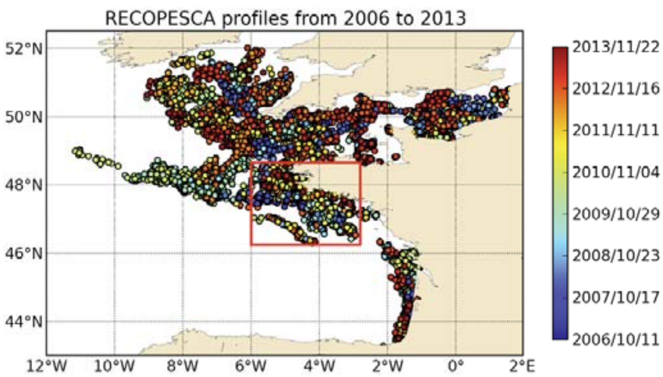


Figure 12: Map of RECOPESCA Temperature profiles since 2006. The rectangle highlight the studied region (46.2°N/48.6°N - 6°W/2.8°W).

Figures 13 displays the average vertical profiles South of Brittany (*46.2°N/48.6°N - 6°W/2.8°W*) in winter (Figure 13, left) and summer (Figure 13,right) for the different years from 2007 to 2013. This result highlights an interannual variability observed for the first time in this region from ship of opportunity measurements. In winter (January to March, Figure 13-left), we can notice that the number of profiles is very different for each year with large number of profiles in 2009 and 2011 and less than 100 available profiles for the other years. However, these average profiles show clearly that the bottom temperature is larger than the surface temperature. For example, more than 0.5°C difference between bottom and surface waters is observed in 2013. This trend is also observed (with a smaller amplitude < 0.5°C) during the other observed years except in 2012 and 2007, which are also the only years when the number of profiles is lower than 50 profiles. In summer (July to September, Figure 13-right), vertical profiles describe the seasonal stratification with surface waters ranging in average from 15.8°C to 18.3°C (depending the considered year) in surface waters and from 10.8°C to 12.5°C around 100m depth. The thermocline lies between 20m and 40m depth. This layer related to the thermocline is also the zone where the standard deviation in profiles is the most important (not shown) related to local and high frequency processes (*e.g.* internal waves) able to upwell or downwell the thermocline with an amplitude reaching several meters. The interannual variability can be ranged from the year 2013 (with a smooth stratification) to 2009 (with a well marked summer stratification). The shape of these summer profiles has to be related to weather conditions (*i.e.* wind, precipitations and heat fluxes) and the previous winter conditions in the water column.
These results highlight the ability of RECOPESCA profiles to catch the interannual variability.

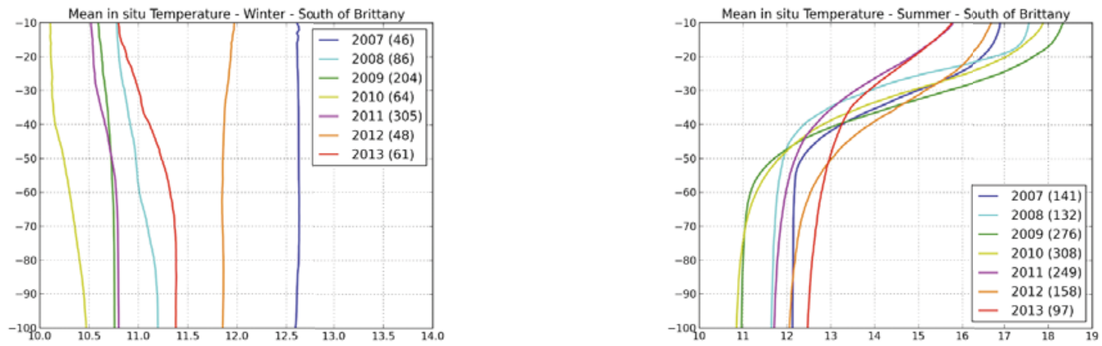


Figure 13: Mean in situ temperature for winter (January-February-March - left) and summer (July-August-September - right) from available vertical profiles for each year South of Brittany (46.2°N/48.6°N - 6°W/2.8°W). Only profiles with measurements deeper than 100m depth are considered. Number in brackets is the number of profiles used to compute the mean profile.

FerryBox

Marine ecosystems are exposed to increasing anthropic pertubations due mostly to the development of industrial activities and urbanisation of the coastal zones. The functionning of marine ecosystems responds to complex interactions between physical and biogeochemical processes depending on natural climatic cycles and are influenced since the last decades by anthropic perturbations, which can modify natural cycles. To distinguish between the natural variability of the biogeochemical cycles and changes induced by anthropic activities, long term time series of observation of physical, biogeochemical and biological parameters are necessary to get a better knowledge of the sensitivity of the ocean to the global change. To address this important question, it is necessary to develop long term studies based on regular sampling. Since 2008, Station Biologique de Roscoff and Ifremer Brest have launched high frequency measurements of hydrological and biological parameters in surface waters on repeated sections in the Bay of Biscay, Celtic Sea and Western Channel. These repeated measurements will contribute to a better knowledge of the seasonal, interannual and decadal variations in these areas and will give access to a better documentation of extreme events (*e.g.* phytoplankton blooms, Loire outputs on the continental shelf) which amplitude and duration are not well known with low frequency observations from classical oceanographic cruises.

The main objective of FerryBox project is to achieve surface measurements of oceanographic parameters using an automatic platform installed on commercial ferries operating regular lines.

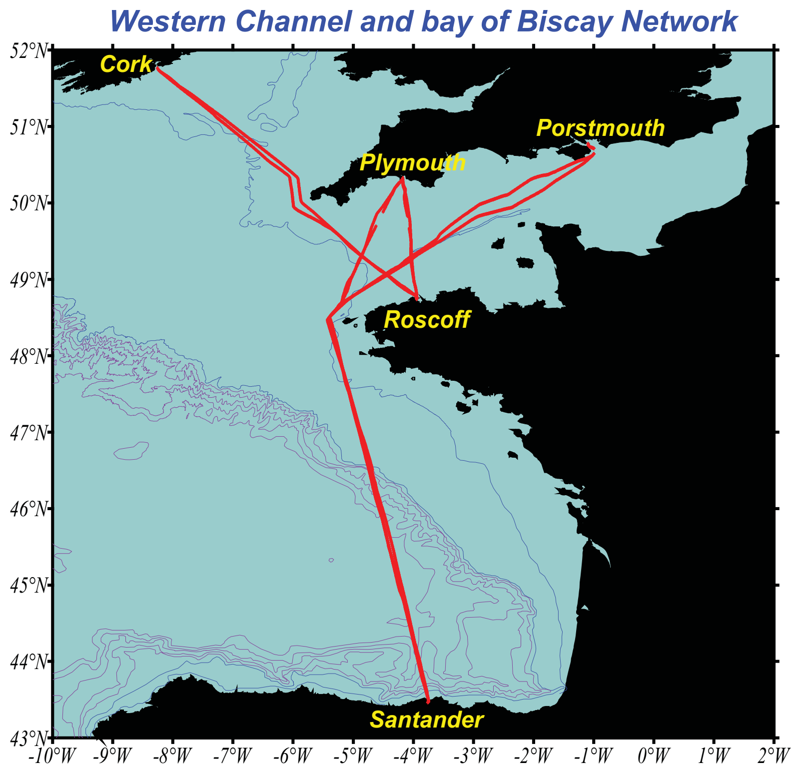


Figure 14: FerryBox routes in the Western Channel, Celtic Sea and Bay of Biscay operated on MV "Pont Aven" and "Armorique" ferries of the Brittany Ferries.

Two ferry box systems have been installed on Brittany Ferries M.V. "Armorique" and "Pont Aven". Complementary sampling strategies have been chosen for an optimal spatio-temporal coverage of the western European seas (Figure 14). A high frequency spatio-temporal sampling is realized with M.V. "Armorique" ferry box along two daily transects in the Western English Channel between Roscoff and Plymouth whereas a spatial coverage of the Western English Channel, Celtic Sea and Bay of Biscay with a weekly sampling is realized with M.V. Pont Aven along transects between U.K., Spain, France and Ireland (Portsmouth and Santander lines, Portsmouth and Saint Malo, Roscoff and Cork and between Roscoff and Plymouth). These lines contribute to the coverage of the European continental shelf by FerryBox lines (http://www.ferrybox.org/routes/) and are integrated in the FP7 EU Jerico program.

The two ferries are equipped with the same systems and sensors. Six parameters (temperature, salinity, dissolved oxygen, chlorophyll fluorescence, turbidity and Colored Dissolved Organic Matter CDOM) are sampled with a 1 minute frequency. Acquisition frequency is a mean value every 1 minute corresponding to a distance of approximately 500m. The different sensors are regularly calibrated with water samples taken from an output valve of the FerryBox system. Temperature and salinity are measured using a Seabird SBE45 thermosalinograph (precisions: ± 0.02°C, ± 0.02 PSU), an Anderaa 3835 optode (precision: ± .3.4 µMole L^{-1}) and a Turner Designs C3 fluorometer for chlorophyll fluorescence, turbidity and CDOM. A set of additional sensors is available and can be installed immediately in case of failures of sensors to ensure permanent measurements at sea. Availability of an additional set of sensors is crucial for operational measurements at sea.

Data collected are transmitted automatically through a GPRS modem to the Roscoff data base at the arrival of ferries in the ports and data are made available through a website (http://abims.sb-roscoff.fr/hf/) where they can be visualized in quasi real time. Data are immediately transmitted to the Coriolis and MyOcean data center for operational oceanography where quality codes are given for the physical parameters.

In the frame of the French FerryBox project, the repeated lines are maintained since May 2010 (MV "Armorique") and February 2011 (MV "Pont Aven"). Examples of results obtained along the Santander – Porstmouth line during 2011 are presented on Figure 15.

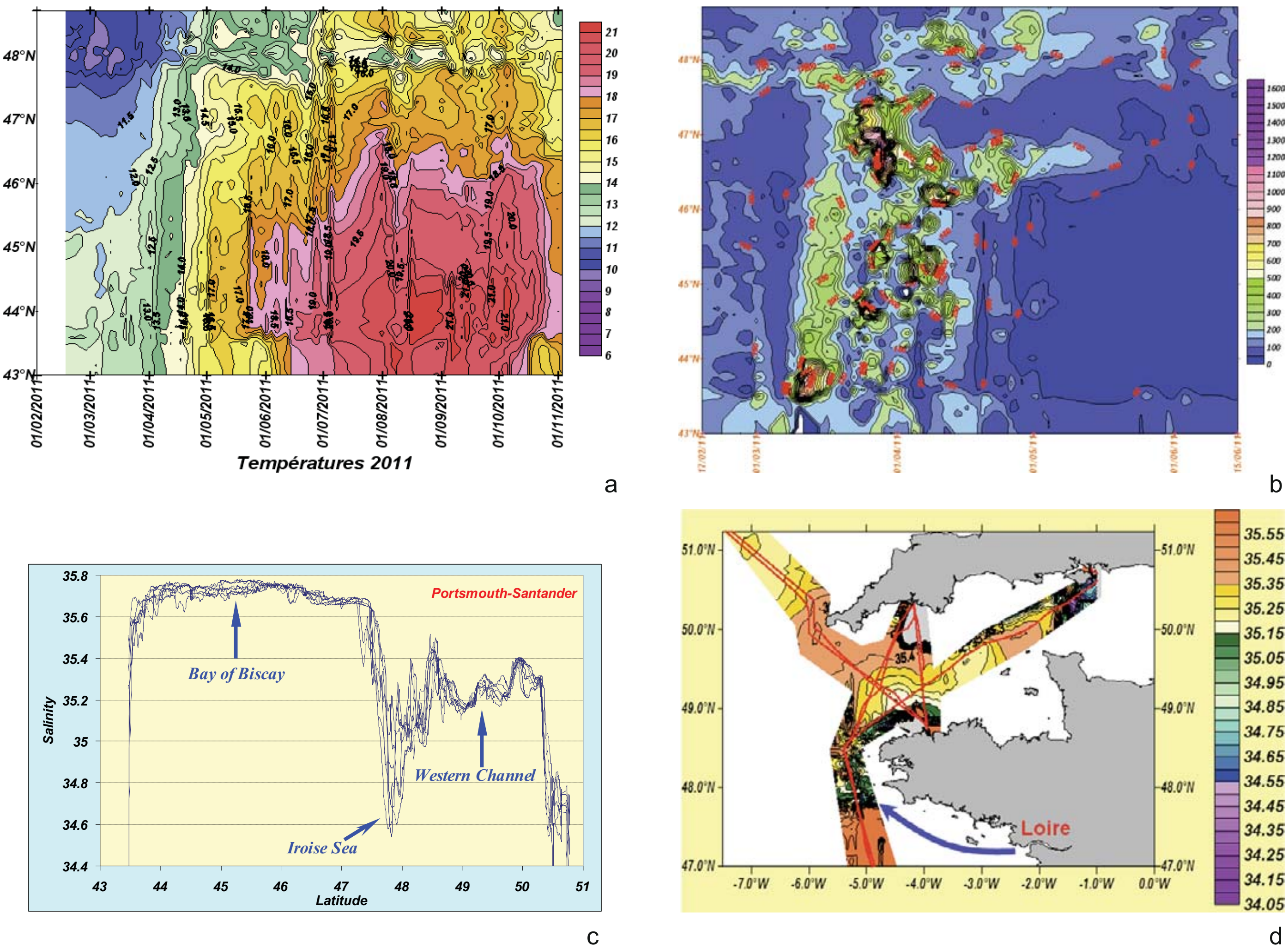


Figure 15. Seasonal evolution of subsurface temperatures during 2011 (a) and chlorophyll fluorescence during spring 2011 (b) along the Santander-Porstmouth line. Evolution of surface salinity in April 2011 along the Santander-Porstmouth line (c) and off Brittany (d) with a salinity minimum at 48°N corresponding to the low salinity waters of the Loire river plume.

<u>*Sequential development of the spring phytoplankton bloom in the Bay of Biscay, Celtic Sea and Western Channel:*</u>

Important differences in surface temperatures (>4°C) were clearly visible during the whole year leading to a late spring heating of the surface waters north of 47°30N (Figure 15a). Due to the early heating of surface waters, the spring phytoplankton bloom was firstly initiated in early March in the southern Bay of Biscay (Table) and then propagated progressively northwards. Three chlorophyll fluorescence maxima were observed during spring 2011(43°46N, 44°34N and 46°48N). In Celtic Sea, the spring phytoplankton bloom was initiated later in early April (when surface waters became warmer leading to a vertical stratification of the water column) and then propagated southwards (Figure 15b). Two maxima of chlorophyll fluorescence were observed at 49°53N and 49°34N. In the Western Channel, the spring bloom developed firstly in the early beginning of April in the northern stratified side whereas the maximum of chlorophyll fluorescence were observed later in the southern part (in late April and May). In this area, the water column is well-mixed over the whole year due the tidal currents and development of phytoplankton is light-limited leading to a late seasonal development. In the Bay of Biscay-Celtic Sea-Western Channel area, the permanent measurements using the FerryBox systems have shown that the spring phytoplankton bloom developed sequentially in space and time over more than two months.

Area	Latitude	Date maximum Fluorescence	Maximum Fluorescence
Bay of Biscay	43°46.8 N	10/03/2011	985
Bay of Biscay	44°34.2 N	24/03/2011	944
Bay of Biscay	46°48.0 N	28/03/2011	1604
Celtic Sea	50°38.4 N	02/04/2011	594
Western Channel	49°53.4 N	05/04/2011	242
Western Channel	49°33.6 N	22/04/2011	642
Western Channel	49°31.8 N	22/05/2011	895

Table 1. Areas, latitudes, dates and maximum fluorescence values of the spring phytoplankton bloom in the Bay of Biscay, Celtic Sea and Western Channel areas.

Loire plume extension on the Armorican Shelf:

Low salinity waters (< 34.6 PSU) were observed off the western coasts of Brittany at 48°N between March and June 2011 (Figure 15c). These low salinity waters were clearly lower than those observed in the Western Channel (≈ 35.2-35.3 PSU) and in the Bay of Biscay (≈ 35.7 PSU). They correspond to the northwestward extension of the Loire river plume on the Armorican shelf. These low salinity waters flow along the south coasts of Brittany and enter the Iroise Sea and the Western Channel as a narrow current. Despite relatively low inputs in 2011 (mean river discharge was 3 times lower than the usual mean discharge), the signature of the low salinity Loire was clearly visible in the entrance of the Western Channel (Figure 15d) and their influence could be even observed in the center of the Western Channel (49°30N – 3°W).

Coastal profilers

Finally, coastal profilers (ARVOR-C/Cm in the present case) form the last pillar of our coastal observing system.

Arvor-C

The Arvor-C is a vertical untethered profiling float, easy to set up and ready to be deployed. It behaves like a virtual mooring, for short to long term observations. It can take measurements at the same location for each profile thanks to the optimized time of ascent and descent through the water column, the short time of transmission at the surface, and its anti-drift capability when grounded on the seabed. The Arvor-C provides a standard set of measurements (pressure, temperature and conductivity), as well as a set of technical information. Multidisciplinary sensors can be integrated on this vertical vehicle, which is designed as an open platform. Additional sensors are being currently fitted to measure dissolved oxygen, turbidity and fluorescence. The Arvor-C is a coastal profiling float, designed to withstand pressures up to 450 meters depth. It can perform up to 320 profiles when cycling at 200 meters depth. The profile repetition rate can be configured from 1 profile every hour. Its ascending speed reaches 15 to 20 centimeters/second. For instance, a 2-second sampling period provides one single measurement every ~35 centimeters. Data are then averaged into 1-meter high slices to reduce transmission duration (André et al., 2010).

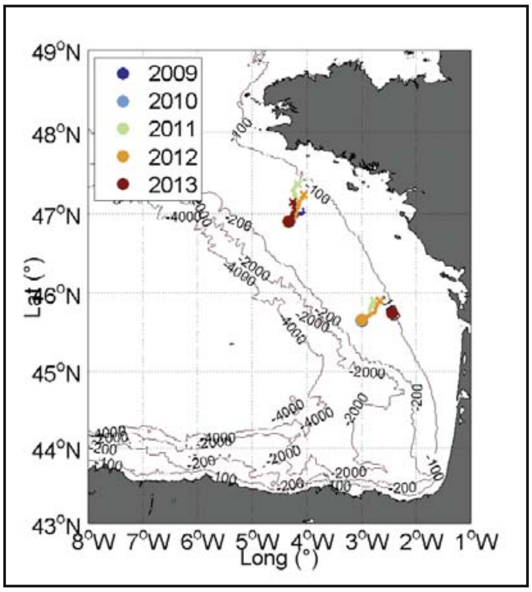
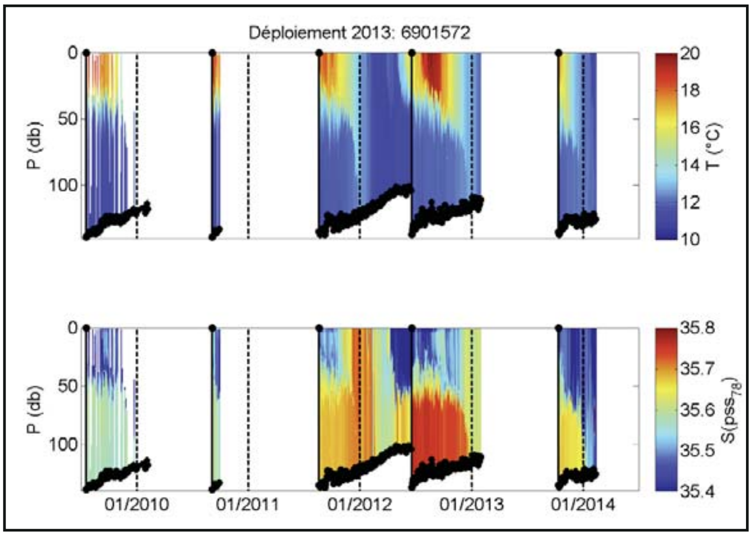


Figure 16

In the frame of the ASPEX project, two ARVOR-C coastal profilers have been maintained in the Bay of Biscay (Figure 16) for years 2009 to 2013. The deployment positions, one in the Northern part and one in the Southern part, have been chosen to collect profiles representing hydrological properties of the “cold pool” (usually names “bourrelet froid” in French) extending above Armorican and Aquitaine shelves. Ten deployments have been operated among which six profilers have been recovered and reused. Four profilers have been lost. The origin of two of these four losses, which happened during the same deployment in 2009, has been associated to a minor design fault of the sensor, which has been corrected. One loss, in 2010, is due to a software bug, corrected today. The last lost profiler is due to destruction during a trawling.

Deployed profilers in the Southern site have been strongly perturbed due to the fishing activity and, then, the corresponding dataset is fragmented. In the Northern part, Figure 17 presents temperature and salinity profiles. We observe on these profiles a good visualization of the annual cycle and the seasonal stratification over the Armorican shelf from 2011. These profiles from 2011 provide the first observations with a high temporal resolution of a full annual cycle of the thermal (Figure 17-up) and haline (Figure 17-down) stratification in this region. During the deployment of the profiler, begin of September 2011, the profiler meets classical stratified conditions with a layer around 40m depth of fresh and warm water at surface, and a layer of saltier and colder water at bottom. The propagation of internal waves, aliased by measurements, is clearly visible through an important noise



on the position of the seasonal thermocline. During the autumnal cooling in 2012, the surface layer cools quickly and becomes saltier. The seasonal pycnocline deepens quickly and is associated to a density contrast, which will decrease until it disappears, around the 1rst January 2012. Surface salinity values are larger than those observed in the bottom layer during summer, showing a contribution of the horizontal advection because the only vertical mixing cannot explain these salinity values. During spring, haline stratification appears quickly in the middle of April. This stratification is used as a precondition for the setup of the thermal stratification reinforcing the haline stratification. The jump in salinity observed mid-June 2012 during the profiler replacement is not due to drift in sensor calibration (confirmed with CTD profiles with differences lower than 0.05°C and 0.02 psu after one year of deployment) but to different hydrological properties between the recovery point and the deployment point. The seasonal cycle observed by the profiler during the 2012-2013 deployment follows broadly similar evolutions.

Figure 17: Temperature and Salinity profiles collected by the ARVOR-C profiler in the Northern part of the Bay of Biscay (see Figure 16). Deployment dates are corresponding to the black continuous vertical lines. Black dashed lines are reprensenting the beginning of each civil year.

Figure 18 shows that even if the temperature and salinity evolutions are similar each year, interannual variations can be observed. Then, the 2012 deployment displays warmer temperature than other years (at surface and at the bottom). Bottom salinity values present interannual variations reaching 0.2 (pss 1978). Summer surface salinity, even if they have a short-term variability more marked, seems on seasonal average less variable from one year to the next one. The series of storms, end of winter 2013, seems to induce an unusual early decrease in the surface salinity. This minimum has been later removed joining bottom values due to winter vertical mixing.

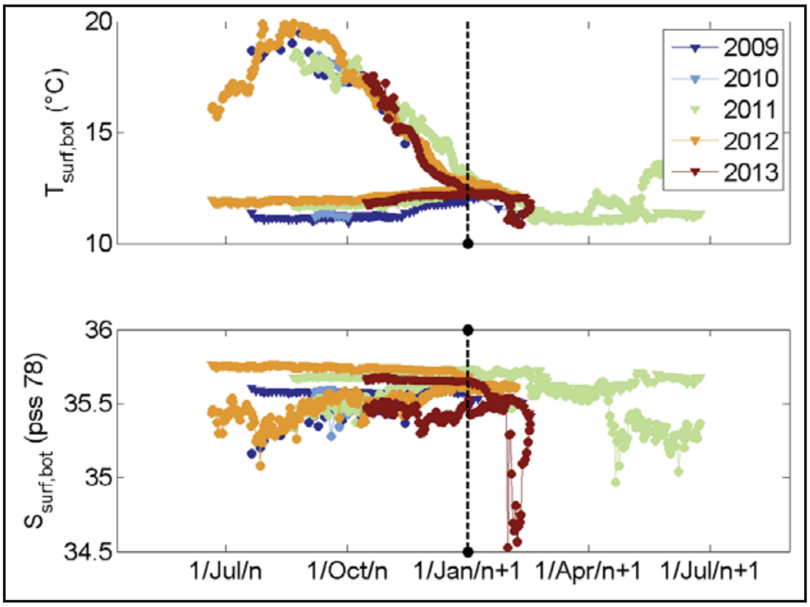


Figure 18: ARVOR-C profilers temperatue (up) and salinity (bottom) observed at surface (circles) and bottom (triangles).

Conclusion

This letter describes an overview of the coastal *in situ* high frequency systems developed and operated with the help of the PREVIMER project. Few illustrations show examples of results obtained with the data collected from these different platforms: fixed platforms, ships of opportunity and coastal profilers.

Through this network, the PREVIMER project contributed to develop coastal *in situ* observing systems along French coasts and to setup solid components of a future French Integrated Ocean Observing System.

Acknowledgements

“Marel Iroise” data are collected and processed according to the terms of the framework agreement jointly signed by IFREMER, CNRS (INSU) and UBO (on behalf of IUEM) n°11/2-210922.

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