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Optimizing observational networks combining gliders, moored buoys and FerryBox in the Bay of Biscay and English Channel

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ABSTRACT

Designing optimal observation networks in coastal oceans remains one of the major challenges towards the implementation of future efficient Integrated Ocean Observing Systems to monitor the coastal environment. In the Bay of Biscay and the English Channel, the diversity of involved processes (*e.g.* tidally-driven circulation, plume dynamics) requires to adapt observing systems to the specific targeted environments. Also important is the requirement for those systems to sustain coastal applications.

Two observational network design experiments have been implemented for the spring season in two regions: the Loire River plume (northern part of the Bay of Biscay) and the Western English Channel. The method used to perform these experiments is based on the ArM (Array Modes) formalism using an ensemble-based approach without data assimilation.

The first experiment in the Loire River plume aims to explore different possible glider endurance lines combined with a fixed mooring to monitor temperature and salinity. Main results show an expected improvement when combining glider and mooring observations. The experiment also highlights that the chosen transect (along-shore and North–South, cross-shore) does not significantly impact the efficiency of the network. Nevertheless, the classification from the method results in slightly better performances for along-shore and North–South sections.

In the Western English Channel, a tidally-driven circulation system, added value of using a glider below FerryBox temperature and salinity measurements has been assessed. FerryBox systems are characterised by a high frequency sampling rate crossing the region 2 to 3 times a day. This efficient sampling, as well as the specific vertical hydrological structure (which is homogeneous in many sub-regions of the domain), explains the fact that the added value of an associated glider transect is not significant.

These experiments combining existing and future observing systems, as well as numerical ensemble simulations, highlight the key issue of monitoring the whole water column in and close to river plumes (using gliders for example) and the efficiency of the surface high frequency sampling from FerryBoxes in macrotidal regions.

1. Introduction

In the middle of the European Atlantic Arc, the Bay of Biscay and the English Channel encompass diverse coastal dynamical regions (Fig. 1). In the southern part, North of Spain, the continental shelf is very narrow and the coastal dynamics is mainly driven by the slope current and local upwellings. When we are travelling to the North along the French coasts, the continental shelf is becoming wider and the main rivers (Gironde, Loire, and Seine in the English Channel) have to be considered as major sources of freshwaters drawing the density gradients over the shelf. The widening shelf is under the influence of tides (Le Cann, 1990) which are shaping the circulation in the English Channel (Salomon and Breton, 1991, 1993). Finally, the Bay of Biscay and English Channel circulation is constrained by atmospheric forcings with a SOMA (September–October/March–April) seasonal response (Pingree et al., 1999).

This region, as most of coastal ocean regions, is under the pressure of the global change (climate and anthropogenic), which can be observed through the different *in situ* and remote observing systems (deCastro et al., 2009; Michel et al., 2009a,b; Costoya et al., 2015).

In this context, coastal existing networks (*e.g.* HOSEA — High frequency Observation network for the environment in coastal SEAs, SOMLIT — Service d'Observation en Milieu LITtoral) are mainly limited along the coast with a small offshore extent. They also mainly focus on surface observations (supplementing satellite observations) but few

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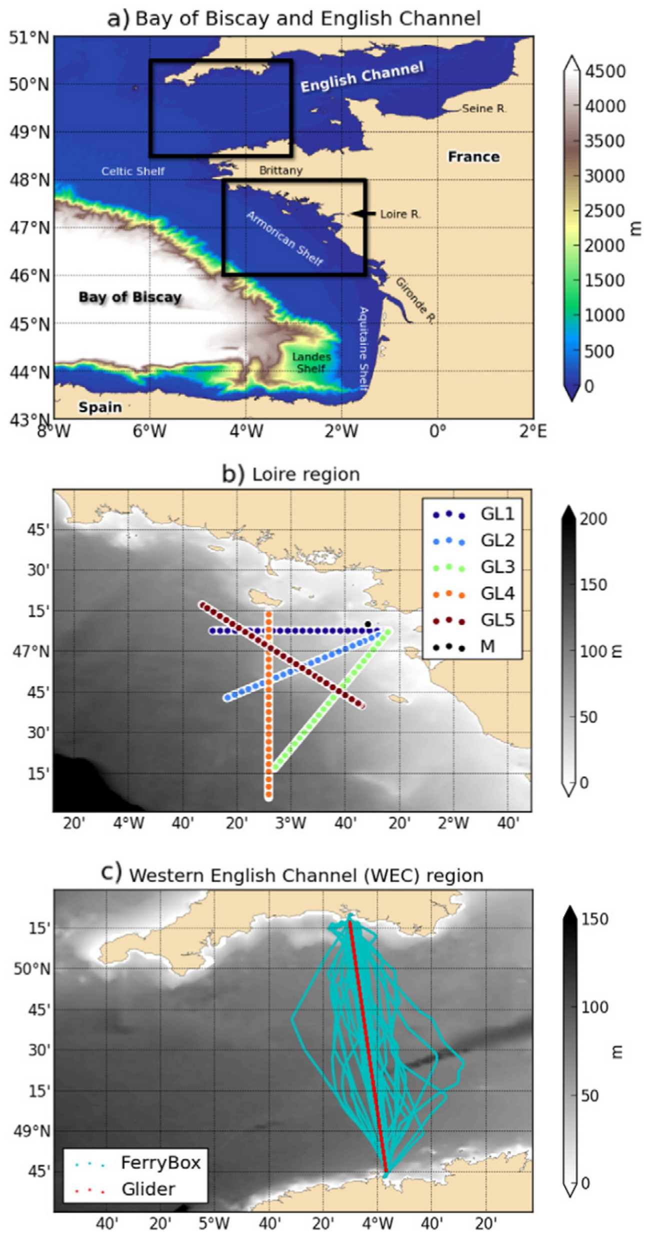

Fig. 1. (a) Map and bathymetry of the Bay of Biscay and the English Channel, showing both subregions. (b) Subregion around the Loire River plume, with sketches of the mooring and glider sections considered (described in Section 4.1). (c) Subregion in the Western English Channel (WEC), with localization of the FerryBox trajectories (blue) and the glider section (red) described in Section 5.1.

continuous measurements are dedicated to the whole water column while it has been observed that deep continental shelf waters are also changing (Gonzalez-Pola et al., 2005; Gómez-Gesteira et al., 2013; Charria et al., 2014).

The following question is then becoming more and more crucial: How could we improve (*i.e.* optimize, develop, extend) existing networks for long term observations in such a dynamically contrasted region under the pressure of global change and in a challenging economic environment?

The present study aims at applying a quantitative method to design local observation arrays as part of a future integrated coastal network. Several approaches can be considered to carry out such design experiments (*e.g.* Schulz-Stellenfleth and Stanev, 2010; Fu et al., 2011), among which Observing System Simulation Experiments (OSSE; *e.g.* Charney et al., 1969; Hackert et al., 1998; Kuo et al., 1998; Frolov et al., 2008; Lin et al., 2010) approaches using data assimilation platforms. In the case of the Bay of Biscay and the English Channel, the ArM (Array Modes) methodology (available and implemented by P. De Mey in the SANGOMA Tools http://www.data-assimilation.net/Tools/; Le Hénaff et al., 2009; Lamouroux et al., 2016) has been applied. This approach is based on ensemble numerical simulations without assimilating observations.

Two regions under two contrasted coastal dynamics have been considered:

- the vicinity of the Loire River plume strongly influenced by freshwater inputs (hereafter called Loire region — Fig. 1b),
- the Western English Channel with a circulation mainly driven by tides (hereafter called WEC region — Fig. 1c).

The evolutions of existing coastal observation networks along the French coast which were considered in the recent years were mostly focused on improvements of the monitoring of main river plumes. On the basis of choices made in related ongoing projects (*i.e.* FP7 JERICO, http://www.jerico-fp7.eu/), the first area selected here is the Loire runoff region (Fig. 1b). This area is influenced by a large river plume with an average discharge around 900 $m^3 s^{-1}$ exceeding 3000 $m^3 s^{-1}$ in winter or early spring (Puillat et al., 2004). The plume spreads northwards and along shore except when runoffs are reduced and under southeastward winds conditions (Lazure and Jegou, 1998). The river freshwater signature can propagate until the entrance of the English Channel (Kelly-Gerreyn et al., 2006). The Loire region under the influence of the river exhibits stratified waters with a propagation mainly controlled by the wind. These conditions justify the deployment of an observation network monitoring subsurface layers. The assessed network is then combining a moored station with a glider endurance line. Based on capabilities of these platforms, five glider sections (along-shore and cross-shore) have been evaluated.

Another key area is the Western English Channel (WEC) region (Fig. 1c) where the circulation is tidally-driven (Salomon and Breton, 1991, 1993). The mean summer non-tidal zonal transport is lower than 0.2 Sv (Hill et al., 2008). The vertical structure of the water column is contrasted between the Northern part stratified in summer (nWEC) and the southern part (sWEC) where it remains mixed during the whole year. These two main provinces are separated by a thermal front around 49.5°N (Marrec et al., 2013, 2014). The WEC surface waters are sampled by a FerryBox system aboard MV Armorique, sailing between Roscoff (France) and Plymouth (UK) on a daily basis since May 2010. The experiment considered here mostly aims to estimate the added value of measurements in the water column using a glider along the FerryBox line, in addition to FerryBox measurements or as standalone measurements.

After introducing the ArM methodology (Section 2) and the ensemble model simulations (Section 3), the experiment in the Loire region is detailed and discussed in Section 4. Section 5 is describing results for the WEC region before the general conclusions of these experiments (Section 6).

2. ArM methodology

The ArM methodology (De Mey, pers.comm., 2014) used here is a stochastic implementation approach described in Le Hénaff et al. (2009) and has also been described in detail by Lamouroux et al. (2016). A few key concepts of the method are briefly described below.

The methodology used here aims at providing an objective criterion for assessing the performance of a given observational array. In this framework, the methodology relies on the following paradigm: a “good” array (regardless the cost-considerations) is an array that can detect and – partly – correct the errors of a pre-existing (hereafter