Spatio-temporal dynamics of biogeochemical parameters and air-sea CO_2 fluxes in the Western English Channel (WEC) based on Voluntary Observing Ship (VOS) measurements with a FerryBox system

Marrec Pierre[1,2], Cariou Thierry, Latimier Marie, Macé Eric, Morin Pascal, Vernet Marc, and Bozec Yann.
[1] CNRS, UMR 7144, Equipe Chimie Marine, Station Biologique de Roscoff, Place Georges Teissier , 29680 Roscoff, France
[2] UPMC Univ. Paris 06, UMR 7144, Adaptation et Diversité en Milieu Marin, Station Biologique de Roscoff, 29680 Roscoff, France
pmarrec@sb-rscoff.fr

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Introduction

- In the context of **climate change** driven by the **raise of atmospheric CO_2** due to **anthropogenic activities,** a better knowledge of **air-sea CO_2 flux** dynamics is essential and particularly in **marginal seas**.
- These ecosystems are very **dynamic** regarding **various physico-chemical parameters** and play a significant role **in the biogeochemical cycle of carbon** and in **oceanic uptake and release of atmospheric CO_2**.
- Because of **the large diversity and heterogeneity** of coastal ecosystems, a robust estimation of **air-sea CO_2 fluxes in coastal ocean** at the global scale remains a **challenge**.
- **High-frequency** measurements using **VOS lines** provide new insights into **the CO_2 system and biogeochemical parameters dynamics in coastal ecosystems**.

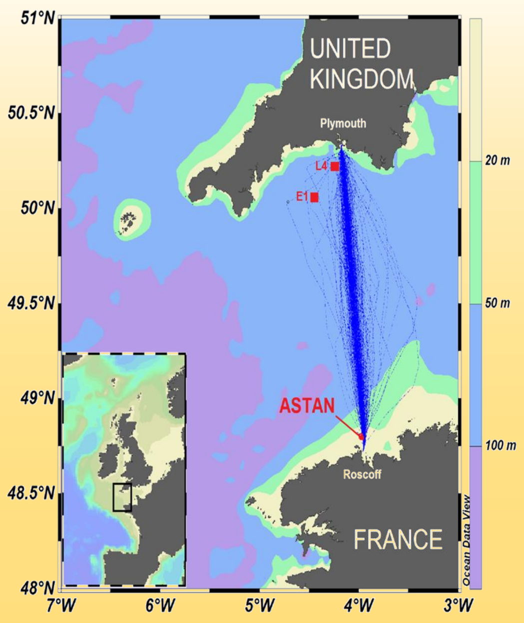
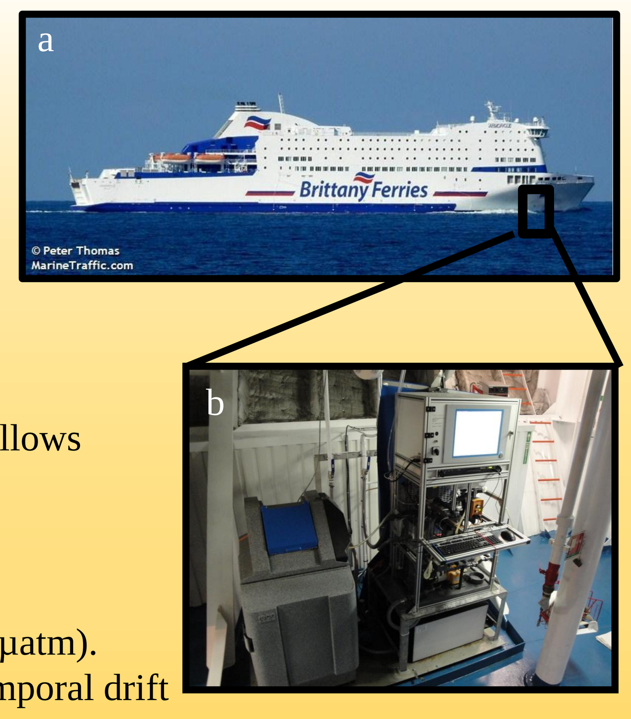


Figure 1. Map and bathymetry of the study area with the tracks of all crossings made between the 25/04/2012 and the 10/08/12 with locations of the ASTAN, E1 and L4 fixed stations. ASTAN : part of the Roscoff Coastal Observatory (SOMLIT). E1 and L4 : part of the Western Channel Observatory (Plymouth Marine Laboratory and Marine Biological association).

Our FerryBox System

- The **VOS** is the ***Armorique* ferry** (Brittany Ferries ®).
- **Ferrybox** engineered by **-4H- JENA**® and installed in **2010**.
- The ferry can cross the WEC up to 3 times a day between **Roscoff** and **Plymouth**.
- VOS allows a **high spatio-temporal** coverage at a **lesser cost**.
- Coupled to an **automated ISCO**® **discrete sampler.**
- **SST** and **SSS** : Sea Bird® SBE45 (Seawater circuit) and SBE38 (in-situ)
- **Dissolved O_2** : Aanderaa® Optode 3835
- **Fluorescence, CDOM, Turbidity** : Turner® C3
- **Partial pressure of CO_2** : CONTROS® HydroC/ CO_2FT (since April 2012)
- From May 2013, a **flow cytometer** : CytoBuoy® CytoSense



Figures 2 a,b. The Armorique ferry (a) and our Ferrybox system (b).

Sensors Calibrations

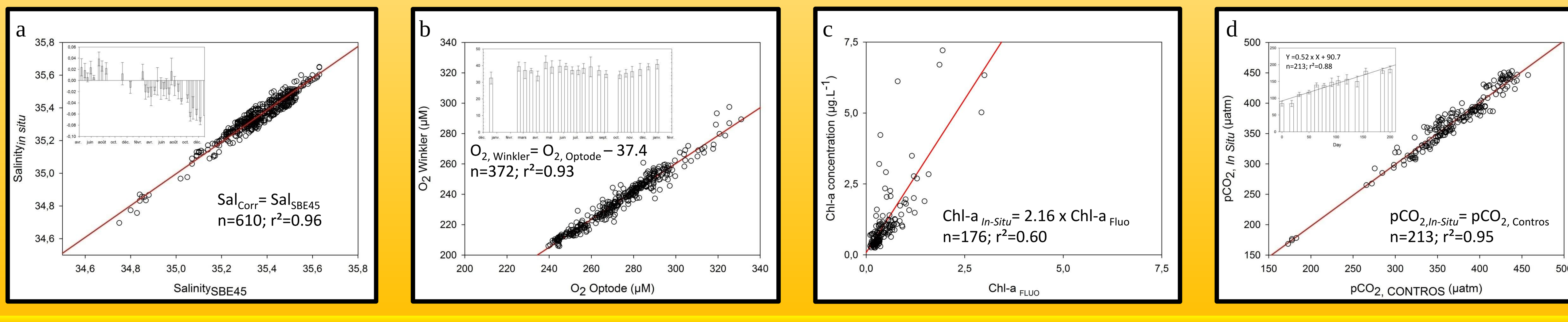
- Sensors are **calibrated from bimonthly discrete measurements** during return crossings on the ferry. Besides sensor calibration, bimonthly discrete samplings allows us to access to other biogeochemical parameters as **nutrients** concentration, **total alkalinity (TA)**, **dissolved inorganic carbon (DIC)** concentration and **pH**.

Salinity
Discrete measurements:
Portasal salinometer (±0.002)

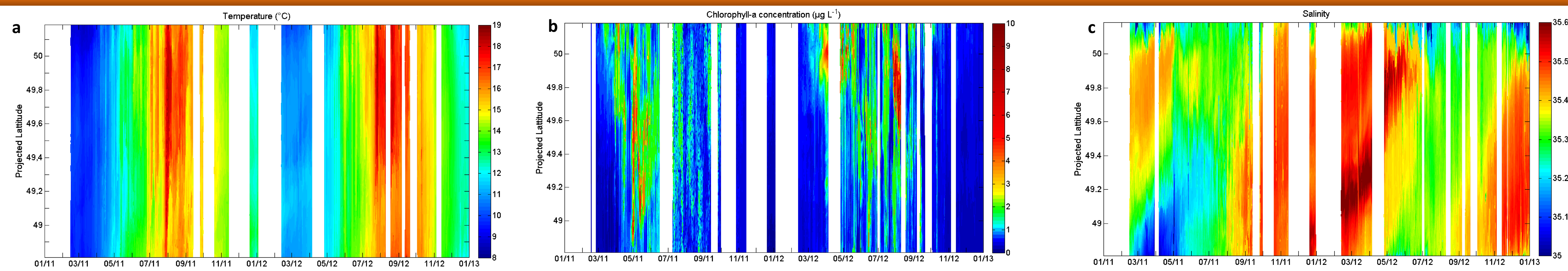
Dissolved O_2
Discrete measurements:
Winkler titration (± 0.5 µmol L^{-1})

Chlorophyll-*a*
Discrete measurements:
Fluorimetry (± 0.1 µg L^{-1})

Partial pressure of CO_2
Discrete measurements:
pCO_2 calculated from TA/DIC (± 6 µatm).
$pCO_{2,CONTROS}$ corrected from the temporal drift of the sensor based on discrete measurements.

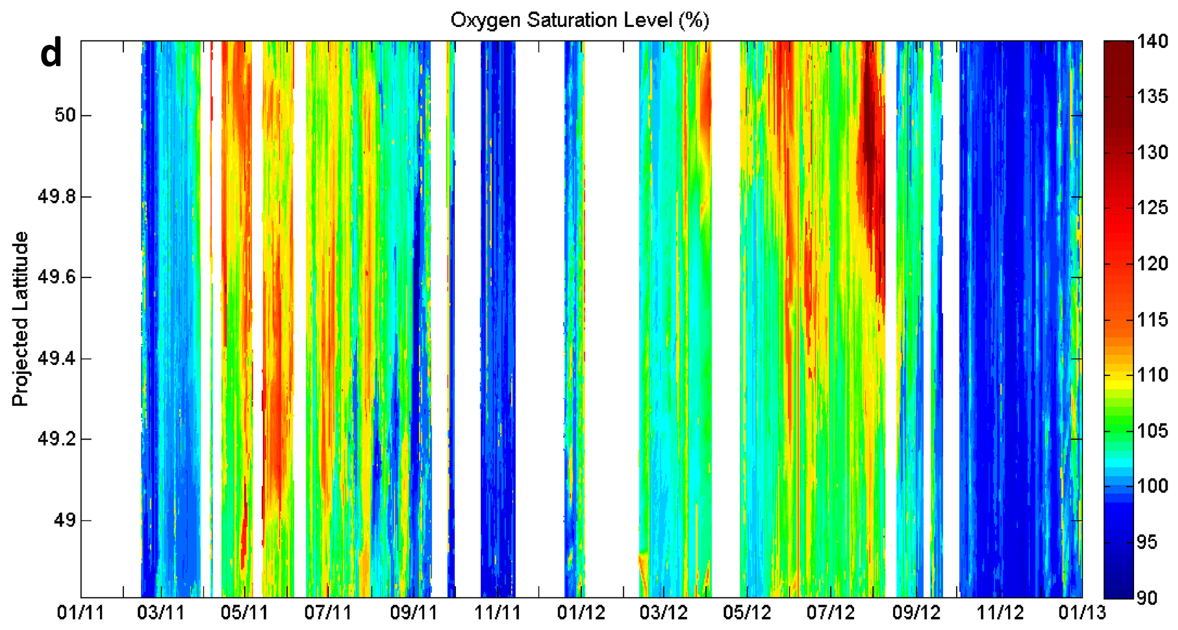


Figures 3 a,b,c,d. Calibration of the sensors installed on the FerryBox with discrete measurements. The inserts show the difference between discrete measurements and sensor values during the period of study.



Contrasted Ecosytems

- From **normalized SST by the mean temperature** at each bimonthly transects between Roscoff and Plymouth (Figure 4f) and from **bimonthly hydrographical profiles performed at fixed station ASTAN and E1** (Figure 1, data not shown), 2 main hydrographical provinces appears:
  - **The northern WEC** (>49.5°N): **Seasonally stratified**
  - **The southern WEC** (<49.5°N): **All-year well mixed**
  - Separated by **a thermal front** from **mid-spring to the end of summer**.
- **Seasonally stratified northern WEC**: enhanced biological activities characterized by an extensive autotrophic phase (earlier spring bloom and delayed fall heterotrophic phase).
- **Permanently well-mixed southern WEC**: shorter autotrophic phase (delayed spring bloom and earlier fall heterotrophic phase)



pCO_2 distribution and Air-Sea CO_2 Fluxes

- **Northern WEC :**
  - pCO_2 below the atmospheric equilibrium from April to September.
  - Strongly related to Chl-*a* distribution with the lowest values during the intense summer bloom. → Mainly driven by biological processes
  - Acted as strong sink (<0) of atmospheric CO_2
  - Start of heterotrophic (>0) phase at the end of September (source of CO_2 to the atmosphere).
- **Southern WEC :**
  - pCO_2 close to the atmospheric equilibrium from April to September.
  - Acted as a weak sink or source of atmospheric CO_2.
  - Start of the heterotrophic phase earlier than in the Northern WEC.

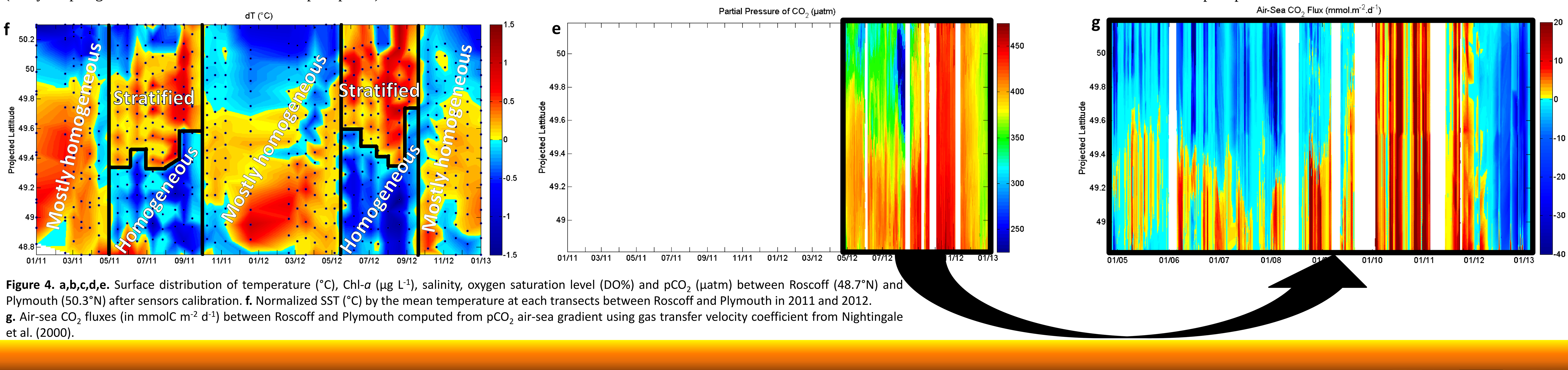


Figure 4. a,b,c,d,e. Surface distribution of temperature (°C), Chl-*a* (µg L^{-1}), salinity, oxygen saturation level (DO%) and pCO_2 (µatm) between Roscoff (48.7°N) and Plymouth (50.3°N) after sensors calibration. **f.** Normalized SST (°C) by the mean temperature at each transects between Roscoff and Plymouth in 2011 and 2012.
g. Air-sea CO_2 fluxes (in mmolC m^{-2} d^{-1}) between Roscoff and Plymouth computed from pCO_2 air-sea gradient using gas transfer velocity coefficient from Nightingale et al. (2000).

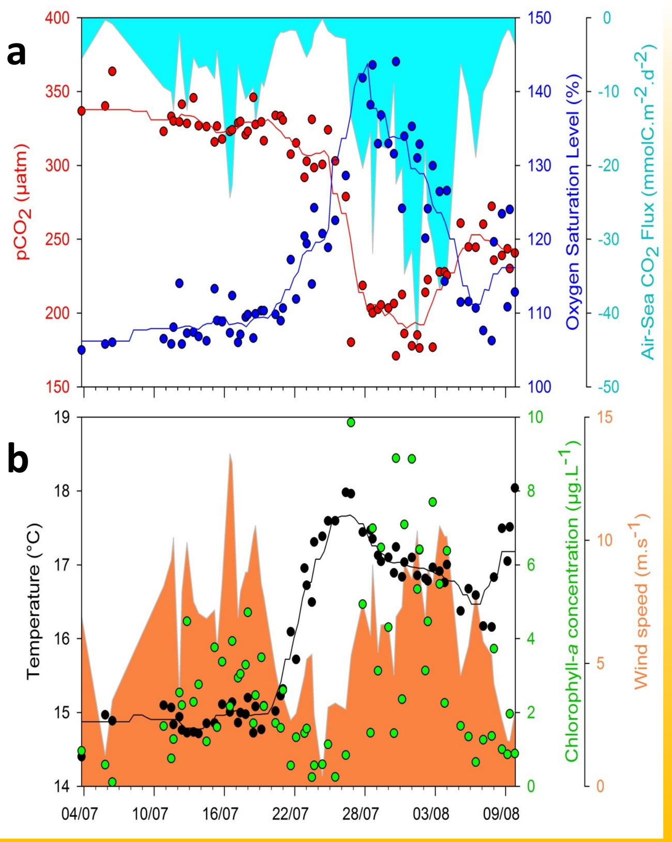


Figure 5. a) Variation of DO% (blue), pCO_2 (µatm, red) and air-sea CO_2 flux (mmolC m^{-2} d^{-1}, cyan area) and **b)** variation of temperature (°C, black), wind speed (m s^{-1}, yellow area) and Chl-a (µg L^{-1}, green). Red, blue and black lines are running average. Data were extracted at 50.00 °N (Fig. 1) from the 3/07/12 to the 9/08/12.

Concluding Remarks and Perspectives

- More than **70% of temporal coverage** over **2 years** with **2 crossings by day** on average.
- Continuous deployment of FerryBox necessitate **careful and frequent maintenance**. Easy for us to be **reactive** if any problem occurs thanks to the **proximity of the ferry terminal** from our lab and to the **frequency of the crossings**.
- The VOS line allows an **excellent survey of biogeochemical parameters variations** throughout the year and **identifying the different processes controlling the dynamics of the CO_2 system** in the contrasted ecosystems of the WEC.
- In addition to surface measurements from the FerryBox, we also have access to **the hydrographical structure of the water column** either side of the WEC at **fixed station ASTAN and E1** (Figure 1).
- The **"fixed station" approach** from the VOS line data (Figure 5) provides **new insight of short-scale variations** of biogeochemical parameters **controlling the CO_2 dynamics** in the WEC.
- We are going to try to **develop specific algorithms** to **estimate surface pCO_2 from satellite data** and to **compute air-sea CO_2 fluxes in the WEC** and **in adjacent seas (Irish/Celtic seas)** which present **similar hydrographical provinces** (seasonally stratified/permanently well-mixed).

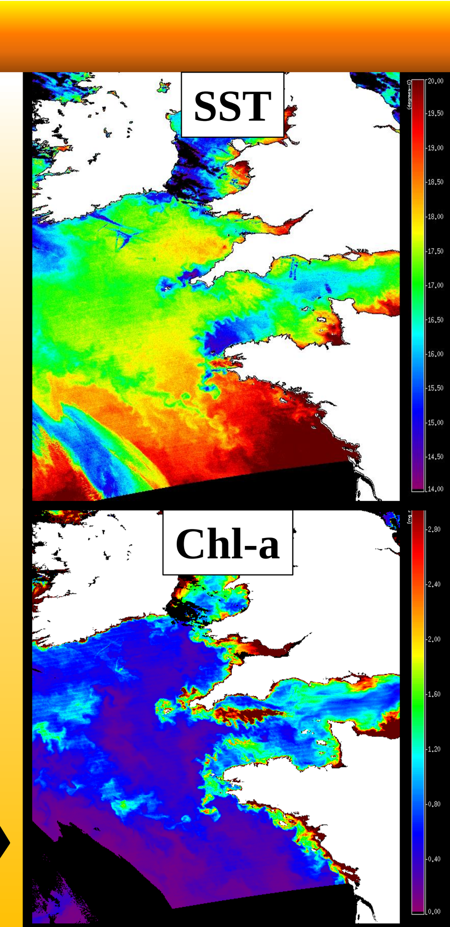


Figure 6. Remotely-sensed Sea Surface Temperature (SST) and Chlorophyll-*a* (Chl-*a*) distribution from MODIS Aqua sensor on the 10th of August 2012.