

Report on the short term scientific mission

**COST-STSM-735-2289:**

**Eddy-covariance technique in estuarine environments**

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## 1 Motivation and background

The coastal ocean has been to a large extent ignored in global carbon budgets, even if the related flows of carbon and nutrients are disproportionately high in comparison with its surface area. It receives massive inputs of organic matter and nutrients from land, exchanges large amounts of matter and energy with the open ocean across continental slopes and constitutes one of the most biogeochemically active areas of the biosphere. Hence, intense air-water CO<sub>2</sub> exchanges can be expected in the coastal ocean (Borges et al., 2005; Borges et al., 2006).

Recent scaling exercises based on published data show that marginal seas at high and temperate latitudes act as sinks of CO<sub>2</sub> from the atmosphere, in contrast to subtropical and tropical marginal seas that act as sources of CO<sub>2</sub> to the atmosphere. Overall, marginal seas act as a strong sink of CO<sub>2</sub> of about -0.45 Pg C yr<sup>-1</sup> (Borges et al., 2005) If confirmed this would lead to a major revision of oceanic CO<sub>2</sub> sink since the open ocean acts as CO<sub>2</sub> sink at a rate of -1.42 Pg C yr<sup>-1</sup> (Takahashi et al., 2009). This sink could be almost fully compensated by the emission of CO<sub>2</sub> from the ensemble of near-shore coastal ecosystems of about 0.40 Pg C

yr<sup>-1</sup>. Although this value is subject to large uncertainty, it stresses the importance of the diversity of ecosystems, in particular near-shore systems, when integrating CO<sub>2</sub> fluxes at global scale in the coastal ocean.

The flux of CO<sub>2</sub> across the air-water interface can be computed according to  $F = k \cdot \alpha \cdot \Delta p\text{CO}_2$ , where  $\alpha$  is the solubility coefficient of CO<sub>2</sub>,  $\Delta p\text{CO}_2$  is the air-water gradient of pCO<sub>2</sub>,  $k$  is the gas transfer velocity of CO<sub>2</sub>. In both open oceanic and coastal environments, highly precise and accurate methods to measure  $\Delta p\text{CO}_2$  are nowadays available, thus, the largest uncertainty in the computation of  $F$  comes from the  $k$  term. Based on numerous theoretical, laboratory and field studies, it is well established that  $k$  depends on a variety of variables such as capillary and breaking waves, boundary layer stability, air bubbles, surfactant surface films, evaporation/condensation, precipitation, but the most important one is turbulence at the air-water interface (in the case of sparingly soluble gases such as CO<sub>2</sub> the critical variable is turbulence in the liquid phase). In open oceanic waters, the gas transfer velocity of CO<sub>2</sub> is usually parameterized as a function of wind speed because wind stress is the main generator of turbulence in these systems.

Based on a fairly large data-set of air-water CO<sub>2</sub> fluxes, measured using the floating chamber method, in three European estuaries (Randers Fjord, Scheldt and Thames), we recently showed that the formulation of  $k$  as a function of wind speed is site specific in estuarine environments (Borges et al., 2004a; Borges et al., 2004b). This implies that substantial errors in flux computations are incurred if generic  $k$ -wind relationships are employed in estuarine environments for the purpose of biogas air-water flux budgets and ecosystem metabolic studies. From one estuary to another, the differences in the  $y$ -intercepts of the linear  $k$ -wind relationships are due to tidal currents (that enhance water turbulence), whereas the differences in the slopes of the regression functions are related to fetch limitation. The contribution of tidal currents to  $k$  is significant in macrotidal estuaries such as the Scheldt and Thames but seems negligible in microtidal estuaries such as Randers Fjord.

In estuarine environments future research efforts should concentrate in the development of a physically more rigorous and probably multi-variable formulation of the gas transfer velocity (including at least wind stress and water current effects on turbulence at the air-water interface), rather than a simple empirical formulation as a function of wind speed.

To assist such theoretical work, more data on air-water CO<sub>2</sub> fluxes are also needed. Natural or purposeful tracer approaches give gas transfer velocity estimates that are on a time scale (day to week) that is larger than the one characteristic of tidal currents (min to hour). To resolve gas transfer velocity variability on short time scales, besides the floating chamber method, micro-meteorological methods (eddy-covariance, gradient flux technique) seem adequate. Estuaries provide ideal settings for the application micro-meteorological methods (low ship motion, high signal-to-noise ratio, i.e. very large fluxes and  $\Delta p\text{CO}_2$ ).

The Chemical Oceanography of the University of Liège has a strong expertise of CO<sub>2</sub> dynamics within coastal ocean and related air-water CO<sub>2</sub> fluxes (Borges, 2001; Borges, 2005; Borges et al., 2005; Borges et al., 2004a; Borges et al., 2003; Borges and Frankignoulle, 1999; Borges and Frankignoulle, 2001; Borges and Frankignoulle, 2002a; Borges and Frankignoulle, 2002b; Borges et al., 2006; Borges et al., 2008; Borges et al., 2004b; Delille et al., 2008; Frankignoulle et al., 1998). While the unit has measured for years air-water CO<sub>2</sub> fluxes using the chamber method, it has not the technical skill to carry out air-water CO<sub>2</sub> fluxes by up to date micro-meteorological methods, and was not able to carry out high-frequency, long-term and large scale measurements of air-water CO<sub>2</sub> fluxes.

I am a researcher at the Chemical Oceanography Unit of the University of Liège. In order to acquire and apply in estuarine environments the eddy-covariance technique to measure air-water CO<sub>2</sub> fluxes, I spent 3 weeks (1 Oct. – 1 Nov. 2008) at the University of Bordeaux-1 (UBordeaux – member of the ENCORA/RFRC network ) within the group of Dr G. Abril that belong to the UMR CNRS 5805 EPOC. Dr G. Abril is presently carrying out a survey of CO<sub>2</sub>, CH<sub>4</sub> dynamics in the Arcachon Bay. The survey includes measurements of air-water fluxes by eddy-covariance technique.

## 2 Material and methods

A large part of the stay has been devoted to field work. We deployed an eddy-covariance system within the bay of Arcachon, a shallow semi-enclosed bay. The bay is strongly influenced by climatic factors and tidal currents. The Bassin receives significant inflow of freshwater and the waters are only partially renewed. The greatest part of the primary production is due to the seagrass *Zostera noltii* . Although the ecosystem remains on the whole in steady state, some evidence of potential eutrophication are visible. For instance, the flux of nitrogen into the Bassin d'Arcachon has increased by more than 50% during the last 25 years (Castel et al., 1996).

The micro-meteorological system has been deployed above intertidal mudflat colonized by *Zostera* seagrass, 3.8 km away from the coast.

The set-up of the system has relatively strong logistics constrain and some issues raised during field work. Several days was needed to set up the mast holding the measurement equipments, the inflatable boat that holds the batteries and the logging station, and then the sensors. The sensors included a Li-7500 open-path analyser, a C-Sat 3D sonic anemometer, a Vaisala Weather Transmitter WXT510 that measure air-temperature, pressure, moisture, precipitation and wind speed and wind direction. Data acquisition was carried out by a CR3000 Campbell micrologger. The whole system was powered by a bench of batteries that must be changed every 4 days requiring several field trips during my stay.

In addition to the measurement of air-water CO<sub>2</sub> fluxes, we carried out a survey of diel cycles of partial pressure of CO<sub>2</sub> (pCO<sub>2</sub>) (Fig. 1), CH<sub>4</sub> concentration, chlorophyll a, suspended matter, dissolved inorganic carbon, particulate organic carbon and  $\delta^{13}\text{C}_{\text{DIC}}$  in order to better understand carbon dynamics within the bay and related air-water CO<sub>2</sub> fluxes.

### 3 Results

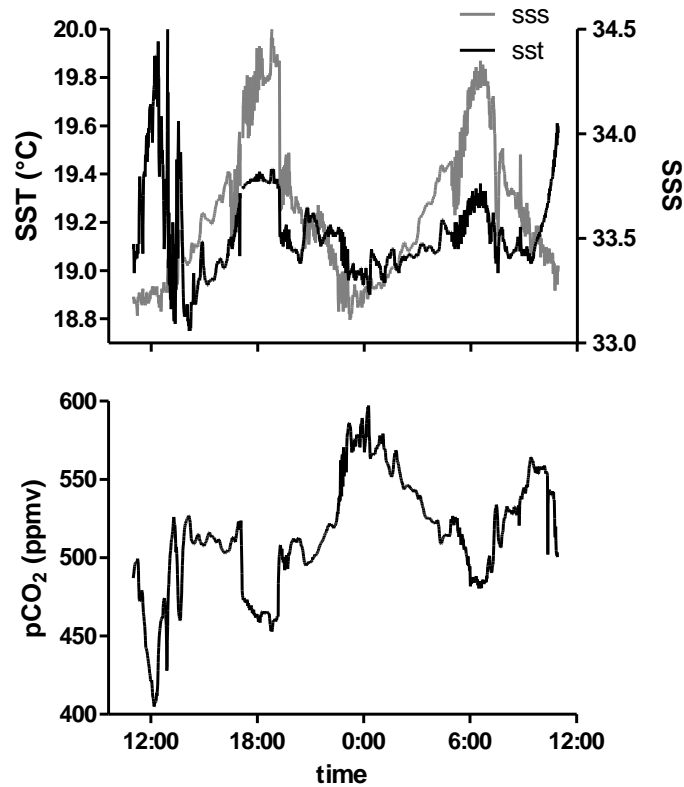


Figure 1. Diel cycle of (top) sea surface temperature (SST), sea surface salinity (SSS) and (bottom) pCO<sub>2</sub> in October 2008 in the Arcachon Bay

During diel survey, pCO<sub>2</sub> ranged from 400 to 600 ppm and was negatively correlated to salinity during nighttime. During daylight, primary production lead to strong decrease of CO<sub>2</sub> with sharp changes that suggest some spatial heterogeneity. Tidal pattern of pCO<sub>2</sub> change is then modulated by sharp increases of temperature and related decrease of pCO<sub>2</sub>. Sharp increases of temperature probably correspond to water masses that warmed up during high water above shallow mudflats. Benthic primary production by *Zostera* seagrass would have decrease pCO<sub>2</sub> in this shallow area. In addition, warmer waters indicate possible enhancement of stratification that promote primary production by phytoplankton.

The ecosystem is proven complex. In such intertidal system, we measured alternatively air-water and air-mudflat CO<sub>2</sub> fluxes, that varies significantly in term of pCO<sub>2</sub> gradients and gas exchange coefficient at the interface. In addition, we observed a tidal alternance of benthic and water processes. Superimposed to these tidal changes, primary production by *Zostera* and phytoplankton are mainly influenced by diel cycle of solar radiation, yet modulated by tidal changes in light and nutrients availability for *Zostera*. In addition, our survey showed large diel pCO<sub>2</sub> cycle and spatial heterogeneity within surface waters.

Hence, data-processing of CO<sub>2</sub> fluxes is not completed yet. Upon classical difficulties to process such data, specific issue raised to assess the foot-print of our measurement in this changing inter-tidal environment that furthermore exhibit a strong spatial heterogeneity.

## 4 Outcomes

This grant allowed me to take part to the preparation, deployment of typical, yet up to date, apparatus for measurement of CO<sub>2</sub> fluxes by eddy-correlation. I have also been involved in data processing and analysis. This expertise will be applied very rapidly, since the Chemical Oceanography Unit of the University of Liège, in collaboration with the Faculté Universitaire des Sciences Agronomiques de Gembloux and the Université Libre de Bruxelles, will deploy similar equipment by January 2009 along the coast of Alaska in Barrow.

In addition, the stay tightened the collaboration between the Chemical Oceanography Unit of the Ulg and the UMR EPOC of the University of Bordeaux 1. Hence, thank to the collaboration between the two groups, during the three last month, one paper (Koné et al., 2009) on the CO<sub>2</sub> dynamics in lagoons of Ivory Coast was accepted for publication in *Estuarine an coast*, while another paper (Koné et al.) on CH<sub>4</sub> dynamics in lagoons of Ivory Coast was submitted to *Biogeochemistry*. In addition a third paper (Delille et al., 2008) related to pCO<sub>2</sub> dynamics within *Macrocystis* kelp beds of the Kerguelen Archipelago benefited for useful discussion with Dr G. Abril, has been corrected and accepted for publication in *Estuarine, Coastal and Shelf Science* and acknowledge the contribution of COST 735 to the paper.

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