CLIVAR-SPAIN CONTRIBUTIONS: Air-sea CO_2 fluxes in the north-eastern shelf of the Gulf of Cádiz (southwest Iberian Peninsula)

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ABSTRACT

An intra-annual investigation of the fugacity of CO_2 (fCO_2) has been conducted in surface waters of the north-eastern shelf of the Gulf of Cádiz (SW Iberian Peninsula) in four cruises made in 2006 and 2007. Intra-annual variability of fCO_2 was assessed and is discussed in terms of mixing, temperature and biology. In the study area of the shelf, thermodynamic control over fCO_2 predominates from early May to late November, and this is opposite and similar in magnitude to the net biological effect. However, biological control over fCO_2 predominates during winter. The results suggest that surface waters in the coastal area are under-saturated with respect to atmospheric CO_2 during most of the year; therefore they represent a sink for atmospheric CO_2 between November and May (-1.0 mmol m^{-2} d^{-1}), but a weak source in June (1.3 mmol m^{-2} d^{-1}). In contrast, the coastal ecosystems studied (the lower estuary of Guadalquivir Estuary and Bay of Cádiz) acted as a weak sink for atmospheric CO_2 during February (-1.3 mmol m^{-2} d^{-1}) and as a source between May and November (2.6 mmol m^{-2} d^{-1}). The resulting mean annual CO_2 flux in the north-eastern shelf of the Gulf of Cádiz was -0.07 mol m^{-2} yr^{-1} (-0.2 mmol m^{-2} d^{-1}), indicating that the area acts as a net sink on an annual basis.

BACKGROUND

A better understanding of the Gulf of Cádiz flux is fundamental before it can be placed in a global context. In this study, we looked at four direct fCO_2 and dissolved oxygen measurement surveys in the north-eastern shelf of the Gulf of Cádiz and its associated inner ecosystems (the lower estuary of the Guadalquivir Estuary and the Bay of Cádiz). This data set provides us fCO_2 with enough resolution to examine the intra-annuality of the air-sea FCO_2 of the north-eastern shelf of the Gulf of Cádiz. This region, covering a 0.6º x 0.6º area, represents ~ 10 % of the northern shelf of the Gulf of Cádiz surface area (Fig. 1), and is a highly dynamic zone both in terms of physical and biogeochemical processes.

The main **objective** of the present paper is to investigate fCO_2 dynamics in the surface waters of the north-eastern shelf of the Gulf of Cádiz (southwest Iberian Peninsula) using four cruises, covering an annual cycle. From the results obtained, it should be possible to assess the relative contribution of the physical and biological processes affecting the fCO_2 dynamics in the study area, and to compute the air-sea FCO_2, taking into account the considerable spatial and seasonal heterogeneity.

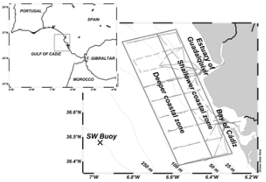

Figure 1. Map of the north-eastern shelf of the Gulf of Cádiz. Isolines represent the bathymetry. The four different zones into which the study site was divided for the discussion are depicted: two coastal ecosystems (Guadalquivir Estuary and Bay of Cádiz) and the coastal zone separated in two parts (shallower and deeper). The cruise track is shown by the broken gray line. The location of the buoy from which meteorological and oceanographical data were obtained is also shown.

Study site

The study was carried out over the north-eastern shelf of the Gulf of Cádiz, which is located on the southwestern coast of the Iberian Peninsula (Fig. 1). The circulation in the north-eastern shelf of the Gulf of Cádiz is controlled mainly by the North Atlantic Surface Water (NASW), which flows towards the east and southeast to the Strait of Gibraltar, as well as by an intermittent counter-current system, which seems to be strongly linked to the wind regime (Lobo et al., 2004). In particular, coastal waters near the mouth of the Guadalquivir River and the Bay of Cádiz present the highest primary production within the Gulf of Cádiz (Navarro and Ruiz, 2006). The coastal fringe of the Gulf of Cádiz is also characterized by the presence of waters warmer and colder than those detected in the rest of the basin during June and February, respectively (Navarro and Ruiz, 2006; Vargas et al., 2003) and by considerable meteorological forcing caused by quasi-permanent episodes of winds. For example, the predominance of western winds is always linked to the generation of upwelling events and therefore to an increase in primary production; on the other hand easterlies lead to a decrease in phytoplankton (García-Lafuente and Ruiz, 2007). Furthermore, the alternation of mixing and stratification periods in the region affects the position of the nutricline and thus also regulates the primary production (Navarro et al., 2006).

Hydrological settings

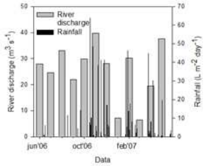

Figure 2. Rainfall and river discharge from the mouth of the Guadalquivir River, during the period of study.

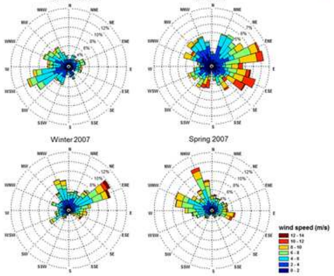

Figure 3. Wind roses showing the predominant wind direction in the sampling area in summer, fall, winter and spring.

RESULTS and DISCUSSION

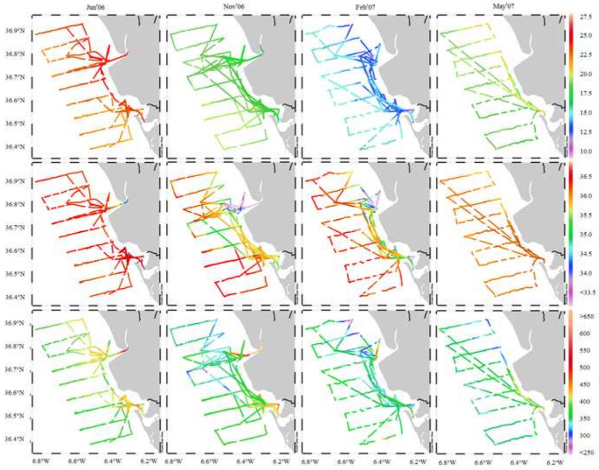

Figure 4. Intra-annual water temperature (in ºC), salinity and fugacity of CO_2 (in µatm) during the sampling cruises: June 2006, November 2006, February 2007, and May 2007.

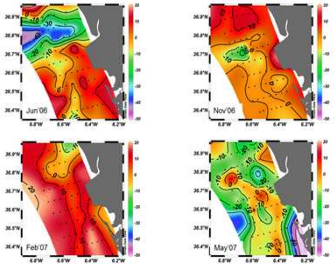

Figure 5. Distributions of apparent oxygen utilization (in µmol kg^{-1}) in surface water, for the four different survey cruises.

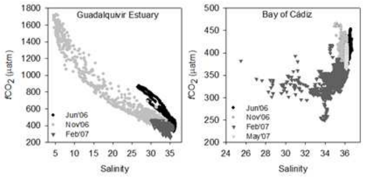

Figure 6. Mixing diagrams for fCO_2 in the Guadalquivir Estuary and the Bay of Cádiz during different cruises: June 2006 (black circles), November 2006 (gray circles), February 2007 (dark grey triangles) and May 2007 (pale grey triangles). Note that fCO_2 and salinity scales are different for the two diagrams and that in the spring no sampling was done in the Guadalquivir Estuary.

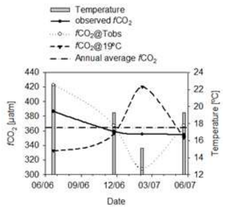

Figure 7. Seasonal variations in observed fCO_2, fCO_2 at the mean temperature (fCO_2@19ºC) and the effect of observed temperature changes on fCO_2 (fCO_2@Tobs). Other parameters plotted are the average temperature for each cruise and the annual average fCO_2.

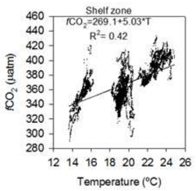

Figure 8. Diagram showing the relationship between fCO_2 and temperature in the shelf.

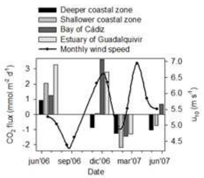

Figure 9. Seasonal variability in air-sea CO_2 fluxes during the four cruises in the four different areas shown in Fig. 1. Monthly-average wind speed data normalized to 10 meters height is also shown.

CONCLUSIONS

In the study area of the shelf, thermodynamic control over fCO_2 predominates from early May to late November, and this is opposite and similar in magnitude to the net biological effect. fCO_2 is controlled mostly by temperature in the shelf area.

High variability of fCO_2 between seasons and between zones has been observed. Higher values were observed in June, and in the lower estuary of Guadalquivir Estuary.

In summary, the coastal zone acts as a sink on an annual scale, and near-shore ecosystems are a source of atmospheric CO_2. The coastal zone of the Gulf of Cádiz ($1.68 \cdot 10^9$ m^2) acts as a sink on an annual scale, absorbing 1.5 10^{-3} Tg-C yr^{-1} (1.25 10^8 mol C yr^{-1}). This flux was calculated for the year 2006-2007. Nevertheless, in the light of the results obtained by Huertas et al. (2006) when higher fluxes were observed in March 96 compared with March 95 due to the increased wind speed, significant inter-annual variability in FCO_2 can be expected.

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