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Inter-annual variability of CO_2 exchanges between an emersed tidal flat and the atmosphere

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ABSTRACT

Carbon dioxide (CO_2) exchanges between a tidal flat (Wadden Sea, Netherlands) and the atmosphere were measured during a three-year survey. CO_2 exchanges were monitored during 1–2 days each month between September 2006 and September 2009 using a flux chamber. The flux of CO_2 was separated into two fluxes: the dark flux and the gross light flux, with the dark flux representing the flux during darkness and the gross light flux the difference between the net CO_2 flux (measured under light) and the dark flux. It was argued that dark and light fluxes may deviate from respiration and photosynthesis, as the fluxes between wet tidal sediment and the atmosphere are affected by the partial pressure of CO_2 in pore water, which is only gradually changed by sources and sinks of CO_2 in the sediment. Light and dark fluxes were empirically related to environmental parameters in order to interpolate between succeeding measurements. The dark flux appeared to increase with temperature and the light flux became more intense with increasing irradiance with signs of saturation at high light levels on many but not all measurement days. These relations with environmental parameters showed seasonal and inter-annual variability. Fluxes were negligible just after the site was emersed and it took up to 3 h of emersion until fluxes were adapted to environmental conditions. Dark and light fluxes both showed strong seasonality with high values in summer and low values in winter. The tidal flat appeared as a source of atmospheric CO_2 in the first year of measurement (+0.35 mol CO_2 m^{-2} yr^{-1}) and a sink in the following two years (−1.59 and −0.72 mol CO_2 m^{-2} yr^{-1}). Since the source of CO_2 was observed during an extremely warm year, we suggest that climate warming might influence the carbon budget of tidal flats.

1. Introduction

Global warming is, among other effects e.g. on biodiversity, expected to reduce the efficiency of the global carbon pump (Thomas et al., 2004; IPCC, 2007). During the last decades, reviews aimed to estimate the role of the open and the coastal ocean in the global carbon cycle (Heip et al., 1995; Frankignoulle et al., 1998; Gattuso et al., 1998; Thomas et al., 2005; Borges et al., 2006; Schiettecatte et al., 2007). Global CO_2 emission scenarios suggest that atmospheric CO_2 concentrations could reach 800 ppm by the end of the century (IPCC, 2007), which would have a critical impact on the biogeochemistry of the ocean. In this context, exchanges of CO_2 between the ocean and the atmosphere appear to be a key factor in the global carbon budget and a description of the exchange processes is needed to determine the potential impact of anthropogenic CO_2 emissions. Over 40% of the carbon sequestration in the oceans occurs along continental margins (Muller-Karger et al., 2005), but CO_2 fluxes vary widely in these areas. For example, the North Sea is a sink for CO_2 (Thomas et al., 2005; Schiettecatte et al., 2007), whereas the surrounding estuaries of Elbe, Ems, Rhine and Scheldt act as sources of CO_2 (Frankignoulle et al., 1998; Borges et al., 2006).

The net direction of CO_2 exchanges is even more variable for intertidal sediments. This is explained by regional differences and the wide range of methods used. For example, flux chamber measurements showed both net CO_2 release (Migné et al., 2004, 2009; Spilmont et al., 2007) and net CO_2 uptake (Spilmont et al., 2005, 2006) at stations located along the French coast of the English Channel, and eddy-correlation measurements showed a strong uptake of CO_2 in spring by a tidal flat in the Wadden Sea (Zemmelink et al., 2009).

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Obviously, O_2 and CO_2 fluxes are interdependent, since CO_2 uptake and O_2 release are closely related during photosynthesis and respiration, although deviations between O_2 and CO_2 fluxes may arise from chemo-physical processes. The net yearly sign of O_2 flux is also still uncertain for tidal sediments in the Wadden Sea. Van Es (1982) measured a net yearly uptake of O_2, suggesting a release of CO_2, in 4 out of 6 stations located in the Dollard estuary where the river Ems flows into the Wadden Sea. Sandy sediments studied in the area have been characterized both by a yearlong net release (Asmus et al., 1998) or uptake of O_2 (Kristensen et al., 1997), whereas muddy sediments were described as net sinks for O_2 (Kristensen et al., 1997; Asmus et al., 1998). These previous results on CO_2 and O_2 exchanges on tidal flats suggest that sediment structure and composition may influence net exchanges and that the trophic status of tidal sediments is not determined yet. Thus, more measurements are needed to determine whether, or when and where tidal flats are a source or sink of atmospheric CO_2. More specifically, multi-annual surveys are needed to estimate the inter-annual variability of the net exchanges, since existing data rely on relatively short lasting studies (i.e. less than two years). In this context, a site, remote from major river outflows, in the Dutch Wadden Sea was selected for the present study. The CO_2 flux chamber technique was selected as a direct method to reach the goal of a better understanding of the fate of atmospheric CO_2 in intertidal sediments and how it could be expected to develop in the context of global warming.

2. Site description

Tidal flats, generally several hundreds of meters wide are found along the coast of the Netherlands and the adjacent Wadden Sea. For the present study, one of these coastal tidal flats was selected that was situated close to the Lutjewad research station (Neubert et al., 2005) to get nearby meteorological data. The tidal flat (53° 24′ 48″ N, 6° 20′ 40″ E; Fig. 1) was remote from major river estuaries: The Ems estuary was located only 30 km to East but water of the Ems flows away from the measurement location and into the German Wadden Sea and North Sea. Most of the flat consisted of a muddy surface of a few centimeters thick topping a sandy underground. At 3–5 cm depth, a black layer was common that was attributed to sulfate reduction by anaerobic mineralization. The surface was gray to brown with the brown glow attributed to the presence of diatoms (e.g. McIntyre et al., 1996). The intensity of the brown glow varied temporally between succeeding measurement days and spatially with most brown spots near the shoreline of high tide. Measurements were mostly taken seawards of the brown spot area at several locations in an area that visually appeared as representative for large parts of coastal tidal flats in this part of the Wadden Sea. Mean annual temperature in the period 1981–2010 was 9.5 °C with a range from 2.8 °C in January and February to 17.0 °C in July and August (http://www.klimaatatlas.nl); mean tidal range was 2.4 m (http://live.getij.nl/getij_resultaat.cfm?location=LAUWOG).

3. Methods

3.1. CO_2 flux measurement

Exchanges of CO_2 between the atmosphere and the tidal flat were measured during emersion (low tide) using the flux chamber method (Migné et al., 2002). Dimensions of the chamber were 0.25 × 0.25 m and 0.15 m height. The chamber was made of UV transmitting Polymethylmethacrylate. Within the flux chamber, CO_2 concentration and air temperature were measured using a Vaisala GMP343 open path analyzer. The instrument was calibrated regularly in the laboratory on CO_2 concentrations of 0 and 507 ppm. The calibration showed good long-term stability. However, some drift occurred in the first half hour of use, so field measurements started half an hour after turning the instrument on. Measurements of CO_2 exchange took place once or twice a month from September 2006 to September 2009, giving a total of 51 measurement days. Measurements were made at variable times between an hour before sunrise until an hour after sunset.

The flux of CO_2 was separated in two components: the dark flux and the gross light flux, with dark flux representing the CO_2 flux during darkness and gross light flux the difference between net light CO_2 flux (i.e. the CO_2 flux measured under light) and simulated dark flux at observed temperature. The light flux was thus considered as showing the impact of irradiance alone on CO_2 fluxes. Dark flux was measured on 14 out of 51 measurement days during natural darkness, generally during the last hour of the night before sunrise. Dark flux was also measured during artificial darkness at daytime using a light blocking flux chamber. The chamber was placed at least 1.5 h prior to measurements for adaptation of quick and slow processes to darkness. A limitation of the chamber technique is that boundary conditions may deviate from the surrounding; some cooling of the sediment in the dark flux chamber was observed due to prolonged light blocking, and measurements were corrected for this effect. The dark flux chamber was flushed with outside air to keep CO_2 concentration within

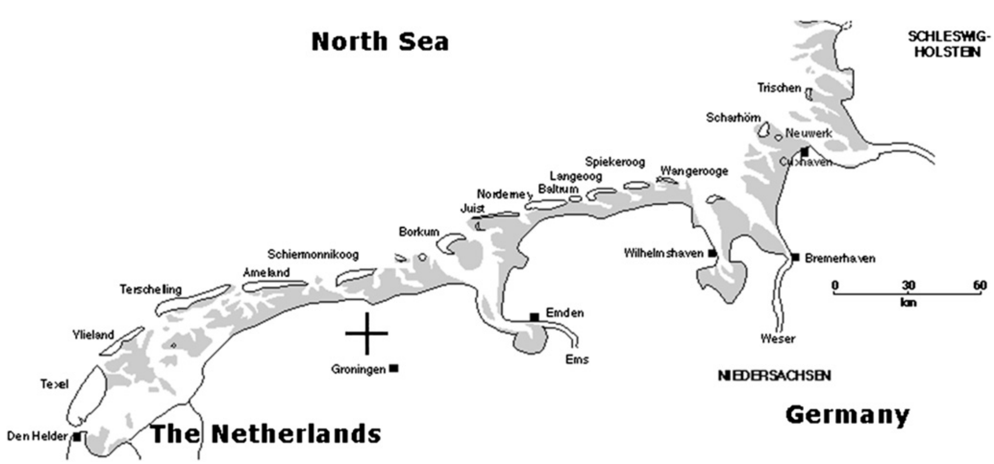

Fig. 1. Map of the Wadden Sea showing the study area (cross). Gray colors represent tidal flats.