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The southeastern continental shelf of the United States as an atmospheric CO_2 source and an exporter of inorganic carbon to the ocean

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Abstract

The US southeastern continental shelf, also known as the South Atlantic Bight (SAB), is a strong source of CO_2 to the atmosphere, which is in direct contrast to recent reports regarding other major continental shelves. Both spatial (cross-shelf) and seasonal variations of the CO_2 system were pronounced in the SAB. Sea surface pCO$_2$ in winter was undersaturated relative to the atmosphere, while oversaturation of pCO$_2$ dominated the entire shelf water in all other seasons. Annually, the SAB releases CO_2 to the atmosphere at an average rate of 30 g C m^{-2} (2.5 mol C m^{-2}). This system also discharges dissolved inorganic carbon to the open ocean (30 g C m^{-2} yr^{-1}). Methods of estimating CO_2 flux and DIC flux are critically evaluated and compared. A carbon mass balance model in the SAB is presented based on inorganic carbon fluxes from this study and organic carbon fluxes from literature. The carbon budget is much closer to balance by using this carbon flux approach than by direct measurements of primary production and respiration. It is concluded that the SAB is a net heterotrophic system annually. Intensified heating, elevated input of inorganic carbon from coastal salt marshes, microbial respiration of marsh-exported organic carbon and the lack of annual spring blooms all contribute to maintaining the SAB as a strong CO_2 source to the atmosphere during the warm seasons. In winter, the primary factor that governs the CO_2 sink in the SAB is likely the cooling process. Strong heterotrophy during warm seasons also sustains the SAB to be an exporter of inorganic carbon to the open ocean annually. The SAB shelf functions differently from the East China Sea, the North Atlantic European Shelves, and the Mid-Atlantic Bight as a source or sink of atmospheric CO_2. The SAB is classified as a "marsh-dominated" shelf as compared to other

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shelves in terms of carbon dynamics. Further work to study carbon dynamics in coastal margins is warranted to interpret their roles in the global CO_2 budget.

Keywords: Carbon cycle; Continental shelves; Carbon dioxide; Dissolved inorganic carbon; Respiration; Ecosystem

1. Introduction

The coastal ocean, which accounts for only 7–8% of the global ocean surface area, generates as much as 15–30% of oceanic primary production (Walsh, 1988; Wollast, 1993; Longhurst et al., 1995). The coastal ocean also accounts for 80% of organic matter burial, 90% of sedimentary mineralization and ca. 50% of calcium carbonate deposition (Mantoura et al., 1991; Pernetta and Milliman, 1995). Over the past 30 years, scientists have debated whether coastal oceans are net autotrophic (i.e., net production of organic carbon) or net heterotrophic (i.e., net consumption of organic carbon) (Smith and Mackenzie, 1987; Gattuso et al., 1998; Mackenzie et al., 2000). It now appears that some continental shelf systems are autotrophic, while estuaries and other nearshore systems are mostly heterotrophic (Gattuso et al., 1998). A closely related but more directly verifiable question is whether the world's continental shelves act as a source or a sink of CO_2 to the atmosphere. Walsh (1981, 1988) proposed that "biological export of shelf [organic] carbon is a neglected sink of the global CO_2 cycle." This hypothesis has been evaluated on many ocean margins from the perspective of nutrient and organic matter biogeochemistry, particle carbon flux measurements, and benthic recycling (Falkowski et al., 1988; Rowe et al., 1988; Reimers et al., 1992; Smith et al., 1992). Although much has been learned, the issue is still quite controversial.

Understanding the CO_2 biogeochemistry of continental shelves is one essential step toward better understanding the global carbon cycle. In contrast to the open ocean, CO_2 dynamics in coastal regions have only begun to receive more attention in recent years (e.g., Frankignoulle et al., 1996; Tsunogai et al., 1999; Van Geen et al., 2000; Frankignoulle and Borges, 2001a; DeGrandpre et al., 2002). Based on research conducted so far, coastal waters are characterized by large spatial and temporal variations of surface water pCO_2 with values ranging from as high as a few thousand μatm to slightly lower than atmospheric level. This is inherently associated with intensive physical, chemical and biological processes in these sites (Mackenzie, 1991). One major challenge in studying the carbon cycling of coastal areas results from the complexity and heterogeneity of the systems. The complex hydrographic setting in the coastal region is often a combined result of multiple river inputs, tidal mixing, coastal currents, upwelling/downwelling, and offshore water intrusion.

Recent measurements of large atmospheric CO_2 flux (~35 g C m^{-2} yr^{-1}) into the East China Sea (ECS) over nearly all seasons allowed Tsunogai et al. (1999) to propose that the world's continental shelves may act as a "continental shelf pump", which transfers about 1×10^{15} g C yr^{-1} (or 1 Pg C yr^{-1}) of atmospheric CO_2 into the open ocean assuming that the other shelves behave similarly to the ECS. By a similar estimation, others proposed the transport to be in a range of 0.3–1.0 Pg C yr^{-1} (Wang et al., 2000; Chen et al., 2001; Thomas et al., 2004). Results from a general circulation model simulation that parameterizes global shelf transports into the deep ocean suggest a shelf pump of 0.6 Pg C yr^{-1} (Yool and Fasham, 2001). These values represent 20–50% of the current oceanic uptake of anthropogenic CO_2 (Sarmiento and Gruber, 2002), which is significant in the global carbon budget. This shelf pump hypothesis is also supported by earlier observations in the North Sea (Kempe and Pegler, 1991) and recent studies in the North Atlantic European Shelves (Frankignoulle and Borges, 2001a) where the air-sea CO_2 gradient and annual flux are similar to the ECS. However, CO_2 fluxes measured in the US Middle Atlantic Bight (MAB) suggested a weaker pump (~12 g C m^{-2} yr^{-1}) (Boehme et al., 1998; DeGrandpre et al., 2002). In some major upwelling shelves, the net DOC production suggests a large CO_2 sink comparable