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The island mass effect and biological carbon uptake for the subantarctic Crozet Archipelago

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Abstract

Marine productivity is often higher downstream than upstream of islands. This so-called island mass effect was tested and quantified with respect to biological carbon uptake and air–sea exchange of carbon dioxide (CO_2) at the Crozet Plateau between November 2004 and January 2005 during two CROZEX cruises. The remote plateau is situated at 45.5–47.0°S 49.0–53.0°E, south of the Subantarctic Front (SAF) in the Polar Frontal Zone (PFZ). Surface waters upstream (south) of the plateau had high nutrient and low chlorophyll (HNLC) concentrations. The fugacity of carbon dioxide (fCO_2) in surface water was just below the atmospheric value and oceanic CO_2 uptake was small ($0.2 \pm 0.1\,mol\,m^{-2}$) throughout CROZEX. The mixed-layer concentration of dissolved inorganic carbon (DIC) decreased by $15\,\mu mol\,kg^{-1}$ from November to January in these HNLC waters, indicating significant biological carbon uptake. Extensive phytoplankton blooms occurred downstream (north) of the plateau in austral spring. These reduced surface water fCO_2 by 30–70 μatm and DIC by 30–60 $\mu mol\,kg^{-1}$ and created an important oceanic sink for atmospheric CO_2 of $0.6–0.8 \pm 0.4\,mol\,m^{-2}$, corresponding to a total uptake of $1.3 \pm 0.8\,Tg\,C$ ($1\,Tg = 10^{12}\,g$). The reduction of DIC in the upper 100 m was much larger downstream ($2–3\,mol\,m^{-2}$) than upstream ($1\,mol\,m^{-2}$) of the plateau in January, further confirming the existence of the island mass effect for the Crozet Archipelago. An additional finding is the sizeable DIC deficit in the HNLC waters upstream (south) of the plateau, suggesting that some HNLC waters of the PFZ are more productive than commonly thought. Deep mixed layers of 60–90 m may hide such sustained, modest marine productivity from detection by satellite.

Keywords: Carbon dioxide; Island mass effect; Iron supply

1. Introduction

The remote Polar Frontal Zone (PFZ), between the Subantarctic Front (SAF) and the Polar Front (PF) (Fig. 1A) (Pollard et al., 2002), is a frontier in marine carbon cycle research. Deep-ocean waters reach the surface south of the PF, travel northward across the PFZ, and leave the surface north of the SAF as Antarctic Intermediate Water (AAIW). The circumpolar PFZ is an important area for the exchange of heat, moisture and biogeochemical properties between the ocean and the atmosphere

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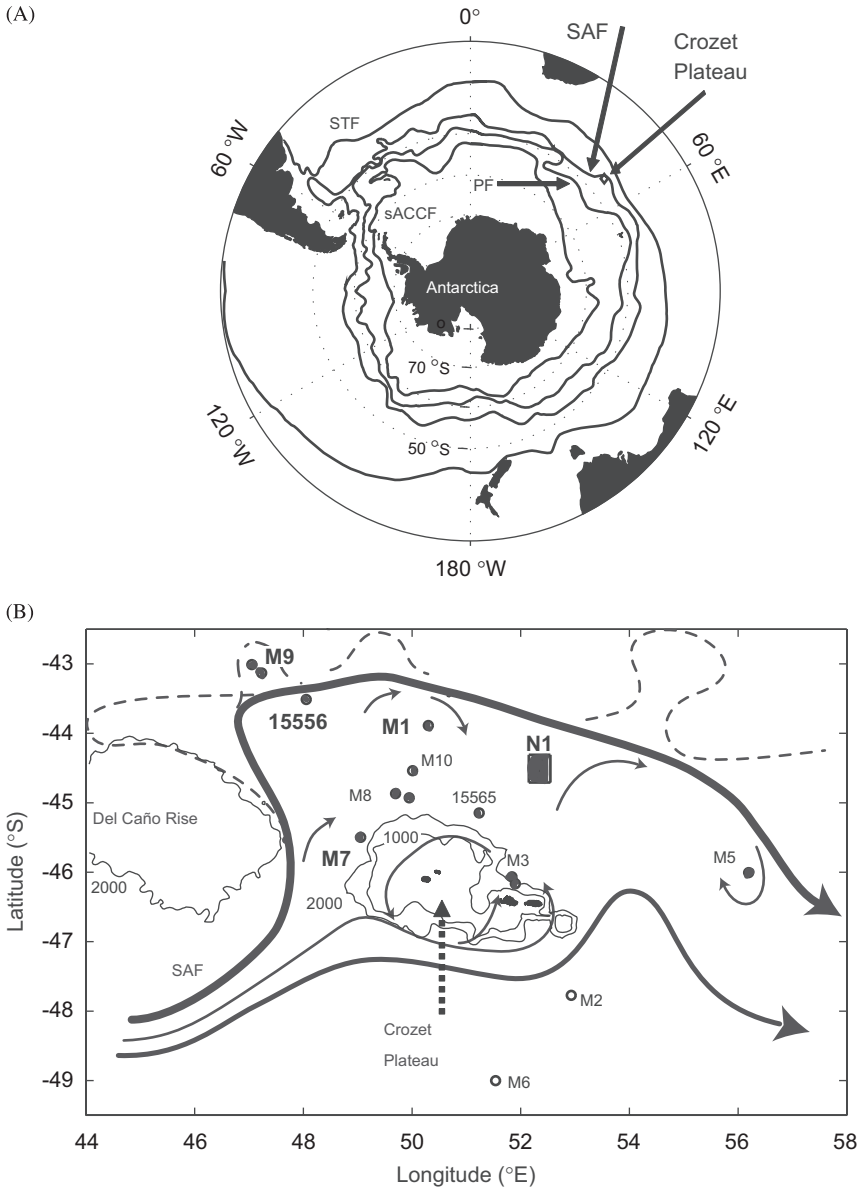

Fig. 1. (A, B) The Crozet Plateau is in the Polar Frontal Zone in a northward bend of the Subantarctic Front (SAF). (A) Other fronts are the Subtropical Front (STF), the Polar Front (PF) and the southern Front of the Antarctic Circumpolar Current (sACCF) (Orsi et al., 1995). (B) Arrows indicate currents in the Crozet area (from Pollard et al., 2007): the fast-flowing SAF (heavy line) with its large meanders (dashed lines); weak currents between the SAF and the plateau; anticyclonic flow around the plateau, and eastward flow south of the plateau. Circles correspond to stations upstream (south) (open circles) and downstream (edge, north, east) (closed circles) of the plateau (Table 1). The closed rectangle indicates area N1. The labels of highly productive sites are in bold. Depth contours are at 1000 and 2000 m (Smith and Sandwell, 1997).

(Speer et al., 2000; Rintoul et al., 2001). Fundamental uncertainties exist on the size of marine productivity, carbon export, uptake of atmospheric carbon dioxide (CO_2), and the storage of anthropogenic CO_2 in the PFZ and adjacent areas (Antoine et al., 1996; Banse, 1996; Behrenfeld and Falkowski, 1997; Rayner et al., 1999; Caldeira and Duffy, 2000; Moore and Abbott, 2000; Gurney et al., 2002; Schlitzer, 2002; Takahashi et al., 2002; Sabine et al., 2004; Lo Monaco et al., 2005; Peylin et al., 2005; Metzl et al., 2006). Undersampling of the marine carbon system is an important factor in the above uncertainties, in particular with high variability of biogeochemical properties in summer