Quantifying Phytoplankton Contributions to Carbon Export using ^{13}C

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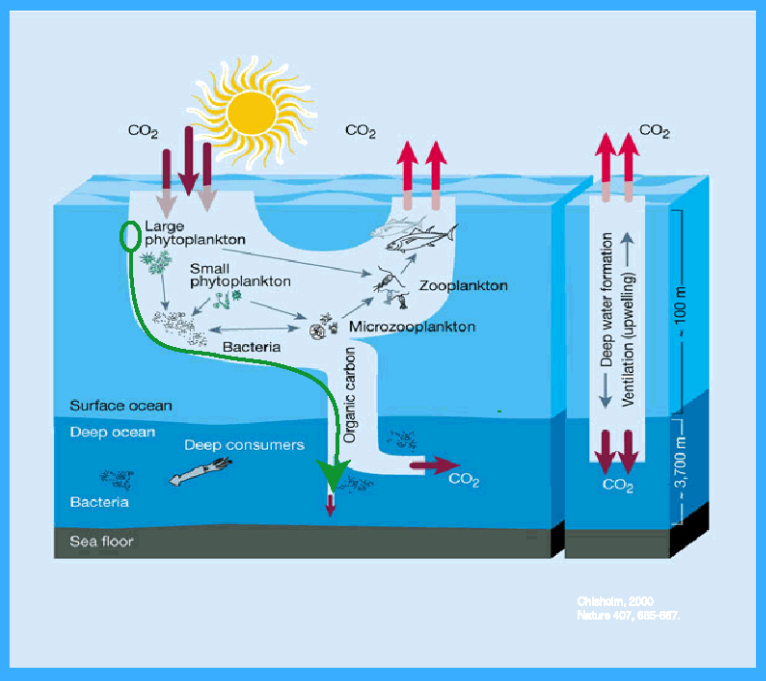

Introduction

Many recent models for the ecosystem control of surface ocean carbon export have emphasized the role of direct export of large phytoplankton, which grow rapidly and thus "escape" grazing by their relatively long-lived predators [Boyd and Newton, 1999; Laws et al., 2000; Michaels and Silver, 1988].

This view has been promoted as a JGOFS paradigm [Ducklow et al., 2001], but the detailed mechanisms of this export pathway and its quantitative significance have yet to be fully explored. If grazing is unimportant, then presumably physical aggregation is involved, because individual large algae appear to sink too slowly [Riebesell and Wolf-Gladrow, 1992; Waite and Nodder, 2001]. There have been few quantitative observations to document this pathway for export, either in the water column, or in sinking particles collected by sediment traps.

Does aggregation selectively remove only the large phytoplankton, or are all particles aggregated and removed? How can we quantitatively assess the relative contributions of small and large phytoplankton to carbon export over the full annual cycle of production and export?

Stable carbon isotope mass balances offer the potential to address these questions, because large phytoplankton contain more ^{13}C than small phytoplankton, and comparison of phytoplankton compositions to the ^{13}C enrichment accompanying the seasonal depletion of dissolved inorganic carbon (DIC) allows their relative contributions to total seasonal export to be quantified. All phytoplankton contain less ^{13}C than their carbon source as a result of the preferential photosynthetic fixation of ^{12}C, but this is modulated by many factors, including the carbon source utilized (CO_2 or HCO_3^-), the particular enzymes involved, growth rates, and phytoplankton size and surface to volume ratio. Models (Rau et al., 1997) and laboratory experiments (Popp et al., 1998) suggest that size is a dominant factor.

Southern Ocean Results

Observations of the organic-^{13}C of Southern Ocean phytoplankton found that large phytoplankton (70-200 micron size class dominated by the pennate diatom, *Fragillariopsis kerguelensis*) were enriched in ^{13}C in comparison to small phytoplankton (1-5 micron size class, comprised of a mix of small diatoms and other algae) by ~ 8 per mil [Trull and Armand, 2001]. This range is consistent with predictions from models and laboratory experiments on the moderation of isotopic fractionation by the limitation of CO_2 supply to larger algae as a function of the cellular surface to volume ratio [Rau et al., 1997; Popp et al., 1998].

In the Southern Ocean study, comparison of phytoplankton organic-^{13}C compositions with the seasonal mixed layer increase in ^{13}C of dissolved inorganic carbon (^{13}C-DIC) suggests that large phytoplankton must have been responsible for the majority of seasonal export.

Comparison of the SOIREE size-fractionated ^{13}Corg values to bulk suspended particles from several WOCE Southern Ocean transects reveals that bulk phytoplankton ^{13}Corg values are lower than that required to explain seasonal DIC depletion. Therefore, large diatom driven carbon export appears to occur without co-export of small phytoplankton - suggesting that aggregation affects only the larger phytoplankton.

In principle, the ^{13}C mass balance approach can be applied to quantitatively assess export contributions from small and large phytoplankton at any site where seasonal surface water ^{13}C-DIC enrichments have been measured. This does require consideration of calcite export and air-sea gas exchange using other constraints such as seasonal alkalinity and pCO_2 estimates, although these terms are often small.

References

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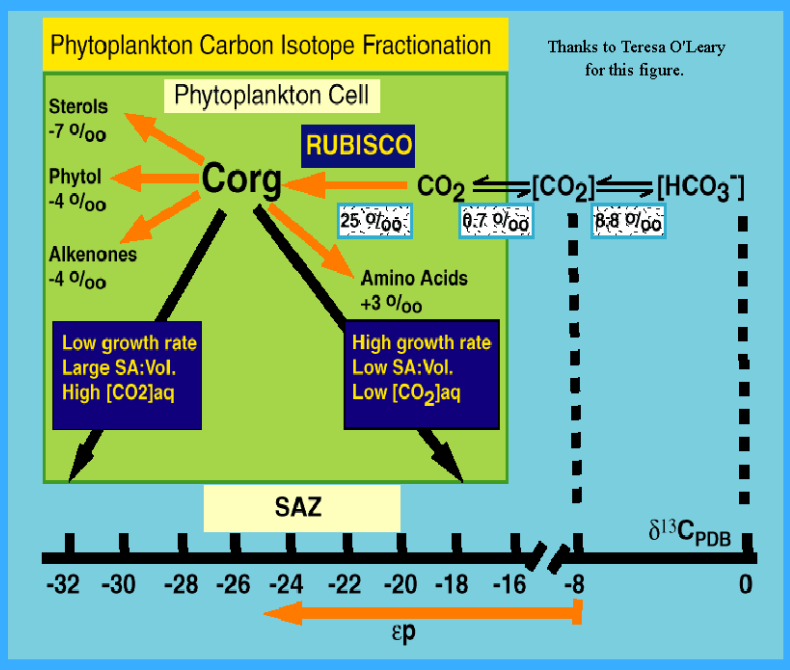
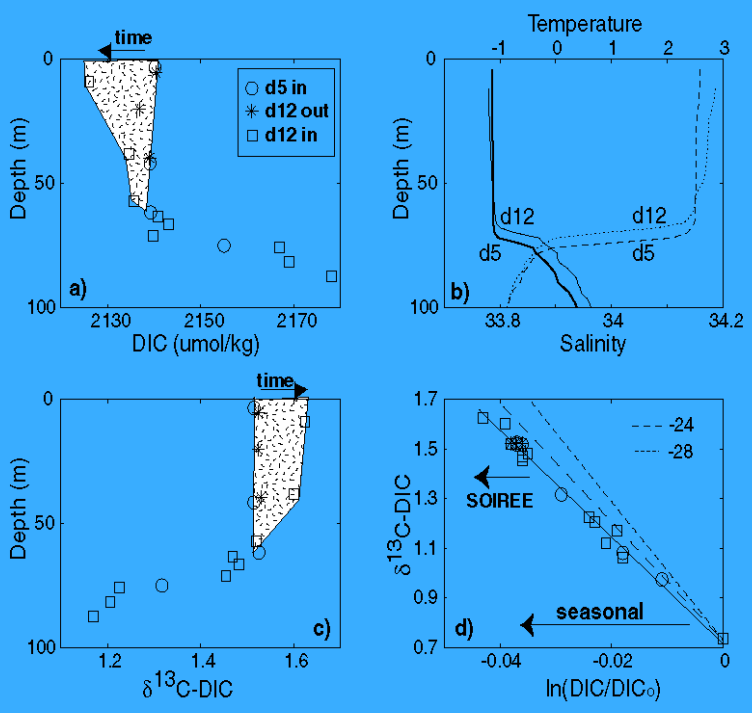
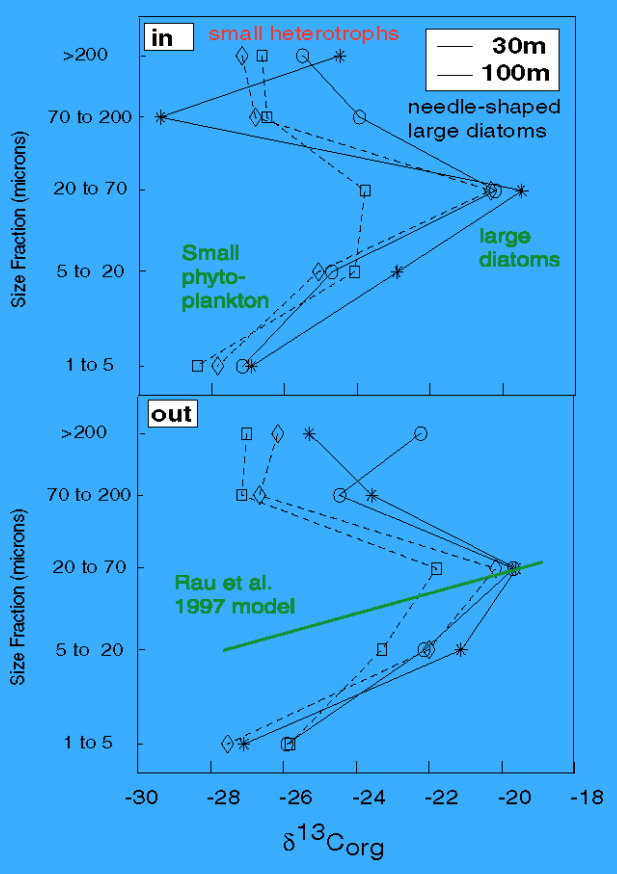


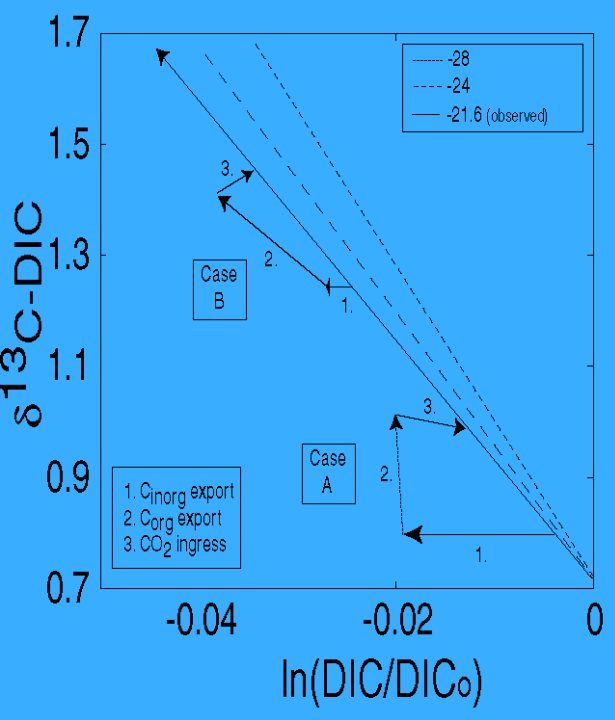
DIC Depletion and ^{13}C enrichment during Seasonal and SOIREE stimulated phytoplankton production



$\delta^{13}C_{org}$ of size-fractionated particles during SOIREE



Including calcite export and gas exchange in the DIC mass balance



$\delta^{13}C_{org}$ of bulk surface particles from Southern Ocean repeat transects along 140E WOCE SR3 line south of Tasmania