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Is there any relationship between phytoplankton seasonal dynamics and the carbonate system?

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Abstract

Production of calcium carbonate by marine calcifying organisms has been shown to decrease under increasing CO_2. This effect appears to be driven by a decrease in $[CO_3^{2-}]$. The modelling study here described aims at investigating whether the success of a marine calcifying phytoplankton species, the coccolithophore *Emiliania huxleyi*, may be tied to $[CO_3^{2-}]$. The work highlights the complex interactions between the carbonate system variables and spring blooms, and the possibility of a link to the competition between calcifying vs. non-calcifying species on the Bering Sea shelf. We find that the strong seasonal cycle in $[CO_3^{2-}]$ is driven primarily by carbon drawdown during spring blooms. The interesting outcome of this work is the fact that *E. huxleyi* bloom timings always coincide with periods of high $[CO_3^{2-}]$, which is consistent with studies showing coccoliths malformations and a slowdown in calcification at low $[CO_3^{2-}]$. Whether the condition of high $[CO_3^{2-}]$ can be considered a crucial ecological factor for the success of *E. huxleyi*, however, remains an open and important question needing further investigation.

Keywords: Modelling; Phytoplankton seasonal dynamics; *Emiliania huxleyi*; Bering Sea; Carbonate system

1. Introduction

Many recent laboratory experiments, but also mesocosms and natural field studies, show a reduction in the production of calcium carbonate by marine calcifying organisms under increasing CO_2 (Spero et al., 1997; Kleypas et al., 1999; Gattuso et al., 1999; Riebesell et al., 2000). According to the "business-as-usual" scenario (IPCC, 2001), atmospheric CO_2 will have doubled from the pre-Industrial Revolution concentration by the middle of this century. As the anthropogenic CO_2 diffuses across the sea surface, surface ocean pH will fall by as much as 0.4 units (Caldeira and Wickett, 2003) and $[CO_3^{2-}]$ will fall by as much as 50% (Zeebe and Wolf-Gladrow, 2001) by the end of the century. The consequences of such a change on calcifiers may be dramatic (Feely et al., 2004). The Bering Sea (Fig. 1) has recently shown drastic (but temporary) changes in its ecosystem with a shift in the dominant summer phytoplankton. Particularly since 1996 (Merico et al., 2003), but most noticeably in 1997 and following years (Vance et al., 1998; Sukhanova and Flint, 1998), the coccolithophore *Emiliania huxleyi* (*E. huxleyi*) appeared in the Eastern Bering Sea (EBS) in very high concentrations (as high as $2.1–2.8 \times 10^6$ cells L^{-1}).

Because of the concern over upcoming ocean acidification and the consequences for marine calci-

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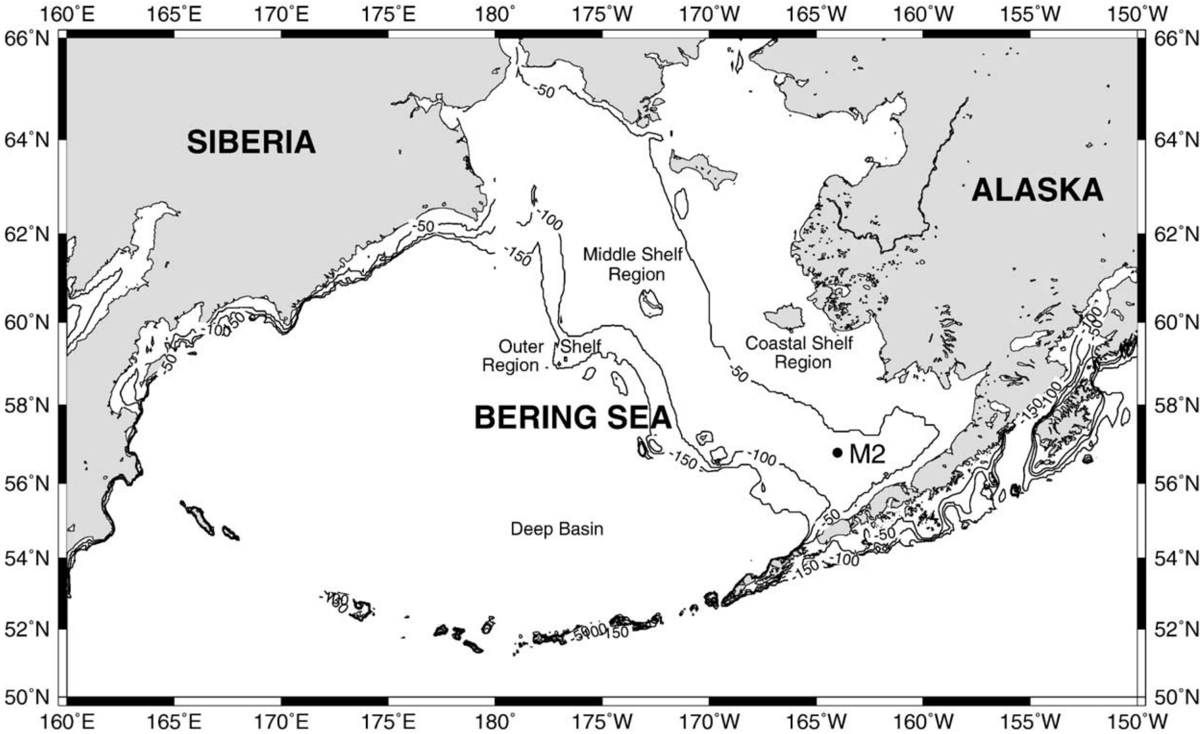

Fig. 1. Map of the Bering Sea with bathymetric contour lines indicating the three hydrographic regions on the shelf: (1) the coastal region from the coast line to the 50 m isobath; (2) the middle region from the 50 m isobath to the 100 m isobath; and (3) the outer region approximately between the 100 m and 150 m isobaths. M2, at 56.8°N,164°W, marks mooring station 2 around which the current model is applied.

fiers, in this paper we investigate whether the natural occurrence of *E. huxleyi* in the Bering Sea could in any way be linked with natural variations in $[CO_3^{2-}]$.

It is important to note that an earlier work (Merico et al., 2004) addressed the question of which environmental factors (e.g. nutrients, grazing, light) could best explain the *E. huxleyi* blooms in the EBS between 1996/1997 and 2000. That topic is not revisited in this paper, except in as much as we look at the possible influence of $[CO_3^{2-}]$, which was not considered in the earlier study. Our focus in the present study is limited to the investigation of a possible link between *E. huxleyi* success in the natural environment and the ambient values of $[CO_3^{2-}]$. More specifically, the following questions are tackled:

(1) Was the interannual variability in $[CO_3^{2-}]$ between 1995 and 2001 consistent with the interannual variability of *E. huxleyi* blooms, such that especially high $[CO_3^{2-}]$ in 1996/1997–2000 could have caused the blooms?
(2) Was the seasonal pattern of $[CO_3^{2-}]$ from winter–spring–summer–autumn consistent with the seasonal distribution of *E. huxleyi* blooms, such that especially high $[CO_3^{2-}]$ in summer could have caused the blooms?
(3) Is there any evidence from the natural ecology of *E. huxleyi* blooms in the EBS (or in other locations) that support a link between $[CO_3^{2-}]$ and *E. huxleyi* success?
(4) Will acidification of the oceans in the future undermine coccolithophores such as *E. huxleyi* or leave them largely unaffected?

1.1. Calcifiers and the carbonate system

The development of a coccolithophore bloom is a major process for the export of calcite ($CaCO_3$) to the deep ocean. Biogenic calcification, however, causes a shift in the equilibrium of the carbonate system toward higher concentrations of CO_2 and it can represent a small sink or a potential source of CO_2 to the environment (Holligan et al., 1993; Paasche, 2002), depending on the degree to which coccolith-weighted faecal pellets lead to enhanced co-transport of organic matter (Buitenhuis et al., 2001).

The processes of inorganic precipitation and dissolution of $CaCO_3$ in seawater are driven by the saturation