UNRAVELING THE DECLINE IN HIGH-LATITUDE SURFACE OCEAN CARBONATE

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ABSTRACT

For perhaps 25 million years, surface waters throughout the ocean have remained saturated with respect to calcium carbonate ($CaCO_3$). Yet increasing atmospheric CO_2 reduces ocean pH and carbonate ion concentration [CO_3^{2-}] and thus the level of saturation. Despite this acidification, it has been estimated that all surface waters will remain saturated for centuries. However, marine calcifiers are still expected to suffer reductions in the rate at which they form their exoskeletons out of $CaCO_3$. Here we show with ocean data and models that the anthropogenic acidification will actually cause some surface waters to become undersaturated within decades, thus exacerbating the problem for marine calcifiers [*Orr et al.*, 2005]. For instance, by 2050 when atmospheric CO_2 reaches 550 ppmv under the IS92a business-as-usual scenario, Southern Ocean surface waters begin to become undersaturated with respect to aragonite, a metastable form of $CaCO_3$. By 2100 as atmospheric CO_2 reaches 788 ppmv under the same scenario,

undersaturation extends throughout the entire Southern Ocean (all ocean south of 60°S) and into the surbarctic Pacific.

In the Southern Ocean, the aragonite saturation horizon (the limit between saturation and undersaturation) rises from its present average depth of 730 m to the surface. In the North Atlantic, the aragonite saturation horizon shoals by 2500 m. Meanwhile, some surface waters of the Weddell Sea also become undersaturated with respect to calcite, the stable form of $CaCO_3$. We show that 21st century transient changes in ocean $[CO_3^{2-}]$ will be much larger than related seasonal, interannual, and decadal variability. We also investigated the relative importance of climate change.

Three coupled climate-carbon models show little effect of climate change on surface $[CO_3^{2-}]$ partly because air-sea CO_2 exchange largely compensates for changes in surface DIC caused by changes in marine productivity and circulation. In subsurface waters, where such compensation is lacking, effects due to climate-induced changes in circulation will exacerbate the decline in high-latitude subsurface $[CO_3^{2-}]$. That is, climate models all project that a future warmer world means a more active hydrological cycle (greater precipitation in the high latitudes). That leads to greater high-latitude stratification [*Sarmiento et al.,* 2004], which decreases surface nutrients (but not to zero) and increases light availability for plankton (shallower mixed layers) [*Bopp,* 2001]. Consequently, surface productivity increases and hence so does subsurface remineralization. That further increases subsurface DIC and decreases subsurface $[CO_3^{2-}]$.

In summary, changes in ocean $[CO_3^{2-}]$ during the 21st century will be driven largely by increases in anthropogenic DIC; effects due to climate-induced changes in ocean circulation will be substantially smaller. Yet $[CO_3^{2-}]$ will be affected more and more as climate change increases. We thus used a set of new carbon-climate simulations from IPSL, to study effects on $[CO_3^{2-}]$ as changes in atmospheric CO_2 and climate continue. At 4 x preindustrial CO_2 ($4xCO_2$), the ocean's saturation state for calcite looks similar to that for aragonite at $2xCO_2$. With sensitivity tests with this model, we attempt unravel the relative contributions of anthropogenic increases in DIC and climate-induced changes in temperature, stratification, export production, and respiration. Additionally, we are making simulations with coupled ocean-sediment carbon-cycle model to quantify the small but growing importance of sedimentary $CaCO_3$ to buffer these large changes over the next millennium.

By the middle of this century, changes in ocean chemistry will threaten high-latitude aragonite secreting organisms including (1) cold-water corals, which provide essential fish habitat; (2) polar and subpolar shelled pteropods, which serve as an abundant food source for marine predators, and (3) coralline algae and some sea urchins, which form parts of their exoskeletons from high-magnesium calcite. Further increases in atmospheric CO2 to values near $4xCO_2$ could devoid the high latitudes of all pelagic calcifiers, even those which secrete calcite.

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