CLIMATE CHANGE FEEDBACKS ON OCEANIC pH AND Ω

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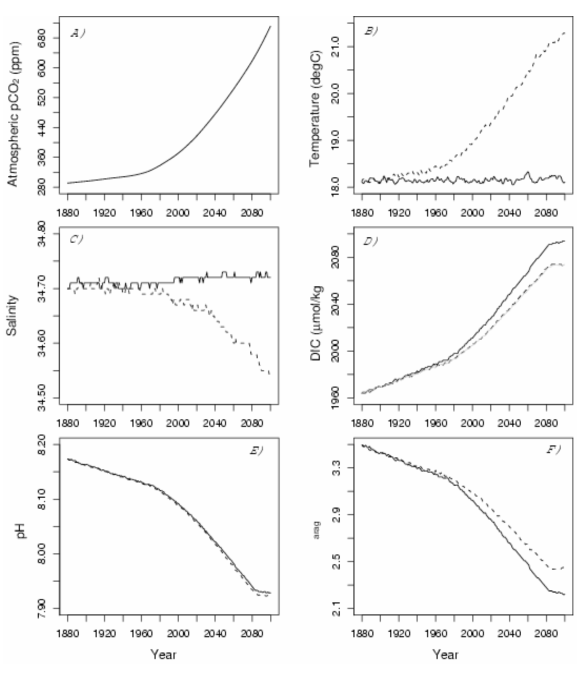
ABSTRACT
Anthropogenic CO_2 uptake by the ocean will decrease both the pH and the aragonite saturation state (Ω_{arag}) of seawater. However, the factors controlling future changes in pH and Ω_{arag} are independent and will respond differently to oceanic climate change feedbacks such as ocean warming, circulation and biological changes. We examine the sensitivity of these CO_2-related parameters to climate change feedbacks within a coupled atmosphere-ocean model. Although surface pH is projected to decrease relatively uniformly by ~0.25 by the year 2100, we find pH to be insensitive to climate change feedbacks, whereas Ω_{arag} is buffered by ~15%. The independent climate change response between pH and Ω_{arag} is attributed solely to the opposing effects associated with ocean warming, which increases Ω_{arag} but lowers pH. Our result implies that future climate change projections for surface ocean pH can be adequately simulated using ocean-only models, however for Ω_{arag} more complex coupled atmosphere-ocean models are required.

INTRODUCTION AND BACKGROUND
Rising atmospheric CO_2 concentrations via fossil fuel emissions will lead to an increase in oceanic CO_2 as the ocean absorbs the anthropogenic CO_2. Increased CO_2 in the upper ocean will alter the chemical speciation of the oceanic carbon system. Under equilibrium conditions, the carbon chemistry in seawater undergoes the following equilibrium reactions as CO_2 enters the ocean.

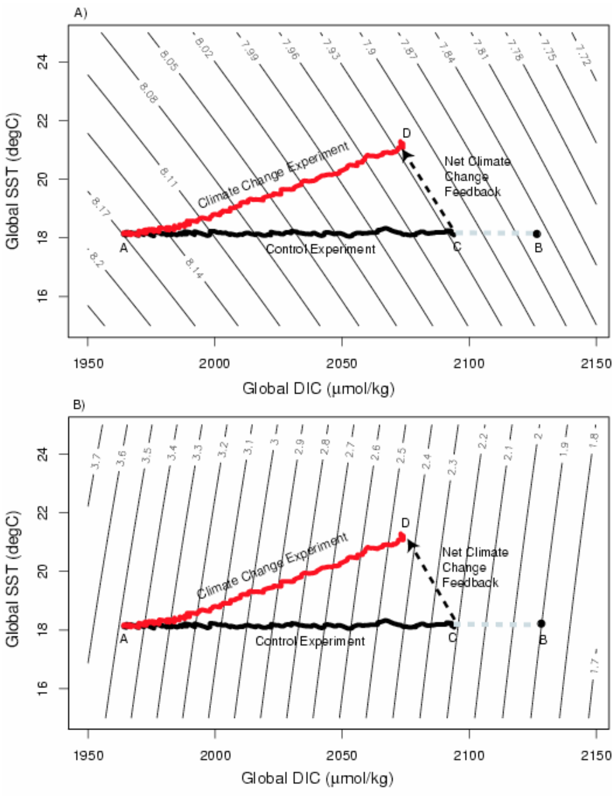
$$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+ \Leftrightarrow CO_3^{2-} + 2H^+ \qquad (1)$$

Two important parameters of the oceanic carbon system are the pH and the $CaCO_3$ saturation state of seawater (Ω). The $CaCO_3$ saturation state of seawater (Ω) is defined by: $\Omega = \frac{[Ca^{2+}][CO_3^{2-}]}{\lambda}$, where λ is the solubility coefficient of different forms of $CaCO_3$ (e.g. calcite and aragonite). The pH of seawater is defined by the amount of H^+ ions available: $pH = -\log_{10}[H^+]$.



Increasing CO_2 concentrations in the surface ocean via anthropogenic CO_2 uptake will have two effects. Firstly, it decreases the surface ocean carbonate ion concentration (CO_3^{2-}) and decreases the calcium carbonate saturation state (Ω). Using an ocean-only model forced with atmospheric CO_2 projections (IS92a), [*Kleypas et al.*, 1999] predicts a 40% reduction in Ω by 2100. Secondly, when CO_2 dissolves in water it forms a weak acid (H_2CO_3), (equation 1) dissociates to bicarbonate generating hydrogen ions (H^+), which makes the ocean more acidic (pH decreases). Using an ocean-only model forced with atmospheric CO_2 projections (IS92a), [*Caldeira and Wickett*, 2003] predicts a pH drop of 0.4 units by the year 2100 and a further decline of 0.7 by the year 2300.

Fig. 1: A) Atmospheric CO_2 projection; B) globally averaged SST from the control experiment (solid line) and climate change experiment (dashed line); C) globally averaged sea surface salinity; D) globally averaged Dissolved Inorganic Carbon (DIC) (μmol/kg) with the additional grey dotted line illustrating the solubility-effect; E) globally averaged pH; F) globally averaged Ω_{arag}.



Future acidification (lowering of pH) may adversely impact marine biota, but our present understanding of the potential biological response is unknown. It is recognised however that a decrease in pH will alter the acid-base balance with the cells of marine organisms. Marine organisms regulate intercellular pH by the metabolic interconversion of acids and bases, the passive chemical buffering of intra- and extra-cellular fluids, and the active ion transport (e.g. proton transport by extra-cellular respiratory proteins such as hemoglobin). Acid-base imbalances in marine organisms can lead to the dissolution of exoskeletal components such as calcareous shells, metabolic suppression, reduced protein synthesis and reduced activity [*Pedersen and Hansen*, 2003]. As both Ω and pH changes have the potential to directly impact marine biota it is important to understand the magnitude of these changes under elevated CO_2 levels and global warming. We use climate model simulations to explore the relationship between climate change and these two carbon parameters to allow an improved assessment of the potential impacts they may have on marine organisms.

Fig. 2: A) Evolution of mean surface pH in relation to DIC and SST for both the control experiment (solid black line) and climate change experiment (solid red line). The *net* climate change feedback is shown as the dashed black vector between the control and climate change experiments. Point A is the initial state in the year 1880. Point B is the pH state (~7.82) in the year 2100 if the ocean absorbed atmospheric CO_2 in equilibrium. Point C is the pH state (~7.93) in the year 2100 for the control experiment (steady state solution). Point D is the pH state (~7.93) for the year 2100 under climate change, and includes feedbacks such as circulation, biological production and temperature. B) Evolution of mean surface Ω_{arag}.

RESULTS AND DISCUSSION

With global warming, we project by 2100 that the surface ocean DIC concentration is 18% less than the control experiment (decline from 135µmol/kg to 110µmol/kg; see Figure 1d). The reduced DIC concentration with climate change largely reflects reduced solubility of CO_2 in the surface water due to the warming. Our results show different climate change sensitivities for pH and Ω_{arag}. We find pH to be insensitive to climate change with virtually no difference between the transient and control experiment (Figure 1e). For both experiments, the globally averaged pH is projected to decrease from 8.17 in the year 1880 to about 7.91 by 2100. Ω_{arag} however, is affected by climate change (Fig. 1f). Globally averaged Ω_{arag} is found to decrease from 3.5 to 2.2 between 1880 and 2100 without climate change, but it decreases to 2.5 when we include the affects of climate change. The dominating affects for the change in pH and Ω_{arag} with global warming is the warming of the surface ocean and the reduced DIC concentration in the upper ocean. For pH, climate change has little impact on the projected changes because the decrease in pH due to warming is nearly equal to but oppositve in magnitude to the pH increase associated with reduced DIC concentration of the upper ocean caused by reduced solubility of CO_2 with ocean warming (Fig. 2). Therefore, projections that neglect climate change provide a reasonable estimate of the future pH change.

References

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