Reviewing the impact of increased atmospheric CO_2 on oceanic pH and the marine ecosystem

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Reviewing the Impact of Increased Atmospheric CO_2 on Oceanic pH and the Marine Ecosystem

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Abstract
The world's oceans are an enormous reservoir of carbon, greater than that on land or in the atmosphere. The fluxes between these reservoirs are relatively rapid such that the oceans have taken up around 48% of anthropogenic CO_2 released to the atmosphere. Elevated CO_2 can potentially affect many processes in marine biogeochemistry and each of these affects will be at least non-linear and potentially complex. Both positive and negative feedback mechanisms exist, making prediction of the consequences of changing CO_2 levels difficult. Although many relevant processes are understood, others such as CO_2 induced acidification of the marine system have only recently emerged as serious issues, backed up by experimental studies. Integrating the net effect of these processes on regional and basin scales is the outstanding challenge which we aim to address via marine system modelling.

Introduction

The 1999 EU Energy Outlook to 2020 suggests that, despite anticipated increases in energy generation from renewable sources, up to 80% will still be accounted for by fossil fuels. On current trends, CO_2 emissions could easily be 50% higher by 2030. Already about 48% of anthropogenic CO_2 has been taken up by the oceans [1] and thus oceans act as a buffer for atmospheric CO_2 concentrations. However, the oceans buffering capacity decreases as it takes up CO_2. In addition, CO_2 in the atmosphere is relatively inert but when dissolved in seawater it becomes highly reactive and takes part in a range of chemical, physical, biological and geological reactions, some of which are predictable while some are more complex. Warming of the oceans will also have an impact as CO_2 is less soluble in warm water and increased vertical stratification will effectively reduce the volume of water available for CO_2 adsorption.

Physical and chemical processes that may be important for future uptake of CO_2 by the oceans

➢ CO_2 buffering capacity of the oceans:	decreasing pH reduced CO_2 uptake
➢ Increased vertical stratification:	reduced CO_2 uptake reduced nutrient supply in photic zone changes in the rain ratio reduction in O_2
➢ CO_2 is less soluble in warm water:	increased sea-air flux increased atmospheric CO_2

Of all the predicted impacts attributed to this inevitable rise in atmospheric CO_2 and the associated rise in temperature (e.g. suppression of the North Atlantic circulation, large-scale melting of ice sheets, destabilisation of methane hydrates, sea level rise) one of the most pressing is the acidification of surface waters through the absorption of atmospheric CO_2 and its reaction with seawater to form carbonic acid [2]. It is predicted that the continued release of fossil-fuel CO_2 into the atmosphere could lead to a surface ocean pH reduction of up to 0.4 units by the end of the century (Fig. 1) and up to 0.77 by 2250 [3]. While climate change has uncertainty, these geochemical changes are highly predictable. Only the time scale, and thus mixing scale length are really under debate. Such dramatic changes in ocean pH have not been seen for about 20 million years of the Earth's history.

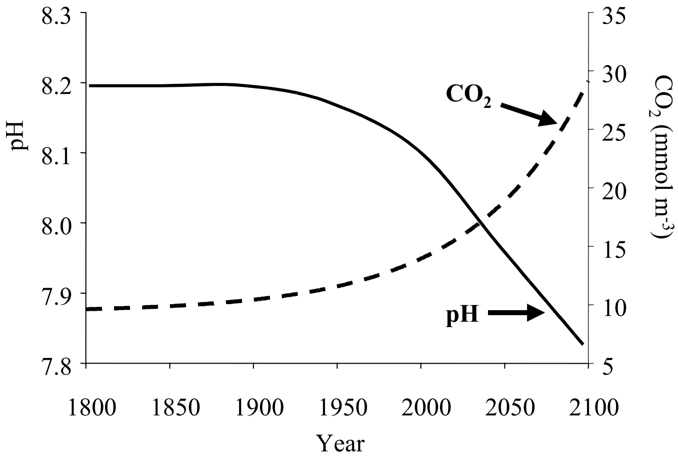

Figure1 The projected change in atmospheric CO_2 concentrations and seawater pH assuming anthropogenic emissions are maintained at current predictions. (IPCC, 1996).

A number of organisations have recognised the importance of high CO_2/lowering pH in surface oceans: International Global Biosphere Programme (*IGBP*), Scientific Committee on Oceanic Research (*SCOR*), Commission On Atmospheric Chemistry and Global Pollution (*CACGP*), International Council for Science (*ICS*) sponsored programmes such as Integrated Marine Biogeochemistry and Ecosystem Research (*IMBER*) & the Surface Ocean-Lower Atmosphere Study (*SOLAS*). A SCOR and IOC funded International Science Symposium held at UNESCO, Paris on 10-12 May 2004 *Symposium on the Ocean in a High- CO_2 World* brought together scientists working in this area for the first time. The consensus from the scientists have been summarised in a report *"Priorities for Research on the Ocean in a High- CO_2 World"* [4] and the overwhelming conclusion was the need for more research in this area. The Royal Society is currently carrying out a study on ocean acidification and the Working Group will publish their findings in early 2005. OSPAR has held a workshop *on the Environmental Impact of Placement of Carbon Dioxide in Geological Structures in the Maritime Area* and recognised the significance of ocean acidification caused by uptake of anthropogenic CO_2 as a strong argument, along with climate change, for global mitigation of CO_2 emission. A report to DEFRA, summarising the current knowledge of the potential impact of ocean acidification (by direct uptake or by release from sub-seabed geological sequestration) concluded that there was a need for urgent research to help inform government of the potential impact of both ocean uptake of anthropogenic CO_2 and its release from maritime sea bed geological structures [5].

Reduced pH is probably the most potent mechanism by which CO_2 will affect marine biogeochemistry [6]. This will disrupt the carbonate chemistry of the system [7] in turn affecting plankton species composition [8], principally by disrupting calcifying organisms such as coccolithophores, pteropods, gastropods and foraminifera [9]. Other non-calcifying organisms may grow in their place and impact the structure and processes occurring in the whole ecosystem. Other organisms that fix calcium carbonate are also at risk due to lowering pH. Amongst these are corals and shellfish. Over long time scales calcium carbonate is the major form in which carbon is buried in marine sediments, hence species composition is intimately linked to the strength of the biological pump or carbon burial [10, 11]. Another pH related mechanism is the inhibition of nitrification [12] and the resulting increase of the NH_4:NO_3 ratio. This again has the potential to change the phytoplankton species composition and the rate of carbon cycling in the marine system. Changes to the phytoplankton community structure are likely to affect the grazer community including economically important species [13-15]. Changes in pH also have the potential to disrupt metal ion uptake causing symptoms of toxicity. Organisms from bacteria to phytoplankton, the main primary producers, may be affected by shifts in the form of nutrients and trace elements required for growth. For example, nitrogen, in particular ammonia-ammonium, is pH dependent, with the concentration of $NH_{3\ (Aq)}$ decreasing as pH declines. Changes in the NH_4^+ / $NH_{3\ (Aq)}$ ratio may also have profound effects on the energetics of nitrogen acquisition. At pH 8.1, ~4% of the ammonia is present as $NH_{3\ (Aq)}$; in mesotrophic waters this may be sufficient to supply the needs of a phytoplankton cell by diffusive entry of $NH_{3\ (Aq)}$. At lower pH, $NH_{3\ (Aq)}$ will be less available (at pH 7.8 the proportion of $NH_{3\ (Aq)}$ will be reduced by ~50%) and phytoplankton and bacteria must rely on active transport systems — *i.e.* nitrate and ammonium transporter or permeases. It is not clear if this change in the energetics of nitrogen acquisition will impose an ecological deficit as a consequence of pH change. Intra-cellular enzymic reactions are also pH sensitive.

Experiments have shown decreased motility, inhibition of feeding, reduced growth, reduced recruitment, respiratory distress decrease in population size, increased susceptibility to infection, shell dissolution, destruction of chemosensory systems and mortality can occur in high CO_2/low pH waters in a the small range of organisms tested to date [review in 5]. The average carbonate saturation state of benthic sediment pore waters could decline significantly, inducing dissolution of metastable carbonate phases within the pore-water-sediment system [7]. Further the benthic sediment chemistry of shallow coastal seas such as the North Sea exhibit a delicate balance between aerobic and anaerobic activity which may be sensitive to varying pelagic CO_2 loads. In short, marine productivity, biodiversity and biogeochemistry may change considerably should oceanic pH be reduced through oceanic uptake of anthropogenic CO_2. There is surprisingly little research on the potential impact of this on marine and global ecosystems and this needs to be redressed.

Modelling techniques provide the only mechanism for resolving whole system impact. Indeed several researchers cite the need for integrated modelling studies [7, 13, 16, 17, 18]. Although the CO_2 focused coupled modelling tools required do not exist in an operational form, we in the UK and specifically at PML are fortunate in having world leading model systems available that can readily be integrated to provide a CO_2 system modelling capability.

Conclusions

Whilst marine acidification seems inevitable and effects on the marine ecosystem are likely to be measurable, we, the scientific community are far from being able to predict with certainty the extent of impact and whether an appreciable decline in resource base may occur. The problem is multi-disciplinary and needs to integrate atmosphere, hydrodynamic and ecosystem modellers, build on experimental knowledge and requires significantly more system measurements to validate models. UK and International momentum is building towards this challenge and many of the collaborations are being forged. However the provision of manpower, computer, experimental and observational resource still needs to be addressed. Ocean acidification is a powerful additional argument to add to that of climate change for reduction of global CO_2 emissions.

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