Beyond Climate: Cabled Experiments to Simulate the Emerging High CO2 Ocean

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A CO2 Enriched Ocean: Enormous Blessing or Future Problem?

It is now commonplace to carry out large-scale CO2 enrichment experiments on land, but no equivalent experiments have yet been carried out in the ocean. Why is that, is there a compelling need, and what are the conflicts and challenges? The scale of surface-ocean CO2 uptake from the atmosphere is now so large that any distinction between a "natural" process, and an industrial policy of (only slightly) indirect surface ocean disposal, is hard to maintain. The 1995 IPCC scientific assessment gave the rate of surface ocean CO2 uptake as 2.0   0.8 GtC/yr as the average for 1980-1989. A more recent estimate (McNeil et al., 2003) gives 2.0   0.4 GtC/yr for the period mid-1990 to mid-1999. This is 21 million tons of CO2 per day, and fluxes of such scale will have biogeochemical impacts. Surface ocean waters are already >0.1 pH units lower than in pre-industrial times (Brewer, 1997), and if the IPCC IS92A "Business as Usual" scenario is followed then by the end of this century we will experience a 55% drop in surface ocean carbonate ion concentrations with major effects on coral reef systems (Langdon et al., 2000), and calcareous plankton (Riebesell et al., 2000), anticipated.

How sensitive are ocean systems to pH changes? If we permit atmospheric CO2 levels to rise to ~ 600 ppm and remain there, then surface ocean waters, and eventually all ocean waters, will experience an ~ 0.3 pH change from pre-industrial levels. Is that an acceptable limit, and why? What burden of fossil fuel CO2 is "acceptable" for climate, or geochemical, or biological, reasons? How might we view the trade-off between the direct effects of CO2 and of the induced effects of climate/temperature? The focus of the ocean science community has been on observing the evolving fossil fuel CO2 tracer signal, and the questions above have simply (and astonishingly) not yet been posed.

References

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[2] Langdon, C., T. Takahashi, C. Sweeney, D. Chipman, J. Goddard, F. Marubini, H. Aceves, H. Barnett, and M.J. Atkinson (2000) Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef. Global Biogeochem. Cycles 14 639-654.

[3] McNeil, B., R.J. Matear, R.M. Key, J.L. Bullister, and J.L. Sarmiento. (2003) Anthropogenic CO2 uptake by the ocean based on the global chlorofluorocarbon data set. Science, 299, 235-239.

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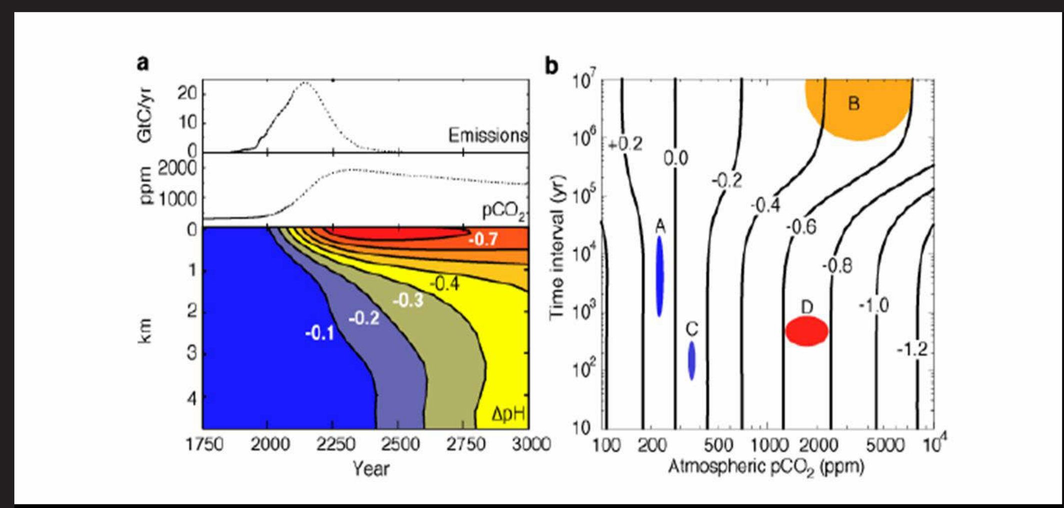
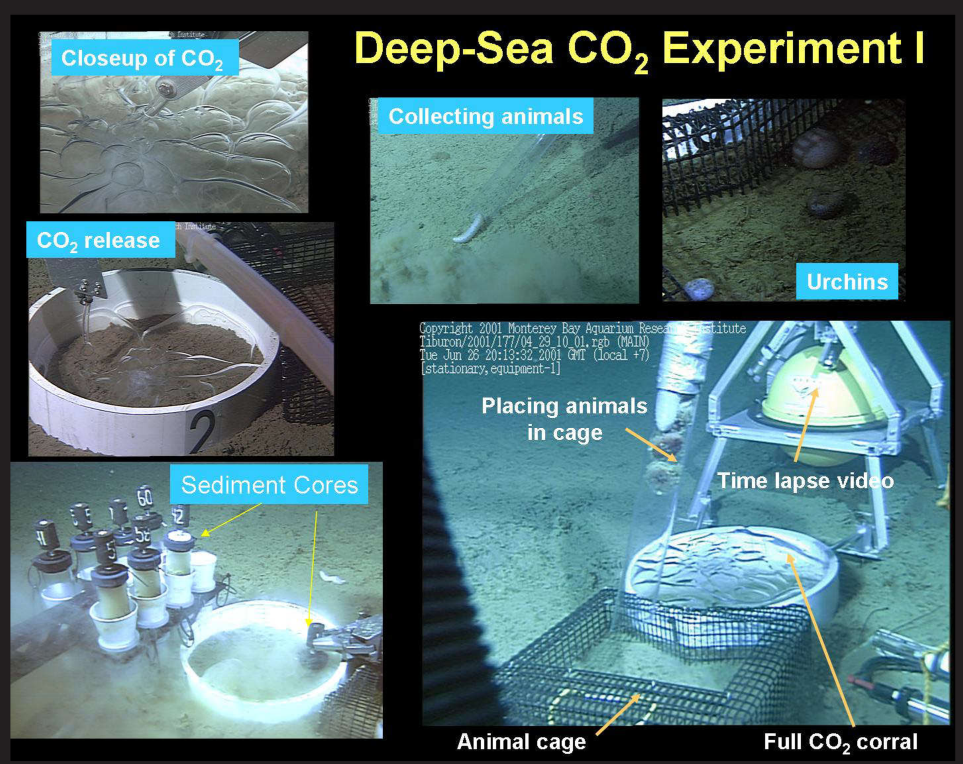
Atmospheric CO2 and average ocean △pH



Atmospheric release of fossil fuel CO2 may make the ocean more acid than it has been for the past 300 myr. a, Atmospheric CO2 emissions, historical atmospheric CO2 and CO2 predicted from this emissions scenario, and change in ocean pH based on horizontally averaged chemistry. b, Estimated maximum surface ocean pH change as a function of final atmospheric pCO2 and the transition time over which this pCO2 is linearly approached from 280 ppm: A, glacial-interglacial CO2 changes13; B, slow changes over the past 300 myr; C, historical changes1 in ocean surface waters; D, unabated fossil-fuel burning over the next few centuries. [5]

Present Status of Ocean CO2 Perturbation Experiments



How does elevated CO2 affect marine animals?

CO2 injection causes;
1 – Elevated CO2 levels
2 – Elevated Seawater Acidity (reduced pH)

Physiological Effects

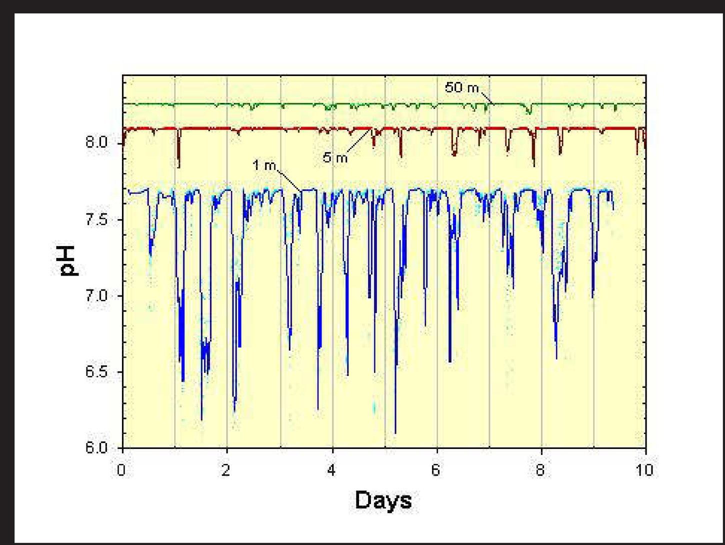
Respiratory Stress
Increased acidity reduces the level of oxygen-binding and transport by respiratory proteins, leading to reduced aerobic capacity.
Acidosis (reduced internal pH)
Disruption of the acid/base balance of animal tissues impairs function and requires energy to restore or maintain optimal internal pH levels.
Metabolic suppression (Torpor)
Elevated CO2, reduced pH, or both can cause some animals to enter a state of reduced metabolic rate and semi-hibernation, reducing their activity, protein synthesis, growth, reproduction, etc.

Healthy ——— Degraded

We can view the current series of deep ocean CO2 injection experiments not simply as disposal strategy tests, but also as controlled enrichment experiments that may allow us to mimic the elevated CO2 levels of a future ocean in much the same way that ecosystems are manipulated on land (Shaw et al.,2002; DeLucia et al., 1999). While these oceanic injection experiments have broken new ground, they are deficient in many ways: it is hard to control the pH perturbation achieved due to the varying tidal forcing (See Figure on right), and very close to the source the CO2 gradients are so large that animals may either not survive, or show little response, depending upon very small changes in position. The experiments carried out so far have been short term due to limits on the amount of CO2 that can deployed by an ROV.

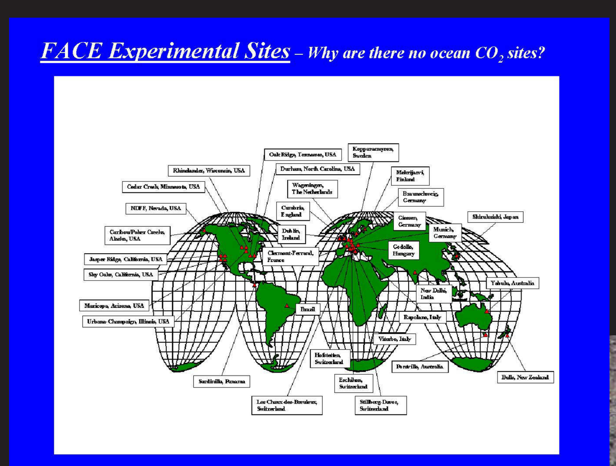
pH Perturbations at Distance from Corral

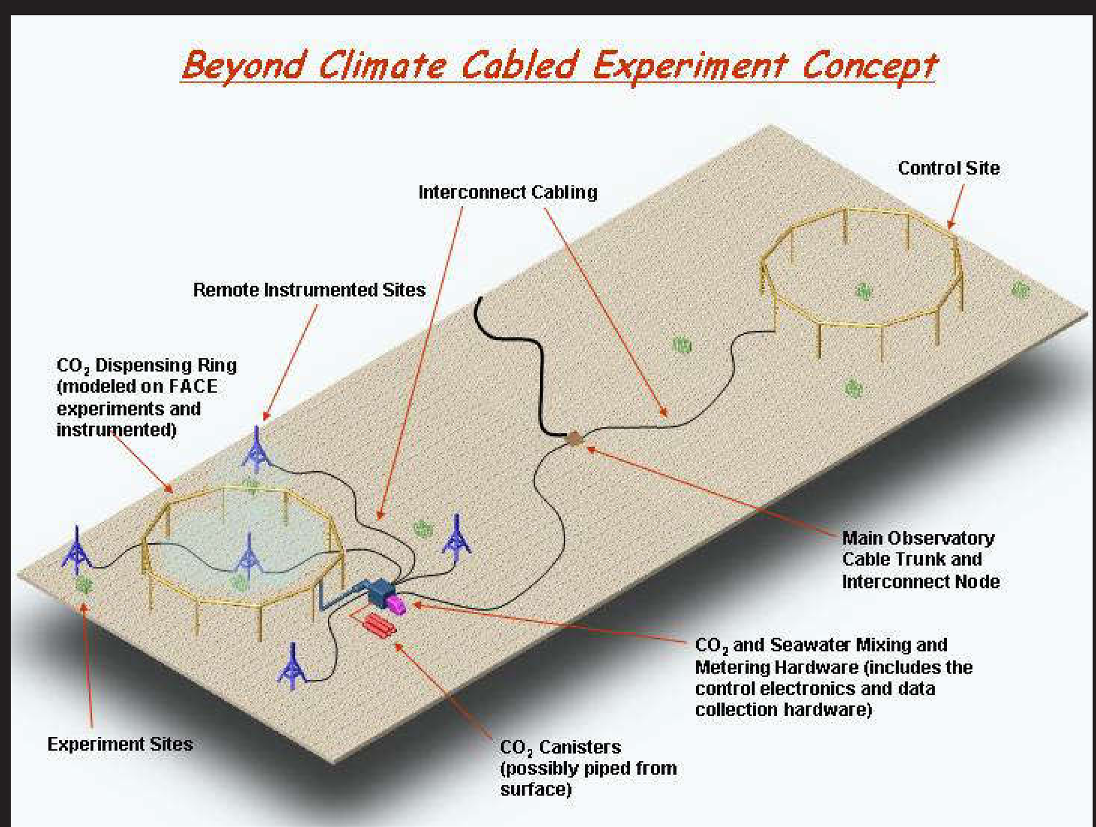
Spiking due to currents and tides causing near field animals and experimental results to be questionable over time. Beyond Climate experiment will address these inaccuracies by regulating the fluctuations to accurately repsent a future pH ocean change



Next Generation of Ocean CO2 Perturbation Experiments

Face Experiment Structure as Background





Designing, testing, and executing a sophisticated set of controlled perturbation experiments on oceanic biogeochemical systems will involve the creative efforts of a large number of scientists and engineers. While we can learn from experiments that have been carried out on land, the translation to oceanic systems will not be easy. Among the problems to be considered are:

A) On land the trees, shrubs, grasses etc. are immobile - oceanic animals move, and the protocols for obtaining valid results will have to be carefully evaluated.
B) CO2 has no atmospheric chemistry, and mixing the source gas into ambient air is a simple problem. Adding CO2 to ocean waters involves the full set of aqueous CO2 system changes, and the lag times associated with them.
C) At depths typically > ~ 350m CO2 will react with sea water to form a hydrate, and flow assurance will have to planned for.
D) The time scale for observing changes may be quite long, for example in the case of carbonate sediment dissolution experiments.
E) The challenge of observing the perturbed area must be addressed by novel sensor techniques - simply taking a large number of cores may damage the experimental site.

However none of the problems are insoluble, and much is known already. With real time control and data flow very rapid advances can be made.

A) *It is possible to extend the work beyond CO2, for example to perturbations of the oxygen content, or temperature, of the system.*
B) A wide range of pH perturbations may be studied.
C) The earliest experimental targets should be in shallower waters, including coral reef systems.

This will permit rapid system development, and provide guidance for steadily deeper deployments.

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