xFOCE: TECHNOLOGY FOR STUDYING OCEAN ACIDIFICATION IMPACTS

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Abstract

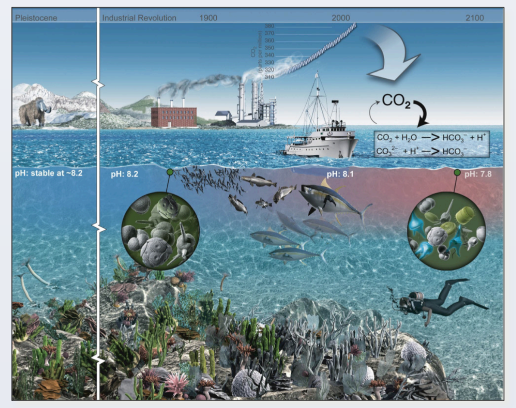
Laboratory and mesocosm studies are only part of the tool set for ocean acidification (OA) studies. In situ experiments over months and longer can provide inference concerning the response of natural communities to ocean acidification not possible with laboratory studies.

Drawing on the long experience of terrestrial Free Air CO_2 Enrichment (FACE) experiments, MBARI has developed experimental methods and technologies for in situ ocean acidification studies, including Free Ocean CO_2 Enrichment experiments, or FOCE.

Here, we describe ***xFOCE, an open source package created to transfer FOCE technology to interested researchers***. xFOCE is a modular system design intended to support a wide variety of OA studies, and to be extensible and adaptable to new requirements for OA research. The ocean science community can use xFOCE to develop cost effective FOCE experiments (lasting weeks to months) in diverse marine environments.

Background: Why FOCE?

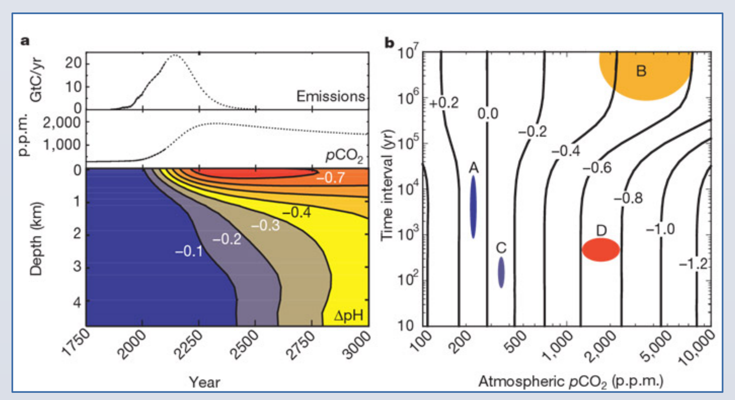
Ocean Acidification (OA) is happening quickly and will be a concern for centuries. Intergovernmental Panel on Climate Change (IPCC) reports have motivated researchers to develop new studies on the potential effects of ocean acidification. In addition, recent meetings between scientists on this topic have indicated that in situ experiments are a top priority in studying OA impacts [1]. The Monterey Bay Aquarium Research Institute (MBARI) has developed the Free Ocean CO_2 Enrichment system (FOCE) as a tool to help the science user community address the current and future OA research needs.



Conceptual diagram illustrating rising atmospheric CO_2 levels, changes in ocean carbonate chemistry, and consequences for marine ecosystems.

In situ perturbation experiments with high CO_2/low pH treatments over long periods are a key to evaluating the biological responses to future OA. The objectives of these experiments vary, but most focus on the biology and ecology of organisms and communities to increasing CO_2 levels (reduced pH) over long periods, under relatively natural conditions. FOCE systems aim to allow researchers to perform experiments with specified (and perhaps variable) levels of CO_2 enrichment for extended periods while other environmental parameters vary naturally.

Atmospheric CO_2 levels are expected to rise rapidly through this century due to continued (or perhaps elevated) use of fossil fuels for global energy needs (Figure below). Rising CO_2 levels in the atmosphere will increase the flux of CO_2 to ocean surface waters.



Atmospheric release of CO_2 from the burning of fossil fuels may give rise to a marked increase in ocean acidity. (Caldeira and Wickett, 2003)

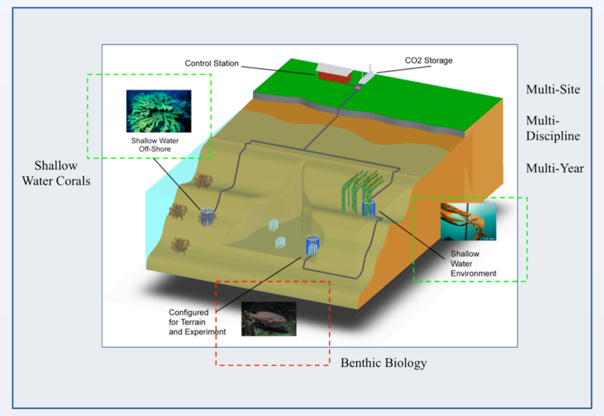
a, Atmospheric CO_2 emissions, historical atmospheric CO_2 levels and predicted CO_2 concentrations from this emissions scenario, together with changes in ocean pH based on horizontally averaged chemistry.

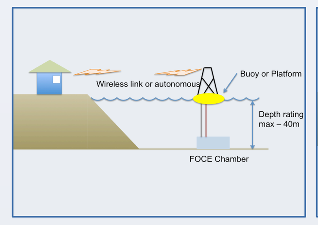
b, Estimated maximum change in surface ocean pH as a function of final atmospheric CO_2 pressure, and the transition time over which this CO_2 pressure is linearly approached from 280 p.p.m. A, glacial-interglacial CO_2 changes13; B, slow changes over the past 300 Myr; C, historical changes1 in ocean surface waters; D, unabated fossil-fuel burning over the next few centuries.

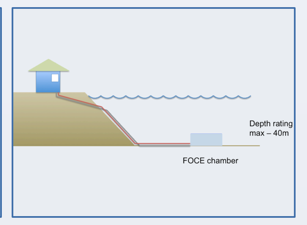
Ocean mixing processes are now moving the signal of ocean acidification to deeper ocean depths, and eventually the oceans will store most (ca. 85%) of fossil fuel CO_2 emitted to the atmosphere. (Archer et al, 1998) Thus, ocean acidification will eventually alter the carbonate chemistry of the entire world ocean. FOCE experimental approaches can be used in various marine environments to increase our understanding of the potential consequences of ocean acidification for marine ecosystems.

xFOCE Concept: Open technology, community enable multi-disciplinary ocean acidification (OA) science

The goal of FOCE is to *provide precise control of pH within in situ experimental chambers with minimal effect on other environmental conditions*, to support experiments evaluating the consequences of ocean acidification on marine organisms and communities.

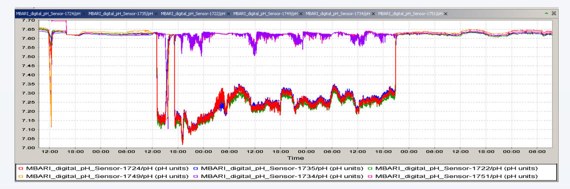




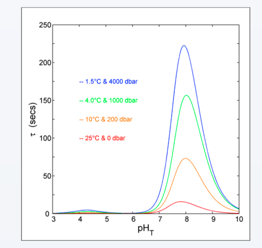


CO_2 enrichment in a FOCE system is achieved by controlling the addition of CO_2 enriched (low pH) seawater (ESW) into experimental chambers on the seabed. The ESW is made by mixing seawater from the site with CO_2. The FOCE system continually adjusts the delivery of ESW to maintain a constant pH offset relative to the surrounding area, or to maintain a specified constant pH level in experimental chambers. Thus, experiments using constant pH levels or specified offsets around natural pH variability can be performed. The key elements of a FOCE experiment include the CO_2 mixing system, sensors to continuously monitor ambient and chamber pH, and a control loop to regulate the flow of ESW to each experimental chamber.

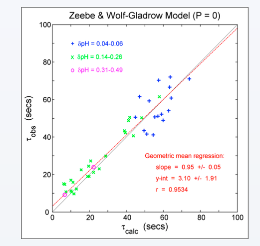
The best configuration for data collection and for generating ESW and power depends upon the experiment site and existing infrastructure.



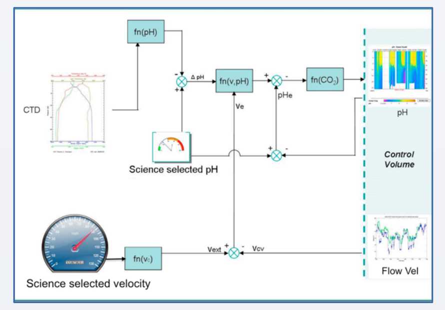
dpFOCE pH offset, Oct 2011



τ as a function of T, P, and pH (Zeebe and Wolf-Gladrow, 2001).

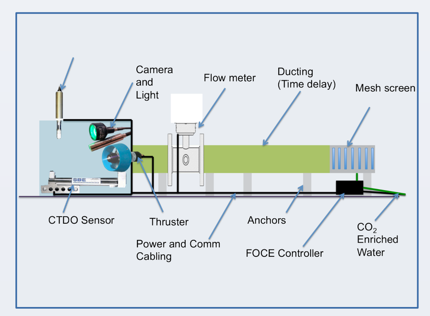


Experimental validation in Monterey Bay by MBARI



FOCE control model

FOCE chamber concept



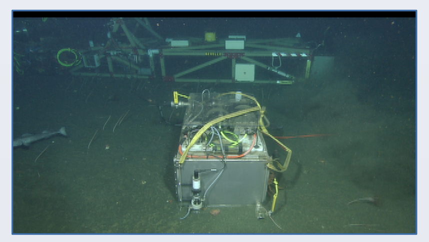
The chemical and physical techniques for controlling CO_2 chemistry are well understood, but depend on the marine environments of interest. The technologies and application techniques used to execute FOCE required considerable time and expertise to develop.

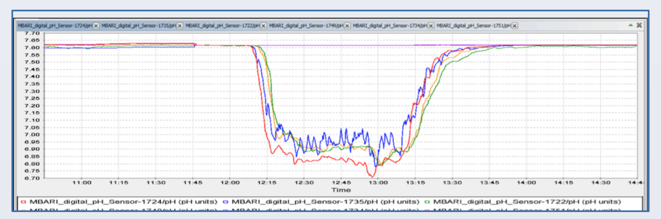
MBARI is now putting FOCE technology and expertise in an open source package called xFOCE.

xFOCE makes FOCE techniques cost-effective and adaptable, reducing the learning curve and making it a useful tool for multi-disciplinary OA studies in any marine environment.

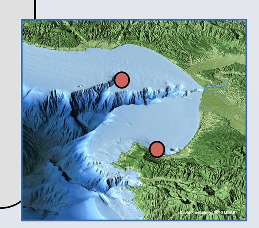
Like other open technology projects, xFOCE includes the idea of community building, to enable more researchers to use FOCE tools and techniques by contributing expertise and technical support.

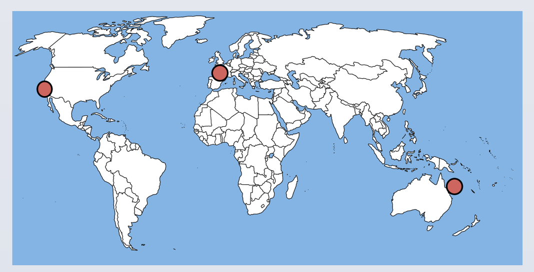
xFOCE Implementations

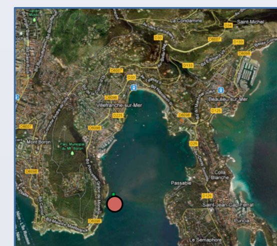


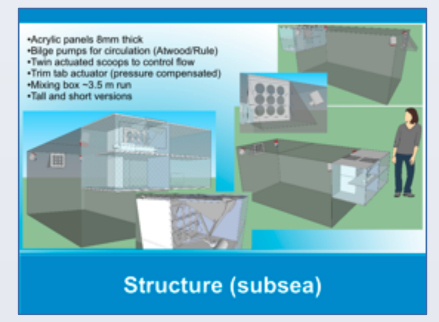


Experiment:	*dpFOCE (Deep FOCE)*
Research:	Carbonate chemistry, biology
Implementer:	MBARI
Deployment:	2008-12 MARS Cabled Observatory
Chambers:	1
Dimensions:	3m x 1m x 0.5m
ESW:	Liquid CO_2, custom mixing chamber
Power:	1 kW (MARS cable)
Telemetry:	10/100 Mbps Ethernet (MARS cable)



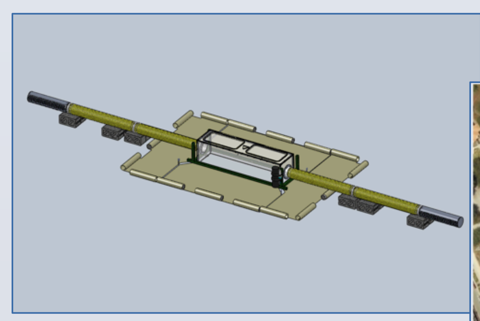


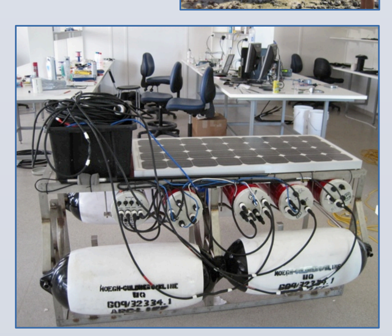




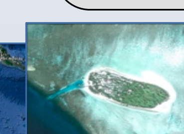
eFOCE images courtesy of Paul Mahacek

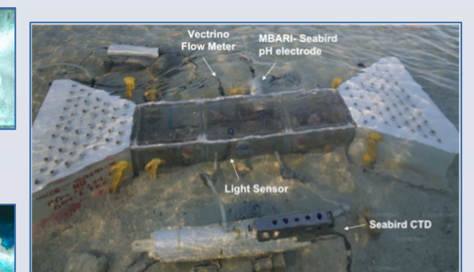
Experiment:	*eFOCE (European FOCE)*
Research:	Biology, Ecology
Implementer:	Laboratoire d'Océanographie at Villefranche
Deployment:	2012 Villefranche
Chambers:	2
Dimensions:	1m x 1m x 2m
ESW:	Bottled CO_2, buoy based mixing/pumping station
Power:	Solar, Wind 40 W
Telemetry:	Serial Radio, 115 kbps





Experiment:	*swFOCE (Shallow Water FOCE)*
Research:	Biology, Ecology
Implementer:	MBARI, Stanford, Center for Ocean Solutions
Deployment:	2013 Hopkins Marine Station
Chambers:	3-5
Dimensions:	2m x 0.5m x 0.5m
ESW:	Bottled CO_2, shore based mixing/pumping station
Power:	Local utility 2 kW
Telemetry:	Copper/Fiber optic cable, 1 Gbps





David Kline, Copyright 2010

Experiment:	*cpFOCE (Coral Proto FOCE)*
Research:	Carbonate chemistry, biology
Implementer:	University of Queensland
Deployment:	2009-10 Heron Island Research Station
Chambers:	3
Dimensions:	1m x 0.2m x 0.2m
ESW:	Bottled CO_2, shore based mixing/pumping station
Power:	Solar, Wind 40 W
Telemetry:	Wi-Fi, 4 Mbps

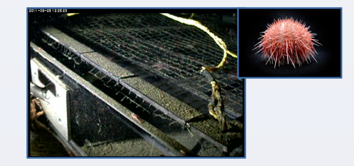
FOCE Science In Monterey Bay

Deep FOCE (dpFOCE)

The dpFOCE system performed in situ experiments in Fall 2011, including deep sea ocean chemistry and biology perturbation experiments. The effects of reduced pH on the feeding behavior of deep sea urchins (*Strongylocentrotus fragilis*) was evaluated under low pH (ΔpH= -0.3 units) and ambient conditions.

Echinoderms are important components of benthic marine ecosystems, occupying roles as predators, grazers, detritivores , and filter feeders, as well as prey for higher trophic levels. They also reshape and reprocess benthic sediments. Echinoderms are thought to be highly sensitive to ocean acidification. Several reports have noted impacts of high CO_2 levels on urchins, affecting rates of growth, survival, calcification, and mortality. dpFOCE is an ideal platform to explore long term, less-studied sub-lethal effects [7] that may present as changes in normal movement, posture and feeding rates. A poster on this work is presented at this conference (Lovera et al., *Testing the Effects of High CO_2 On the Feeding Behavior of Deep Sea Urchins*).

Urchin observation track on dpFOCE



Shallow Water FOCE (swFOCE) studies

swFOCE will be installed in mid 2013, and will support a variety of science experiments involving collaborators from the sponsoring institutions (MBARI, Center for Ocean Solutions, Hopkins Marine Station) and beyond. Initial studies will focus on the effects of ocean acidification on larval settlement and recruitment of barnacles, as well as the role of OA in mediating interactions between newly settled barnacles juveniles and their potential predators and competitors. Thus, FOCE technology will help identify the role of ocean acidification in shaping not only the performance of individual species (e.g. growth, behavior, survival, reproduction), but also the strength of biological interactions among species. swFOCE is also a demonstration of xFOCE.

Building a FOCE Community

We are working with our collaborators to build a user community around xFOCE. In the coming months, we plan to implement an xFOCE community web site, hosted by the Center for Ocean Solutions, as the place to go to for the information, technology, and news researchers need to use xFOCE.

The xFOCE site will be a place to connect with experienced users and and developers, making it easy to get started and find answers to your research questions.

The site will also provide technical resources for developers, including mechanical and electrical designs, software, documentation, vendor information, publications, and more.

More Information

xfoce.org

mbari.org

mlo.stanford.edu/kelpforest.htm

centerforoceansolutions.org

efoce.eu

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