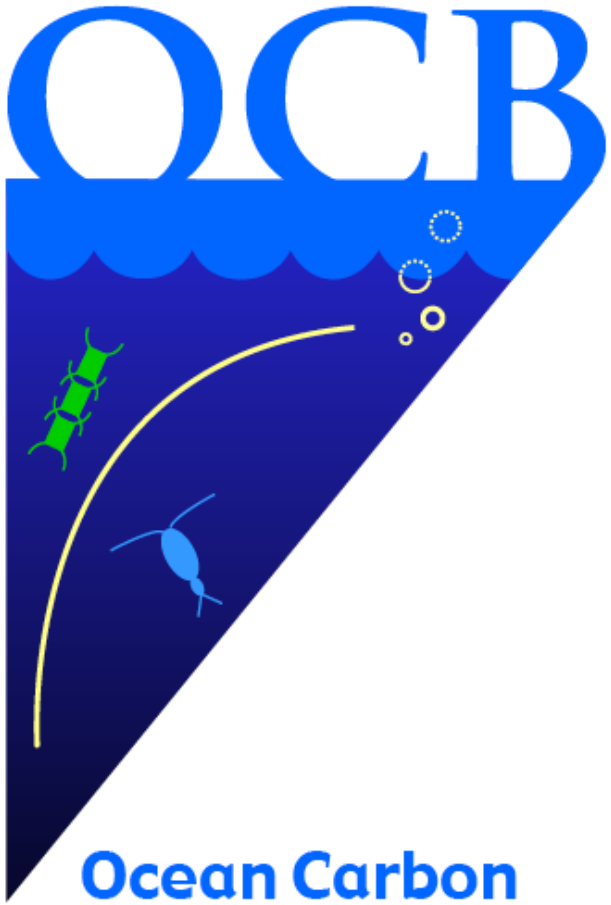


Ocean Carbon
& Biogeochemistry

Scoping Workshop on Ocean Acidification Research

9-11 October 2007

Scripps Institution of Oceanography

USGS
science for a changing world

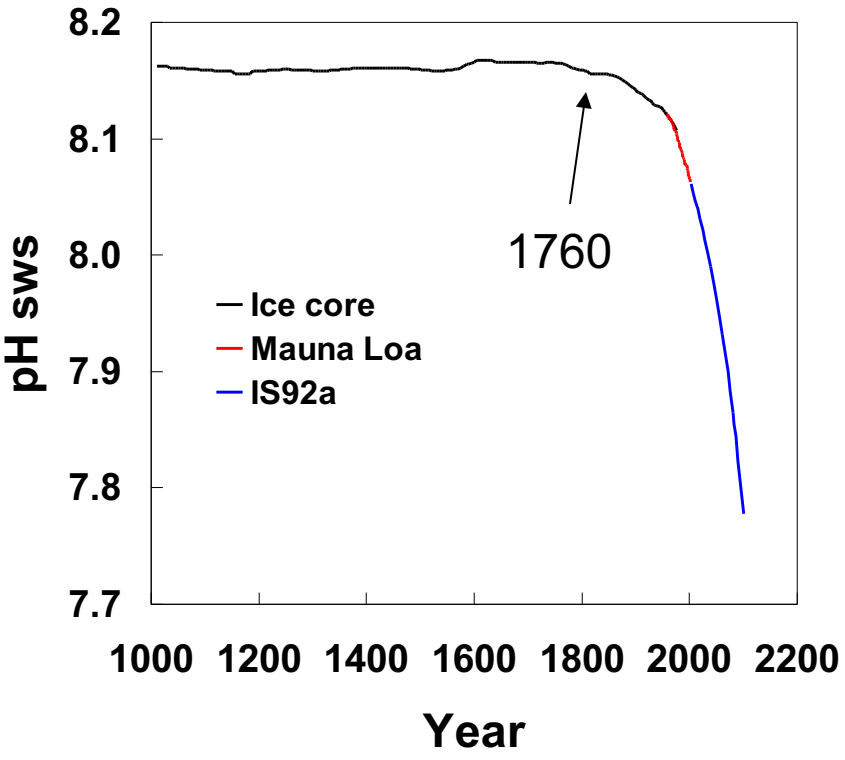
OCB
Ocean Carbon & Biogeochemistry

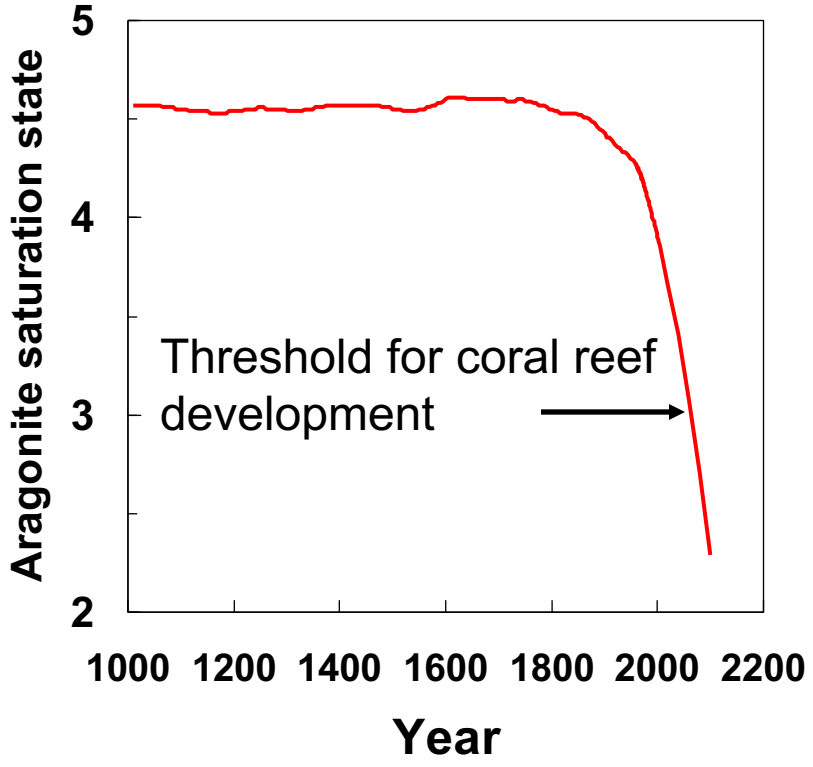
Scoping Workshop on Ocean Acidification Research

Steering Committee:

Barney Balch
Andrew Dickson
Vicki Fabry
Richard Feely
Burke Hales
David Hutchins
Joanie Kleypas
Chris Langdon
Chris Sabine

At some point in the next 100 years it is very likely that some critical thresholds will be exceeded





Ocean Carbon & Biogeochemistry

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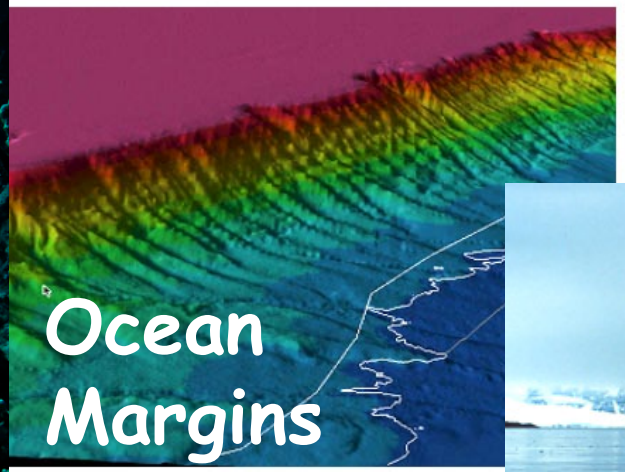
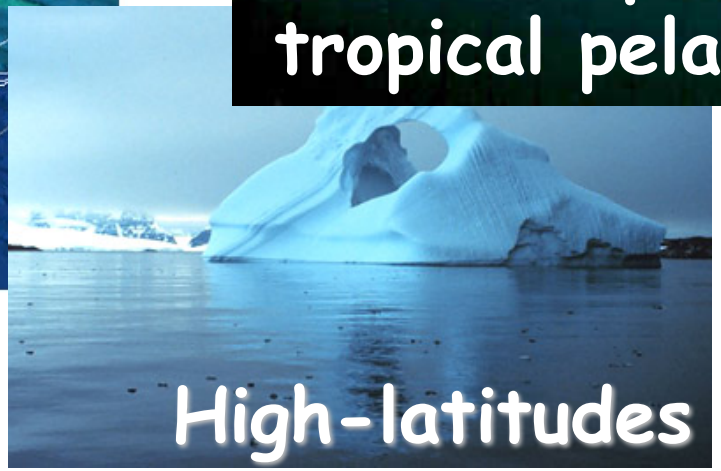
Focus on 4 Ecosystems:





Scoping Workshop on Ocean Acidification Research

Workshop Goals

- Develop coordinated research implementation strategies to address present and future ocean acidification impacts
- Identify specific activities and timelines needed to advance research priorities

Standardization of Protocols

URGENT

Measurements of inorganic carbon system in seawater

- TA, DIC and pCO_2 are preferred because CRMs or standards exist
- Send samples out for analysis if unable to run locally

Manipulation of seawater chemistry

- Bubbling with CO_2-enriched air or HCO_3^- followed by acid addition accurately simulates natural changes;
  - Acid addition alone may overestimate calcification response if organism can also utilize HCO_3^-;

Measurements of Calcification Rates

- Fully determine the carbonate chemistry at the beginning and end of experiments
- Design experiments so changes in $[CO_3^{2-}]$ are small relative to difference between treatment levels
- Urgent need for intercomparison of calcification measurements, e.g. TA, Ca, ^{45}Ca, $Ca^{14}CO_3$, PIC, skeletal denisty*extension, and buoyant weighing methodologies

Meetings to discuss protocols needed within next 6 months because work is ongoing

Establish Baselines

URGENT

- **Synthesis** - existing data on carbonate chemistry and rates of calcification/dissolution/nitrogen fixation in each habitat
- **Monitoring** of carbonate chemistry and community structure in each habitat
  - Enhance activities at existing long term time series sites
  - Identify new key regions to monitor
  - Establish new coastal time series sites from tropics to high latitudes
    - West coast needs special emphasis because of periodic aragonite undersaturation on parts of continental shelf
    - Arctic time-series site is urgently needed
- **Data management** - Ensure that data are archived and disseminated in a useful way

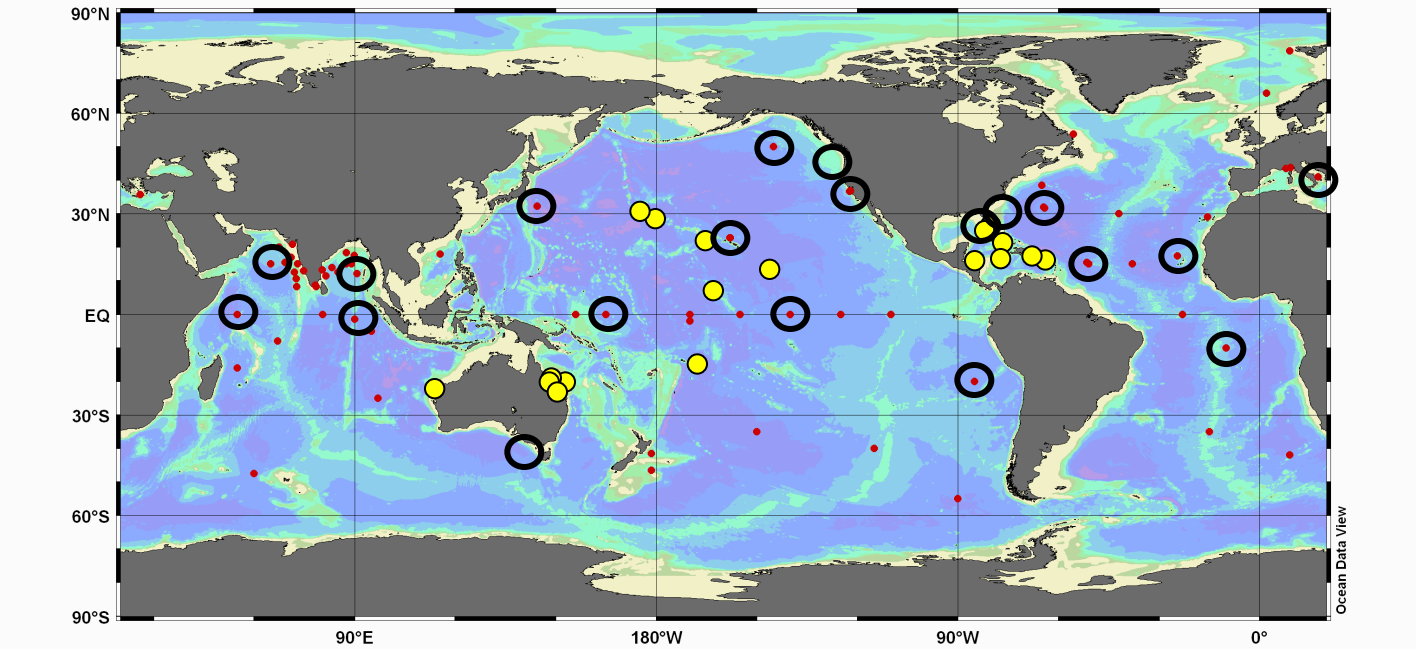
Technical needs

- Instrumentation for autonomous measurements of TA or DIC (surface & subsurface) URGENT
  - Goal: deploy at least one carbonate chemistry monitoring stations per year in each habitat (new habitats may need to be added)
- Measuring physiological stress
  - enzymes
  - Gene expression tests

NOAA Ocean Acidification Research

Developing new directions and approaches

- Mesoscale CO_2/pH perturbation experiments at the community to ecosystem level, similar to FACE experiment
- Coral reef metabolic monitoring at a variety of oceanographic settings
- Open ocean mid- to long-term perturbation experiments
- Develop international collaborations



Coral Reef Monitoring Sites Ocean Acidification Monitoring Sites

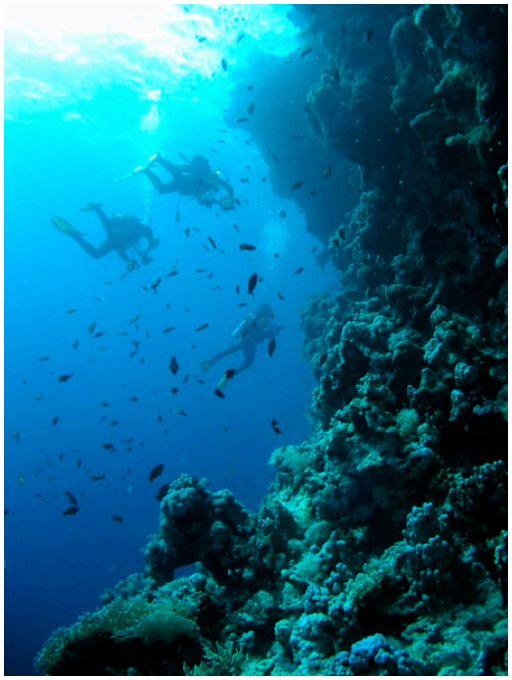
Establish Ocean Acidification Observational Network

- Urgently need to deploy OA-observing assets in each affected habitat
  - Some combination of buoys, stations that are reoccupied on a regular basis, regularly repeated survey cruises
- Need to make sure that carbonate chemistry is measured at all existing long term time series sites
- West coast needs special emphasis because of periodic undersaturation with respect to aragonite on continental shelf
- Need to set a goal of deploying 5 new time-series mooring sites each year for carbonate chemistry

Modelling

- Incorporate modelling during planning and through final stages of experiments and field observation studies
- Develop regional ecological and biogeochemical models for each habitat to assist in design of field experiments
- Use large scale global models to scale up regional OA-related effects
- Model/data intercomparison exercises to validate the models

Habitat-specific recommendations



Tropical coral reefs

ESTABLISH BASELINE: URGENT

1. Calcification/dissolution studies on a number of reefs
   - resolve differences in community structure
   - develop functional relationships with temperature, light, nutrients and saturation state
   - e.g. there are no published calcification rates for Caribbean reefs
2. low cost water sample monitoring program
   - characterize carbonate chemistry of a broad sample of reefs across the globe
   - Note that reef waters can be appreciably different than nearby oceanic waters

URGENT

MANIPULATIVE EXPERIMENTS: dissect species level responses to the combined stress of rising temperature and falling saturation state (short and long-term)

REMOTE SENSING: detect and document significant changes in benthic cover and reef framework

SCLEROCHRONOLOGY: coral growth, calcification and density

- document long term changes
- develop paleo proxies for pH ($\delta^{11}B$) or saturation state (Sr/Ca)

High latitudes

ESTABLISH BASELINE – Carbonate chemistry and distributions, abundances and calcification rates of calcareous organisms in the Ross Sea, Antarctic Peninsula and Bering Sea

URGENT

OA surveys to data-poor, high latitude areas; recommend 6 new surveys (doubling number of surveys in 5 years)

Remote sensing - satellite algorithms for basin-wide surveys of PIC concentrations to track possible changes over time

Bering Sea LTER to track 1) changes in CO_2 chemistry & calcareous biota; 2) how fisheries and marine mammal populations may be impacted by loss of key prey species; 3) possible regime shifts, etc

URGENT

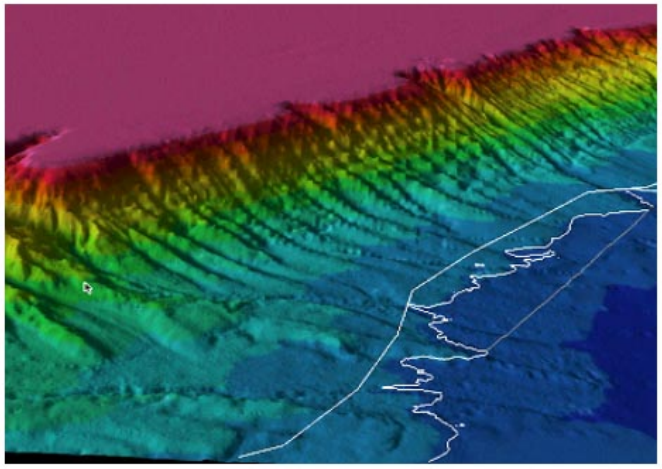
Station P - establish sediment traps (no longer being done by IOS), vertical distributions & abundances of coccolithophorids, forams and pteropods; biogeochemical processes (standing stocks and production of PIC, dissolution, primary productivity, PIC & PIC sinking fluxes, etc)

CO_2 manipulation studies are needed for following species;

URGENT

Coccolithophorids, forams, pteropods, cold-water corals, benthic molluscs, crustaceans, echinoderms, pathogens

Dissolution of biogenic carbonates, esp. high mag calcite, aragonite



Ocean margins

REPEAT COASTAL CO_2 SURVEY CRUISES – the first one last year revealed waters undersaturated with respect to aragonite all along the continental shelf of west coast of the US and at the surface near California-Oregon border

URGENT

NETWORK OF CO_2 OBSERVATIONS – moored pCO_2 sensors along west coast of North America

PROCESS CRUISES should be organized to observe the response of coastal ecosystems to transient undersaturated conditions

LAB AND MESOCOSM STUDIES are needed to observe short and long term response of commercially and/or economically important shellfish & other taxa to ocean acidification (should look at impacts on the full life cycle)

URGENT

DISSOLUTION - better quantify dissolution of biogenic carbonates, particularly high magnesium calcite and aragonite

Tropical/subtropical pelagic

Lab CO_2 studies - isolated cultures of organisms from key functional groups (e.g. N_2 fixers, calcifiers, picophytoplankton)
- Multivariate interactions with other variables
- Long term studies to look at adaptation

Ship and mesocosm based CO_2 experiments using natural communities
- Should also look at pH-mediated changes in particle aggregation, scavenging and adsorption, particulate carbon export, remineralization, bacterial production, activity of ecto-enzymes, metal speciation
- Metabolism of organisms at higher trophic levels, and on spatial and temporal shifts in species distributions and biogeochemical regimes

CO_2 gradients - upwelling regions and shallow hydrothermal vents to conduct a natural CO_2 perturbation experiment

Repeat survey cruises - detect changes across broad spatial scales of key organisms that could be related to gradients in carbonate chemistry

Time-series observations - Supplement measurements with abundance and activity of key OA-affected organisms

Next steps
(research)

- Establish standardized protocols
- Establish baseline information on abundances of likely OA- impacted organisms in each habitat
- Establish baseline rates of calcification and dissolution in each habitat
- Establish ocean acidification observing network
- Short and long-term manipulative experiments to understand the sensitivity of organisms to change in ocean chemistry

Next steps
(administrative)

- National Research Council Report on ocean acidification
- OA subcommittee that reports to OCB
  - Coordinate national research activities among Federal agencies
  - Establish international collaborations to develop global network of observations & process studies
  - Establish OA data repository in OCB data management system
  - Establish training schools for interdisciplinary OA research
  - Establish OA website & outreach programs