Russell E. Brainard

Anne Cohen (WHOI), Charles Young (UH)

NOAA Pacific Islands Fisheries Science Center

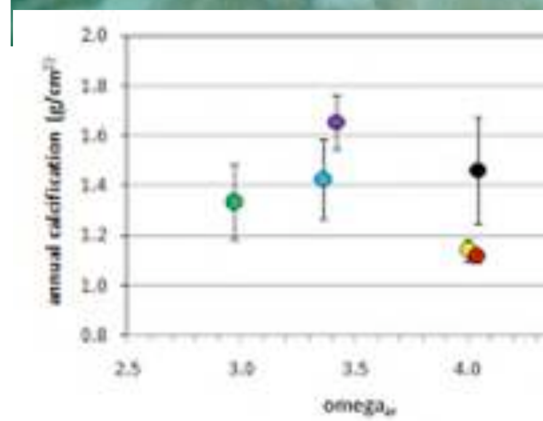
January 2010

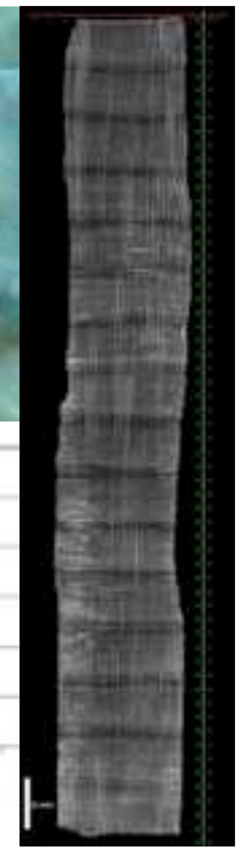
PALEO, PROXIES, & MODELING

Recent spatial and temporal historical patterns of calcification of corals across the Pacific Islands

Coring of massive corals and sampling branching corals to determine recent history of coral calcification rates across the Pacific Islands

- Using CT scan (WHOI) to examine 3-D internal structure of corals and determine calcification/extension rates
  - Sampling broadly across the Pacific Islands
  - Early findings from American Samoa, upwelling equatorial islands in central Pacific





PALEO, PROXIES, & MODELING

Bärbel Hönisch

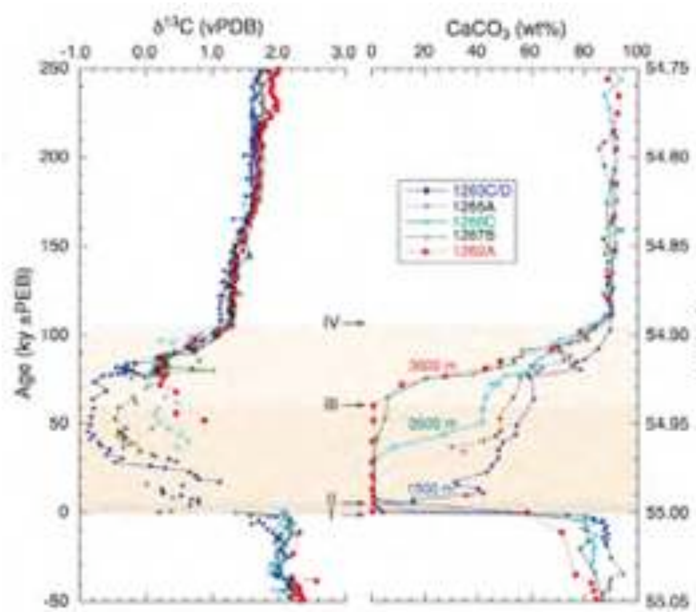
J. Zachos, E. Thomas, R. Zeebe

LDEO of Columbia University

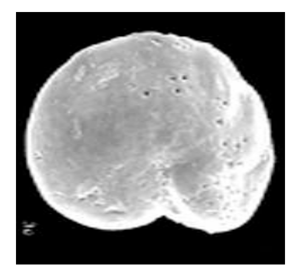
2009

Collaborative Research: Reconstructing deep-sea acidification during the Paleocene-Eocene Thermal Maximum

Boron isotopes in benthic foraminifers collected in the eastern South Atlantic suggest deep-sea pH decreased by ~0.3 units



Zachos et al. 2005



Bärbel Hönisch

LDEO of Columbia University

2008

PALEO, PROXIES, & MODELING

Validation of the B/Ca proxy for surface seawater pH and application to measure anthropogenic ocean acidification

B/Ca in cultured planktic foraminifers increases with pH and salinity but the sensitivity is low compared to glacial/interglacial pH-variations.

Bärbel Hönisch

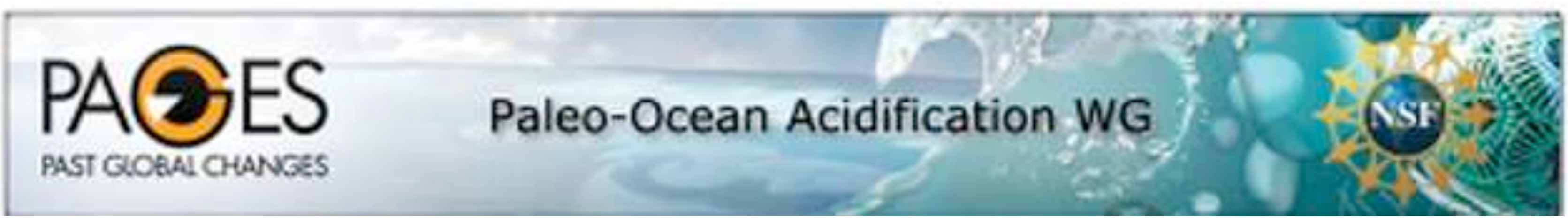
LDEO of Columbia University

D. Schmidt, S. Barker, J. Zachos, T. Kiefer

2010

Workshop on Paleo-ocean Acidification and Carbon Cycle Perturbation Events

Paleoceanographers discussed the definition of an ocean acidification event, proxy evidence for chemical and physical ocean changes and biological consequences. A synthesis report is in preparation.



Bärbel Hönisch

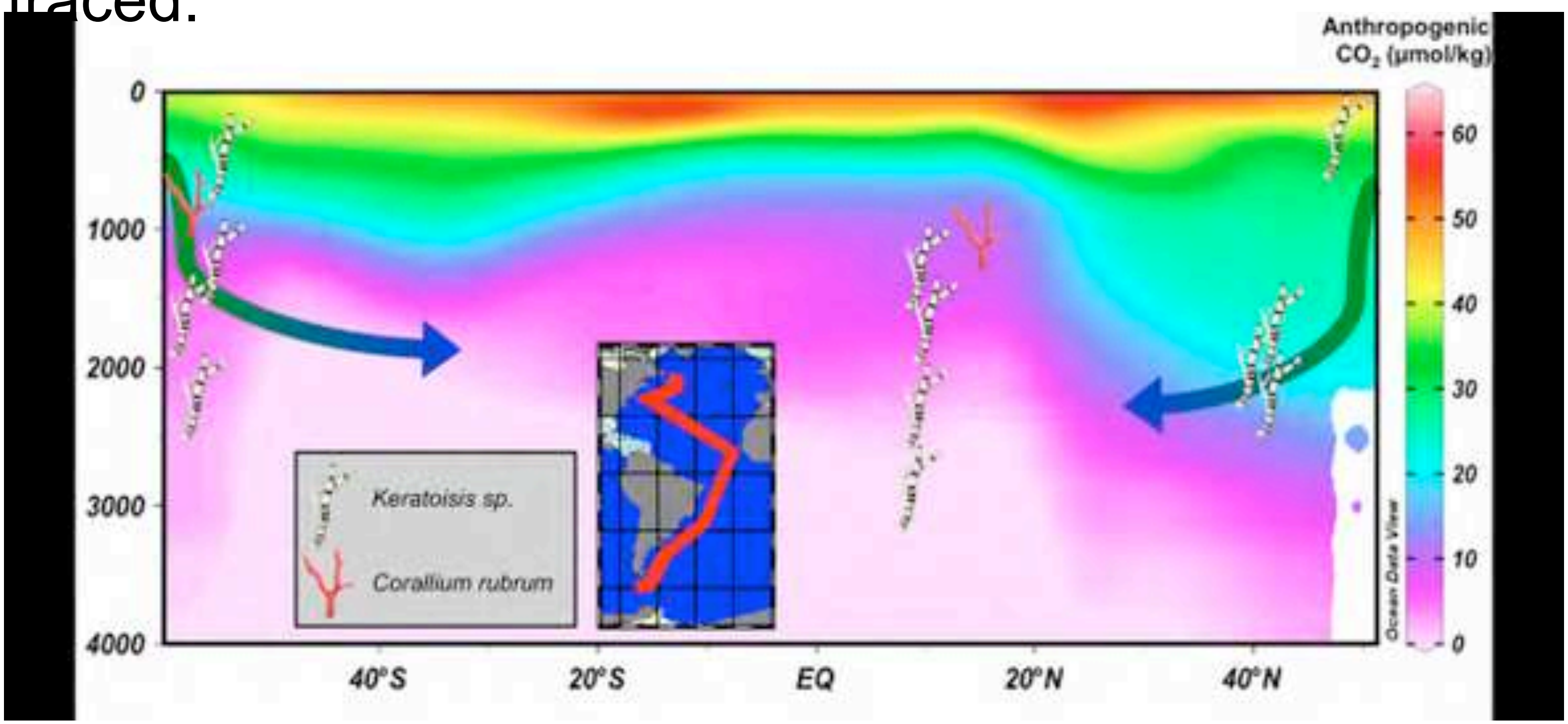
LDEO of Columbia University

2010

PALEO, PROXIES, & MODELING

Ocean Acidification - Category 1: Calibration and application of the boron isotope seawater-pH indicator in deep-water corals

Live-collected deep-sea (bamboo) corals will be calibrated for boron isotopes and B/Ca and anthropogenic OA will be traced.



Lisa A. Levin

Ariel Anbar; Achim Herrmann; Gwyneth Gordon (ASU)
Mike Navarro; Christina Tanner (SIO)

Scripps Institution of Oceanography

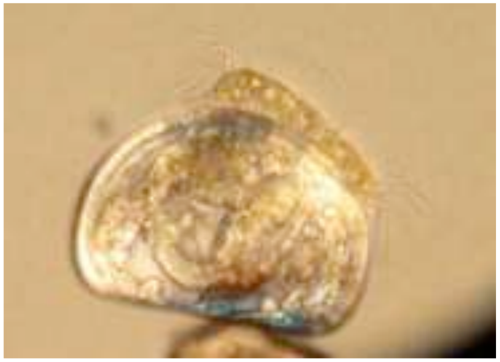
July 2011

PALEO, PROXIES, & MODELING

Development of geochemical proxies to evaluate larval pH-exposure history

To develop proxies to determine pH exposure history for living organisms in their larval state.

- Lab rearing experiments with controlled pH and O_2:
  - *statoliths of market squid embryos
  - *prodissoconch of mussel larvae
- Trace elements (Mg, Mn, Pb, Cu, U, Ba, Sr, B)
- Isotopic ratios (δ^{11}B, δ^{238}U and δ^{44}Ca)



Adina Paytan

A. Russell & T. Hill

UCSC

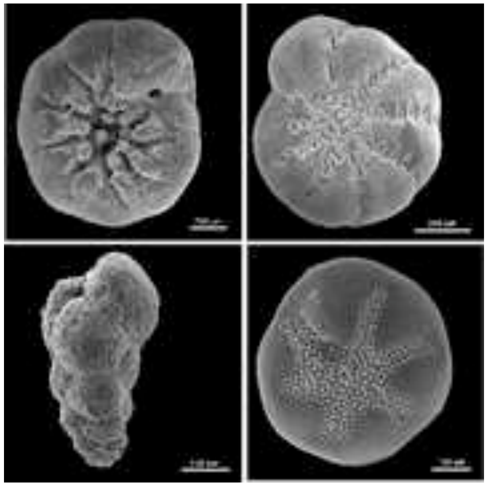
June 2009

PALEO, PROXIES, & MODELING

Acidification of California coastal waters: A geologic record of natural and anthropogenic pH variability

Reconstruct paleo-pH along the CA coast

- Interesting info about project
  - **Location** – CA coast cores (Santa Monica, Santa Barbara, Elkhorn)
  - **Early results** – B/Ca Calibration for Pacific G. bulloides different than Atlantic data.



Justin B. Ries

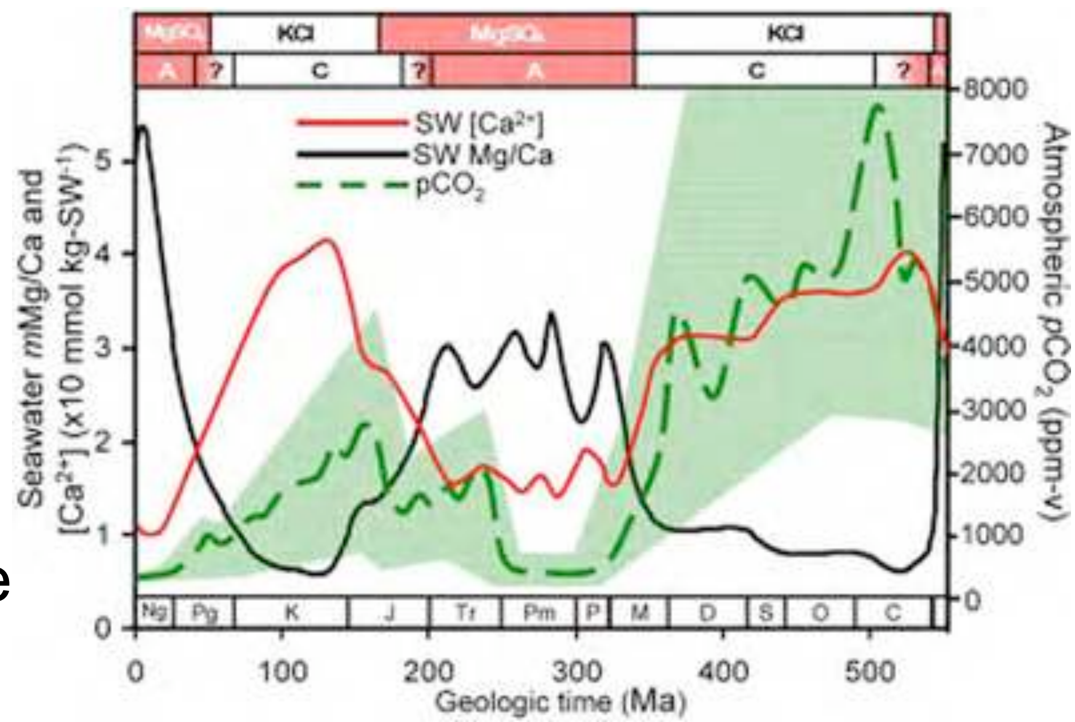
UNC – Chapel Hill

July 2010

PALEO, PROXIES, & MODELING

Geochemical and petrographic investigation of a novel calcite-aragonite sea transition in terminal Proterozoic time (American Chemical Society #50214-DNI8)

Using geochemical and petrographic information within limestones of terminal Proterozoic age (549-548 Ma) to reconstruct changes in seawater Mg/Ca ratios and their impact on the earliest metazoan marine calcifiers (Namacalathus and Cloudina)



Ries, 2010, Biogeosciences

Justin B. Ries

Karl Castillo

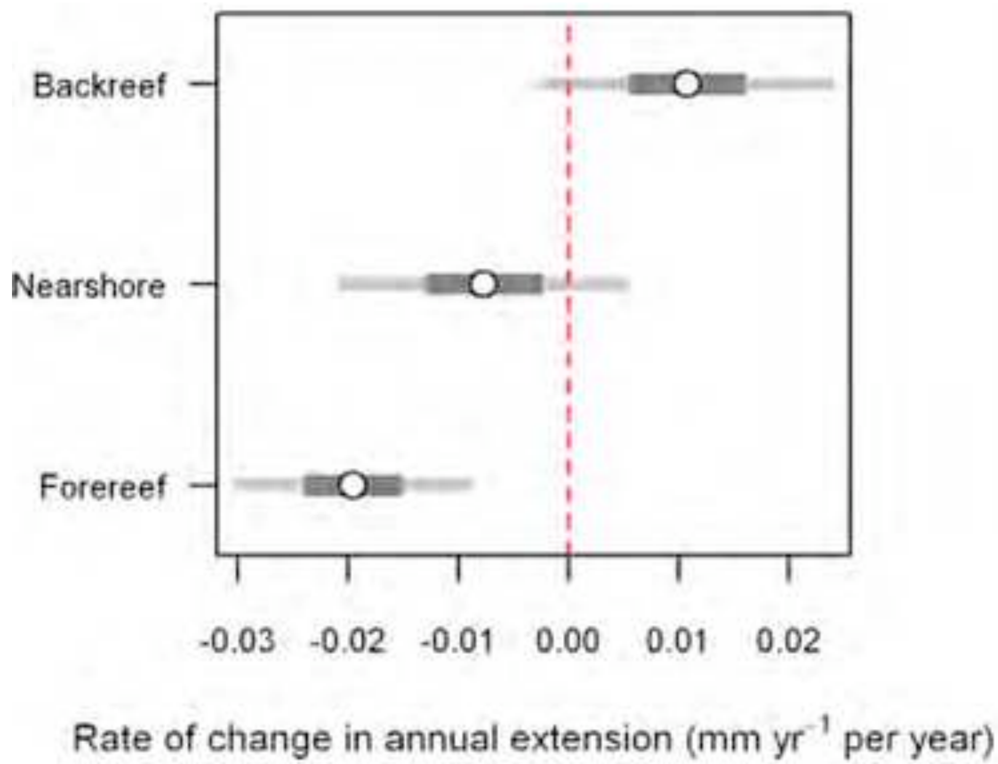
UNC – Chapel Hill

February 2009

PALEO, PROXIES, & MODELING

Reconstructing the impact of thermo-chemical changes in Carribbean seawater on coral extension rates over the past century

Coral extension rates, paleotemperatures and paleo-seawater-pH are being reconstructed for the past century from 13 cores obtained from nearshore, backreef, and forereef colonies of the reef-building coral *Siderastrea siderea* (Meso-american Barrier Reef System).



Castillo, Ries, Weiss, 2011, PLoS ONE

Tim Wootton

Cathy Pfister, Albert Colman, Pam Martin

University of Chicago

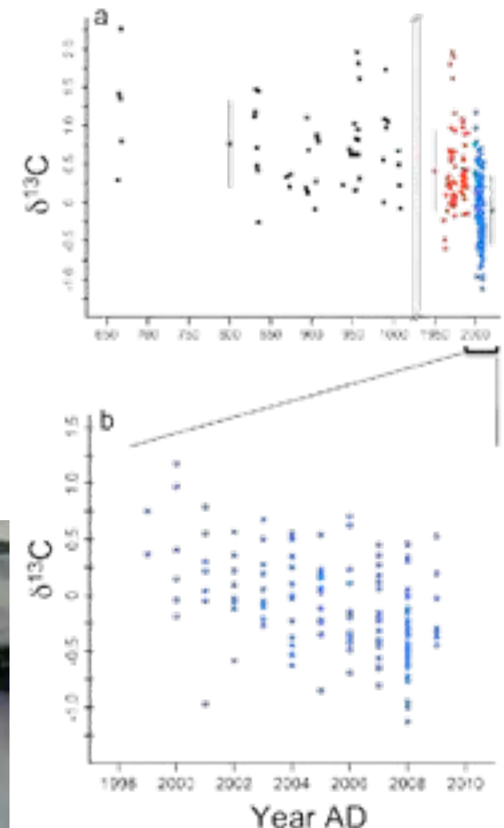
Unfunded

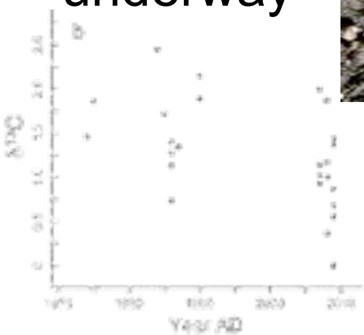
PALEO, PROXIES, & MODELING

Historical Context of Rapid pH Decline

Use historical and modern shell material to explore whether observed pH change is unusual over the past 2300 yr

- ✓ Tatoosh Island, WA, has unique record of shell material: 45 yr of intensive ecological research, >2300 yr of shellfish harvest by Makah tribe.
- ✓ $\delta^{13}C$ in mussels declines with measured pH
  - – Historically unprecedented
  - – Limpets also show decline
- Analysis of rare earth and trace elements underway





Kimberly K. Yates

R. Moyer (lead, Mendenhall Fellow)

U.S. Geological Survey

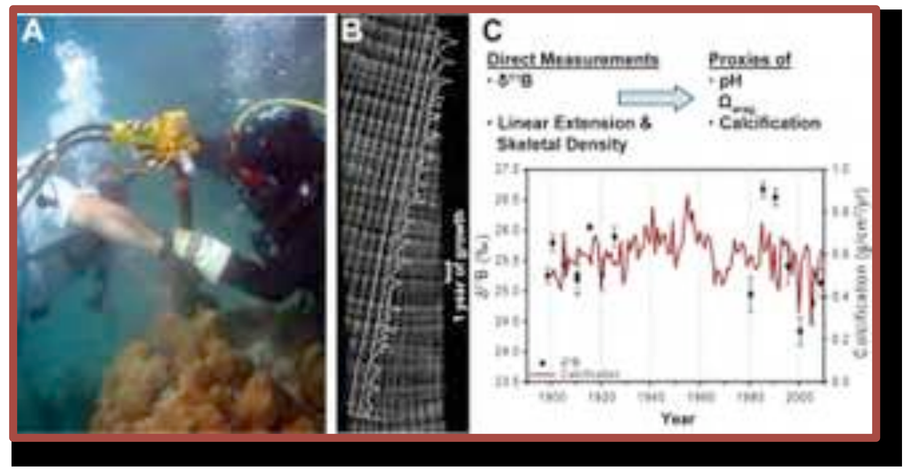
November 2008

PALEO, PROXIES, & MODELING

Coral Reef Calcification: Past, Present, Future

Measure modern and historical rates of coral calcification and reconstruct past changes in seawater pH

- Locations
  - Florida Keys, Puerto Rico
- ✓ Measured in coral cores
  - Linear growth rate & density
  - Boron isotopes as pH proxy
- ✓ Measured modern growth rates
- Will model change in coral growth and seawater pH from pre-industrial to present



James C. Zachos

UCSC

B. Hönisch, R. Zeebe, E. Thomas

May 2009

PALEO, PROXIES, & MODELING

Collaborative Research: Reconstructing deep sea acidification during the Paleocene-Eocene Thermal Maximum

A model/proxy comparison of the changes in seawater pH and $\Delta[CO_3^{2-}]$ in response to a massive (>4500 Pg) C release.

- Interesting info about project
  - Primary Objective: to establish timing and magnitude of changes in surface and deep sea carbonate saturation using B isotope and B/Ca proxies of pH and $\Delta[CO_3^{2-}]$
  - Includes a modern core-top calibration of B/Ca in extant and descendent species of Eocene benthic foraminifera, *Oridorsalis umbonatus* and *Nuttalides umbonifera*
  - Locations: Shatsky Rise, Walvis Ridge
  - The B/Ca ratios of mixed-layer planktonic foraminifera indicate a large, sustained decline in surface saturation.

James C. Zachos

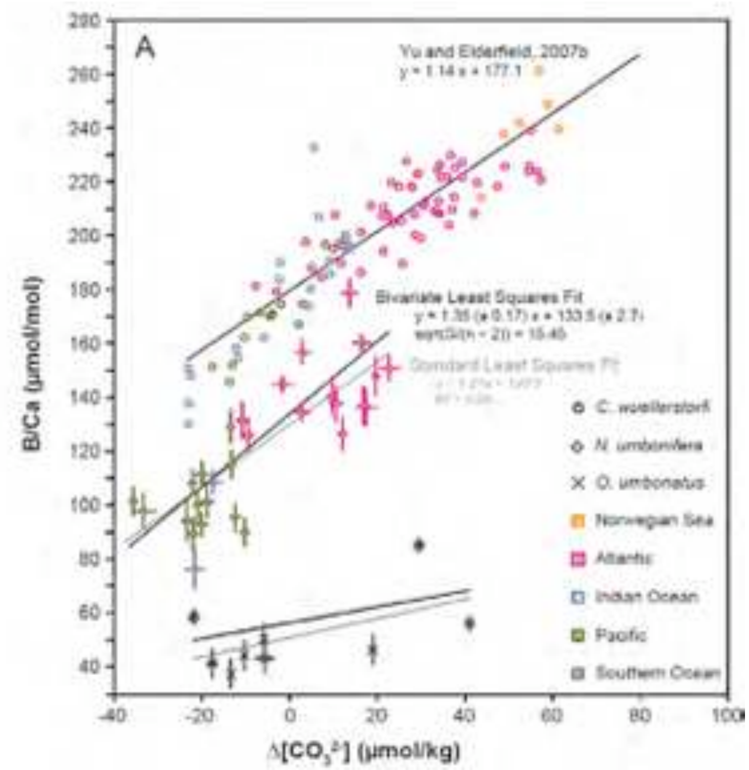
UCSC

B. Hönisch, R. Zeebe, E. Thomas

May 2009

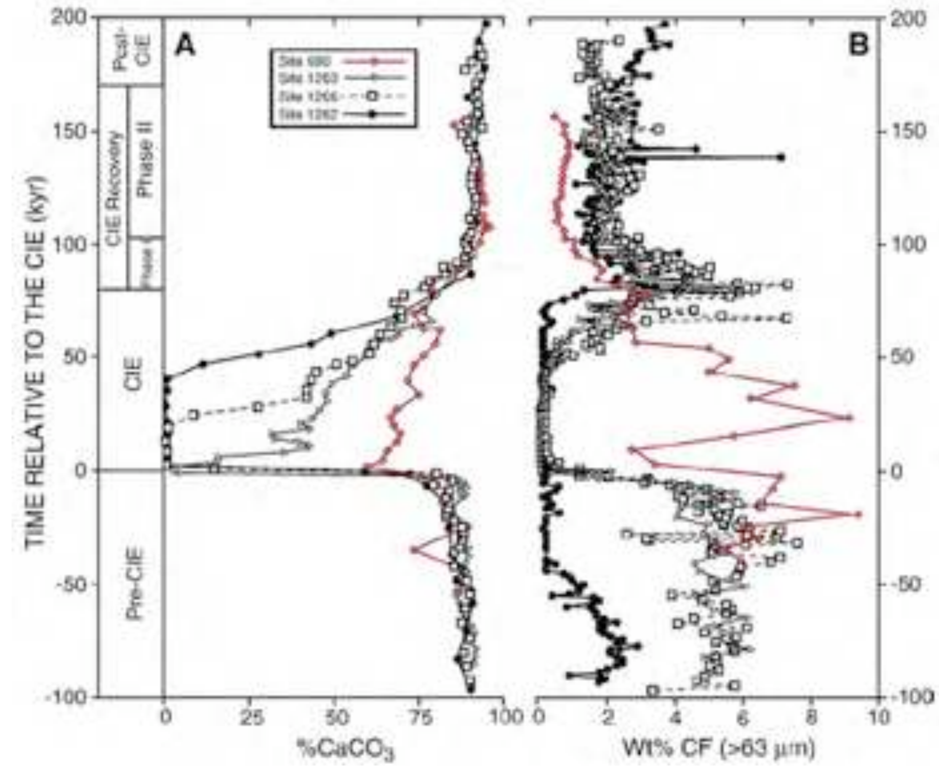
PALEO, PROXIES, & MODELING

Core Top B/Ca Calibration



Brown et al., submitted

PETM Dissolution Horizon



Kelly et al., 2010

Richard E. Zeebe

SOEST, Univ. Hawaii

J. Zachos and 8 other PI's

06/01/2006

PALEO, PROXIES, & MODELING

Collaborative Research: Dynamics of carbon release and sequestration: Case studies of two early Eocene hyperthermals

Publications:

Zeebe, R. E. and J. C. Zachos., "Reversed deep-sea carbonate ion basin-gradient during Paleocene-Eocene Thermal Maximum.", *Paleoceanography*, PA3201, vol. 22 (2007).

Zachos, J. C., G. R. Dickens, and R. E. Zeebe, "An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics.", *Nature*, p. 279, vol. 451, (2008).

Zeebe, R. E., Zachos, J. C., and G. R. Dickens., "Carbon dioxide forcing alone insufficient to explain Paleocene-Eocene Thermal Maximum warming", Nature Geoscience (2009).

Stuecker, M. F., and Zeebe, R. E, "Ocean chemistry and atmospheric CO2 sensitivity to carbon perturbations throughout the Cenozoic", *Geophys. Res. Lett.*, p. , vol. 37, (2010).

Uchikawa, J. and R.E. Zeebe, "Examining possible effects of seawater pH decline on foraminiferal stable isotopes during the Paleocene-Eocene Thermal Maximum", *Paleoceanography*, PA2216, vol. 25, (2010).

Richard E. Zeebe SOEST, Univ. Hawaii

J. Zachos, B. Hoenisch, E. Thomas

07/01/2009

PALEO, PROXIES, & MODELING

Collaborative Research: Reconstructing deep sea acidification during the Paleocene-Eocene Thermal Maximum

Publications:

Komar, N. and R. E. Zeebe, "Changes in oceanic calcium from enhanced weathering did not affect calcium-based proxies during the Paleocene-Eocene Thermal Maximum", Paleoceanography, in revision (2011).

Lori Adornato

Kaltenbacher, Byrne

SRI International

September 2010

OBSERVATIONS & MONITORING

Collaborative Research: Development of an in situ sensor for high-resolution measurements of total dissolved inorganic carbon

Develop and test a total carbon (C_T) measurement capability on the in situ Spectrophotometric Elemental Analysis System (SEAS) platform.

- ✓ Design and fabricate optical cell
- ➢ Conduct lab tests
- Characterize C_T measurement temperature dependence
- Field test
- Collect concurrent pH and C_T field data
- Publish results

Simone Alin

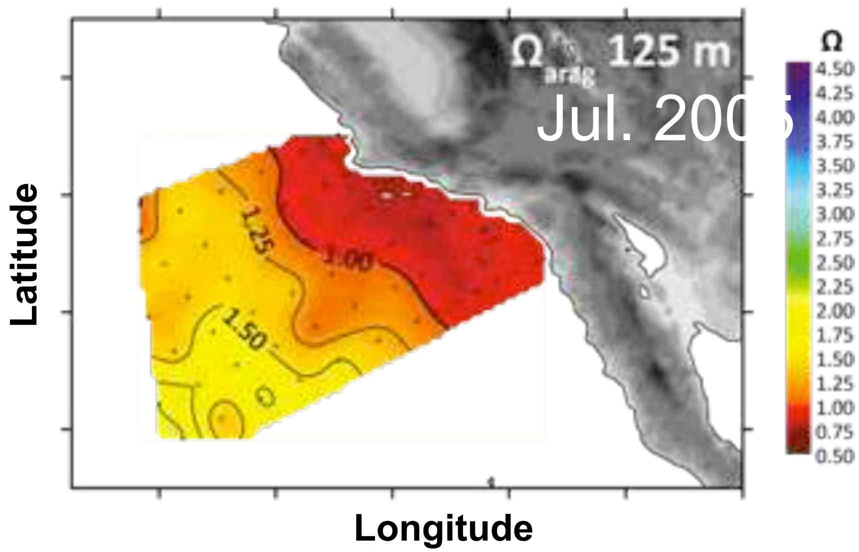
NOAA/PMEL and others

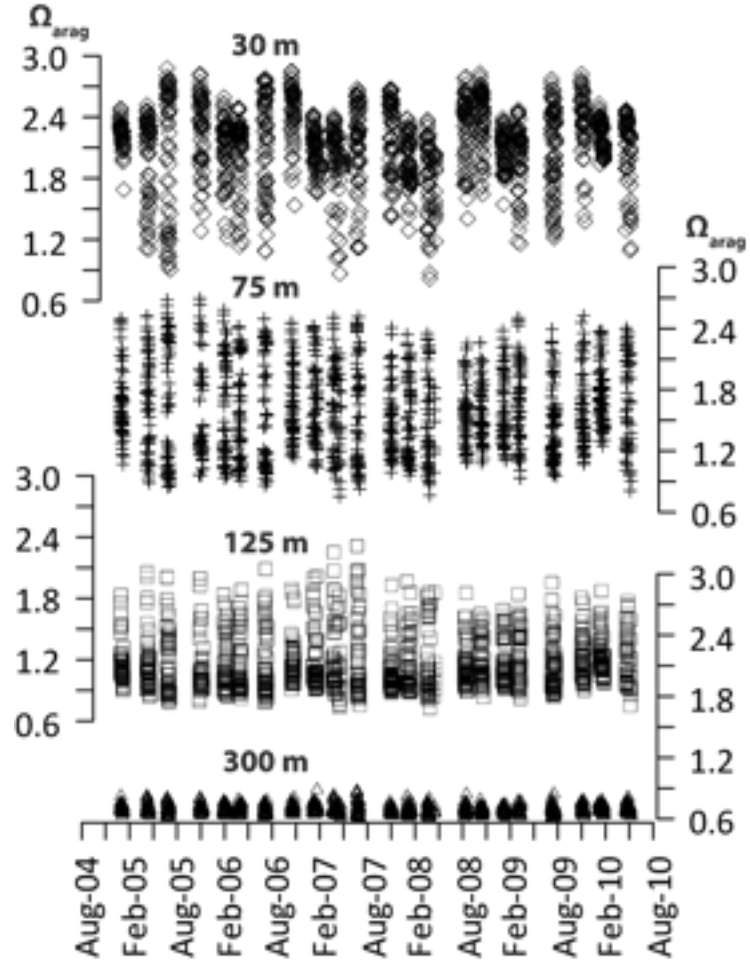
R. Feely, A. Dickson, M. Hernandez, L. Juranek,
M. Ohman, R. Goericke

OBSERVATIONS & MONITORING

Reconstructing OA Conditions in the Southern California Bight

Saturation states and *p*H for 2005−2010 reconstructed from CalCOFI oxygen and T (°C) data for southern California Current System





James K B Bishop

Univ. Cal., Berkeley

WETLabs, Inc.; Scripps Inst Dev Group

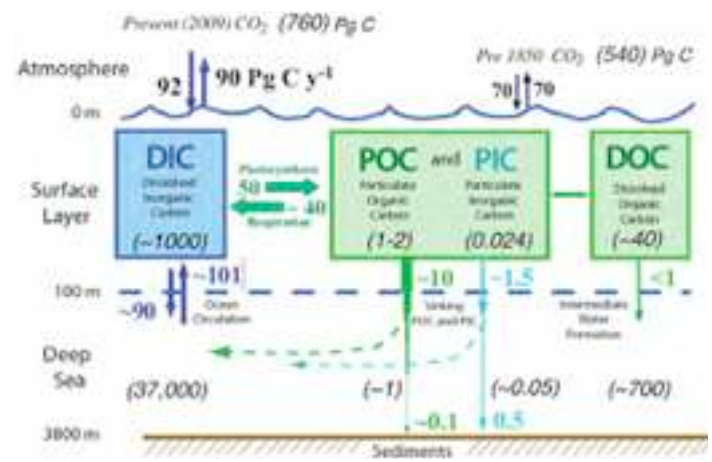
OCE 09654888 July, 2010

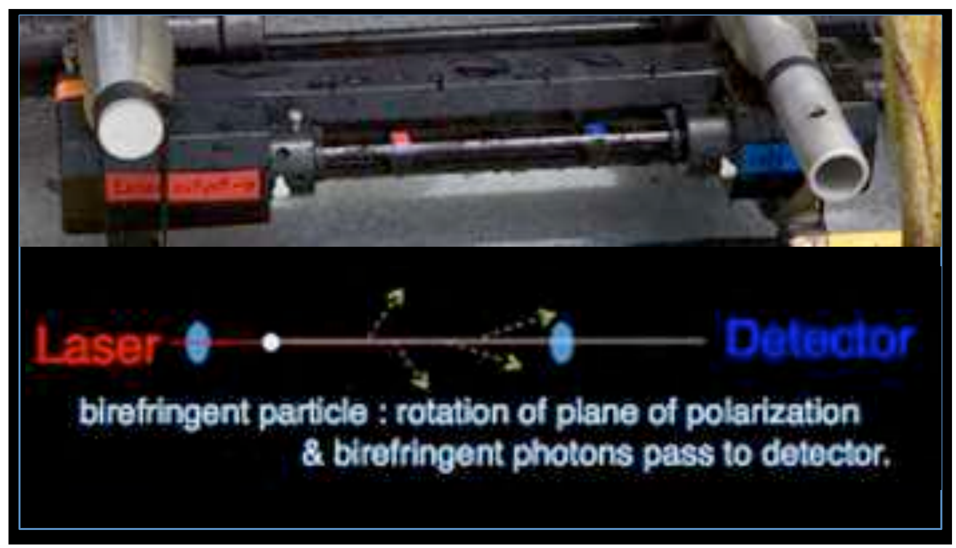
OBSERVATIONS & MONITORING

Autonomous Particulate Inorganic Carbon (PIC) Sensor

PIC concentration sensor for CTDs / ARGO floats. $CaCO_3$ dynamics.

- ✓ Next Gen. Design: optics & electronics.
- ○ Thermal/Pressure Testing (in progress)
- • Ship CTD deployment calibration (May, July, Aug 2011)
- • Carbon Explorer Float deployment (2012) subarctic N Pacific.





James K B Bishop

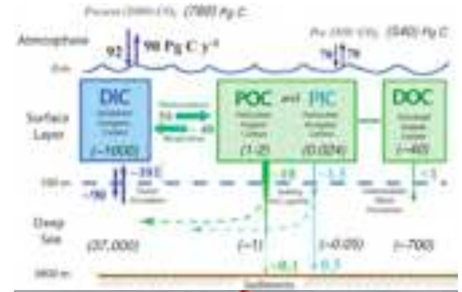
Univ. Cal., Berkeley

LBNL and Scripps Inst. Dev. Group

OCE 0936143, October, 2009

OBSERVATIONS & MONITORING

Carbon FLUX Explorer Development



sedimentation sensor on profiling float.

- 3 Imaging modes.

Part. Org. C/ Inorg. C Flux.

- twilight zone deployment (100-1500 m)

- Real Time 24/7/365 observations.

- ✓ Next Gen. Design: Imager/Systems
- ✓ Bench/Lab Testing; Ballasting
- ✓ Field test (October 2011)
- ○ Finalize Design (in progress)
- • Field Testing 3 CFE's (May, July - Aug 2011)
- • Operational Deployment (2012)

Russell E. Brainard

Richard Feely, Anne Cohen, Nichole Price,
Molly Timmers, Charles Young, Nancy Knowlton

NOAA Pacific Islands
Fisheries Science Center

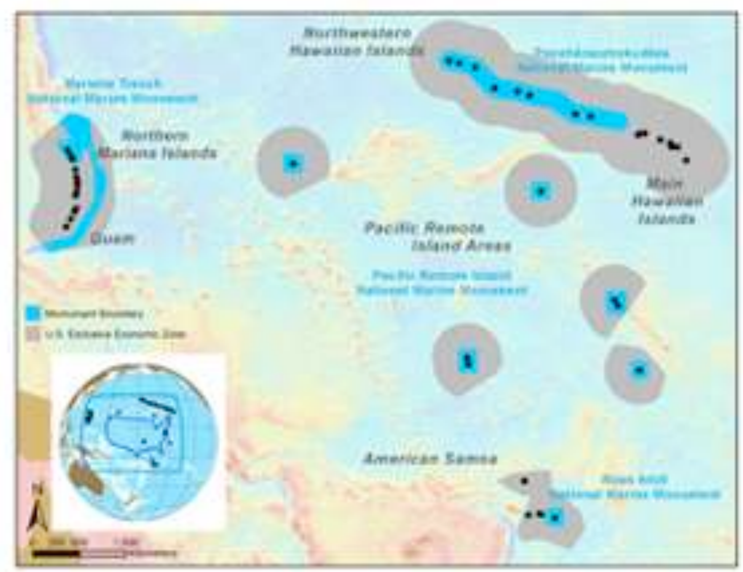
January, 2006

OBSERVATIONS & MONITORING

Monitoring Ecological Impacts of Ocean Acidification Across the Pacific Islands

Conduct interdisciplinary integrated monitoring of the ecological impacts of ocean acidification across the U.S. Pacific Islands.

- Monitor spatial and temporal patterns of carbonate chemistry
- Monitor calcification rates of corals and crustose coralline algae
- Monitor cryptic biodiversity

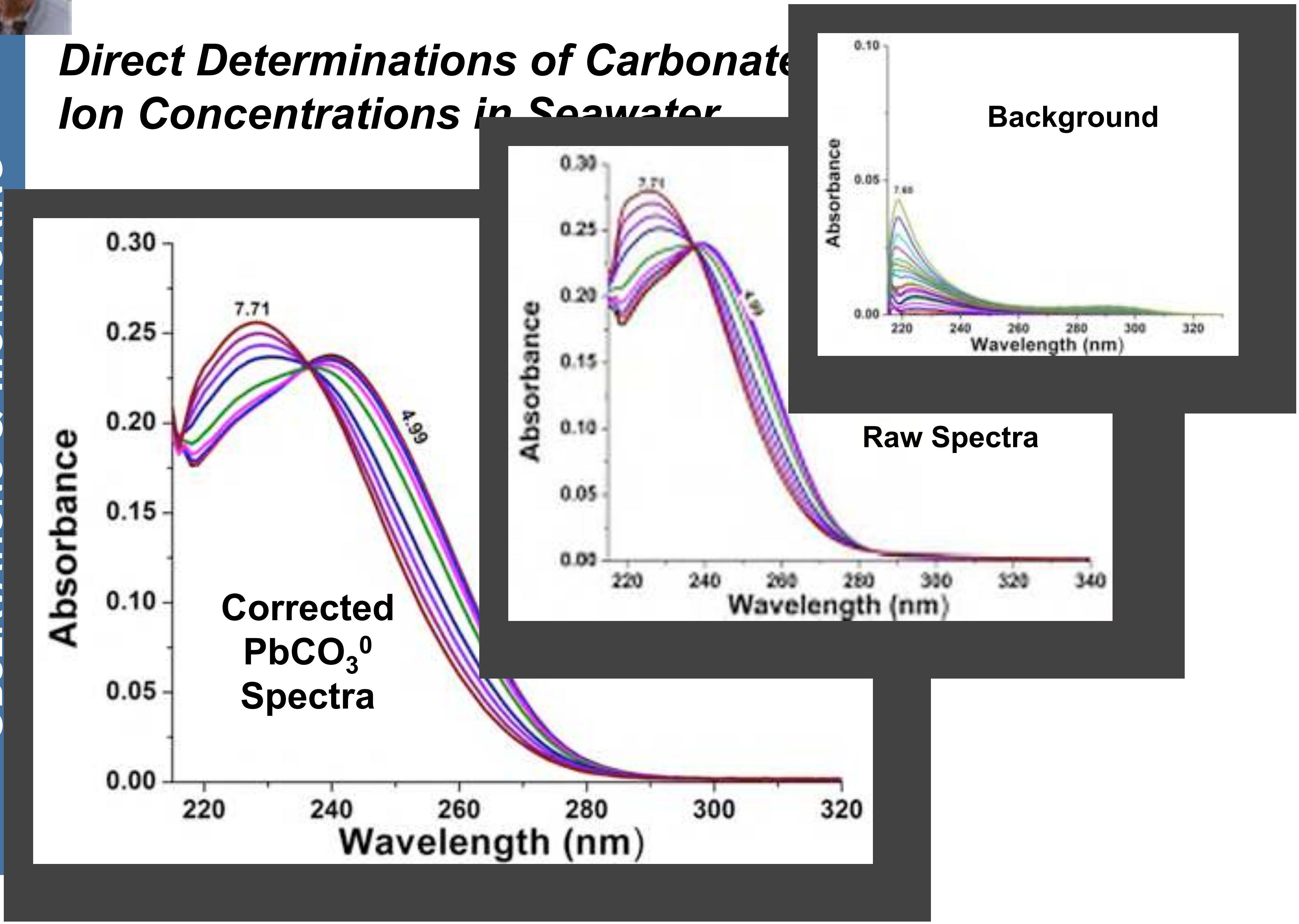


Robert H. Byrne

University of South Florida
March, 2011

OBSERVATIONS & MONITORING

Direct Determinations of Carbonate Ion Concentrations in Seawater

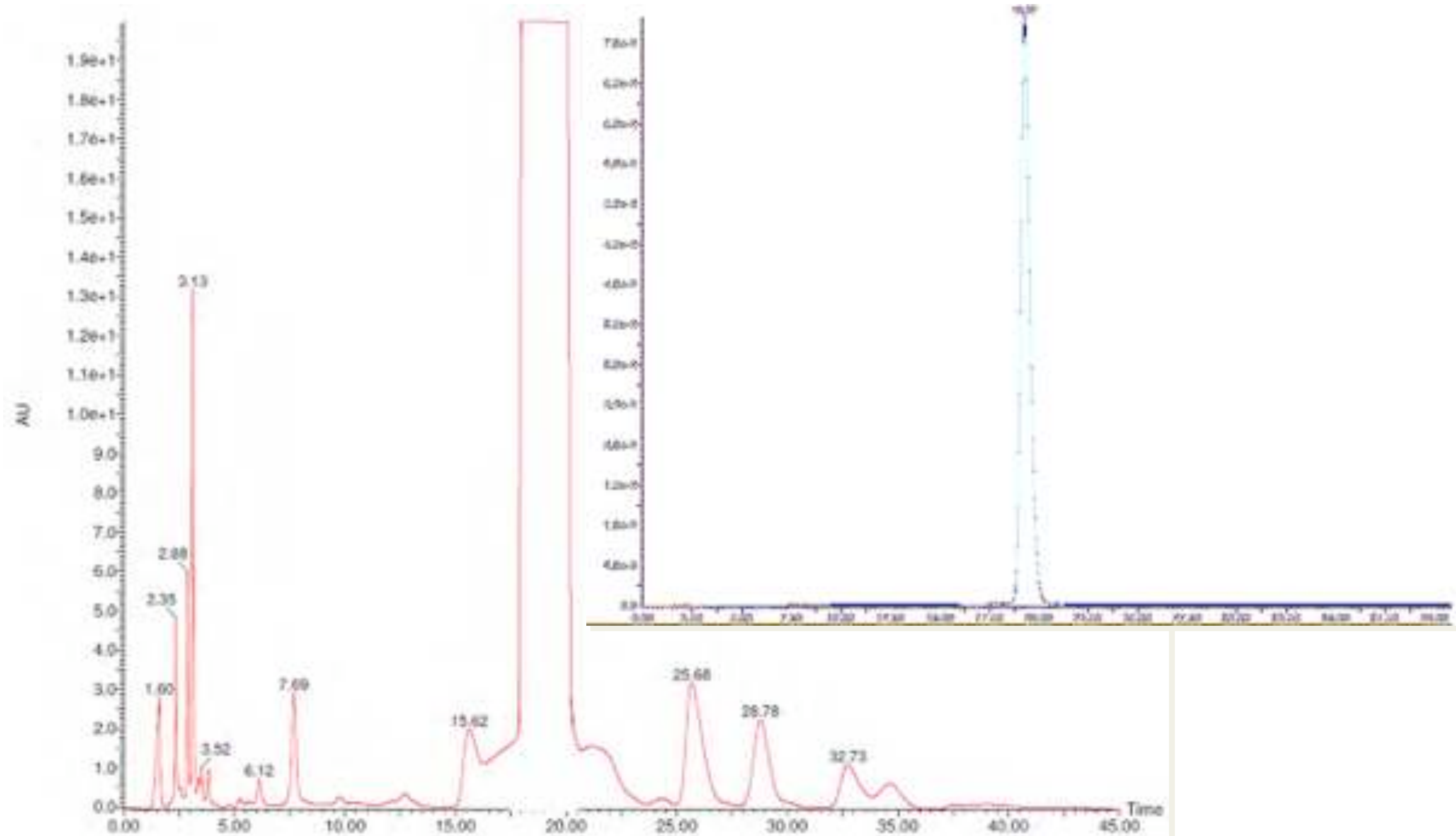


Robert H. Byrne

University of South Florida
March, 2011

OBSERVATIONS & MONITORING

Purification of meta Cresol Purple for Measurements of Solution pH



Chromatographs of raw and purified m-cresol purple

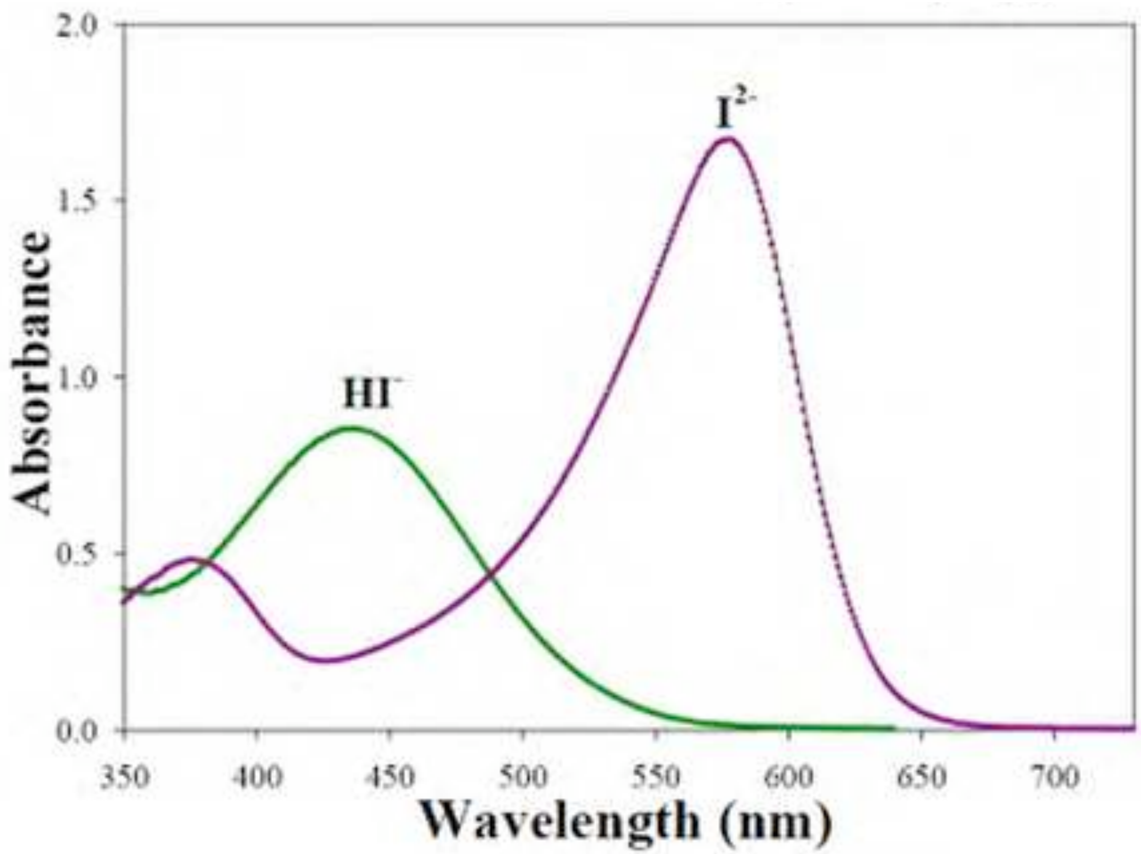
Robert H. Byrne

University of South Florida
March, 2011

OBSERVATIONS & MONITORING

Characterization of mCP Absorbance Ratios and Equilibrium Behavior in Seawater

$$pH = -\log(K_2^T \cdot e_2) + \log\left(\frac{R - e_1}{1 - Re_3/e_2}\right)$$



Wei-Jun Cai

Hu & Noakes at UGA, C. Sabine
and others at NOAA-PMEL

University of Georgia

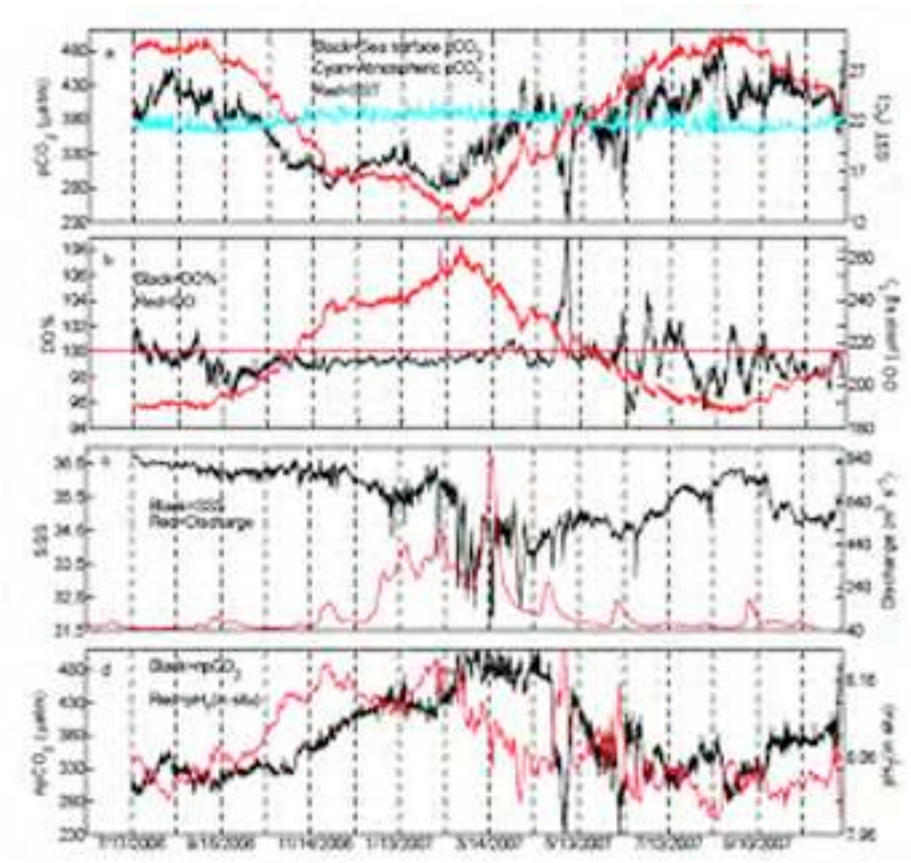
June, 2010

OBSERVATIONS & MONITORING

NOAA National OA Monitoring Program, Grays Reef NMS site (offshore GA)

Collect and interpret high resolution *p*CO_2 and pH data at NOAA buoy 41008.

- ✓ Collected surface water *p*CO_2 data since 2006
- ✓ Collected surface water pH data since 2010
- ✓ Collected bottom water data
- ✓ Data interpretation (This site is controlled largely by SST but also affected by river inputs).



OBSERVATIONS & MONITORING

Francis Chan

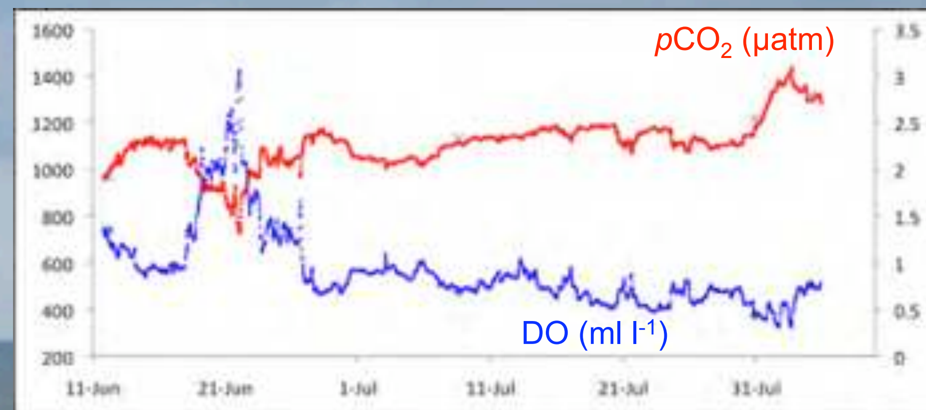
Bruce Menge

Oregon State University

August 2009

EAGER: Initiation of a pH/pCO_2-sensing mooring platform on the Oregon coast

- Evaluate the feasibility of maintaining continuous pH and pCO2 time-series
- Examine the scales of variability in OA stress and its coupling to low-oxygen stress in an upwelling shelf



PISCO
Partnership for Interdisciplinary Studies of Coastal Oceans

Chavez, Friederich, Barth, Chan, Hill, McManus, Russell, Washburn

MBARI, OSU, UCD, UCSB

Blanchette, Gaylord, Hofmann, Menge, Palumbi, Raimondi, Sanford

October, 2010

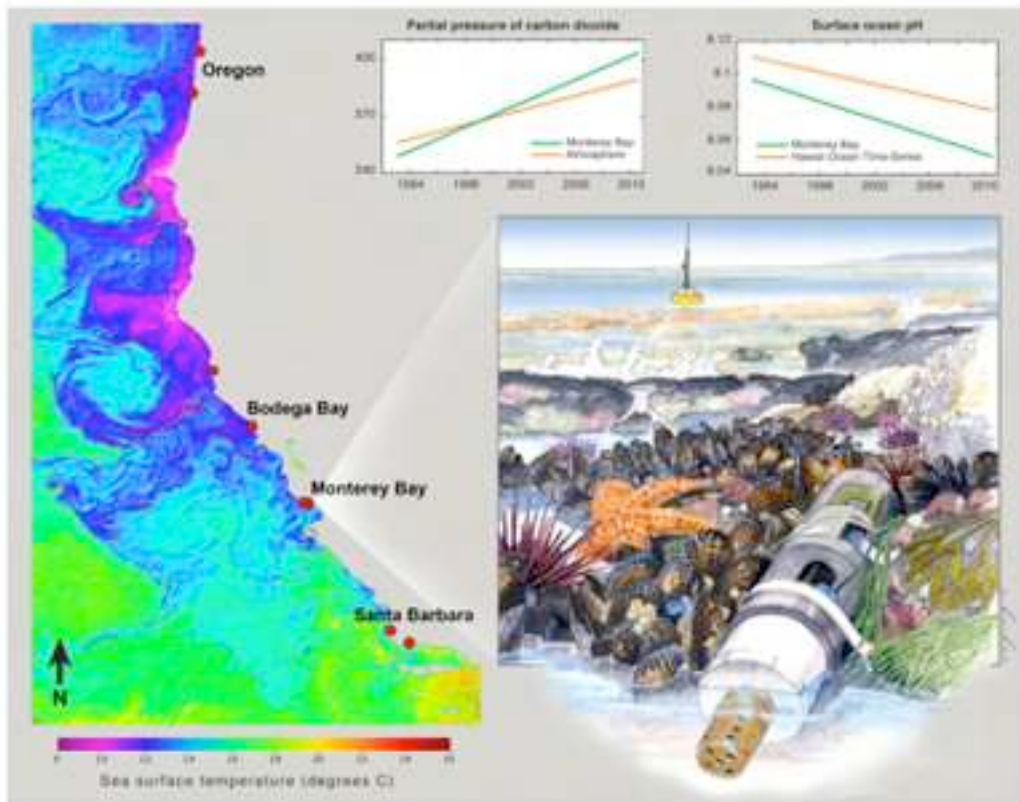
OBSERVATIONS & MONITORING

Collaborative Research: Acclimation and adaptation to ocean acidification of key ecosystem components in the California Current Large Marine Ecosystem

Develop, test and deploy a pH sensor for the intertidal.

Provide ocean context

- ✓ Develop
- ✓ Test
- ✓ Field test
- Deploy April 1
- Moorings, ships
- Physics
- Seawater chemistry



Michael DeGrandpre

Jim Beck, Andrew Dickson

University of Montana

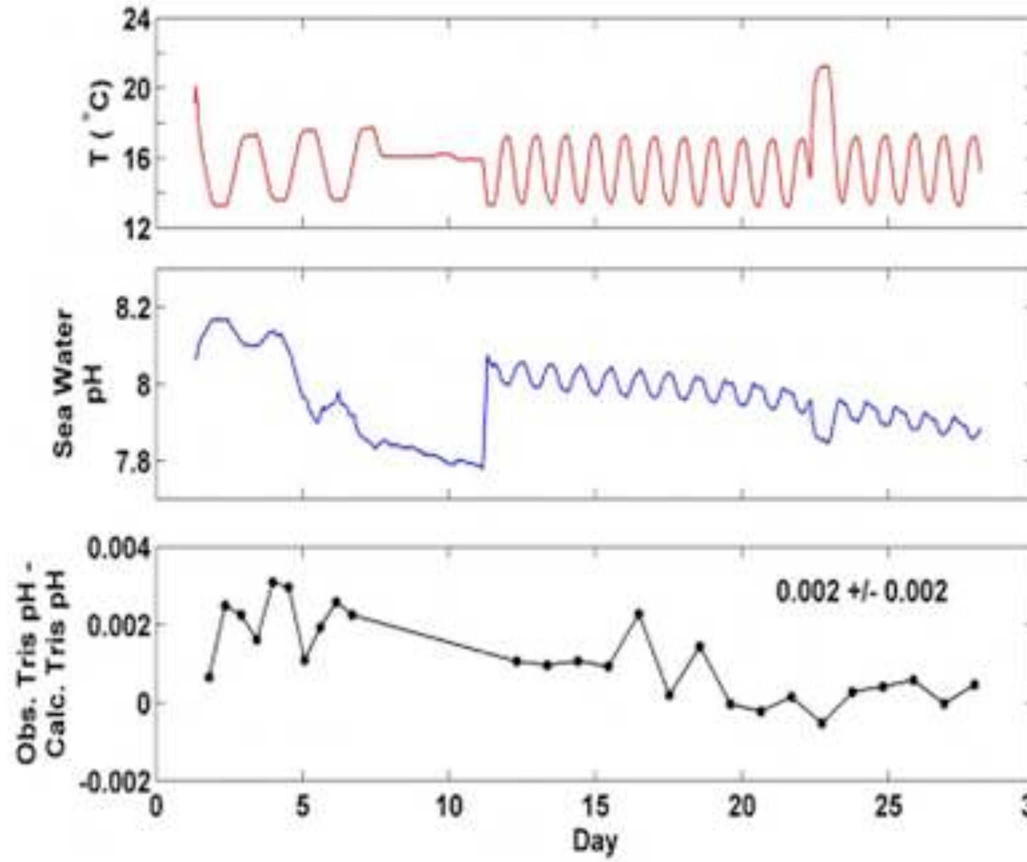
August 2008

OBSERVATIONS & MONITORING

Collaborative Research: An autonomous indicator-based pH sensor for oceanographic research and monitoring

Commercialize an autonomous, in situ indicator-based pH sensor for ocean measurements.

Results from the tank testing of a SAMI-pH instrument configured to occasionally measure the pH of a Tris buffer (at the instrument temperature) so as to provide quality control.



Andrew Dickson

UC San Diego

April 2010

OBSERVATIONS & MONITORING

The quality control of oceanic CO_2 measurements: Preparation, certification, and distribution of reference materials.

Seawater based reference materials certified for total alkalinity, total dissolved carbon dioxide; pH reference materials based on Tris buffers in synthetic seawater

- ✓ Distribute ~8,000 bottles of seawater RM per year
- ✓ Prepare prototype batches of Tris buffer
- Start preparing Tris buffers for regular distribution
- Assess overall uncertainty of certified values assigned to reference materials

Richard A. Feely[1]

[1]PMEL/NOAA, [2]OSU

S. Alin[1], L. Juranek[1], C. Sabine[1] and B. Hales[2]

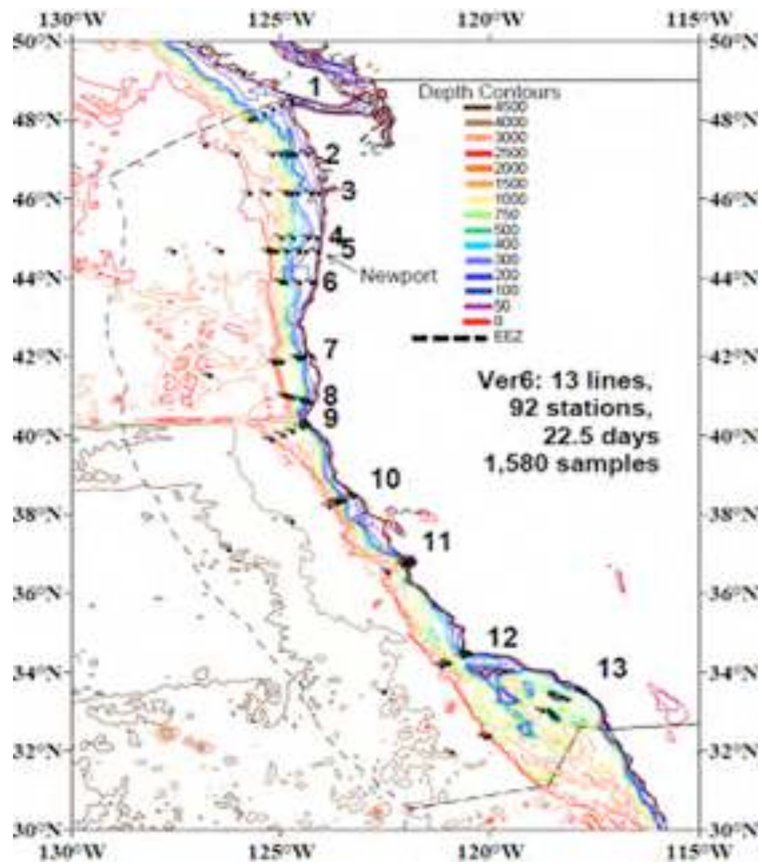
March 22, 2011

OBSERVATIONS & MONITORING

Collaborative Ocean Acidification and Hypoxia Studies along the Cascadia Margin

Develop Algorithms for Predicting pH and Aragonite Saturation in Hypoxic Waters of Cascadia Margin.

- ✓ Conduct time series cruises in the summer of 2011
- ✓ Develop algorithms for hypoxic and non-hypoxic regions
- ✓ Test robustness of algorithms
- ✓ Use algorithms with field data from moorings and gliders



OBSERVATIONS & MONITORING

Dwight Gledhill

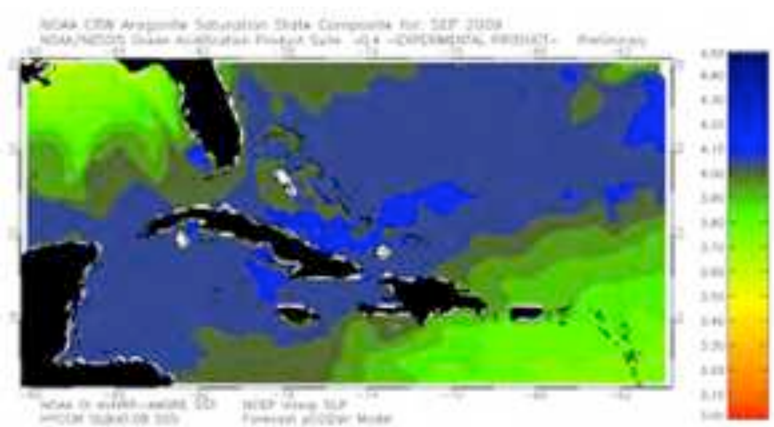
Wanninkhof, Pierrot, Eakin, Liu

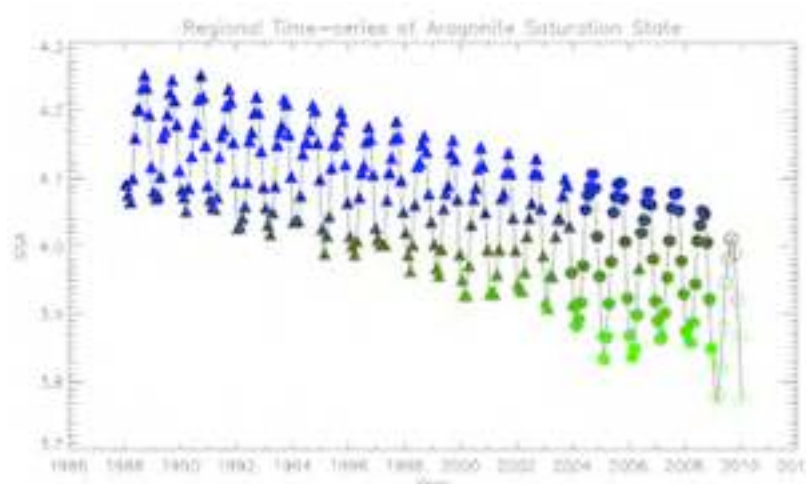
NOAA AOML

June, 2010

Ocean Acidification Product Suite v0.5

The OAPS offers monthly synthesis of satellite and modeled environmental datasets to provide a synoptic estimate of sea surface carbonate chemistry in the Greater Caribbean Region. Currently, carbonate mineral saturation state is decreasing across the region at a rate of about 3% per decade and exhibits considerable spatial and seasonal variability.





http://coralreefwatch.noaa.gov/satellite/current/experimental_products.html

Refinements under development include:
+ Improved constraint of biological modification
+ Effects of vertical entrainment

Jason Grear and Janet Nye

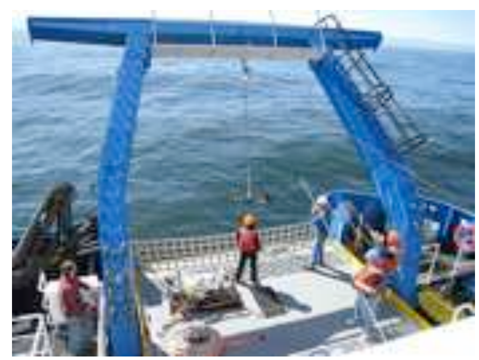
US EPA

OBSERVATIONS & MONITORING

Coastal surveys of pCO2, total alkalinity, and dissolved inorganic carbon

We are assessing current and needed equipment with an emphasis on supporting current OA research in Narragansett Bay (see slides by J. Grear and J. Nye).

- ✓ TOC analyzer for DIC
- ✓ Auto titrator for TA
- Considering pCO2 system for alternating deployment on survey vessels (e.g., O.S.V. Bold) and our laboratory seawater intake.
- Coordinating with NOAA
- Broader regional survey needs?



Gretchen Hofmann

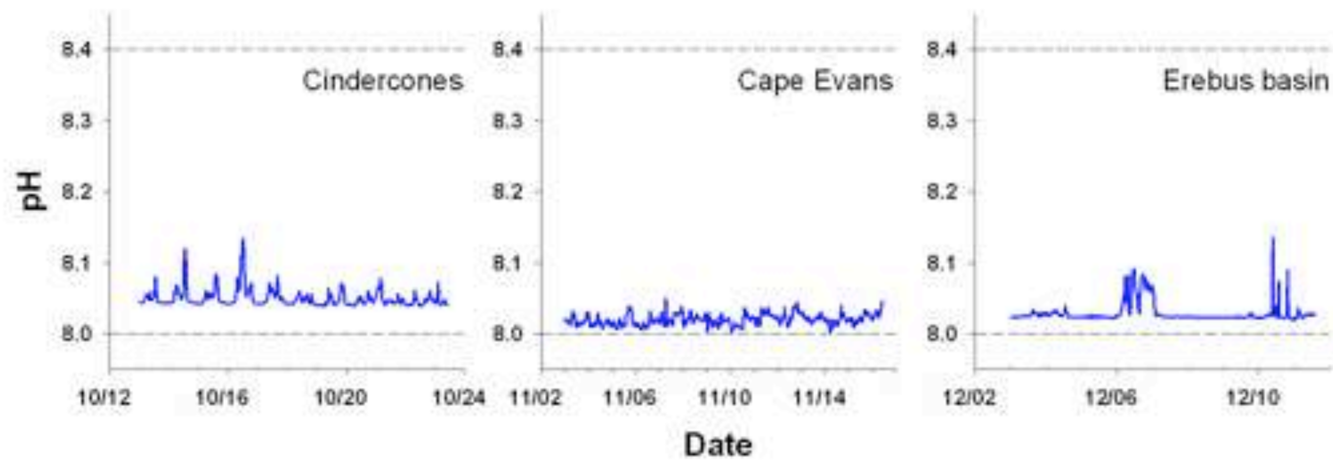
University of California,
Santa Barbara

April, 2010

OBSERVATIONS & MONITORING

SeaFET deployment in McMurdo Sound

Using an autonomous pH sensor, we also explored the pH dynamics of the coastal waters of McMurdo Sound



<u>**Time series data for SeaFET deployment at three sites in McMurdo Sound**</u>

- At all sites, the sensor was deployed at ~15 m depth below the sea ice
- Two shallow sites (total depth of ~75 feet) had abundant adult urchins (Cindercones, Cape Evans) and sensor was deployed ~1m from the benthos
- Erebus Basin was a deep water site (depth is ~500m) and the sensor was suspended on the water column at 15m depth below the sea ice

Kris Holderied

Mathis J., Doroff A.

NOAA Kasitsna Bay Lab

October, 2010

OBSERVATIONS & MONITORING

Variability in Subarctic Estuarine Ocean Acidification: Kachemak Bay, Alaska

Pilot study to assess spatial/temporal variability of ocean acidification in a subarctic estuary influenced by glacial water input, upwelled ocean waters and phytoplankton blooms.

- Water sampling by Kasitsna Bay Lab and Kachemak Bay NERR
- Carbonate analysis by Univ. of Alaska Fairbanks
- Sampling coordinated with NOAA NMFS Kodiak Lab and Gulf of Alaska OA surveys and mooring data

Kasitsna Bay lies on the south side of Kachemak Bay, Alaska–near glaciers and upwelled Gulf of AK waters

OBSERVATIONS & MONITORING

Ken Johnson

MBARI

12/22/09 - 11/30/12

Todd Martz, Alex Gu, Stephen Riser

NOPP – Development of an Integrated ISFET pH Sensor for High Pressure Applications in the Deep-Sea

Modify the Honeywell DuraFET® for use on profiling floats

- ✓ Design a high-pressure test system for evaluating sensor prototypes (MBARI/SIO)
- ✓ Perform accelerated lifetime testing on prototype ISFET sensors over 0-2000 dbar (MBARI/SIO)
- Re-design the high-pressure ISFET encapsulation for high-volume production (HON).
- Establish T-P calibrations (MBARI/SIO)
- Deploy prototype Deep-Sea DuraFET on Apex floats in 2012-2013 (UW).

Laurie Juranek

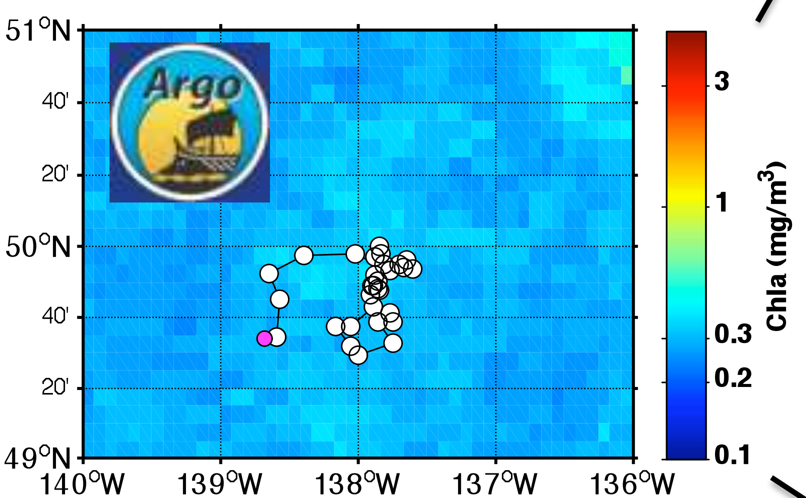
JISAO-UW/NOAA-PMEL

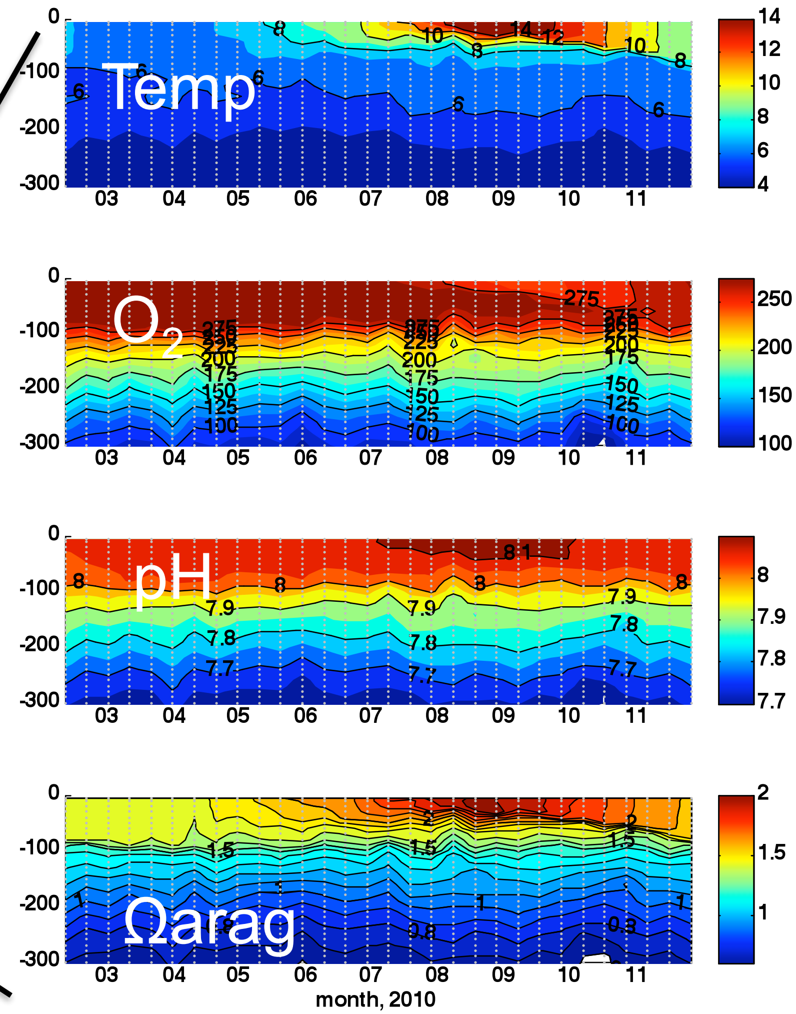
R.A. Feely, S.R. Alin, C.L. Sabine

OBSERVATIONS & MONITORING

Empirical algorithms to predict pH, Ω from hydrographic data

Allows low-cost monitoring of carbon system parameters in areas of interest from profiling floats and AUVs





Dr. Chris Langdon

J. Corredor, M. Degrandpre, K. Yates,
D. Gledhill, W. McGillis, B. Loose

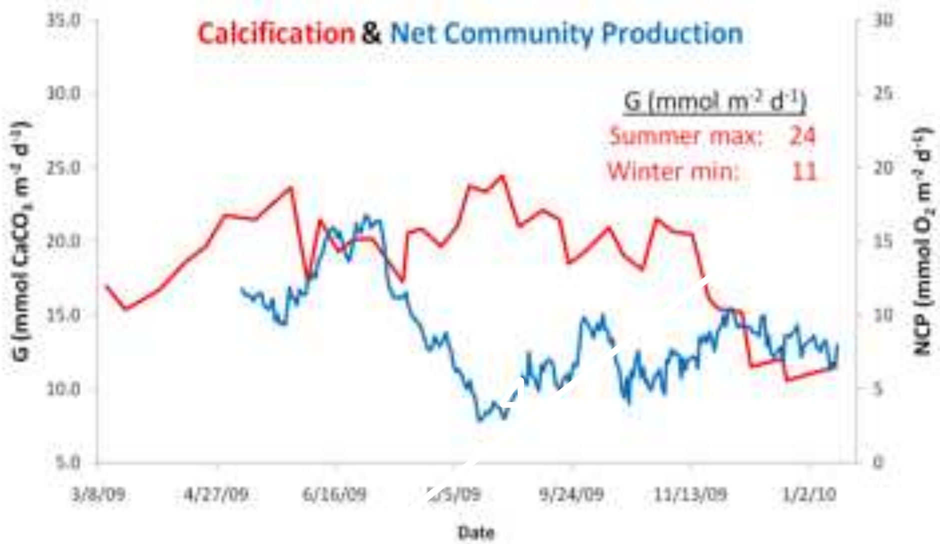
Rosenstiel School of Marine and Atmospheric Sciences

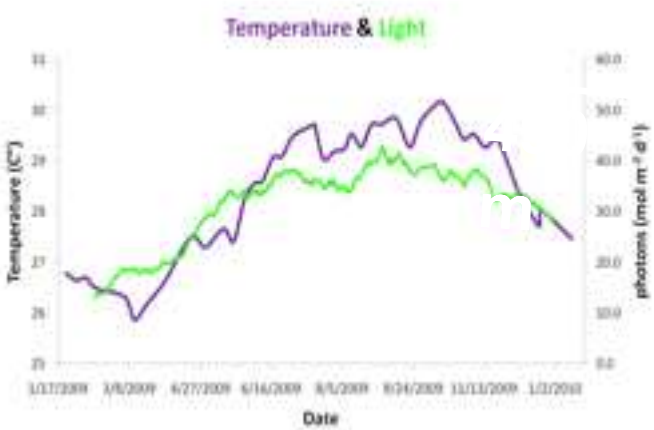
OBSERVATIONS & MONITORING

Year-Long Time Series of Coral Reef Calcification based on the Eulerian Method – Establishing a Baseline

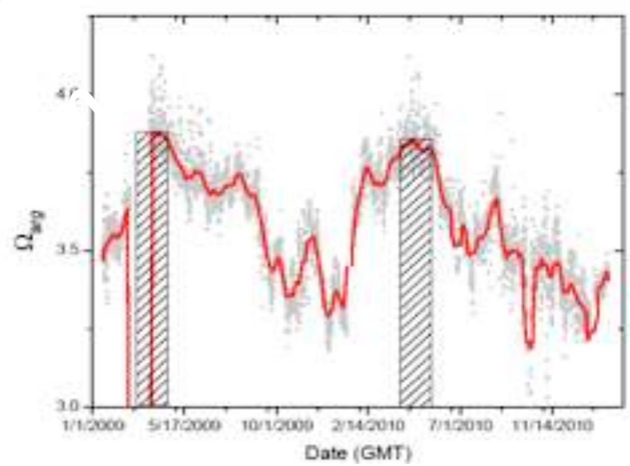
Measurements

- TA & pH – *weekly*
- Current Speed – *every 6 min.*
- MAP pCO_2 – *every 3 hrs.*
- Temp & Salinity – *every 3 hrs.*
- ICON light – *hourly*





La Parguera, PR



Lisa A. Levin

Todd R. Martz, Christina A. Tanner

Scripps Institution of Oceanography

Sept 2009

OBSERVATIONS & MONITORING

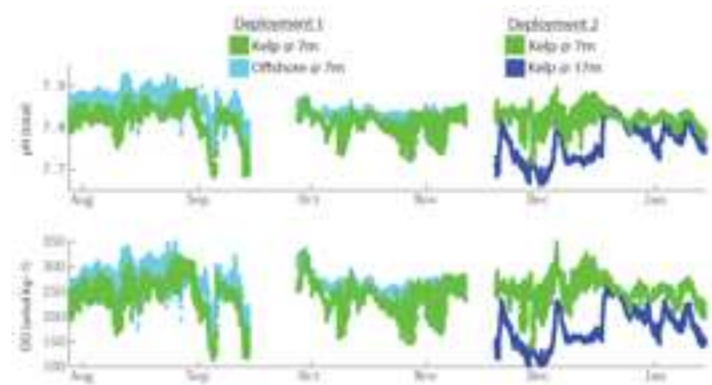
Macrophyte-induced variability in coastal ocean pH and consequences for invertebrate larvae

To address the interplay between anthropogenically driven pH changes and the inherently variable coastal ocean, and directly test the implications for invertebrate larvae.

- ✓ Deployment of sensors
- ✓ Produce high-frequency data sets of pH/DO
- ✓ Characterize variability
- ✓ Identify driving mechanisms

Results:

- o High correlation between DO and pH at 7m depth
- o Observed intermittent upwelling events
- o Kelp modulates pH/DO on diel cycle
- o Extreme variability driven by tidal forcing



Todd Martz

Scripps Institution of Oceanography

01/01/09 – 12/31/11

OBSERVATIONS & MONITORING

OCE-0844394 Evaluation and Adaptation of an Ion Sensitive Field Effect Transistor for Seawater pH Applications

Evaluate the Honeywell DuraFET® for use in autonomous systems operating in the upper 100m of the ocean.

- ✓ DuraFET modifications for dual reference electrodes and low-power design.
- ✓ "SeaFET" now being commercialized by Satlantic Inc.
- ✓ "SeapHOx" integrated sensor package includes a pumped manifold and additional sensors for oxygen & salinity.
- Now working to establish calibration protocols and validate sensor performance in field tests.

Todd Martz

Scripps Institution of Oceanography

Brian Ward, Paul Maguire, Jim MaLaughlin

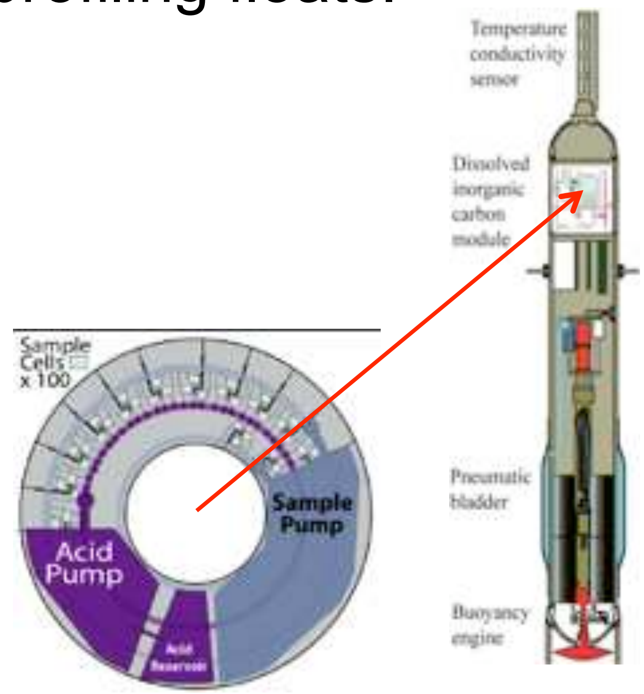
07/15/10 - 06/30/14

OBSERVATIONS & MONITORING

OCE 0961250 - Development of a Micro-Rosette Sensor for Total Dissolved Inorganic Carbon Measurement from Autonomous Lagrangian Ocean Profilers

Build the first microfluidic sampling device ("micro-rosette") and use it to sample the ocean from profiling floats.

- Samples captured as the float ascends the water column.
- Samples analyzed at depth on an isopycnal during the float park cycle.
- Potential to analyze more properties because sensors are no-longer limited to fast-response devices that must measure on the fly as the float ascends.
- Requires multi-disciplinary work between chemical oceanographers and nanoengineers.



Jeremy T. Mathis

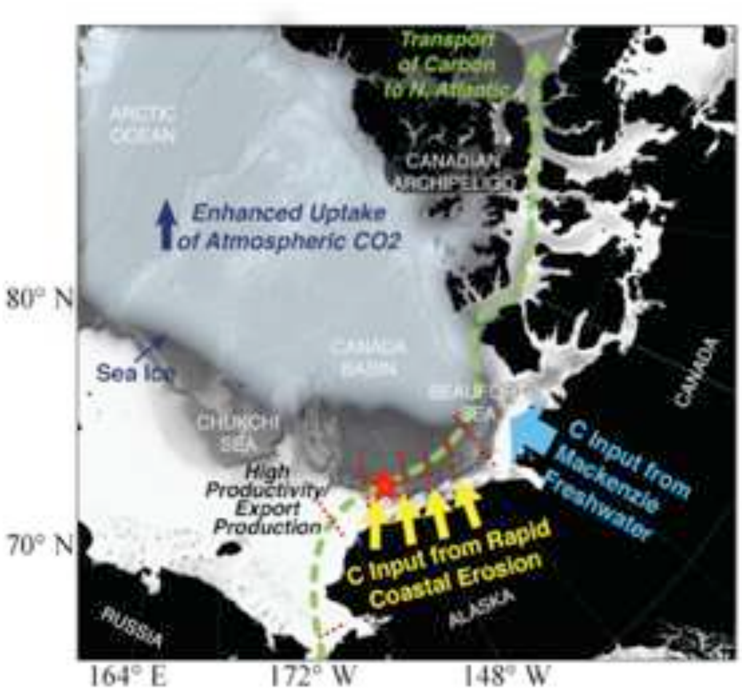
Laurie Juranek(APL – UW)
Richard Feely (NOAA – PMEL)

University of Alaska Fairbanks

September, 2011

OBSERVATIONS & MONITORING

Observation and Prediction of Ocean Acidification in the Western Arctic Ocean - Impacts of Physical and Biogeochemical Processes on Carbonate Mineral States (Funding from NSF)



Objective 1 – Better constrain the impacts of low alkalinity ice melt, high pCO_2 river runoff, the remineralization of organic matter and the upwelling of deep Arctic basin waters onto the Chukchi/Beaufort shelves on saturation states in the surface and bottom waters.

Objective 2 – Develop region-specific algorithms to relate Ω to standard hydrographic parameters (e.g., T, O2, S) for evaluation of trends in saturation states when full carbon system measurements are absent. These algorithms could be applied to data collected on autonomous moorings to provide empirically predicted aragonite saturation states at unprecedented resolution.

Objective 3 – Constrain the biogeochemical feedbacks on saturation states by determining how gradients in physical forcing (upwelling, ice-melt, river discharge, major currents) affect late season biological CO2 uptake and export, and how primary production/export in turn influence surface/ subsurface saturation states.

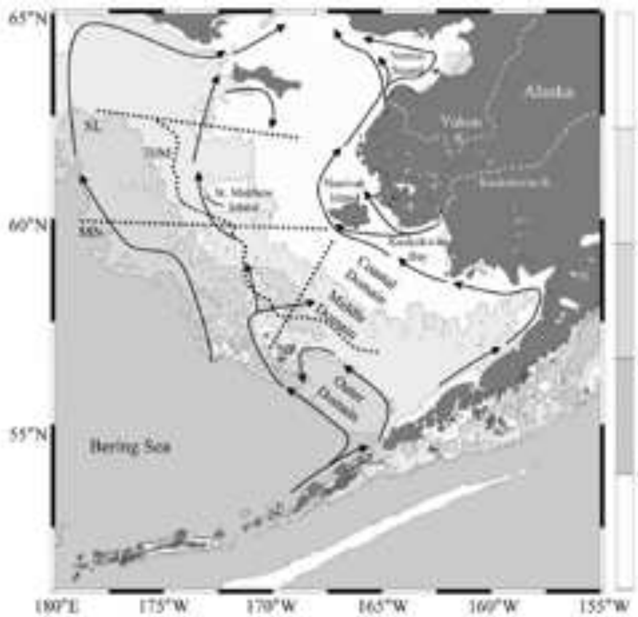
OBSERVATIONS & MONITORING

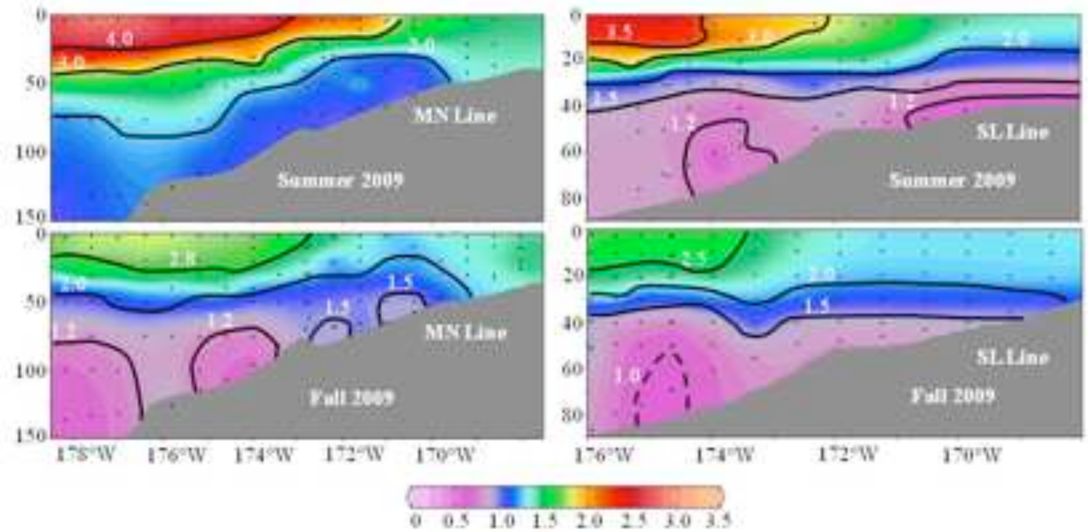
Jeremy T. Mathis

Jessica Cross (UAF PhD student)

University of Alaska Fairbanks
September, 2008

Biogeochemical Assessment of the North Aleutian Basin Ecosystem: Current Status and Vulnerability to Climate Change (funding from BOEM)





Observations of aragonite Ω (show in color) and calcite Ω (shown with contour lines) along the MN and SL transects lines in summer and fall of 2009.

Current Publications from this Work

Mathis, J.T., Cross, J.N., Bates, N.R., Lomas, M.L., Moran, S.B., Mordy, C.W., Stabeno, P., (2010). Seasonal Distribution of Dissolved Inorganic Carbon and Net Community Production on the Bering Sea Shelf (Biogeosciences, 7, 1769–1787)

Mathis, J.T., Cross, J.N., Bates, N.R., (2011) Coupling Primary Production and Terrestrial Runoff to Ocean Acidification and Carbonate Mineral Suppression in the Eastern Bering Sea J. Geophys. Res., 116, C02030)

Bates, N.R., Mathis, J.T., Jefferies, M.A., (2010). Air-Sea CO2 fluxes on the Bering Sea Shelf. (Biogeosciences Discuss., 7, 1–44, 2010).

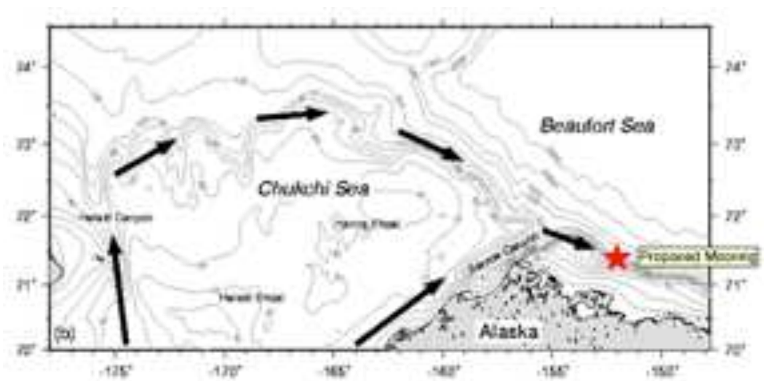
OBSERVATIONS & MONITORING

Jeremy T. Mathis

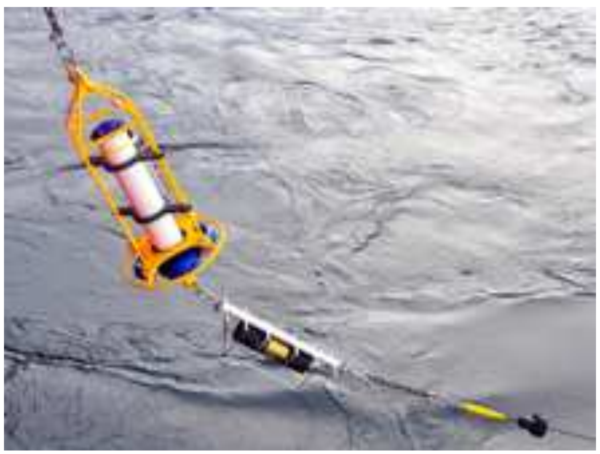
Bob Pickart (WHOI)
Kate Stafford (APL – UW)

University of Alaska Fairbanks
Deployed in September, 2010

An Interdisciplinary Monitoring Mooring in the Western Arctic Boundary Current: Climatic forcing and ecosystem response (Funding from NSF)



The mooring contains two profilers (one attached to the mooring wire and one tethered to the top float) working in tandem to sample the entire water column from the seafloor to the underside of the ice.



Each profiler is measuring **pressure**, **temperature**, **conductivity** (salinity), **dissolved oxygen**, **pH**, **turbidity**, **chlorophyll fluorescence**, and **nitrate**. It will provide one complete profile a day, and a second profile from 40m to the bottom. Two **SAMI II *p*CO_2 sensors** are deployed at fixed depths on the mooring (30 m and 100 m).

The mooring will be in place for 5 years.

OBSERVATIONS & MONITORING

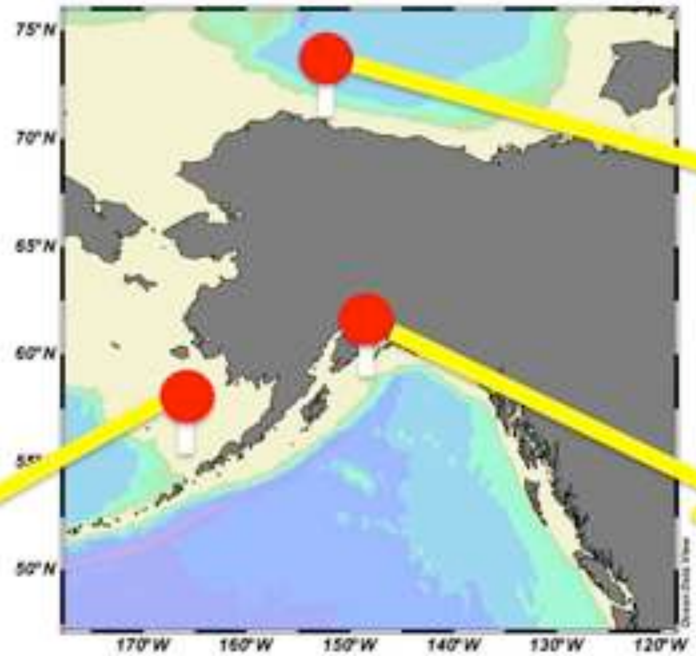
Jeremy T. Mathis

Chris Sabine (NOAA-PMEL)
Laurie Juranek(APL – UW)
Richard Feely (NOAA – PMEL)

University of Alaska Fairbanks

Deployed in 2011

Ocean Acidification Moorings in the Bering Sea and Gulf of Alaska (funding from the NPRB and NOAA)



- Continuous subsurface and bottom pCO_2, pH, nitrate, DO, florescence and turbidity

M2

- Seasonal surface pCO_2 and pH, nitrate, DO, florescence and turbidity
- Continuous bottom pCO_2, pH, nitrate, DO, florescence and turbidity

GAK 1

- Continuous surface and bottom pCO_2, pH, nitrate, DO, florescence and turbidity

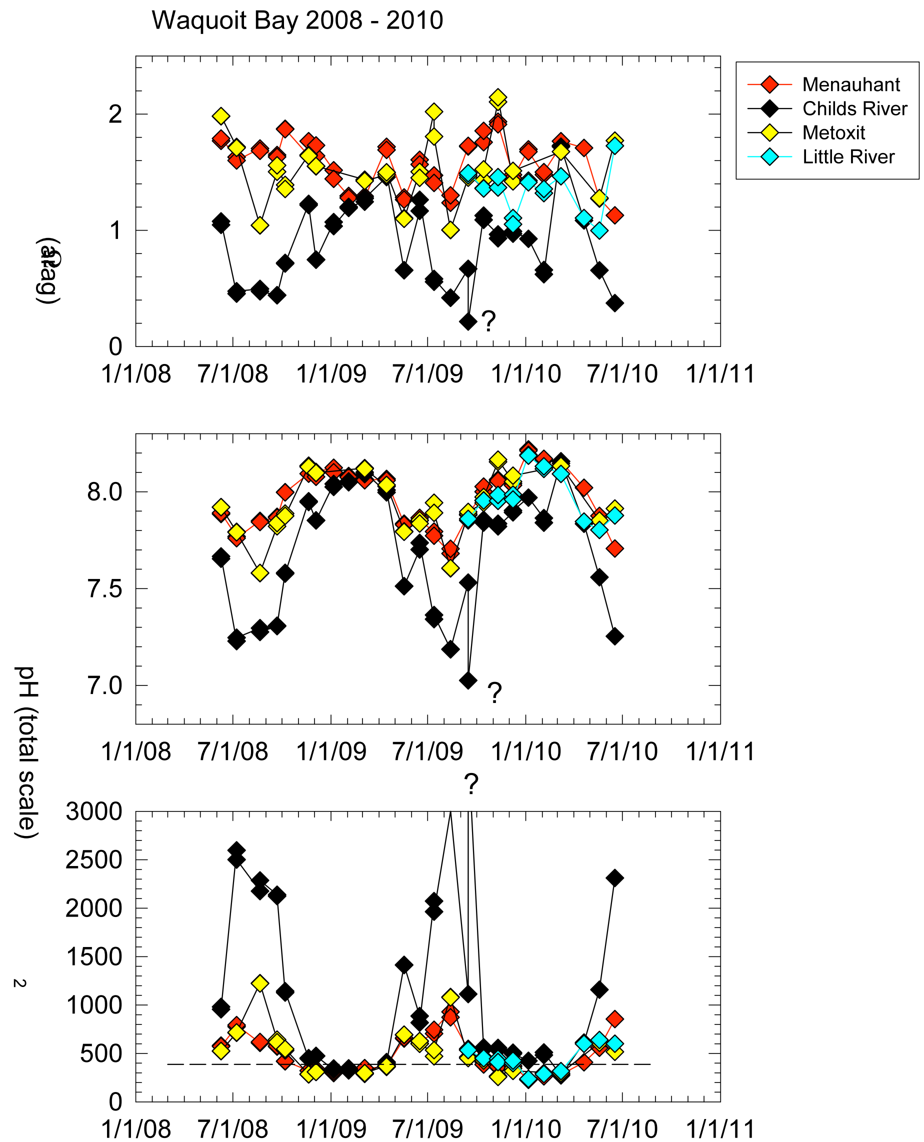
Daniel McCorkle

WHOI

Time series of pCO_2, pH and Ω in Waquoit Bay, MA

OBSERVATIONS & MONITORING

- Strong annual cycles in pCO_2, pH, and aragonite saturation state, driven by benthic organic matter decomposition (highest in summer)
- Natural + eutrophication
- The OA future is here in Waquoit Bay



Paul McElhany & Shallin Busch

NOAA-NWFSC

Corriegh Greene, Julie Keister

Summer 2011

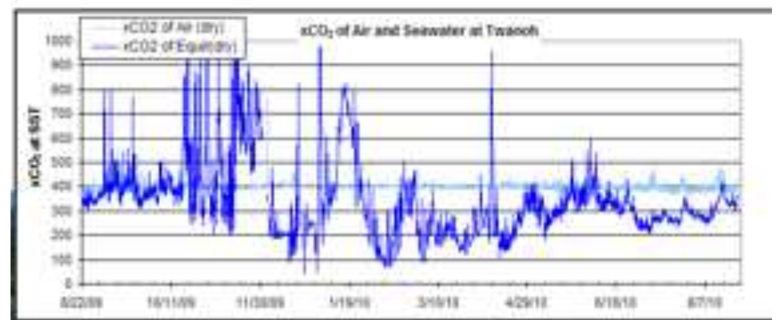
OBSERVATIONS & MONITORING

Fine-scale Spatial and Temporal Monitoring of Carbon Parameters in Puget Sound

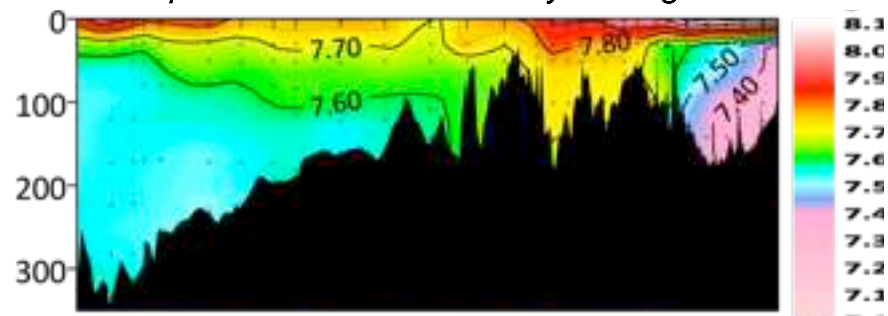
Describe the carbon chemistry environment experienced by coastal zooplankton populations to inform experiments and modeling

- Coupled biological/chemical sampling along transects
  - Measure zooplankton distribution and abundance
  - Measure pH and alkalinity as zooplankton are collected
- Continuous pH monitors
  - Seafet sensors deployed at locations of biological importance

Examples of variable pCO2 and pH



Surface pCO2 from PMEL buoy in Puget Sound



Transect of pH through Puget Sound as a function of depth (from Feely et al 2010)

Christina McGraw

Clark University

K. Currie, P. Boyd, C. Hurd, K. Hunter

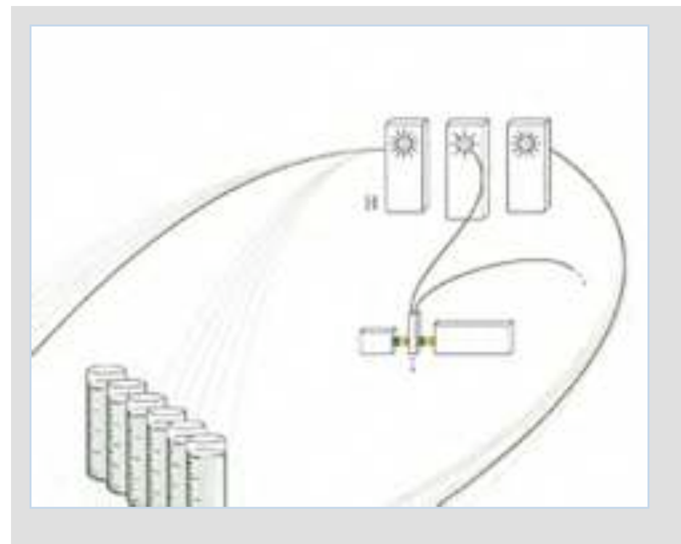
June 2008

OBSERVATIONS & MONITORING

Autonomous OA culture systems with spectrophotometric pH measurement

Culture systems control pH to within 0.02 pH units. A_T is also monitored so carbonate chemistry is each tank is known.

- ✓ 2 ship-board culture systems (deployed in the Tasman Sea)
- ✓ 2 trace-metal clean systems
- ✓ 24-tank system mimics daily and seasonal fluctuations



Culture systems are being used to study a wide range of New Zealand and Antarctic organisms.

Christina McGraw

Clark University

C. Hurd, A. Radu

January 2011

OBSERVATIONS & MONITORING

New sensors for field measurements of the carbonate system

Two sensor platforms are being developed to obtain high resolution measurements of carbonate. Real-time monitoring will allow us to investigate regional differences and the interactive effects of multiple variables on calcification rates.

- 2011-2012
  - Incorporation of sensors into sensing networks to obtain time-resolved 3D maps of carbonate within defined areas
- 2012
  - Microsensors to measure gradients in ion fluxes within diffusion boundary layers

Lisa Robbins

P. Knorr, R. Byrne, X. Liu, D.Gledhill, K. Daly, C. Smith, K. Yates, J. Kleypas

USGS- St. Petersburg

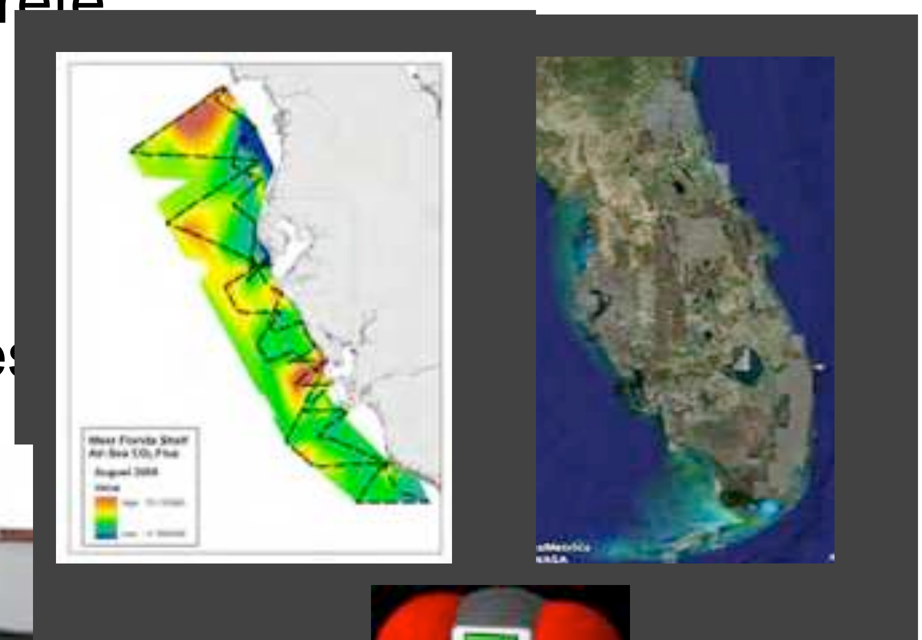
2008-2013

OBSERVATIONS & MONITORING

Response of Florida Shelf Ecosystems to Climate Change

"Monitoring and modeling Florida shelf carbonate chemistry"

- ✓ 3 cruises 2008-2009 collected pH, DIC, pCO_2 using USF MICA & discrete samples
- ✓ Ten cruises underway in 2011-2012
- ✓ Use CO2calc for data analyses



http://coastal.er.usgs.gov/flash
http://pubs.usgs.gov/of/2010/1280

Lisa Robbins

K.Yates, R. Byrne, J. Lisle, J. Wynn, P. Knorr, M. Hansen, X. Liu

USGS- St. Petersburg

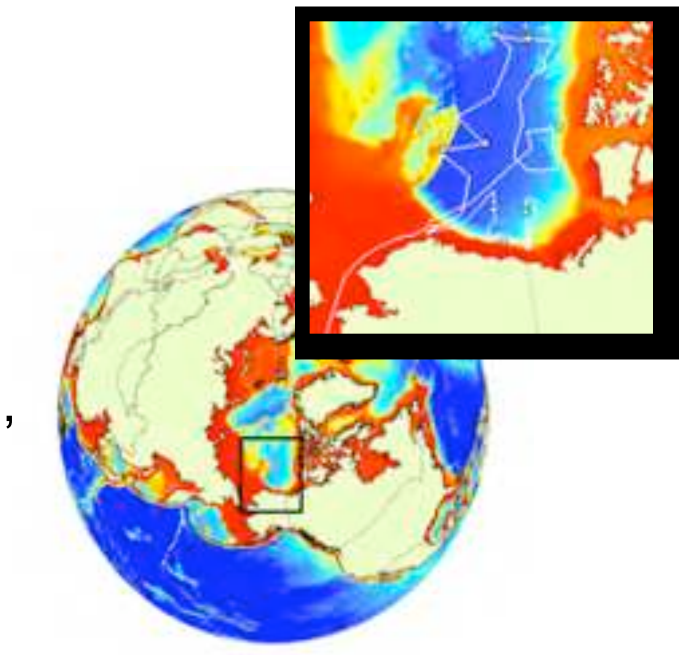
2010-2012

OBSERVATIONS & MONITORING

Arctic research related to ocean acidification

Collecting high resolution data sets of seawater chemistry in Arctic Ocean as auxiliary to Extended Continental Shelf (Law of the Sea) cruise on CGC Healy

- ✓ 2010: 5 week cruise in Beaufort Sea and Canada Basin
- ✓ pH, pCO_2, DIC collected underway every two min- MICA
- ✓ 600 discrete samples, nutrients, isotopes, microbial samples, & 10 CTD casts
- 2011: 7 week cruise thru Canada Basin to Alpha Ridge
- Similar data collection to 2010 and testing equipment & methods



http://coastal.er.usgs.gov/ocean-acidification/polar.html

Lisa Robbins

USGS- St Petersburg

Ellen Raabe, John Lisle

2009-2011

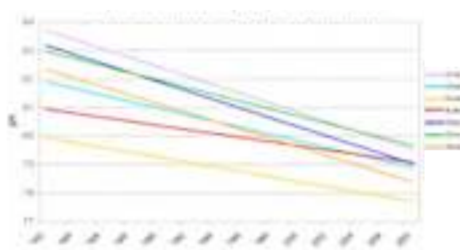
OBSERVATIONS & MONITORING

Florida Shelf Response to Climate Change Research

"Changing conditions in Florida shellfish beds"

Our group is analyzing 25 years of Florida water quality records from estuarine locations on Atlantic and Gulf to look at estuarine acidification

- Data from Florida Department of Agriculture and Consumer Affairs Shellfish Monitoring Program
  - How has pH, temperature, and salinity changed over 25 years?
  - 10 estuaries from around Florida (Atlantic a
    are being analyzed
  - >80,000 data records
  - 7 out of 10 estuaries statistically significant trends



http://coastal.er.usgs.gov/flash

Christopher L. Sabine

NOAA/PMEL

many collaborators from U.S. and abroad

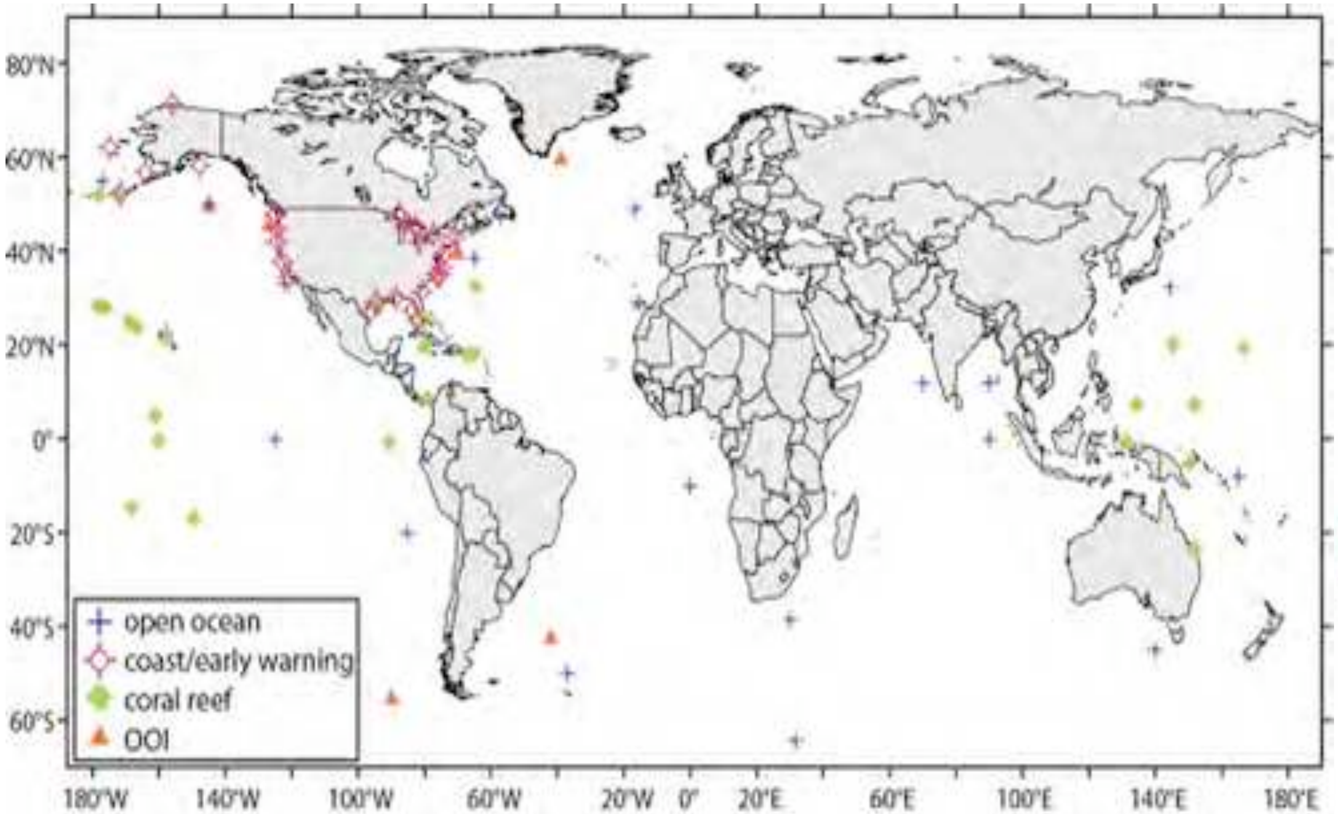
February, 2010

OBSERVATIONS & MONITORING

NOAA Ocean Acidification Monitoring Project

Goal: Develop the monitoring capacity to quantify and track ocean acidification and its impacts in open-ocean, coastal, and Great Lakes systems.

Below is a map of monitoring sites we would like to establish



Christopher L. Sabine

Christian Meinig (NOAA/PMEL), Andrea Fassbender (Univ. of Washington)

NOAA/PMEL

May, 2010

OBSERVATIONS & MONITORING

Development of a Robust Moored DIC Sensor for Carbon Cycle Studies

Goal: Develop a moored DIC system modeled after the $MAPCO_2$ sensor

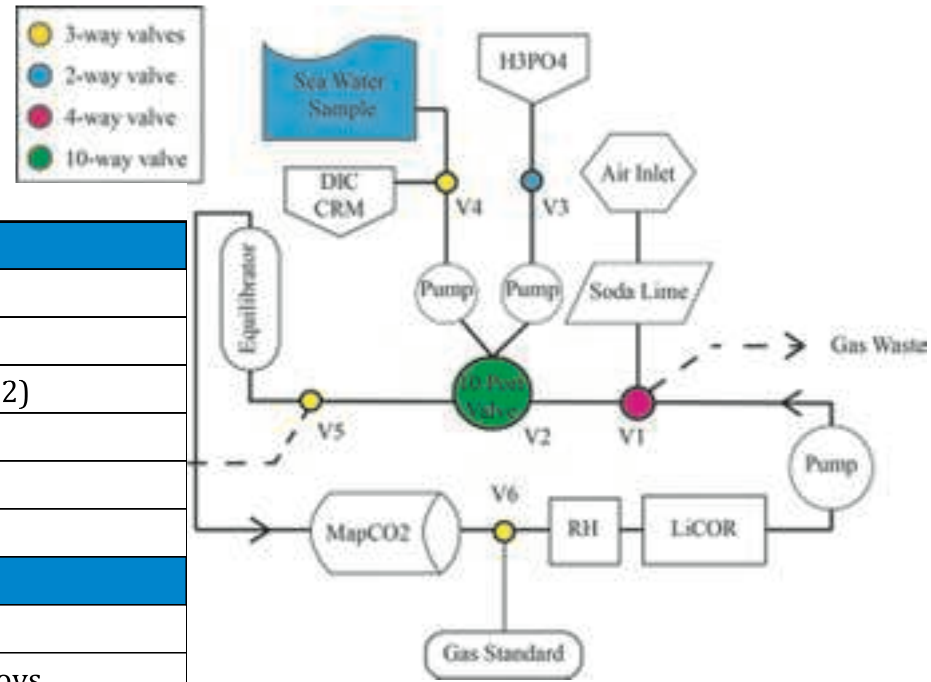
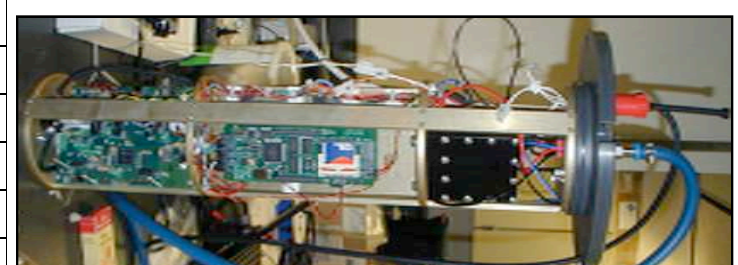


Table 1. Scientific Requirements of the PMEL DIC System

Science Requirements	
Measurement Range	1500 to 2500 ± 2 μmol kg^{-1}
Technique	NDIR detection of acidified seawater
Calibration - gas	WMO standard gas (at least 1, maybe 2)
Calibration - liquid	Andrew Dickson CRM
Biofouling Protection	Maintain accuracy for 400 days
Endurance	Up to 400 days unattended
Engineering Capabilities and Functionality	
Cost	<$40K (similar to $MAPCO_2$)
Platform	Configurable to numerous surface buoys
Survivability	Robust design for tropics and high latitude
Configuration	Modular design, field serviceable
Service	Field serviceable by 1 technician w/ basic training
Power	Alkaline cells, field swapable
Aux Channels	2 ea.
Communications	Bi-directional Iridium Modem
Additional Sensors	GPS, CTD, MET, others as needed



Christopher L. Sabine

C. Meinig, N. Lawrence-Slavas, R. Bott, T. Martz (Scripps), Liquid Robotics Inc.

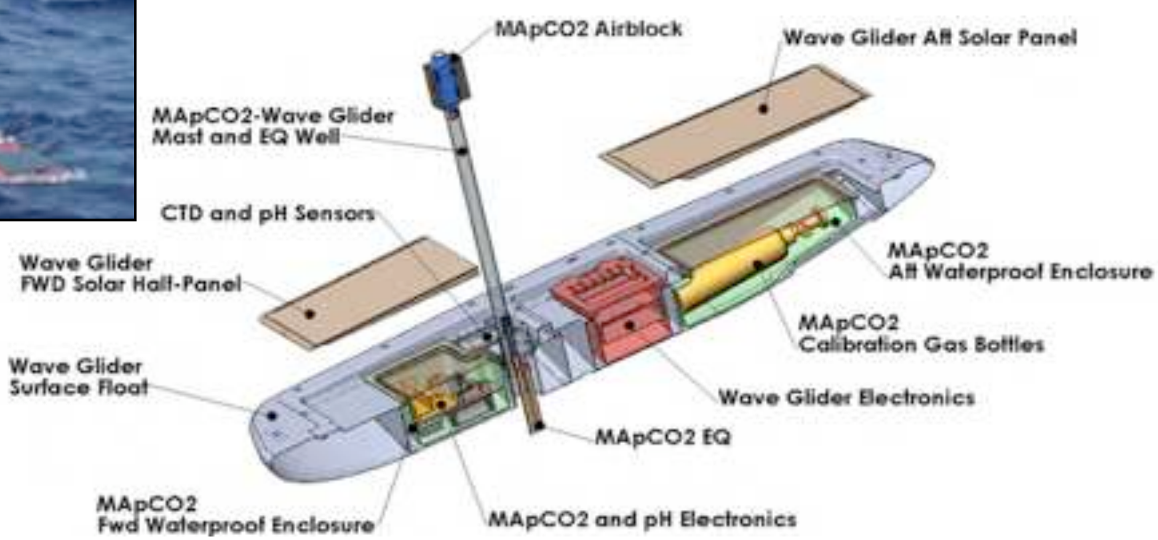
NOAA/PMEL

October , 2010

OBSERVATIONS & MONITORING

New Capabilities for Long-Term, Mobile CO_2 and Ocean Acidification Measurements

Goal: Integrate a carbon measurement package into a Wave Glider



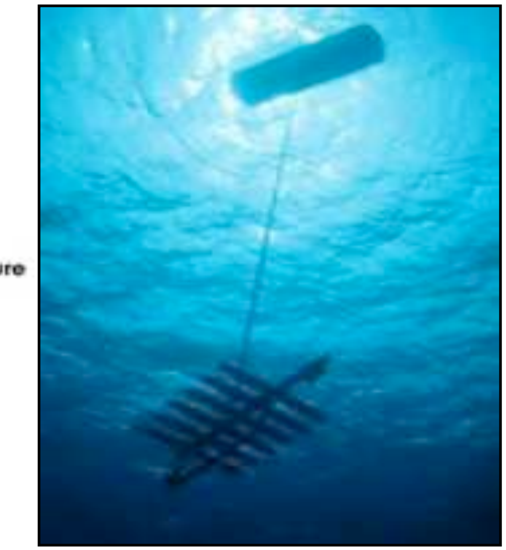


Table 1: Global Climate Change Carbon Science Payload for the Wave Glider AMV.

Supplier	Sensor	Measurement	Calibrated Range & Accuracy
NOAA PMEL	$MAPCO_2$	pCO_2 SW & Air (ppm)	200 to 600 ± 3 (stable over ~year)
Scripps (Martz)	custom pH	SW Acidity (*p*H)	0 to 14 ± 0.01 (±0.005 stability ~wks)
Seabird Electronics	Glider Payload CTD	Conductivity (S/m)	0 to 6 ± 0.0003 (0 to 9 ± 0.0010)
		Temperature (°C)	1 to 32 ± 0.002 (-5 to +45 ± 0.010)
		Pressure (dbar)	0 to 100 ± 0.1% FS (same)
		Salinity (PSS 78)	0 to 35 ± 0.005 (0 to 45 ± 0.015)

OBSERVATIONS & MONITORING

Sergio Signorini

C. R. McClain, S. Häkkinen, A. Olsen, A. Omar, I. Skjelvan, M. Chierici, J. Olafsson, N. Metzl, and G. Reverdin

NASA GSFC

February, 2011

Assessment and Impact of Carbon Variability in the Nordic Seas

In situ and Sat measurements in support of data analysis, algorithm development, and model forcing and validation

- Underway VOS pCO_2
- Time series of pH, pCO_2
- T, S, nutrients, Chl-a
- DIC, alkalinity
- Existing time series sites (OWSM, IS-ts)
- Satellite products (Chl-a, SST, POC, PIC, PP)

Autonomous Flow Through

Adrienne Sutton

PMEL/NOAA

C. Sabine, R. Feely

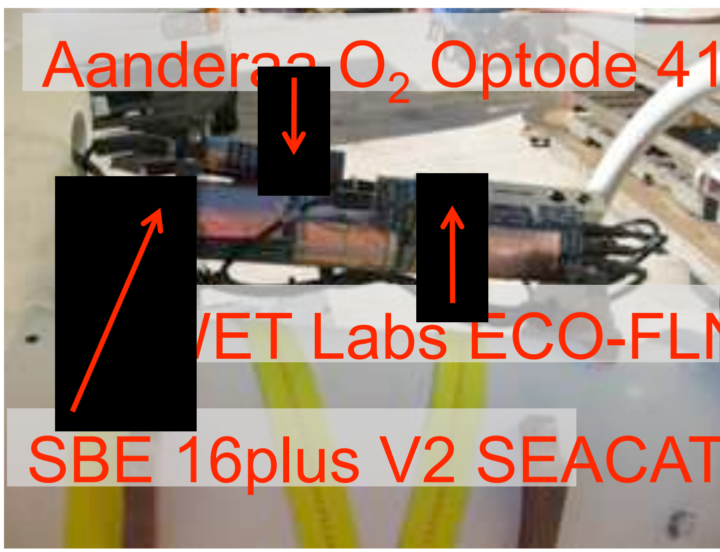
Feb, 2010

OBSERVATIONS & MONITORING

High resolution OA time series in the surface ocean

Deploying CO_2, pH, and other biogeochemical sensors on moorings to assess OA variability over daily to seasonal cycles.

- OA instrument package:
  - MAPCO_2
  - SAMI^2 pH



Taro Takahashi

LDEO, Columbia Univ.

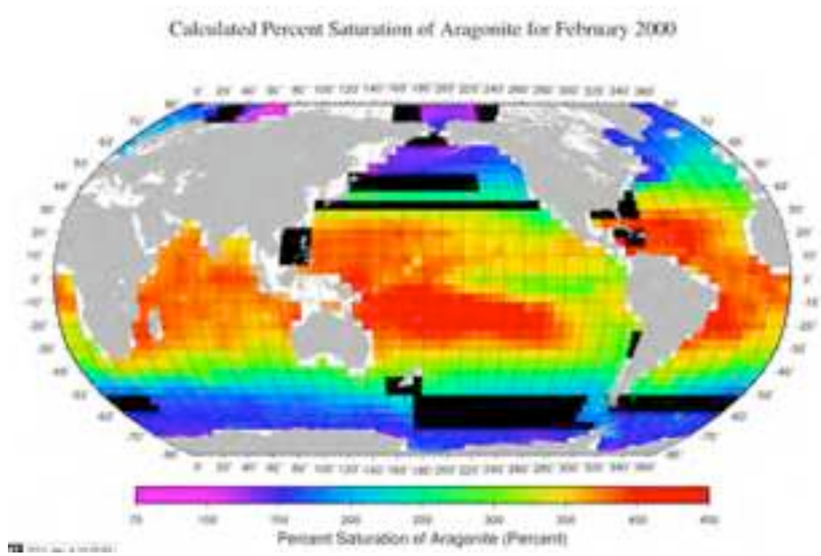
January 1, 2011

OBSERVATIONS & MONITORING

Climatological Mean Distribution of pH and $CO_3^{=}$ in Global Ocean Waters in the Unified pH Scale

Project summary: Based on the total alkalinity, DIC, pCO_2 and nitrate data, the monthly distribution of pH and aragonite saturation are obtained over the global ocean for year 2000.

- ✓ pH (total H^+ ion scale) of the global open ocean surface water varies 7.95 to 8.22.
- ✓ Seasonal amplitude of pH is ~0.15 in high latitude areas.
- ✓ While warm waters are saturated with aragonite up to 450%, high-latitude winter waters are near saturation.



Kimberly K. Yates

U.S. Geological Survey

L. Robbins, R. Moyer, C. Rogers, J. Mallela,
R. Langton, D. Gledhill, J. Corredor, R. Byrne

October, 2000

OBSERVATIONS & MONITORING

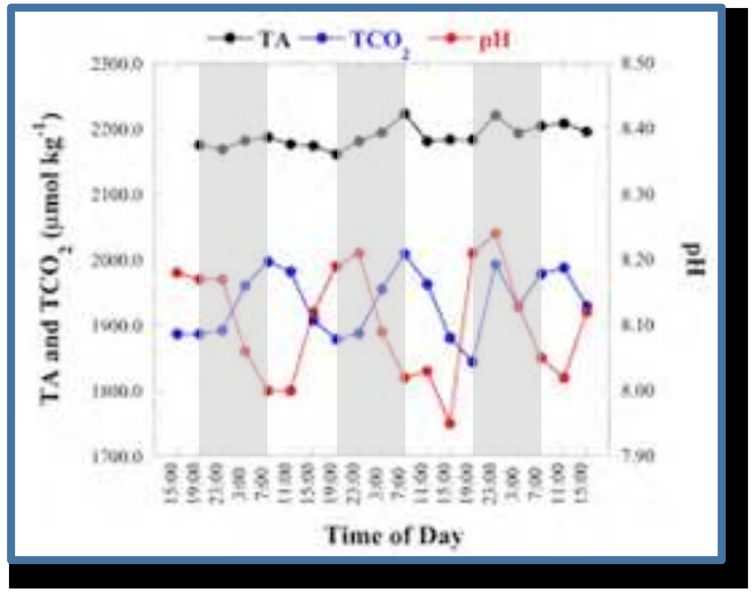
Variation of carbonate system parameters (CSPs) in coastal ecosystems

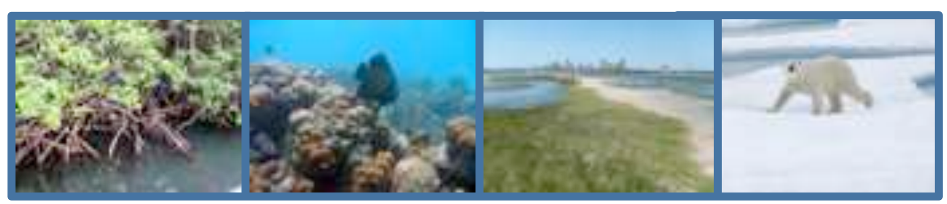
Measure spatial and temporal variation of CSPs in coastal ecosystems of Florida, the Caribbean, Hawaii, & the Arctic

- Locations
  - Florida Bay, Biscayne National Park, U.S. Virgin Islands, Puerto Rico, Tampa Bay, Dry Tortugas, Bahamas, Tobago, Hawaii, Arctic Ocean

✓ Determined trends and range of variation

✓ Examined biological, chemical, and physical controls





OBSERVATIONS & MONITORING

Zhaohui Aleck Wang

R. Wanninkhof, T-H Peng, W.J. Cai, X. Hu, R.H. Byrne

Woods Hole Oceanographic Institution

June, 2010

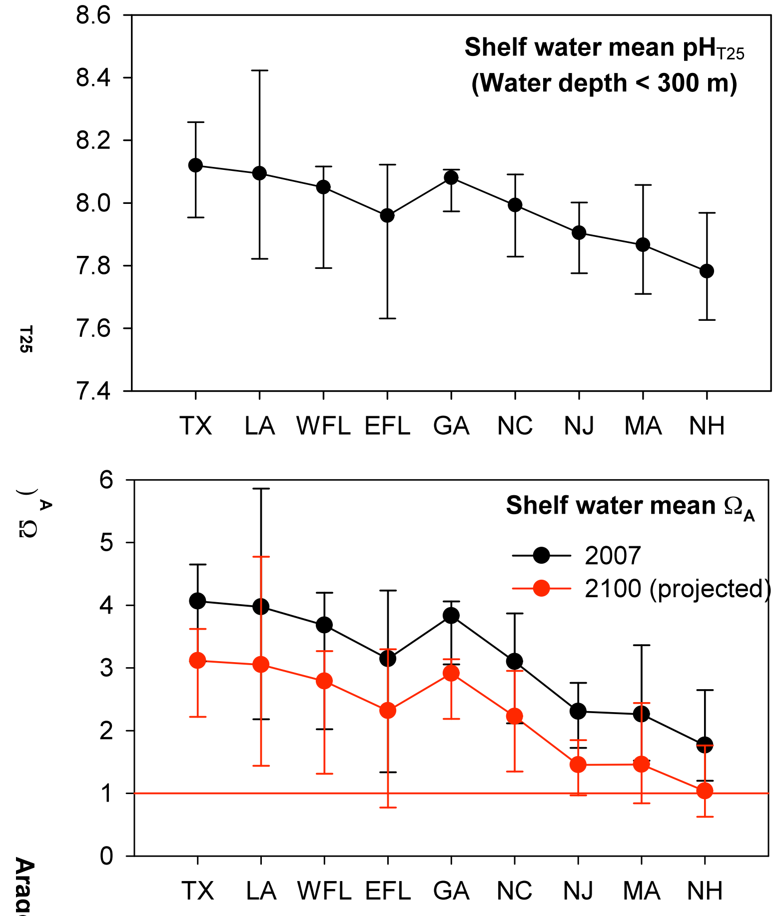
Distributions of the Marine CO_2 System along the U.S. Atlantic and Gulf of Mexico Coast

The U.S. northeastern coastal water may be vulnerable to the Ocean Acidification (data from the Gulf of Mexico and East Coast Carbon (GOMECC) cruise, July 10 – Aug 04, 2007):

✓ South-north decreasing trend in the mean shelf water pH_{T25}, companied by the decrease of aragonite saturation state (Ω_A)

✓ The U.S. northeastern coastal water may be more vulnerable to OA in the coming decades

✓ By Year 2100, part of the U.S. northeastern water will be under-saturated with respect to Ω_A



Wang et al., to be submitted

Tim Wootton

Cathy Pfister

The University of Chicago

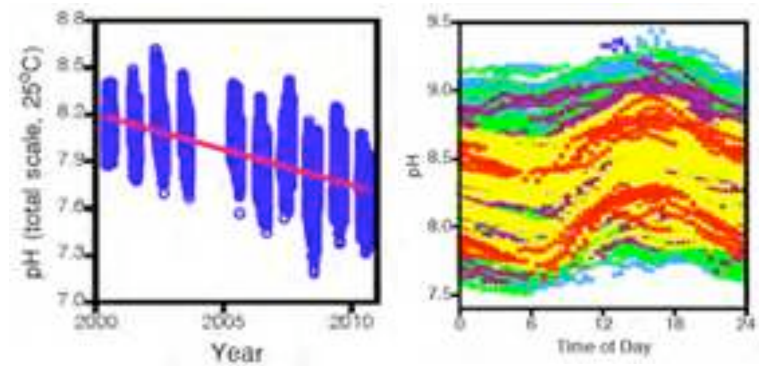
June 2010 (LTREB)

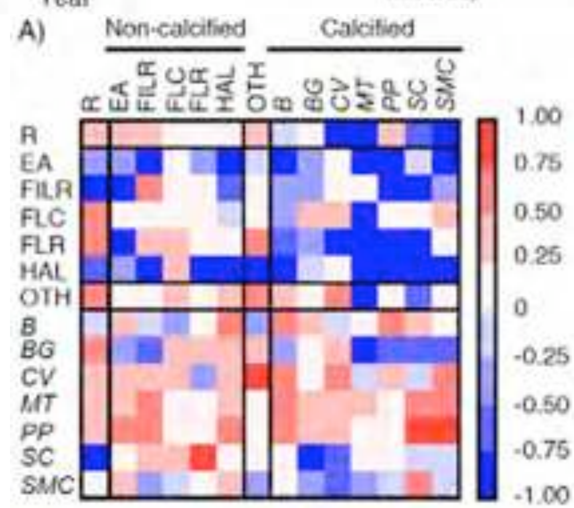
OBSERVATIONS & MONITORING

Ecological Dynamics in an Experimentally-Tractable Natural Ecosystem

Generate time series of ocean condition and species dynamics to develop models of ecological networks.

- ✓ Census species abundance and replacement rates (18 yr)
- ✓ Monitor ocean conditions w/Hydrolab probe (>50,000 measures over 11 yr)
- ✓ pH declining faster than expected
  - – Strong biological signals (diurnal, etc.)
- ✓ Species replacement rates are associated with pH decline
  - – Calcifiers perform more poorly, uncalcified fleshy algae perform better





Tim Wootton

Cathy Pfister

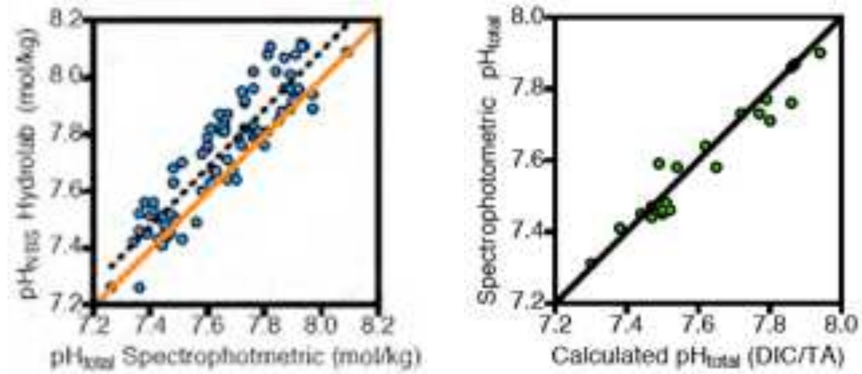
The University of Chicago

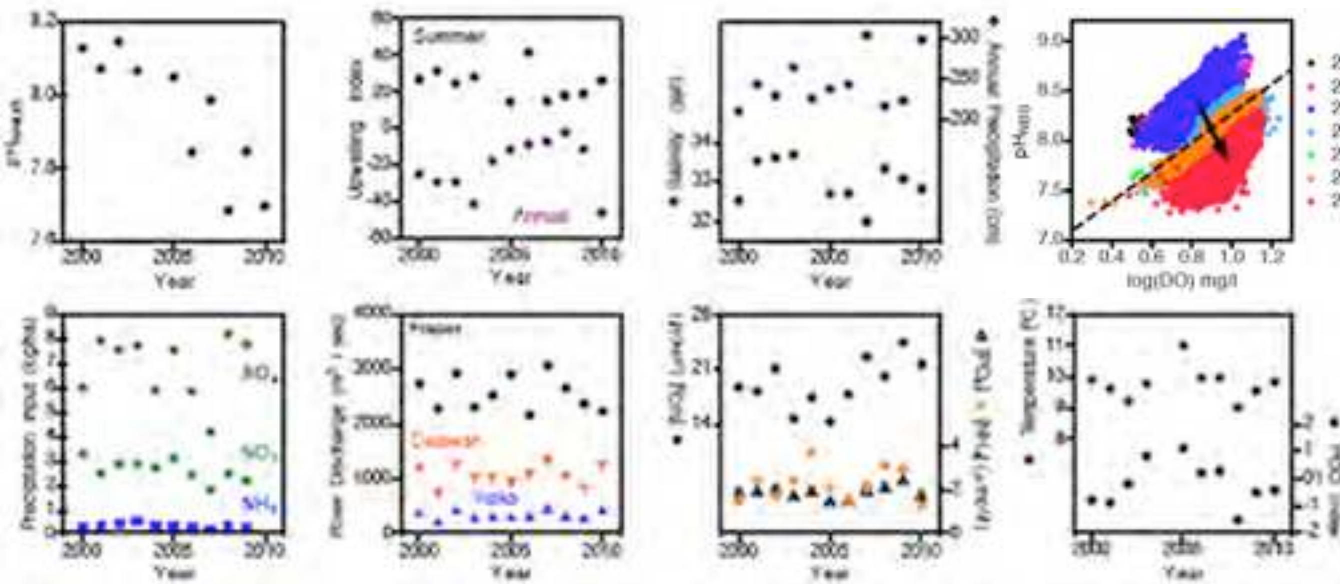
June, 2010 (LTREB)

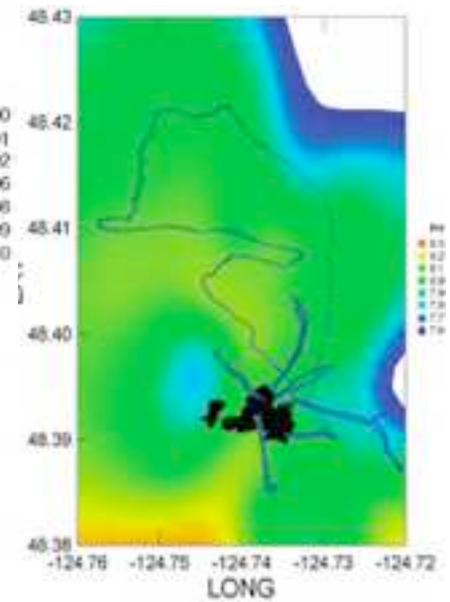
OBSERVATIONS & MONITORING

What is Driving Rapid pH Decline?

- ✓ Consistency checks with more accurate methods (pH_{spec}/DIC/TA)
- ✓ Consistent pH regionally
- ✓ Interannual trends in non-$CO_{2,atm}$ drivers: no "smoking gun"







Colleen Burge

Harvell, Mydlarz

Cornell University

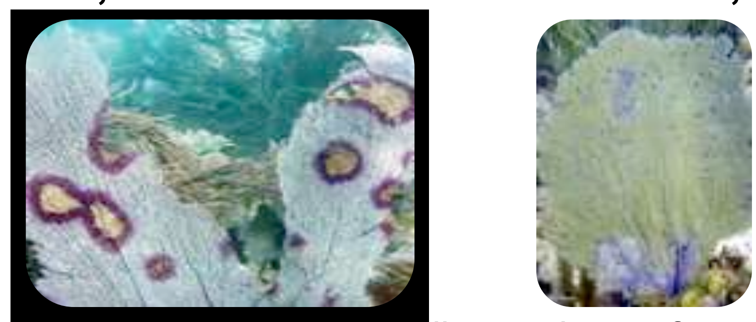
June, 2009

PHYSIOLOGICAL RESPONSES

Influence of Temperature and Acidification on the Dynamics of Coral Co-infection and Resistance

Study the interaction of environment, disease transmission, & host response

- 2009-2010
  - Pathogen isolation & characterization
  - Initial pathogen experiments
- 2011
  - Co-infection experiments
  - Temperature & acidification experiments



Visual observations of disease in sea fans
Putative lesions of left: *Aspergillosis* &
Right: a Labyrinthulomycota (Photos: EWeil)

Potential differentially expressed genes (blue boxes) in sea fans exposed to *A. sydowii* (A), a Labyrinthulomycota (L), or control media.

Ronald S Burton

Scripps Institution of Oceanography

March, 2010

PHYSIOLOGICAL RESPONSES

Genomic and Evolutionary Approaches to Understanding Physiological Response to Ocean Acidification

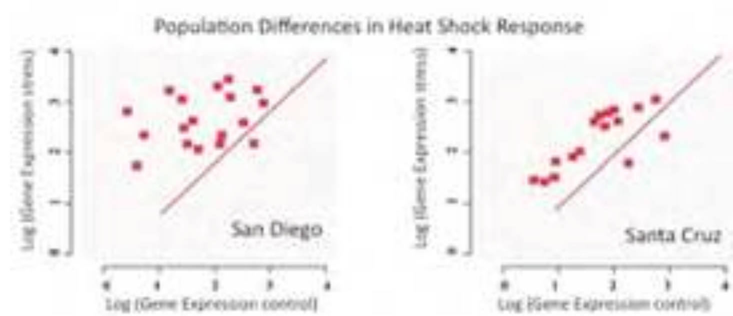
Where we are:

- Essentially all physiological OA studies in metazoans involve only acute stress responses
- Extensive genetic variation within and between populations is largely ignored
- Strong focus on relatively few species

Where we probably should go:

- ***Experimental evolution studies***, covering multiple generations, to assess potential for adaptation to OA and other stresses
- ***Population genomic studies*** indicate the potential for local adaptation
- Broaden the range of species studied
- Employ new technologies and examine both *gene expression **and** protein diversity*

The intertidal copepod *Tigriopus californicus: a model system for genomic and evolutionary* responses to environmental change



The more pronounced up-regulation of heat shock genes in the San Diego population may explain its higher stress tolerance compared to the Santa Cruz population.

Shallin Busch & Paul McElhany

NOAA-NWFSC

Michael Maher, Jason Miller, Sarah Norberg, Carolyn Friedman, Julie Keister, Steven Roberts, Paul Williams

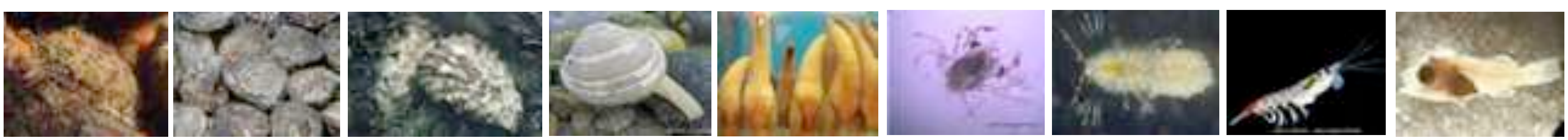
June 2009

PHYSIOLOGICAL RESPONSES

Response of coastal species to ocean acidification

Understand the demographic, morphologic, and genomic responses of Puget Sound species to future coastal chemistry

- Experimental conditions designed to mimic climate change and variability in pH, dissolved oxygen, and temperature
- Study species chosen by their economic, ecological, and conservation importance
  - Research focuses on early life stages
  - Collect data that can inform ecological models



Study species at Northwest Fisheries Science Center: pinto abalone, Olympic oyster, Pacific oyster, littleneck clam, geoduck, Dungeness crab, copepods, krill, rockfish

Wei-Jun Cai

University of Georgia

A. Grottoli and M. Warner

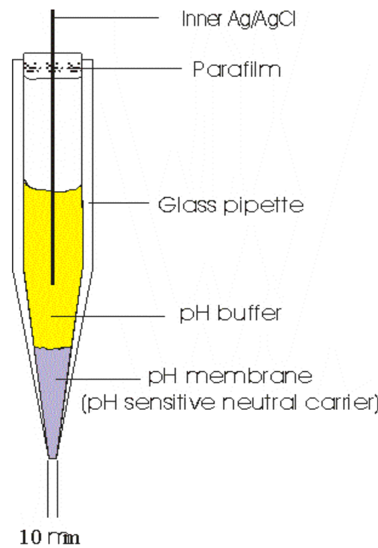
Sept, 2010

PHYSIOLOGICAL RESPONSES

NSF-OA: Interactive Effects of Temperature, Nutrients, and Ocean Acidification on Coral Physiology and Calcification

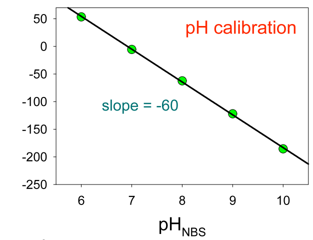
Development of microelectrodes and applications to coral internal pH and CO_3^{2-} measurements

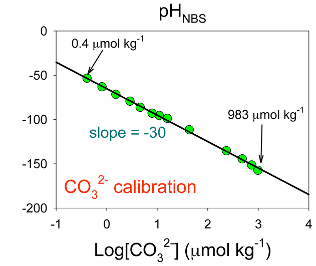
- 2010-2012
  - Develop microelectrodes
  - Calibrate microelectrodes
- Summer 2011 & 2012
  - Measuring carbonate parameters during coral incubation
  - Collecting microelectrode profiles

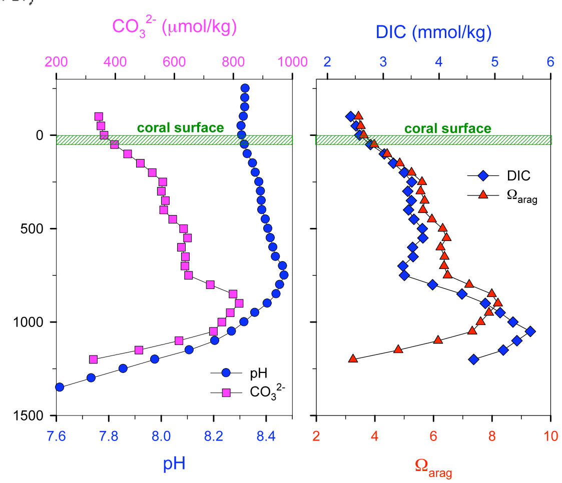


Tip size ~10-20 μm

Turbinaria spp.







Robert Carpenter

Peter Edmunds

California State University, Northridge

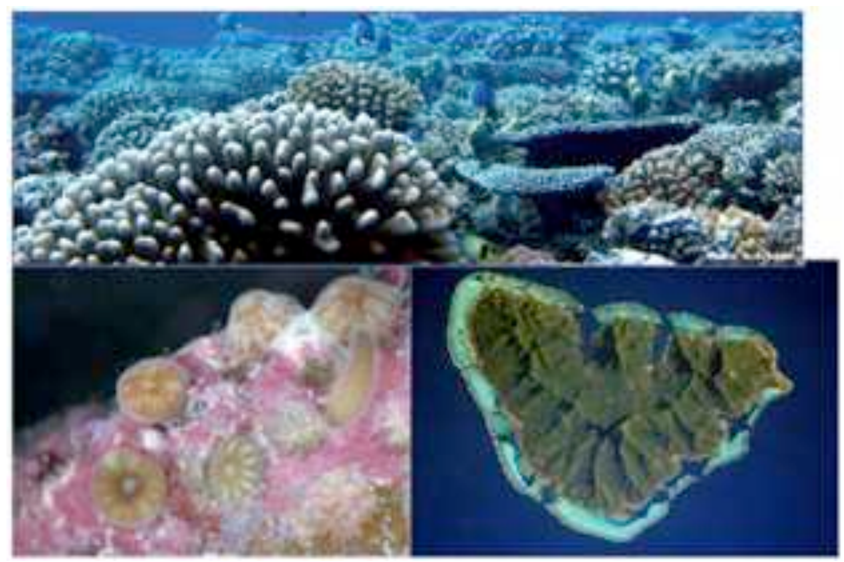
January 2011

Effects of OA on the Organismic Biology and Ecology of Corals and Calcified Algae

PHYSIOLOGICAL RESPONSES

Experiments to quantify responses of calcification and photosynthesis/respiration of corals and algae to OA

- Microcosm Experiments
  - 8 coral species, 8 calcified algal species, 6 levels of pCO_2
  - Multi-factor experiments (light, temperature, nutrients)
  - Recruitment/Bioerosion
- Field Measurements
  - Reef-wide Calcification (varying community structure)
- Regional Comparisons
  - Moorea, Hawaii



PHYSIOLOGICAL RESPONSES

Emily Carrington

UW Friday Harbor Laboratories

Carrington, Summers, O'Donnell & Martone

September, 2010

Effects of ocean acidification on coastal organisms: an ecomaterials perspective

How does OA and other environmental factors affect the structural integrity of organisms?

- Target Organisms
  - Bivalve mussels
  - Calcified coralline algae
  - Crab-whelk-mussel trophic cascade
- Responses Quantified
  - Tissue composition
  - Material properties
  - Organismal performance (ecologically relevant)

PHYSIOLOGICAL RESPONSES

Anne Cohen

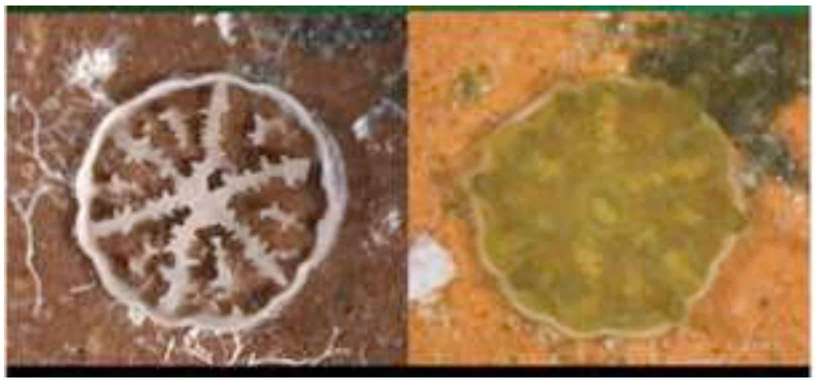
McCorkle, Tarrant, de Putron

Woods Hole Oceanographic Institution

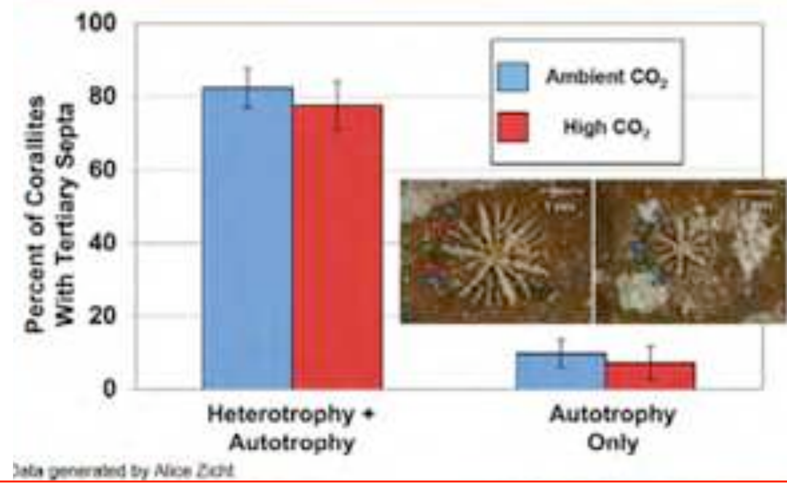
08/29/2010-09/30/2013

An Investigation of the Role of Nutrition in the Coral Calcification Response to Ocean Acidification

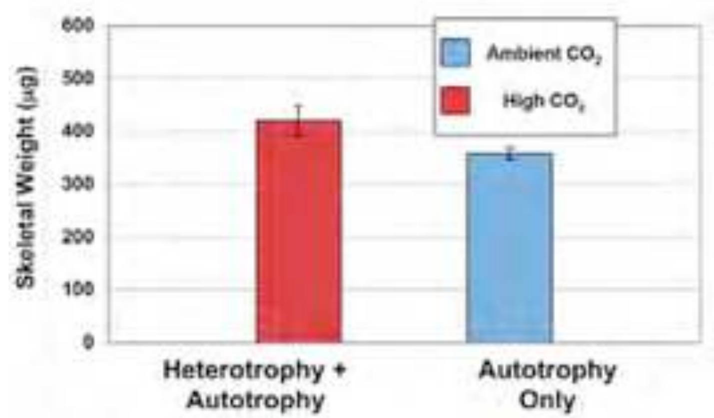
Favia fragum corallite (left) and live primary polyp (right)



1) Impact of CO_2 and nutrition on development



2) Impact of CO_2 and nutrition on $CaCO_3$ production



Drenkard et al., 2011 and *in prep*

SUMMARY OF INITIAL RESULTS

- Corals reared under ambient (420 ppm) and high (1670 ppm) CO_2 at 28°C corresponding to Ω_{ar} = 3.7 and 1.6, were either fed or unfed:

1. Rate of skeletal development, evidenced by timing of appearance of tertiary septa, was influenced by energetic status only, not CO_2
2. Corallite size was significantly larger in fed corals than unfed corals, in ambient and high CO_2 treatments
3. $CaCO_3$ production (skeletal weight) was higher in fed, high CO_2 corals than in unfed, low CO_2 corals

Clay Cook

Harbor Branch / FAU / NSF

March, 2011

PHYSIOLOGICAL RESPONSES

Affiliate Prof. Of Biology, Harbor Branch Oceanographic Institute at Florida Atlantic University

NSF Program Director, BIO/IOS 2008-2010

- BIO representative on NSF / OA working group, 2010
- Program Director, Symbiosis, Defense and Self-recognition
- General research interest in coral physiology, symbiosis

PHYSIOLOGICAL RESPONSES

Robert Foy

Kodiak Laboratory, AFSC,NMFS,NOAA

Long, W.C., Swiney, K.

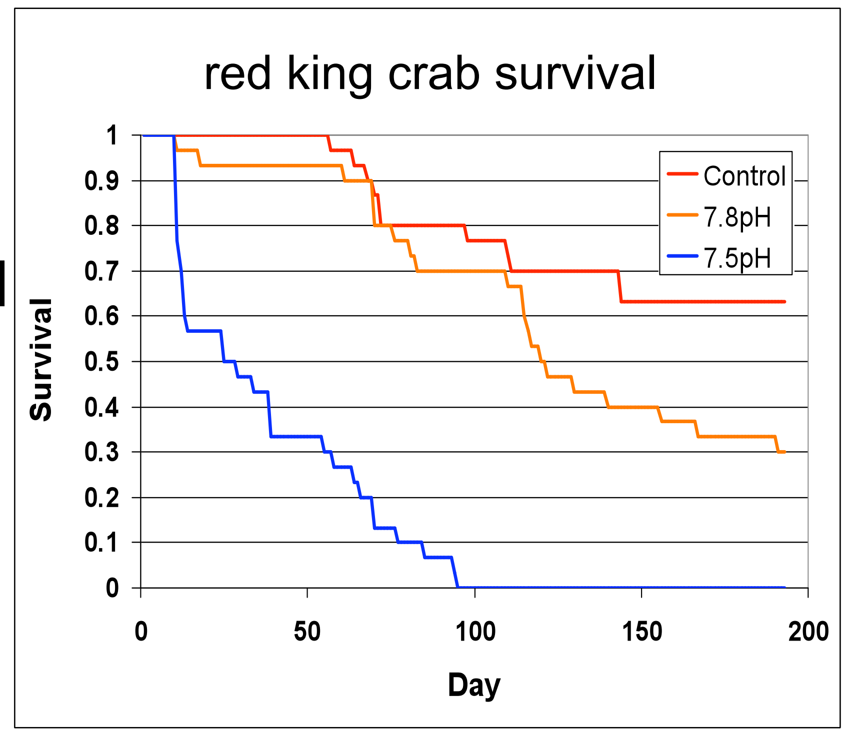
May, 2007

Effects of OA on embryogenesis, larvae condition, and adult survival of commercial crab species in Alaska

Experimental studies on *Paralithodes spp. Chionoecetes* spp., and *Lithodes* sp.

Control 7.8 pH 7.5 pH

- 2008 pilot studies
- 2009 design CO_2 delivery
  - Flow through
  - pH control
- 2010 experimental work on red king crab and Tanner crab.
- 2011 refine response variables
  - Energetics, condition, microarray
  - Stock modeling
  - Economic impact studies



Martin Grosell

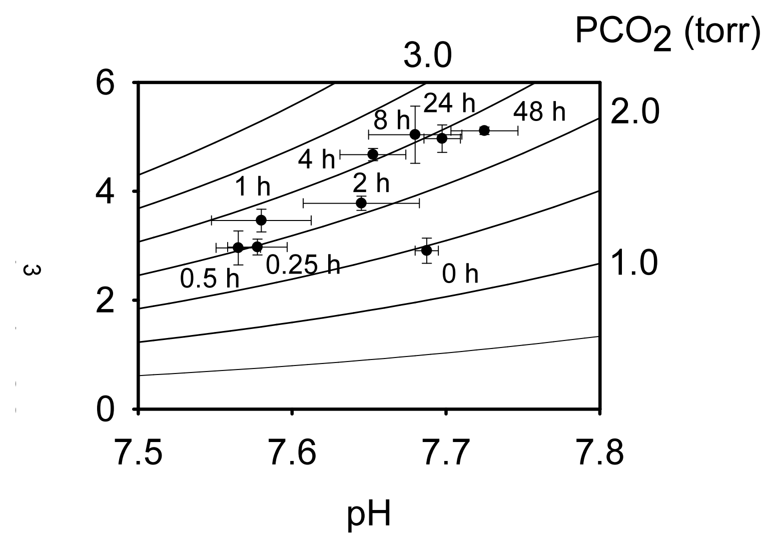
RSMAS, University of Miami

March, 2011

PHYSIOLOGICAL RESPONSES

Impact of CO_2 on acid-base balance, rectal base excretion and intestinal carbonate formation in marine fish

- Objectives
  - Characterize the magnitude and time course of acid-base balance disturbances during exposure to elevated CO_2 (560-1900 ppm)
  - Describe the mechanisms of compensation for CO2 induced acidosis
  - Examine the potential for acclimation to elevated CO2 during prolonged exposure



Blood acid-base status during exposure to 1900

Martin Grosell

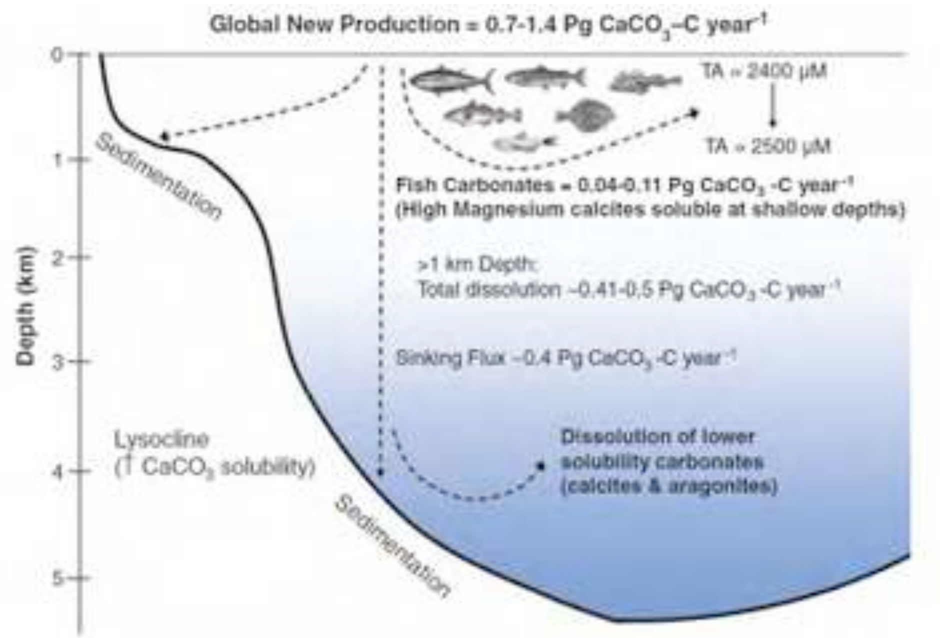
RSMAS, University of Miami

March, 2011

PHYSIOLOGICAL RESPONSES

Impact of CO_2 on acid-base balance, rectal base excretion and intestinal carbonate formation in marine fish

- Objectives (continued)
  - Determine the impact of elevated CO_2 on the piscine contribution to the oceanic inorganic carbon cycle



Piscine contribution to the inorganic carbon cycle
Wilson….& Grosell, Science, Vol 323, 2009

PHYSIOLOGICAL RESPONSES

Gretchen Hofmann

University of California,
Santa Barbara
April, 2010

Effect of ocean acidification on early life history stages of the Antarctic sea urchins

In this project, we are characterizing the response of embryonic and larval Antarctic sea urchins (*Sterechinus neumayeri*) to ocean acidification and ocean warming (ANT-0944201)

On the ice, we collect urchins and raise cultures of larvae at variable CO_2 levels and then assess numerous performance metrics

(Photo by Shawn Harper)

(images not to scale)

Pauline C. Yu

UC-Santa Barbara

September, 2010

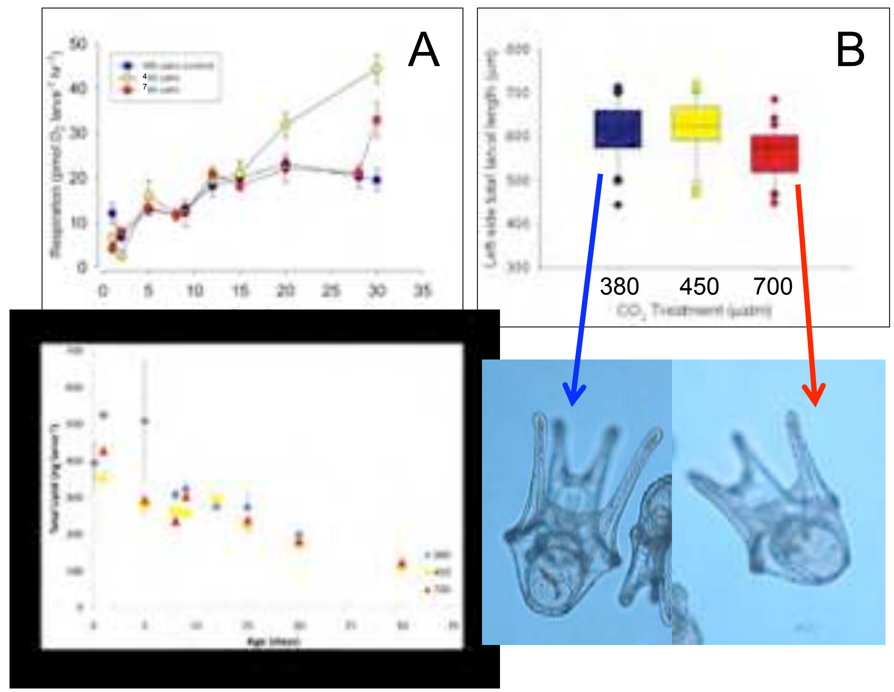
Hofmann

PHYSIOLOGICAL RESPONSES

Effects of ocean acidification on developmental physiology of the Antarctic sea urchin, <u>S. neumayeri</u>

Metabolism, lipid budget, enzyme activity and proteomics of larvae of *S. neumayeri* under elevated CO_2.

- Fall 2010-Spring 2011
  - ✓ Morphometrics
  - ✓ Lipid utilization
  - ✓ Respiration
- Summer 2011
  - – Enzyme activity
- Fall 2011-Summer 2012
  - – Proteomics
  - – Multistressor expt.



Respiration (A), day 30 arm lengths (B), lipid (C), and day 30 plutei of <u>S. neumayeri</u> at control and elevated pCO_2

Gretchen Hofmann

Evans TG, Yu P, et al.

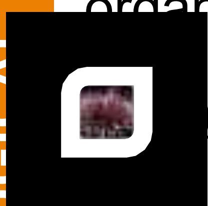
University of California,
Santa Barbara

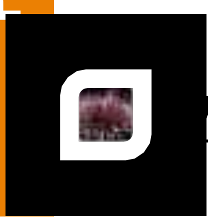
PHYSIOLOGICAL RESPONSES

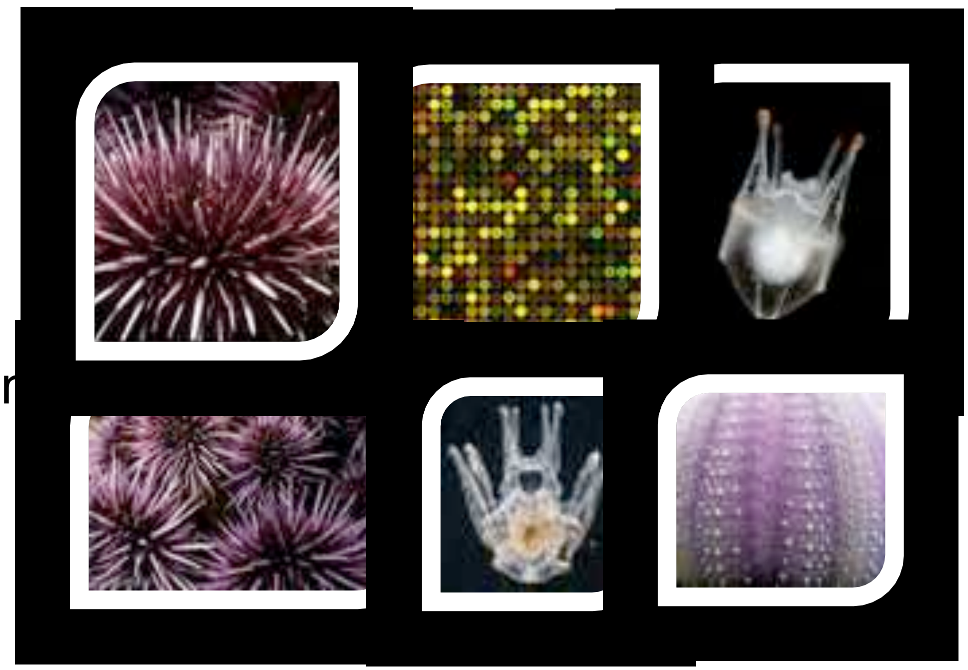
Synergistic effects of climate-related variables on larval sea urchins

Characterize the response of larval purple sea urchins (*Strongylocentrotus purpuratus*) to the synergistic interaction of two climate change-related factors: ocean acidification and ocean warming (IOS-1021536)

Larvae cultured under varying levels of pCO_2 and temperature will be analyzed using a suite of experimental tools that span levels of biological organization:







rganismal

-morphometric and survival analyses

iochemical

-calcification rate, respiratio lipid content, total protein

hysiological

-transcriptomics

Physiological Responses

Hofmann, Palumbi

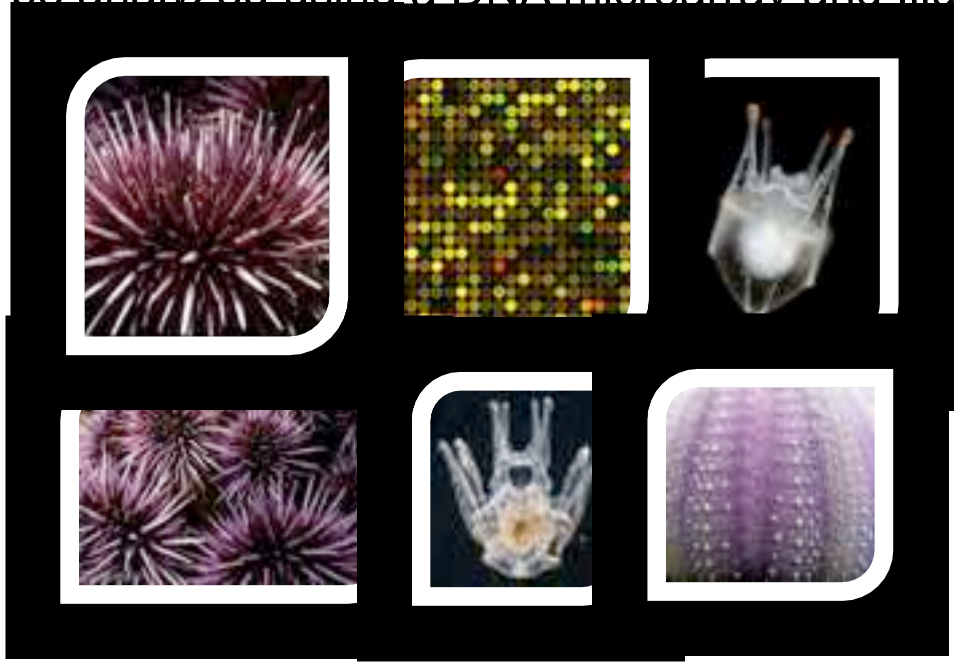
Barth, Blanchette, Chavez, Gaylord, Hill, Hofmann,
McManus, Menge, Raimondi, Russell, Sanford, Washburn

UC Santa Barbara
Stanford University

Collaborative Research: Acclimation and adaptation to ocean acidification of key ecosystem components in the California Current Large Marine Ecosystem

Gene expression analysis in the OMEGA project

- Characterize the response of larval purple sea urchins (*Strongylocentrotus purpuratus*) to the pCO_2 levels characteristic of coastal upwelling & assess the genetic structure of populations at the field sites ranging from OR to CA
- The transcriptome of larvae cultured under varying levels of pCO_2 and temperature will be analyzed using a DNA microarray and Illumina sequencing.



Kris Holderied

NOAA Kasitsna Bay Lab

Descoteax R., Iken K., Mathis J.

May, 2010

Effects of ocean acidification on development of larval crabs in Alaska

Laboratory study exposing early life stages of three crabs to pH levels expected to occur over the next two centuries

- Crab species: Tanner (*Chionoecetes bairdi*), Dungeness (*Cancer magister*) and Pygmy Rock (*Cancer oregonensis*) crabs.
- Measure effects of low pH on larval development and calcification of the larval exoskeleton

NOAA Kasitsna Bay Laboratory and OA treatment system

Kris Holderied

Morris J., Sunda B., Currin C.

NOAA Center for Coastal Fisheries and Habitat Research

Awaiting funding

PHYSIOLOGICAL RESPONSES

Effect of ocean acidification on phytoplankton, shellfish and fish species

Proposed controlled laboratory studies to determine:

- Effect of lower pH/ increased CO_2 on growth of calcifying and competing non-calcifying marine phytoplankton species
- Effect of lower pH on growth and larval development of temperate and tropical fish and shellfish
- POCs: Bill.Sunda@noaa.gov
  James.Morris@noaa.gov

Microalgae covered with calcium carbonate plates

Brian Hopkinson

University of Georgia

Francois M.M. Morel, Michael Bender

September, 2010

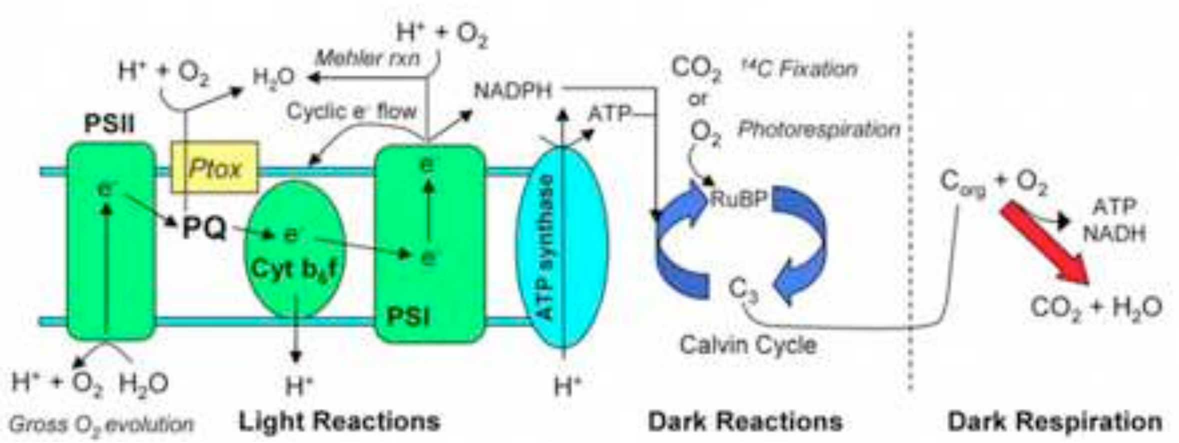
PHYSIOLOGICAL RESPONSES

Effects of pCO_2 and pH on photosynthesis, respiration and growth in marine phytoplankton

Isolating energetic sources for increased phytoplankton growth and photosynthesis at high CO_2

Hypotheses:

1. At high CO_2, the carbon concentrating mechanism can be down-regulated allowing increased photosynthetic efficiency
2. At low pH, respiration decreases because less energy is required for pH homeostasis



Possible energy sources

Physiological Responses

Cheryl Kerfeld& Annette Salmeen

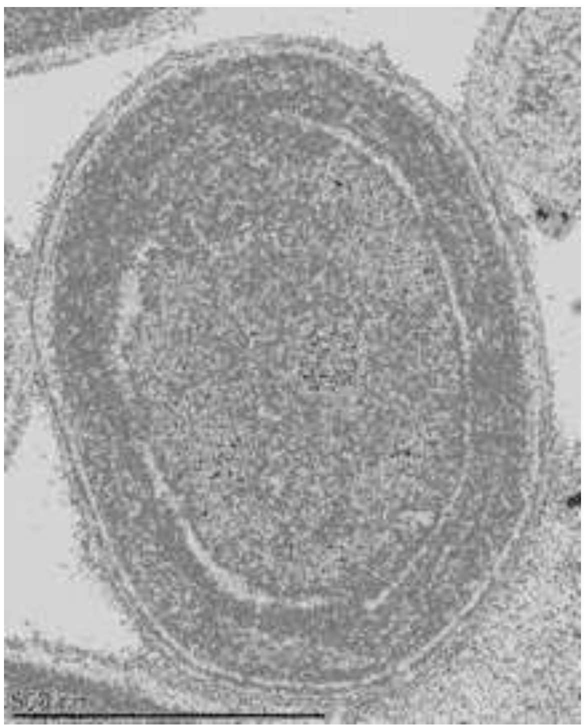
JGI/UC Berkeley

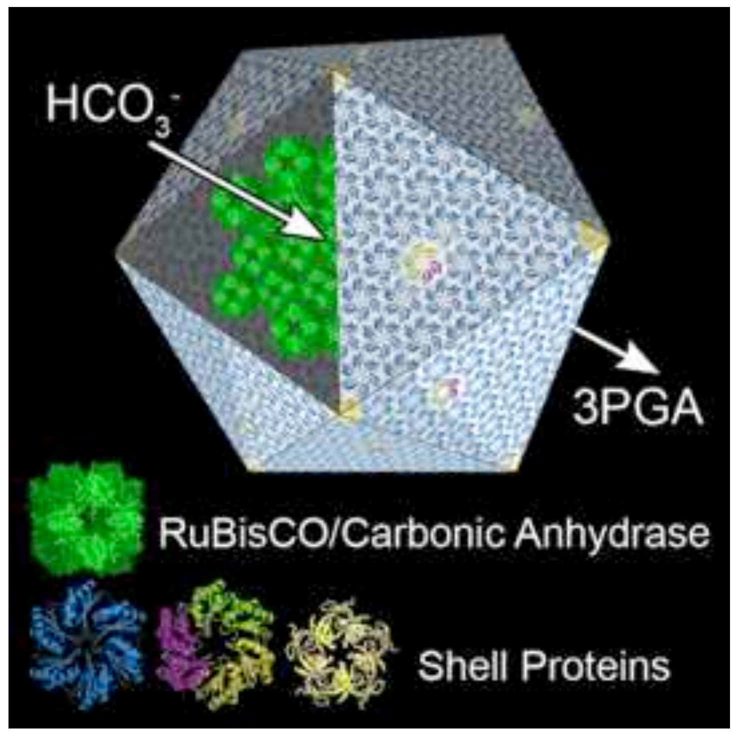
March, 2009

Kerfeld, Ting, Heinhorst and Cannon

Structural, Functional, and Ecological Characterization of the Prochlorococcus Carboxysome, the Ocean's Primary Molecular Module for Carbon Fixation

Structurally and functionally characterize the marine cyanobacterial carboxysome and bioinformatically examine the distribution of the cyanobacterial carbon concentrating mechanism in the open ocean





Left: Transmission electron micrograph of *Prochlorococcus* MED4 containing a single carboxysome. Right: Schematic model of carboxysome structure and function

Ilsa B. Kuffner

T. D. Hickey, R. Z. Poore

U.S. Geological Survey

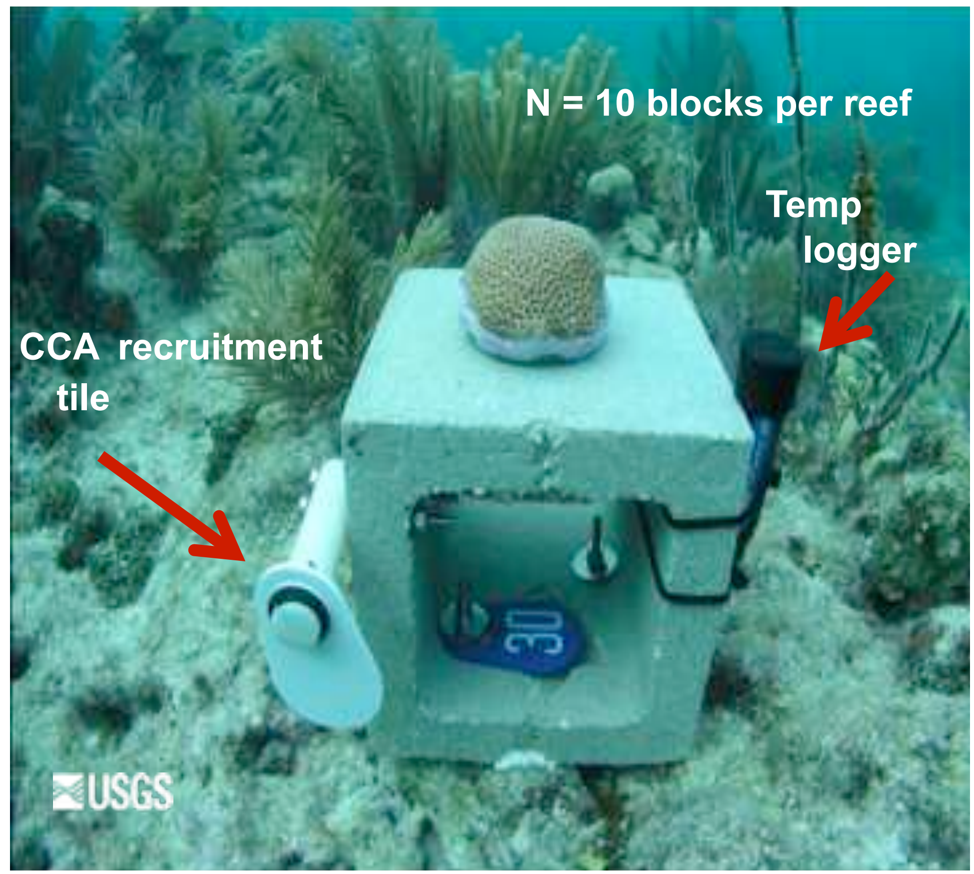
April 2009

PHYSIOLOGICAL RESPONSES

Long-term monitoring of coral and algal calcification in the Florida Keys, U.S.A.

Measuring summer and winter coral growth at four reef sites using buoyant weight and alizarin-red staining.

- ✓ Establish stations (N = 40)
- ✓ *In-situ* temperature & SEAKEYS oceanographic data
- ✓ Two years of growth data, *Siderastrea siderea* & CCA
- Correlate calcification with temperature, modeled carbonate system parameters, and other variables
- High-resolution Sr/Ca temperature proxy calibration



PHYSIOLOGICAL RESPONSES

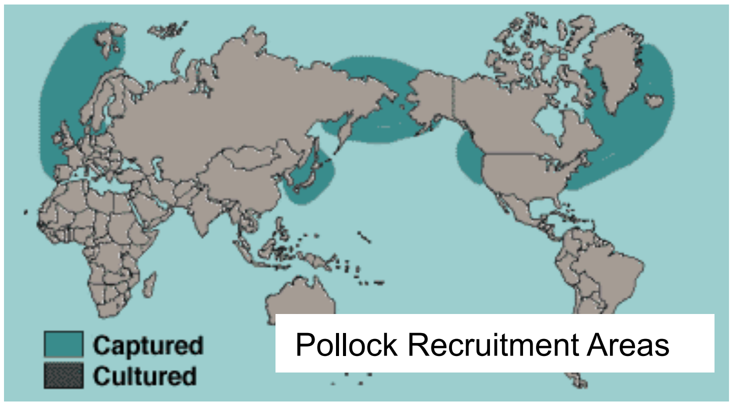
Jeremy T. Mathis

Tom Hurst (NOAA – Hatfield Lab)
Elena Fernandez (UAF MS Student)

University of Alaska Fairbanks

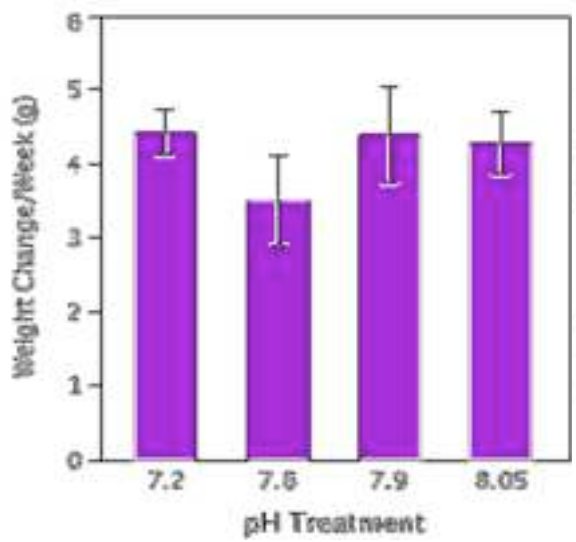
December, 2010

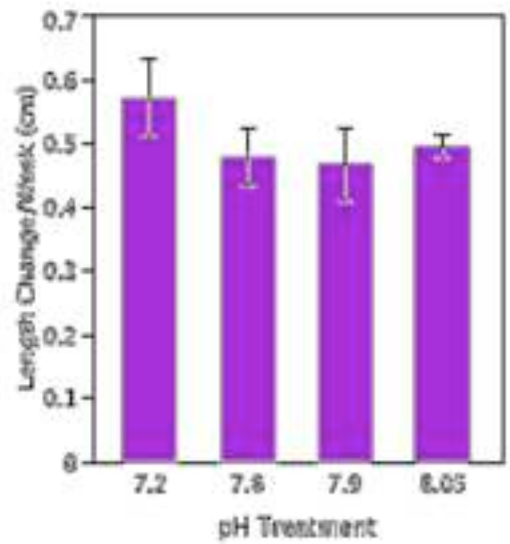
Present and Future Impacts of Ocean Acidification on Juvenile Walleye Pollock Metabolic Processes and Growth Rates



1. Does acidification show a significant effect on standard metabolic rate of larval and juvenile Pollock?

2. Which metabolic enzymes (PK, LDH, and CS) does ocean acidification effect, and how?





Daniel McCorkle
Anne Cohen

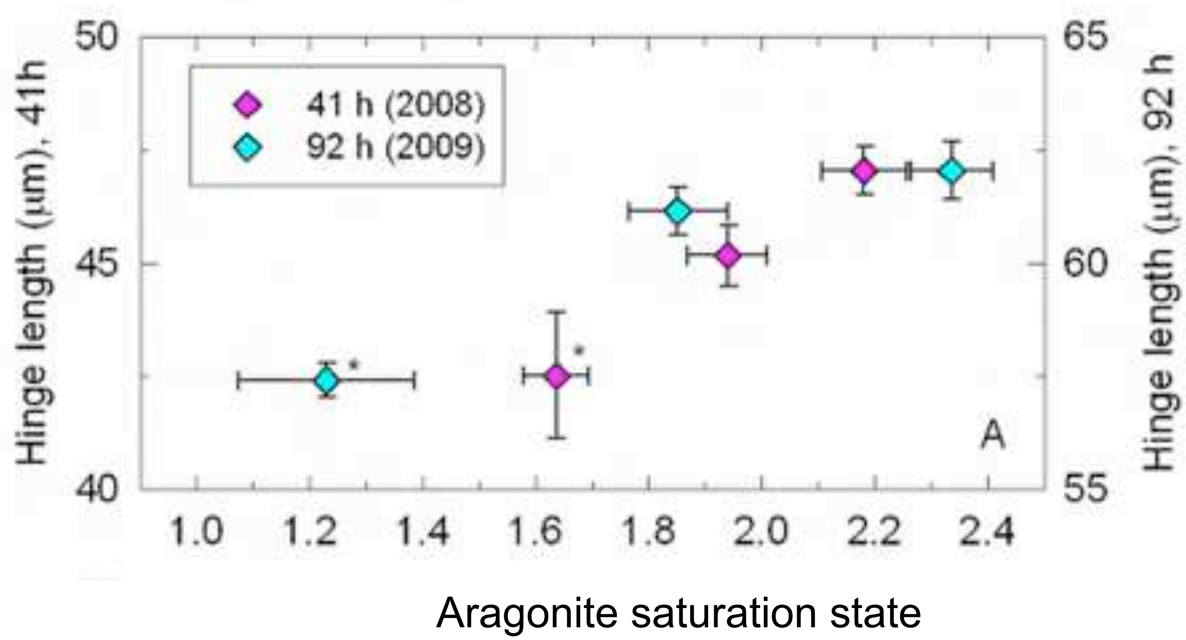
WHOI

Soggin, Pinard, Kraus

PHYSIOLOGICAL RESPONSES

Impact of ocean acidification on survival and early shell development by the bay scallop <u>Argopectin irradians</u>

- Shell size (hinge length) decreases as saturation state decreases.



PHYSIOLOGICAL RESPONSES

Paul McElhany & Shallin Busch

NOAA-NWFSC

Mike Maher, Jason Miller, Sarah Norberg

June, 2009

System for OA Species-Response Experiments at Northwest Fisheries Science Center

- Independently controls **CO_2, DO, and temperature**
- **Dynamic control** of all parameters to mimic natural patterns at tidal, diurnal and other scales
- Simulates **pre-industrial conditions** by removing CO_2
- Over-parameterization of carbon measurement for **accurate and precise** control
- Large volume for simultaneous experiments on **multiple species**

NWFSC system for OA species response experiments

Currently at Montlake Lab with 3x2 factorial experiment capacity.
Moving to Mukilteo Lab with 3x3x3 factorial experiment capacity.

PHYSIOLOGICAL RESPONSES

Shannon Meseck

NOAA/NMFS

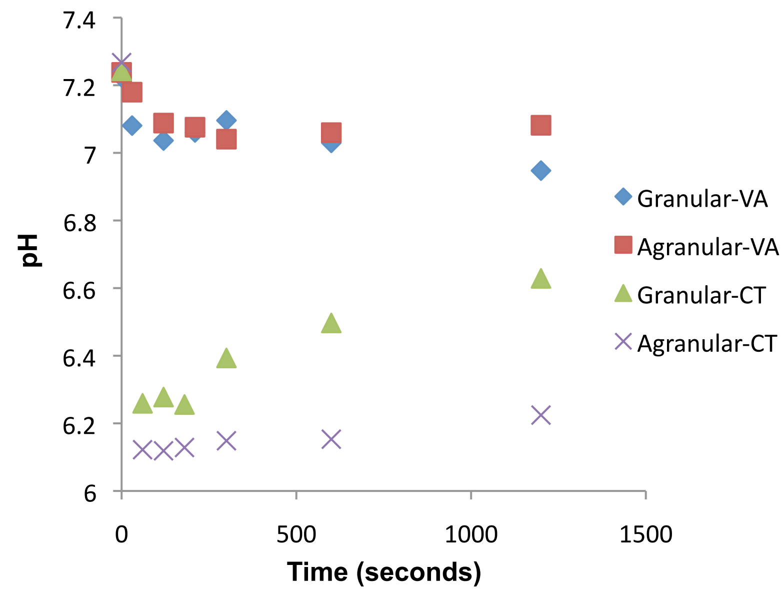
Meseck, Wikfors, Foy

2011?

The Response of King Crab Hemocyctes to Ocean Acidification

Molecular probes to measure hemocyte pH_i and Ca_i

- Fall 2010
  - Calibrated SNARF
  - *In vivo* experiment on blue crab, *Calinectes sapidus,* hemocyctes at pH 7.2
- Summer 2011
  - Determine pH of King Crab hemocyctes in adults grown under different CO_2 concentrations



In vivo experimental recovery of pH for blue crab hemocyctes

Shannon Meseck

NOAA/NMFS

Croxton, Alix, Wikfors

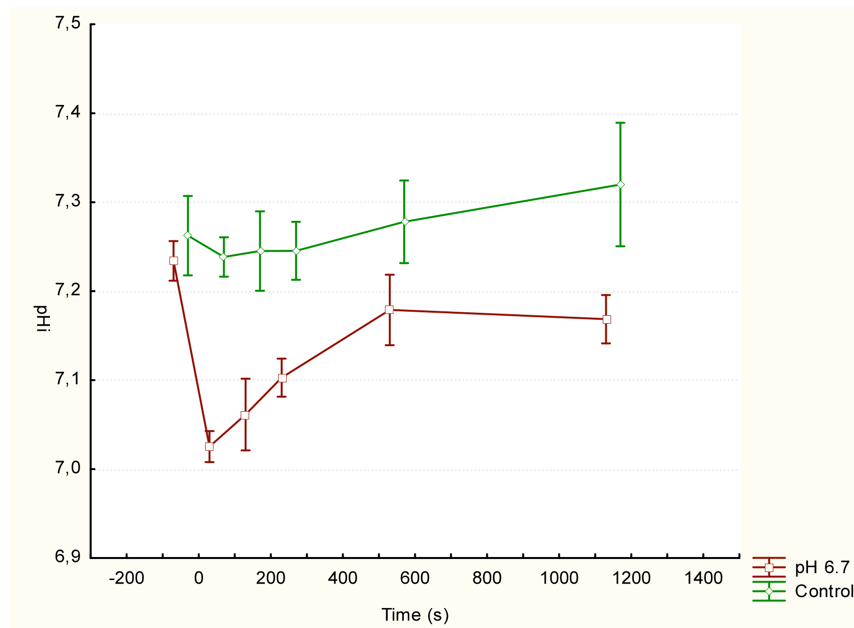
2011?

PHYSIOLOGICAL RESPONSES

Physiological Resiliency of Bivalve Hemocytes, Primary Calcifying Cells, to Extracellular Acidification

Molecular probes to measure hemocyte pH_i and Ca_i

- 2010
  - *In vivo* calibration of hemocyte pH_i and Ca_i for *Crassostrea virginica (Eastern oyster)*
- 2011
  - determine *in vivo* hemocyte pH_i and Ca_i for
    - *Mercenaria mercenaria*,
    - *Mytilus edulis*,
    - *Argopecten irradians irradians*,
    - *Spisula solidissima*,
    - *Placopecten magellanicus*



Regeneration of pH_i after exposure to high CO_2 water

Mónica V. Orellana

J. Ashworth, A. Lee, E. V. Armbrust, N. S. Baliga

Institute for Systems Biology
Seattle, WA

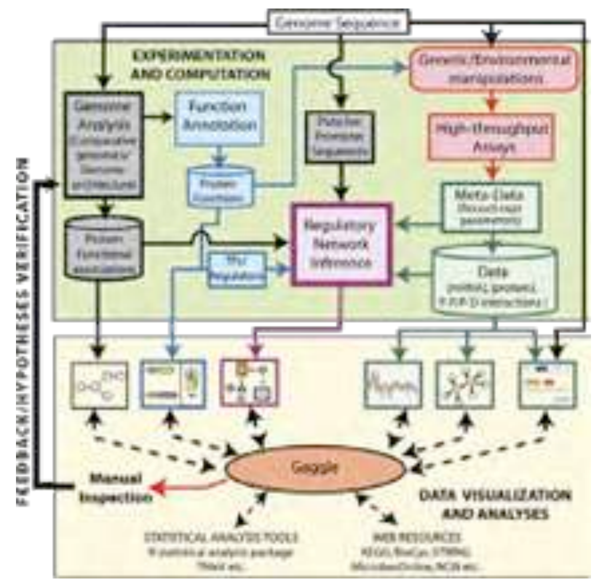
March 2011

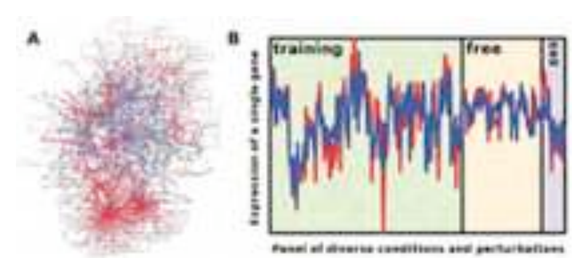
PHYSIOLOGICAL RESPONSES

A Systems Biology Approach to Diatom Responses to Ocean Acidification and Climate Change

Elucidate cellular networks under varying conditions; model and predict physiological, chemical, and environmental responses.

- 2010
  - design arrays and experiments
  - map spectrum of expression changes
- 2011
  - finely track specific perturbations
  - construct *de novo* regulatory network models by machine-learning
- Beyond
  - validate network predictions
  - biological mechanisms > emergent properties
  - predict environmental responses, adaptations





Adina Paytan

UCSC

D. Potts

October 2010

PHYSIOLOGICAL RESPONSES

Enhancing Opportunities for Ocean Acidification Research and Education at the University of California, Santa Cruz

Setting up a culturing facility to grow important organisms that characterize the Monterey Bay ecosystem at different CO_2 levels will be set at the Longs Marine Laboratory and conducting some culturing manipulations

- Fall 2010
  - Set up culturing facility
  - Test carbonate chemistry
- Winter & Spring 2011
  - Experiments with *Balanophyllia*
  - Experiments with *Euphausia*
- Summer 2011
  - Other organisms

Growth and recruitment of a common solitary coral in California, the orange cup coral *Balanophyllia elegans* under different pCO_2 and feeding conditions.

PHYSIOLOGICAL RESPONSES

Beth Phelan-Hill

NOAA, NMFS

2011

Phelan, Hare, Fogarty, Stock, Wikfors, Meseck, Chambers, Poach, Wieczorek, Perry, Widman, Milke, Redman, Croxton, Alix

Northeast Regional Ocean Acidification Research Implementation Plan

- 2010 - NOAA Ocean and Great Lakes Acidification Research Plan
  - Monitoring
  - Ecosystem response
  - Modeling
  - Data synthesis
  - Human dimensions
  - Outreach
- 2011- Experimentation on priority species
  - Phytoplankton
  - Shellfish
  - Fish

PHYSIOLOGICAL RESPONSES

Beth Phelan-Hill

NOAA,NMFS

Chambers, Phelan, Poach, Wieczorek

March, 2011

Ocean acidification effects on resource finfish species

Determine the effects of increased pCO_2 on early life history stages of commercially important fish species

- 2010
  - Identified candidate resource species representing broad ecological and life history types for the northeast.
  - Developed an experimental design with multiple CO_2 levels and water temperatures for both eggs and larvae.
  - Selected response variables to be used as bio-indicators of responses to experimental factors.
  - Designed and constructed a controlled CO_2 /temperature flow-through experimental system for exposing fish eggs and larvae.
- 2011
  - Conduct experiments on pCO_2 and temperature effects on winter flounder eggs and larvae.
  - Measure response variables. 1) viability of gametes, embryos, and larvae, 2) duration of embryonic and larval periods, 3) sizes, condition, and energy reserves of larvae at hatching and settlement.

PHYSIOLOGICAL RESPONSES

Beth Phelan-Hill

NOAA/NMFS

Perry, Redman, Meseck

2011?

Effects of Elevated Levels of Carbon Dioxide on Otolith Condition and Growth of Juvenile Scup

Examine otolith structural abnormalities, asymmetries, size and mass and measure somatic growth in young-of-the-year scup

- 2010
  - Prepared research plans, budgets, and designed an experimental flow through seawater system to investigate OA effects on fish.
  - Ordered supplies, equipment and began building the system.
  - Prepared a poster for the OA workshop in Seattle, WA.
- 2011
  - Completed construction of OA experimental seawater system.
  - Conduct an experiment to assess the effects of increased levels of pCO_2 on otolith condition and growth of young-of-the-year scup.
  - Perform sample and data analyses from this experiment for manuscript submission to a peer-reviewed journal in 2012.

Sean Place

Dudycha

University of South Carolina

May, 2011

PHYSIOLOGICAL RESPONSES

Identifying adaptive responses of polar fishes in a vulnerable ecosystem

Acclimate notothenioid fish to elevated CO_2 & temperature, measure energetic costs, stress response, and cellular damage.

- Fall 2011/ 2012
  - acclimate Antarctic species
  - measure metabolic scope/ cellular energy allocation
  - measure cellular damage
- Spring 2012/ 2013
  - build annotated transcriptome
  - characterize gene expression
- Fall 2013
  - repeat for temperate New Zealand species

The cryopelagic circumantarctic notothenioid fish *Pagothenia borchgrevinki*

Nichole Price

Jennifer Smith (PI)

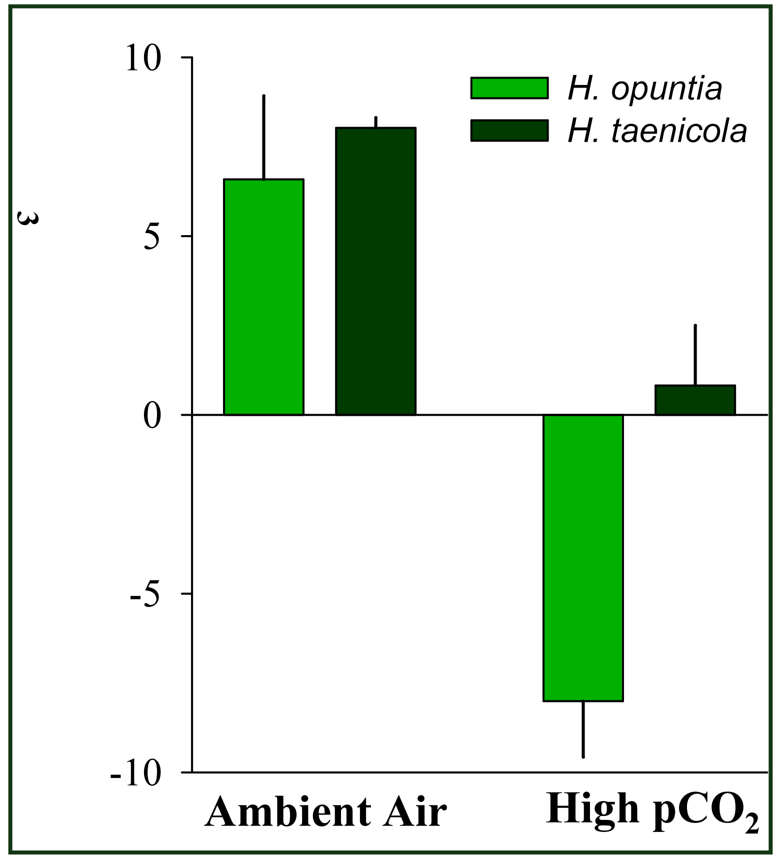
Scripps Institution of Oceanography

June, 2010

PHYSIOLOGICAL RESPONSES

Physiological response of benthic algae to OA

We are quantifying changes in photo-physiology, respiration, growth, morphology, mineralogy, and calcification of fleshy and calcified benthic algae in response to OA.



CO_2 bubbling experiment with 2 species of Halimeda
Price et al. (in review)

Justin B. Ries

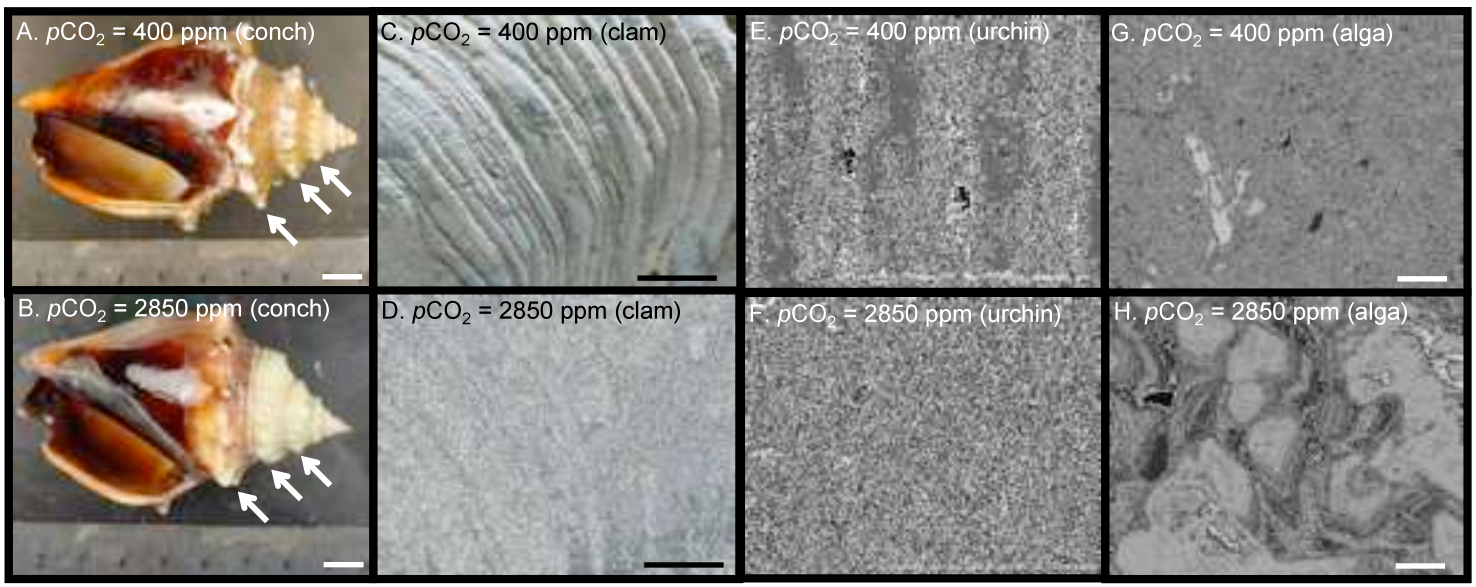
UNC – Chapel Hill

September 2010

PHYSIOLOGICAL RESPONSES

Investigating the effects of $CaCO_3$ saturation state & temperature on the calcification rate and skeletal properties of benthic calcifiers (NSF BIO-OCE #1031995)

Experimental investigation of the effect of CO2-induced ocean acidification on calcification rates, elemental composition, mineralogy, and biomechanical properties of benthic marine calcifiers.



Lisa Robbins

P. Knorr, P. Harries (Co-Advisor), P. Hallock, J. Wynn

USGS- St. Petersburg

2008- 2012

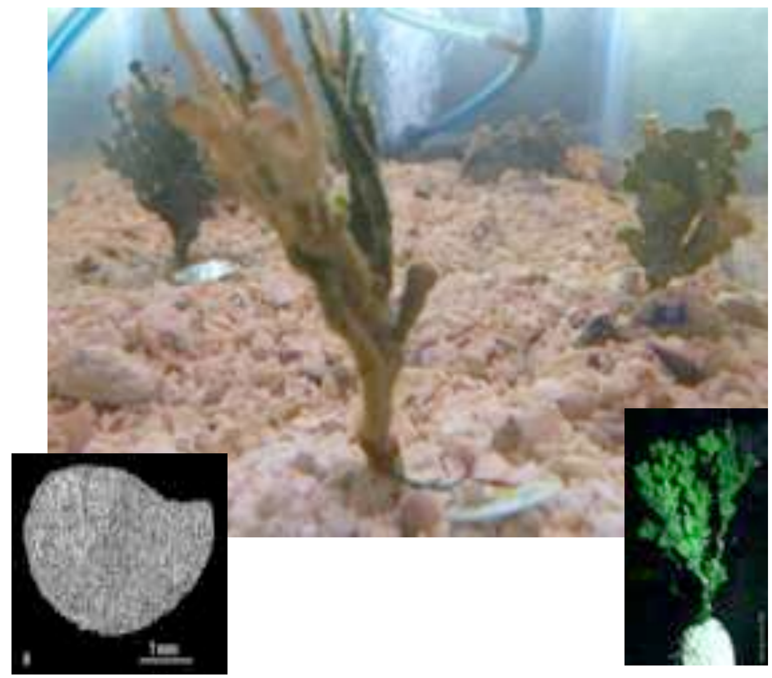
PHYSIOLOGICAL RESPONSES

Response of Florida Shelf Ecosystems to Climate Change

"Effects of increased CO_2 on calcification and carbonate sediment contributions of *Halimeda* and larger foraminifera"

Paul Knorr Ph.D. dissertation at University of South Florida

- *Halimeda* and larger forams are major carbonate sediment producers on FL shelf
- Laboratory experiments using elevated pCO_2 levels
  - pH-stat experiments
  - Monitor carbon chemistry
  - Analyze ultrastructure, isotopes
- Defending 2012



http://coastal.er.usgs.gov/flash

Jeffrey Runge

Co PI: John Christensen

University of Maine

November, 2010

PHYSIOLOGICAL RESPONSES

Impact of ocean acidification on survival of early life stages of planktonic copepods in the genus Calanus in the northern oceans.

Study effects of increased CO_2/lower pH on hatching success, growth and development of subarctic and arctic *Calanus* species; measure surface and vertical distributions of pH across the coastal shelf and in the deep basins of the Gulf of Maine.

- Spring 2011- Fall 2013
  - Experiments investigating pH effects on hatching success: *C. finmarchicus; C. glacialis; C. hyperboreus*
  - Similar experiments to investigate effects on growth and development of early life stages
- Summer/Fall 2012
  - Research cruise to measure spatial and vertical distribution of pH in the Gulf of Maine and conduct shipboard experiments on *C. finmarchicus*

Calanus finmarchicus

PHYSIOLOGICAL RESPONSES

Inna Sokolova

UNC Charlotte

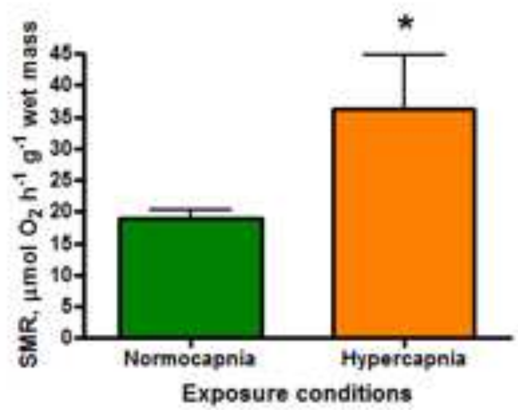
Sokolova & Beniash

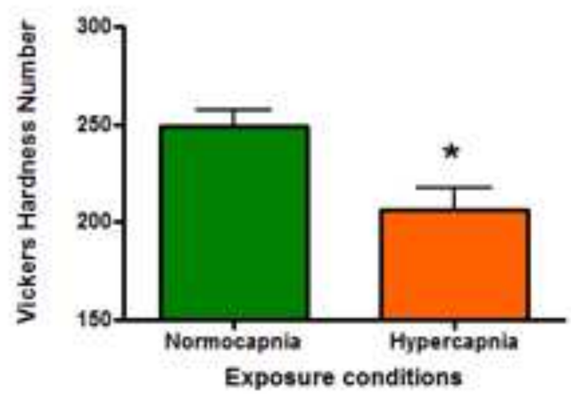
August, 2010 – July 2013

Interactive effects of ocean acidification (OA) and temperature on marine bivalves

We hypothesize that impacts of elevated temperature and pCO_2 on biomineralization and physiology will be different in mollusks with different shell mineralogy

- Model species:
  - oysters (*C. virginica*) – calcitic shells
  - hard shell clams (*M. mercenaria*) – aragonitic shells
  - blue mussels (*M. edulis*) – mixed calcite and aragonite
- Biomineralization studies:
  - Shell growth
  - Shell structural and mechanical properties
  - Expression of biomineralization-related genes
- Physiological endpoints:
  - Survival and body growth
  - Aerobic metabolism
  - Cellular and whole-organism energy status
  - Oxidative stress and antioxidant defense





PHYSIOLOGICAL RESPONSES

Lars Tomanek

Jonathon Stillman

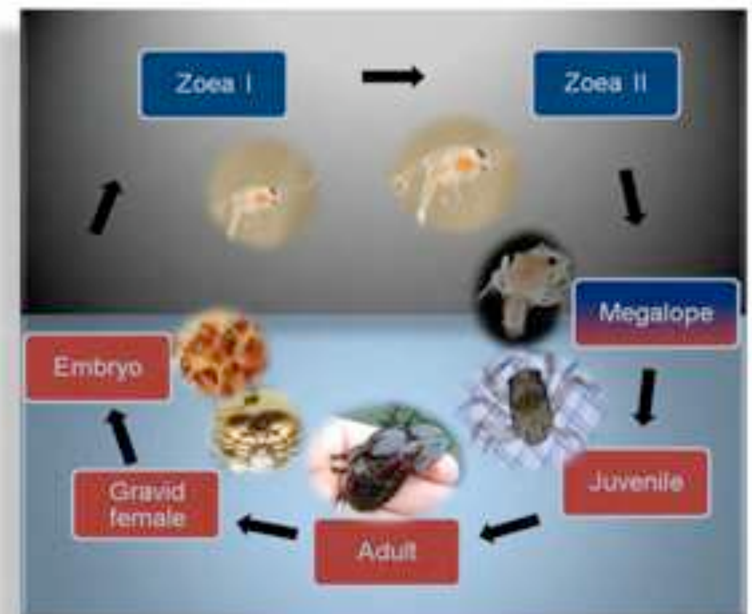
Cal Poly San Luis Obispo

March, 2011

Synergistic effects of temperature and pH variability on physiology (transcriptome and proteome) of crabs

Assess changes in morphology, respiration rate, proteome and transcriptome of porcelain crabs larvae & adults

- Winter – Summer 2011
  - **Larvae** are reared and **adults** will be exposed to various temperature ranges & pH values
  - Measure respiration & heart rates
  - Analyze changes in transcriptome and proteome of larvae and adults



Life-cycle of porcelain crabs

Waldbusser, GG

B. Hales, C. Langdon, B. Haley

Oregon State University

October, 2010

PHYSIOLOGICAL RESPONSES

A mechanistic understanding of the impacts of ocean acidification on the early life stages of marine bivalves

Determine mechanism of acidification action on a suite of bivalves utilizing unique carbonate chemistry manipulations.

- Summer 2011
  - Small scale experiments on directed physiological responses.
  - Construct experimental system for integrated rearing experiments of growth, survival, and shell development.
- 2012 and beyond
  - Working with larvae and post-larvae of *Crassostrea gigas, Ostrea lurida, Mytilus californianus, Mytilus galloprovincialis, Macoma nasuta*, and *Ruditapes philippinarum.*

Waldbusser, GG

MA Green (Lead PI)

Oregon State University

November, 2006

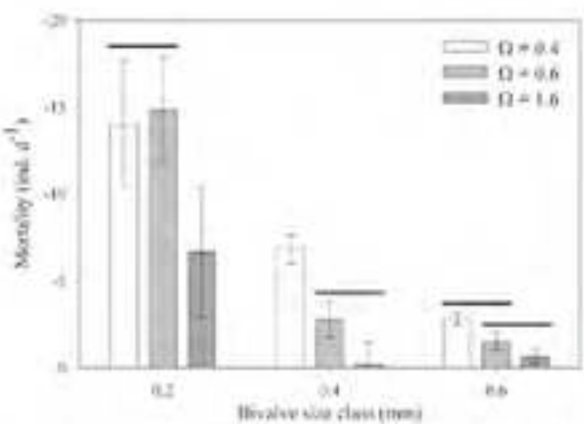
PHYSIOLOGICAL RESPONSES

Dissolution mortality of juvenile bivalves in coastal marine deposits

Determine the potential role of dissolution mortality on burrowing clam populations.

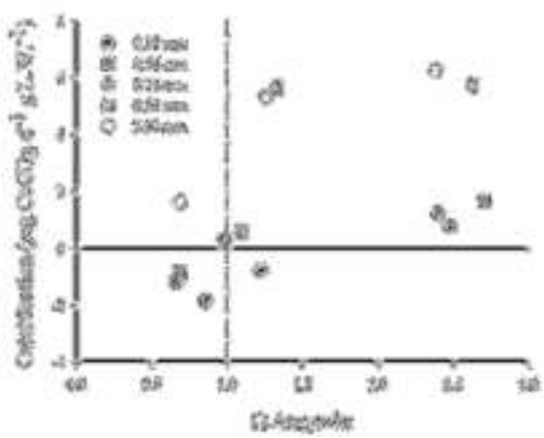
Mercenaria mercenaria Response to Acidification

Mortality



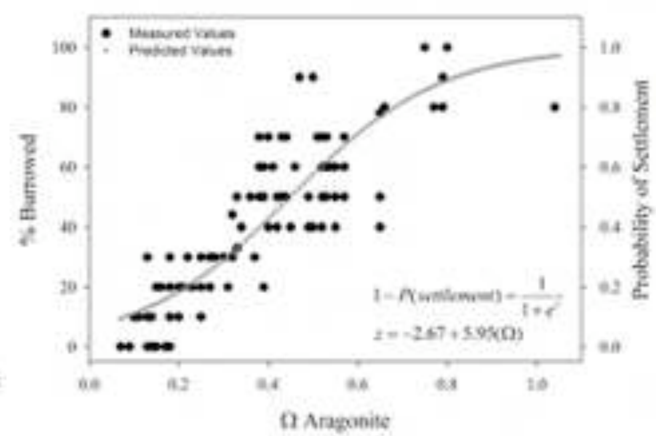
Green et al. 2009, Limnol. Oceanogr.

Shell Calcification



Waldbusser et al. 2010, Mar. Ecol. Prog. Ser.

Recruitment



Green et al. in revision

Mark Warner

University of Delaware

Grottoli, Cai

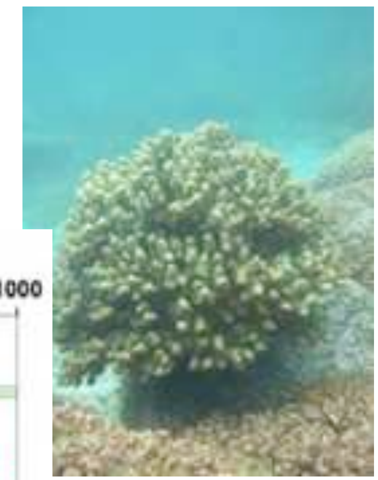
September, 2010

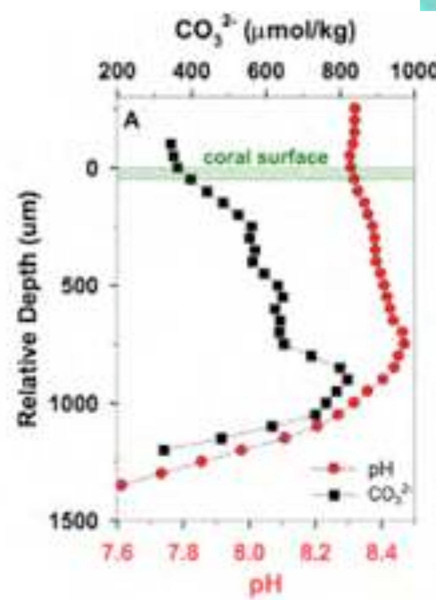
PHYSIOLOGICAL RESPONSES

Interactive effects of temperature, nutrients, and ocean acidification on coral physiology and calcification

Assess how CO_2, temperature, and N and P can impact coral-algal symbioses and calcification

- Summer 2010
  - Construct pH controlled aquarium system
  - Expose corals to elevated CO_2 and temperature
- Summer 2011
  - Expose corals to elevated CO_2, temperature, and nutrients, similar to that noted in upwelling environments





Microelectrode profile of carbonate & pH inside a coral

Tim Wootton

Cathy Pfister, Sophie McCoy

University of Chicago

Unfunded

PHYSIOLOGICAL RESPONSES

Responses to pH Change: Performance and Interactions

Laboratory Experiments on Key Intertidal Species

- Ongoing: Coralline Algae
  - Laboratory manipulations of CO_2, grazers, temperature
  - Test performance, effects on grazing, competition
- Planned
  - Calcified consumers (limpets, whelks) and prey (fleshy algae, barnacles)
  - Mussel byssal thread studies

ECOLOGY & SYSTEMS

Andreas J. Andersson

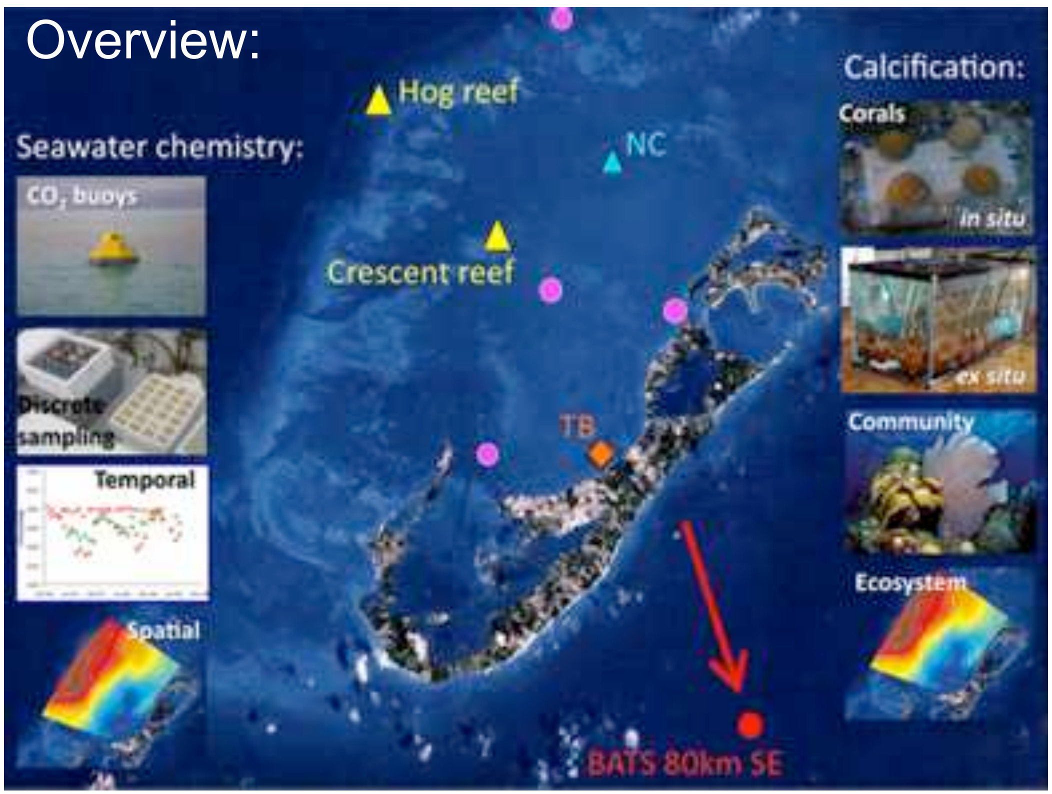
Nick Bates, Samantha de Putron

BIOS

Oct 1, 2009

<u>Ber</u>muda ocean <u>a</u>cidification and <u>co</u>ral reef <u>in</u>vestigation - BEACON

Investigate the effect of seawater CO_2 chemistry on coral and coral reef calcification in the *natural environment* on different *temporal* and *spatial* scales



- **Why Bermuda?**
  - Marginal coral reef
  - Variable pH and $[CO_3^{2-}]$
  - Healthy reef system
- **Results**
  - Net ecosystem calcification = 0 in winter
  - **C**oral **R**eef **E**cosystem **F**eedback hypothesis

Russell E. Brainard

Molly Timmers and Robert Toonen (UH), Gustav Paulay (UF), Chris Meyer & Nancy Knowlton (SI)

NOAA Pacific Islands Fisheries Science Center

January 2008

ECOLOGY & SYSTEMS

Ocean Acidification: assessing spatial patterns and temporal trends in cryptic biodiversity of coral reefs around the globe

Systematic monitoring of spatial patterns and temporal responses of cryptic biodiversity to ocean acidification using Autonomous Reef Monitoring Structures

- Long-term systematic monitoring to assess changes in benthic community structure of coral reefs
  - Global distribution of ~600 ARMS

Russell E. Brainard

Cristi Braun (UH), Nichole Price &
Jen Smith (SIO), Peter Vroom (OA)

NOAA Pacific Islands
Fisheries Science Center

January 2010

ECOLOGY & SYSTEMS

Ocean Acidification: calcification rates of crustose coralline algae in the Pacific Islands

Systematic monitoring of spatial patterns and temporal trends of calcification rates using Calcification Acidification Units (CAUs) across the Pacific Islands

- Interesting info about project
  - ~700 CAUs deployed across American Samoa, Pacific Remote Islands, Northwestern Hawaiian Islands
  - Deployed in arrays of 5 CAUs at 5 sites around each island

ECOLOGY & SYSTEMS

Denise Breitburg

Tim Targett, Kenny Rose, Howard Townsend & Bruce Michaels. (Charles Culberson, collaborator)

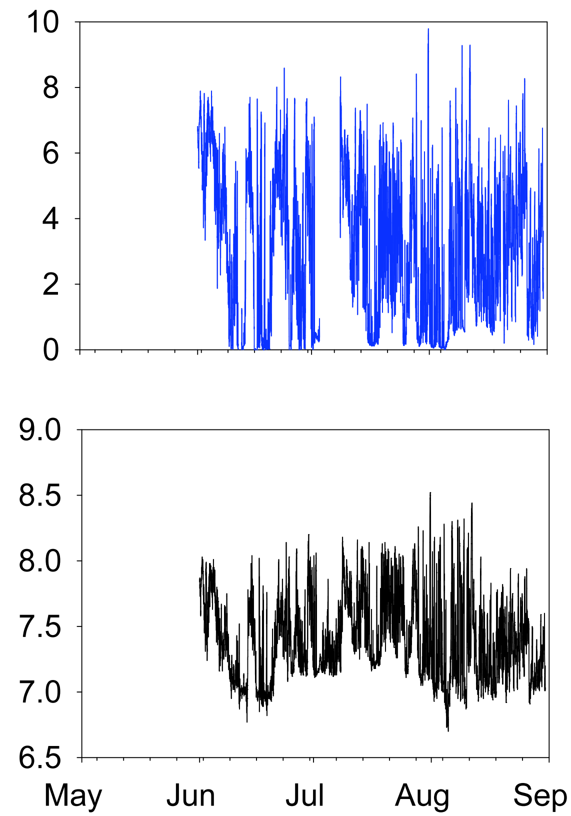
Smithsonian Environmental Research Center

1 August 2010 start

CHRP: SHALLOW WATER HYPOXIA – TIPPING THE BALANCE FOR INDIVIDUALS, POPULATIONS AND ECOSYSTEMS

We're testing effects of diel-cycling dissolved oxygen and pH on growth, disease, reproduction and behavior of oysters and fish, and using models to scale up to changes at the population and whole food web levels of organization.

- Interesting info about project
  - Scaling from individual to food web effects
  - Working in shallow, eutrophic estuarine waters with full pH unit diel variation
  - Interesting DO results, but won't be starting pH manipulations until this summer



ECOLOGY & SYSTEMS

Shallin Busch & Paul McElhany

NOAA-NWFSC

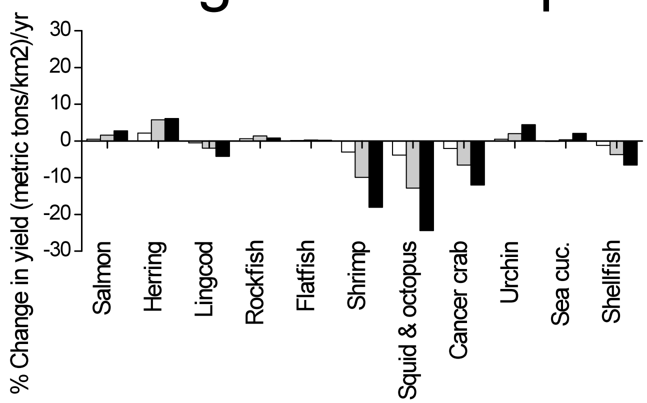
Chris Harvey, Cameron Ainsworth, Jameal Samhouri, William Cheung, Tom Okey, John Dunne

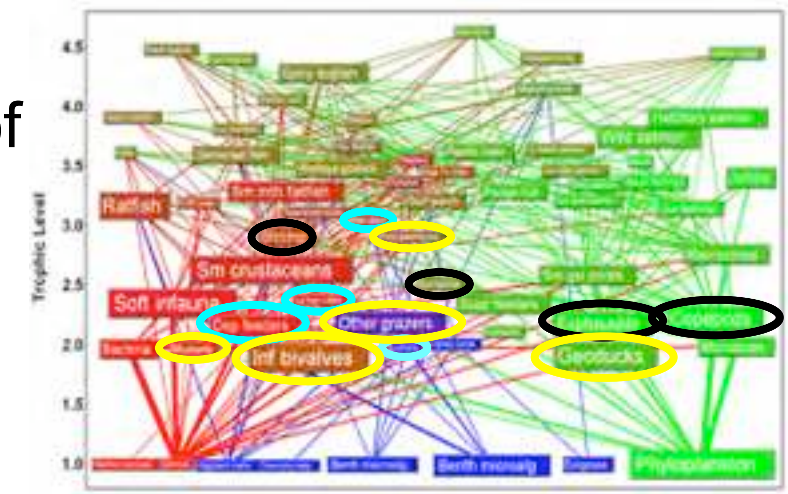
June 2009

Food web response to ocean acidification

Explore how ocean acidification may impact food webs by running simulations with scenarios of species response to OA

- One project uses a food web model of Puget Sound; another, 5 food web models from the North Pacific
- Developed species-response scenarios based on literature review
- Built database of mineralogy of all Puget Sound species





Above: Food web model of Puget Sound's central basin, with circles around functional groups predicted to be impacted by OA. Left: Change in harvest from Puget Sound after 50 yr OA scenario.

ECOLOGY & SYSTEMS

Francis Chan

Oregon State University

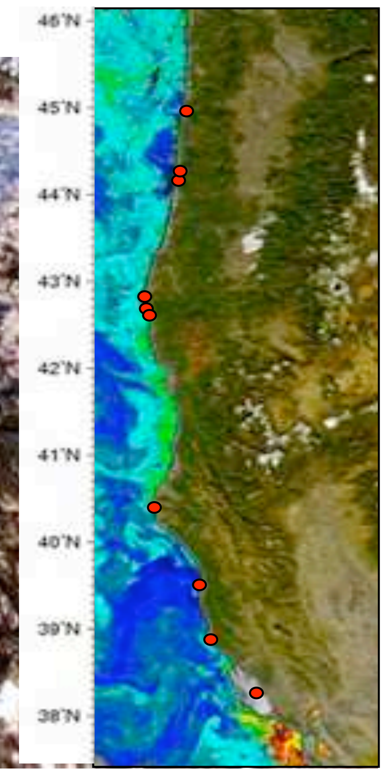
Bruce Menge, Sally Hacker, Karina Nielsen

April 2011

Collaborative Research: The role of calcifying algae as a determinant of rocky intertidal macrophyte community structure at a meta-ecosystem scale.

How will future changes in carbonate chemistry influence the outcomes of key ecological interactions that structure intertidal communities along the California Current?

- Field studies (chemistry monitoring, macrophyte dynamics, ecological interaction experiments) across 12 sites over 7° of latitude:
- Lab studies of macrophyte performance in relations to pCO_2, light, nutrients, temperature



Cyndy Chandler

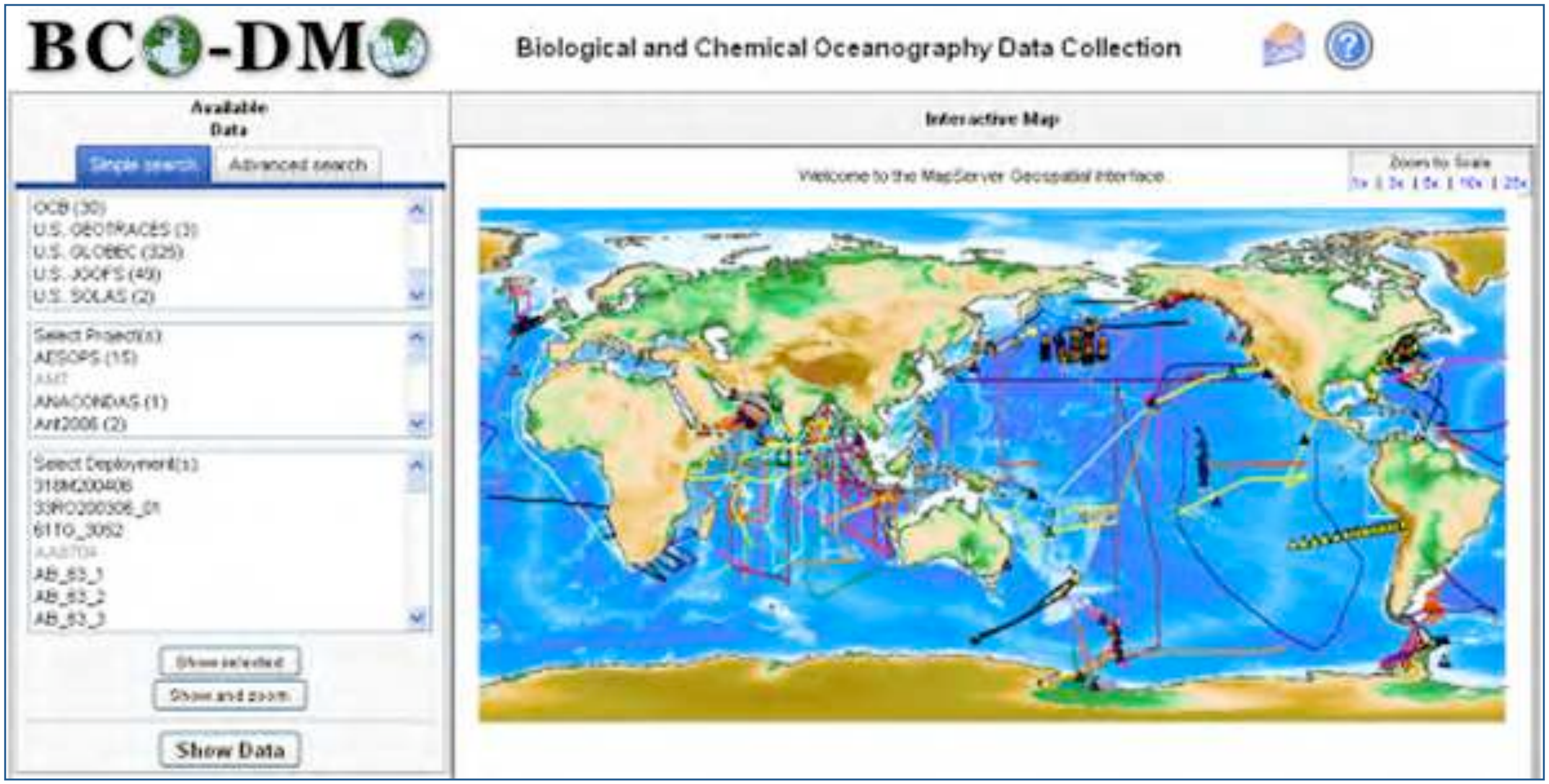
WHOI

P. Wiebe, D. Glover, R. Groman

October 2006

Biological and Chemical Oceanography Data Management Office

http://bco-dmo.org



Providing data management support for NSF OCE Biology and Chemistry, and OPP ANT O&E funded researchers.

ECOLOGY & SYSTEMS

Robert W. Chapman

SCDNR

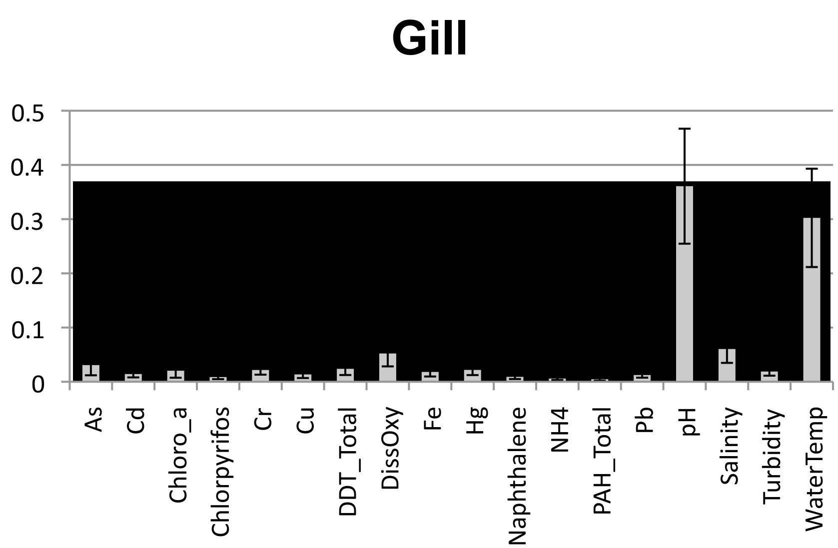
June 2005

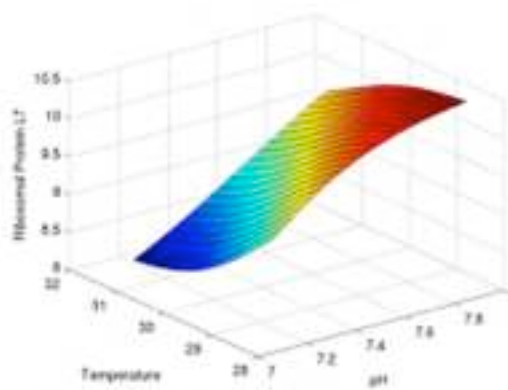
Annalaura Mancia, Marion Beal, Artur Veloso, Charles Rathburn, Anne Blair, A. F. Holland, G. W. War*, Guy Didinato, Inna M. Sokolova, Ed Wirth Edward Duffy,and Denise Sanger

ECOLOGY & SYSTEMS

The transcriptomic responses of the eastern oyster, Crassostrea virginica, to environmental conditions. Chapman et al. Mole. Ecol. (2011)

- The project demonstrates non-linear interactions of temperature and pH on gene expression
  - The left figure illustrates the average sensitivities of 250 genes to various environmental conditions. The figure on the right illustrates the expected response of rpL7 to temperature and pH.





Robert Foy

AFSC, NMFS, NOAA

2009

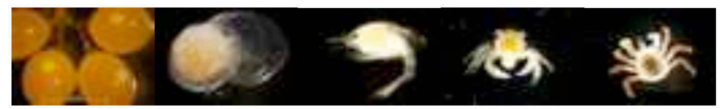
Cairns S. (Smithsonian Institution), Capito M., Cohen A. (Woods Hole Oceanographic Institution), Carls M., Eisner L., Guinotte J. (Marine Conservation Biology Institute), Hurst T., Dalton M., Long W.C., Mathis J. (U. Alaska), Napp J., Pinchuk A. (U. Alaska), Punt A., Schaufler L., Sewall F., Sigler M., Stone R., Swiney K., Vanderhoof L., Watling L. (U. Hawaii)

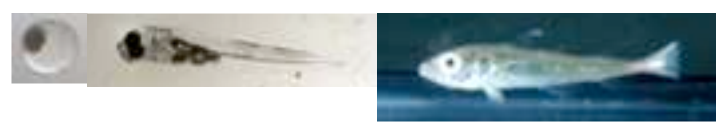
ECOLOGY & SYSTEMS

Alaska Fisheries Science Center OA Research

The assessment will focus on commercially and ecologically important species most likely to be directly affected by ocean acidification, especially larval and juvenile stages.

- Projects
  - AK King crab growth survival
  - AK King crab population abundance
    - Socioeconomic forecast and bioeconomic models
  - Carbonate analytical measurements
  - Growth and survival of Pacific cod and walleye pollock
  - Calcium carbonate mineralogy of Alaskan corals
  - Food web effects on walleye pollock





Brian Gaylord

Bodega Marine Laboratory

Tessa Hill, Ann Russell, Eric Sanford

2009

ECOLOGY & SYSTEMS

OA in an upwelling zone: Impacts on open-coast and estuarine foundation species

Determine impacts on mussels and oysters through multiple life stages, in the lab and field

- Ecological costs in settling mussels
  - More than just reduced calcification → loss of function
  - Smaller, thinner, weaker shells, lower tissue mass
  - Elevated predation and desiccation risk
- Carryover effects in oysters
  - 2-week exposure only during larval phase → juvenile growth still decreased 4 months later

- Experiments informed via moored and discrete seawater monitoring

Jason Grear

US EPA

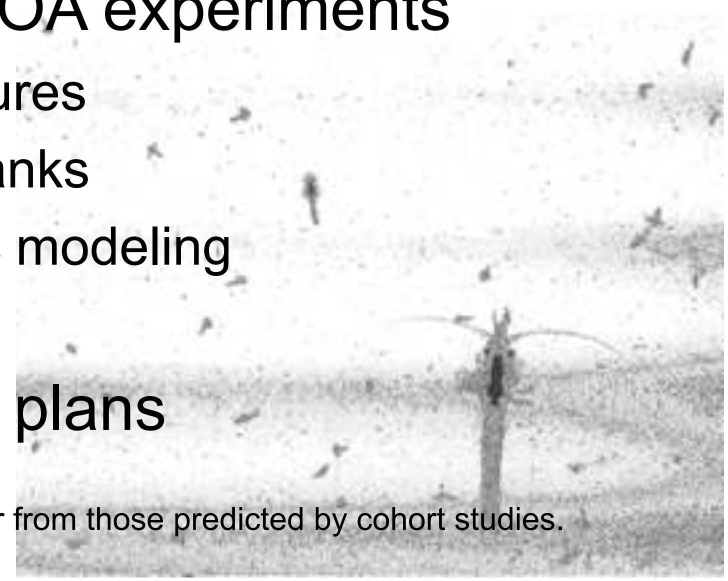
Doranne Borsay Horowitz
Ruth Gutjahr-Gobell

ECOLOGY & SYSTEMS

Predicting effects from population vs. cohort studies

This project developed methods for detecting stressor effects on crustacean vital rates within intact, structured populations

- Findings[1]
  - Cohorts are not populations and give differing results
  - Population studies are difficult but are getting easier
- Methods were recently applied in OA experiments
  - Continuous bubbling of air/CO_2 mixtures
  - Replicated flow-through population tanks
  - Digital imaging; inverse demographic modeling
  - Data analysis currently under way
- See Janet Nye slide for additional plans



[1]Grear et al. Mysid population responses to resource limitation differ from those predicted by cohort studies. Accepted, in revision for MEPS

Kris Holderied

Piniak G., Fonseca M.

NOAA Center for Coastal Fisheries and Habitat Research

Awaiting funding

ECOLOGY & SYSTEMS

Role of sea grass beds in mitigating ocean acidification impacts on coral reefs and shellfish

Proposed project to assess how sea grass beds may mediate impacts of increasing carbon dioxide concentrations and associated pH changes on coral reefs.

- Monitor sea grass photosynthesis, distribution, density and productivity near coral reef OA monitoring sites (e.g. Puerto Rico)
- Determine OA mitigation potential of sea grasses and develop forecast scenarios
- POC: Mark.Fonseca@noaa.gov

CCFHR diver assessing sea grass beds

Terrie Klinger

University of Washington

ECOLOGY & SYSTEMS

Regional Research Collaborations

We have established regional research collaborations to address ocean acidification and associated stressors. Collaborations are inclusive of the entire west coast, and extend to federal & state agencies, industry, and NGOs.

Key themes:

- Impacts on commercial fisheries, shellfish aquaculture, and key habitat-forming species
- Ocean observation via NANOOS and others
- Integrative graduate education
  - IGERT proposal pending
- Capacity for human adaptation

Ilsa B. Kuffner

A. J. Andersson, P. L. Jokiel, K. S. Rodgers, F. T. Mackenzie

U.S. Geological Survey

November 2005

ECOLOGY & SYSTEMS

Effects of ocean acidification on coral reef organisms

Methods:

- Realistic diurnal cycles
- Open system (natural larval recruitment)
- Long-term (9 months)

Results under OA treatment:

- Crustose coralline algal community severely inhibited
- Corals calcified 15 – 20 % slower
- Results predict that coral reef communities will change, calcify less, and possibly start dissolving under doubling of pCO_2

Kuffner IB et al. (2008) Nature Geosci 1:114-117
Jokiel PL et al. (2008) Coral Reefs 27:473-483
Andersson AJ et al. (2009) Biogeosciences 6:1811-1823

Gareth Lawson

WHOI

Andone Lavery, Peter Wiebe, Aleck Wang

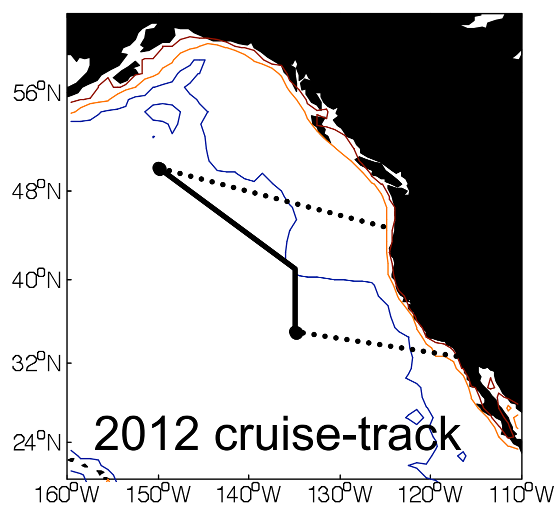
October, 2010

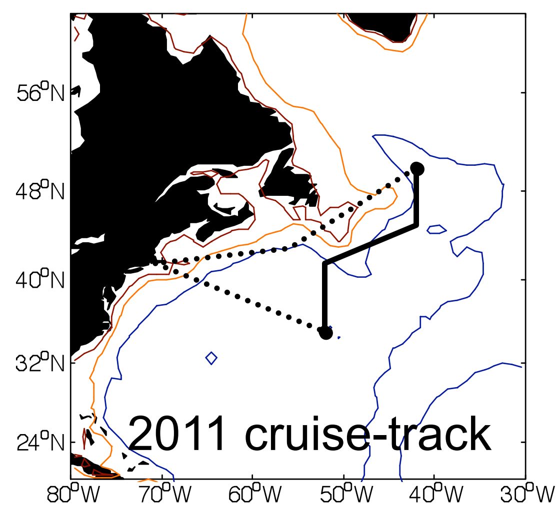
ECOLOGY & SYSTEMS

Horizontal and Vertical Distribution of Thecosome Pteropods in Relation to Carbonate Chemistry in the Northwest Atlantic and Northeast Pacific

Surveys of the *in situ* distribution and vertical movements of thecosome pteropods over gradients in aragonite compensation depth

- Cruises to the Atlantic (2011) and Pacific (2012)
- Coincident sampling for zooplankton and carbonate chemistry
- Developing and applying acoustic methods for studying pteropods





Lisa A. Levin

Todd R. Martz, Christina A. Tanner

Scripps Institution of Oceanography

Sept 2009

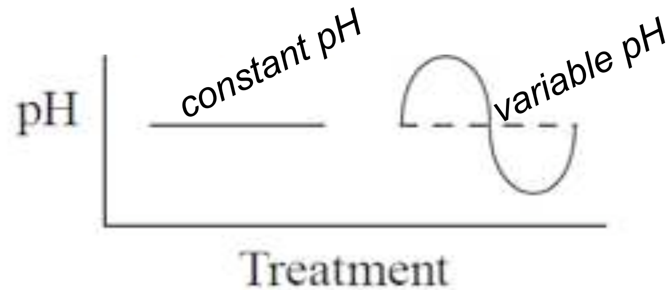
ECOLOGY & SYSTEMS

Macrophyte-induced variability in coastal ocean pH and consequences for invertebrate larvae

To address the interplay between anthropogenically driven pH changes and the inherently variable coastal ocean, and directly test the implications for invertebrate larvae.

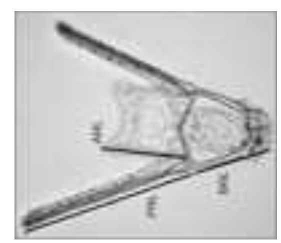
- Lab experiments →

  Hypothesis: Invertebrate larvae respond differently to constant versus varying carbonate chemistry.



- Field experiments

  Objective: To develop a multi-parameter relationship between larval health and *in situ* DO, pH and temperature conditions.



Regression Model	Parameters
Growth, Survivorship	T,S,O_2,pH

ECOLOGY & SYSTEMS

Derek Manzello

NOAA/AOML

Ian Enochs

October 2009

Coral growth and reef framework persistence of the Florida Reef Tract with accelerating ocean acidification

This project is simultaneously determining the ambient seasonal variability of seawater carbonate chemistry across an inshore/offshore gradient on the Florida Reef Tract (FRT) and relating this to 1) carbonate cement abundances within reef framework components, 2) species-specific coral growth patterns, and 3) rates of bioerosion.

- Interesting info about project
  - The carbonate chemistry of nearhshore patch reef environments on the FRT is much more favorable for coral calcification relative to those reef environments offshore and may potentially serve as OA refugia

Jim McClintock

University of Alabama at Birmingham

Chuck Amsler and Robert Angus

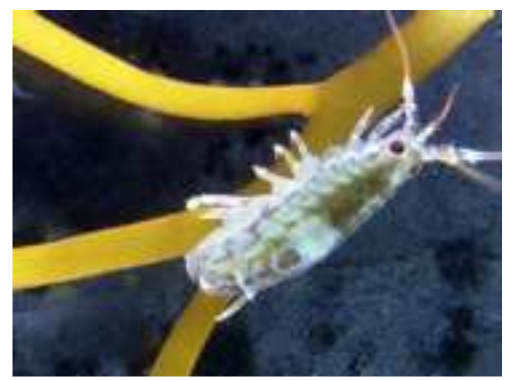
NSF - June 1, 2011

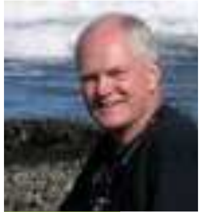
ECOLOGY & SYSTEMS

The effects of ocean acidification and rising sea surface temperatures on shallow-water benthic organisms in Antarctica

The project employs both single-species and multi-species level approaches to evaluating the impacts of rising ocean acidification and seawater temperature on representative calcified and non-calcified macroalgae, on calcified and non-calcified mesograzers, and on a calcified macrograzer, all of which are important ecological players in the rich benthic communities.

- Interesting info about project
  - Goals: To evaluate the individual and combined effects of rising ocean acidification and sea surface temperatures on shallow-water calcified benthic organisms in western Antarctic Peninsular marine communities.
  - Location: Palmer Station, Antarctic Peninsula
  - To begin: June, 2011





Bruce Menge

Barth, Blanchette, Chan, Chavez, Gaylord, Hill, Hofmann, McManus, Palumbi, Raimondi, Russell, Sanford, Washburn

Oregon State

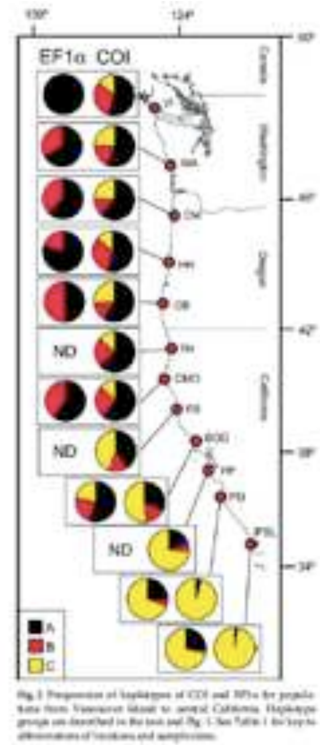
October 2010

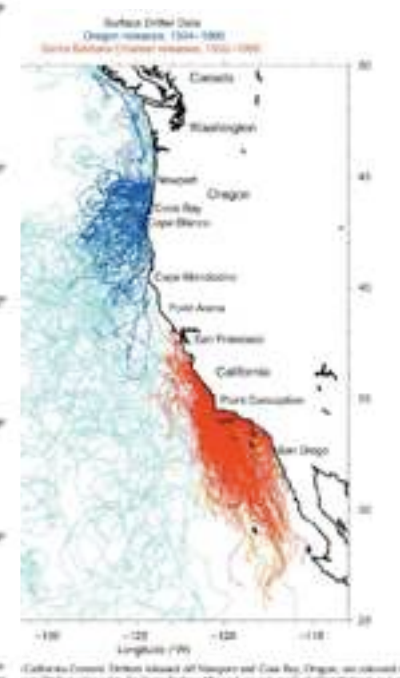
ECOLOGY & SYSTEMS

Collaborative Research: Acclimation and adaptation to ocean acidification of key ecosystem components in the California Current Large Marine Ecosystem

Investigate how important coastal invertebrates respond to varying sea water chemistry

- Assess acclimatization, use genetic tools, conduct larval rearing, collect in situ measurements of animals and the environment, provide oceanographic context
- California Current
- Team ready to start fieldwork on April 1, 2011





Shannon Meseck

NOAA/NMFS

King, Wikfors, Milke, Meseck

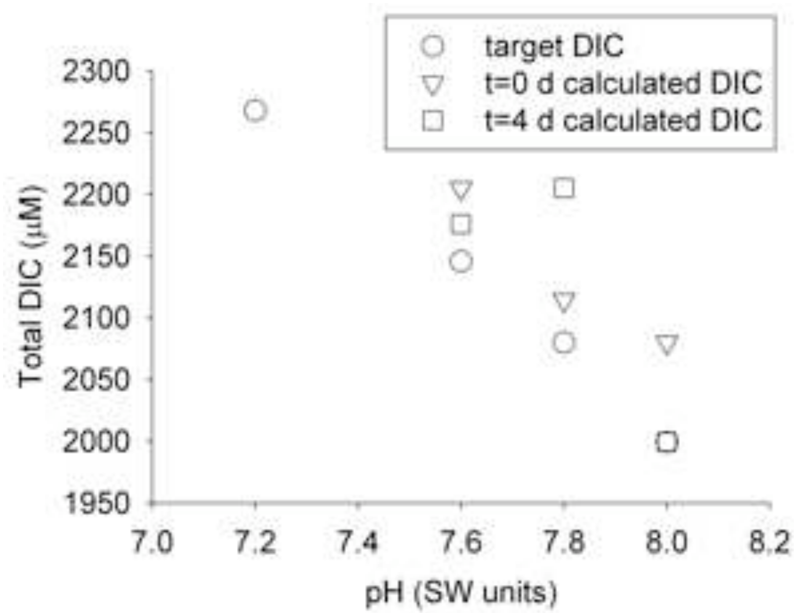
2011?

ECOLOGY & SYSTEMS

Phytoplankton nutritional value for fishery-based food webs

Determine how increased pCO_2 affects phytoplankton community composition and nutritional value

- 2010
  - Determined mass flow controllers optimal for phytoplankton cultures
- 2011
  - Test 4 common species of phytoplankton
    - *Thalassiosira pseudonana*
    - *Thalassiosira oceanica*
    - *Alexandrium fundyense*
    - *Emiliania huxleyi*
  - Determine if elevated pCO_2 changes fatty acids and lipids



Target total DIC values and calculated total DIC values growth experiments with the CO_2 bubbling method

Margaret W. Miller

NOAA/NMFS

Langdon (Univ of Miami)

May, 2011

ECOLOGY & SYSTEMS

Effects on early life stages of spawning reef corals and algal interference

- 2011-13
  - Experimental temp*CO2 exposures for larval duration
  - 3 spawning coral spp.
- Observational study on macroalgal colonization and productivity at field CO2 monitoring sites
  - Florida Keys
  - Puerto Rico
- Previous experiments on fertilization, settlement, and survivorship for elkhorn coral larvae

Gamete bundles being released from elkhorn coral colony for external fertilization. Both gamete dilution and CO2 increase threaten this bottleneck in spawning coral life history

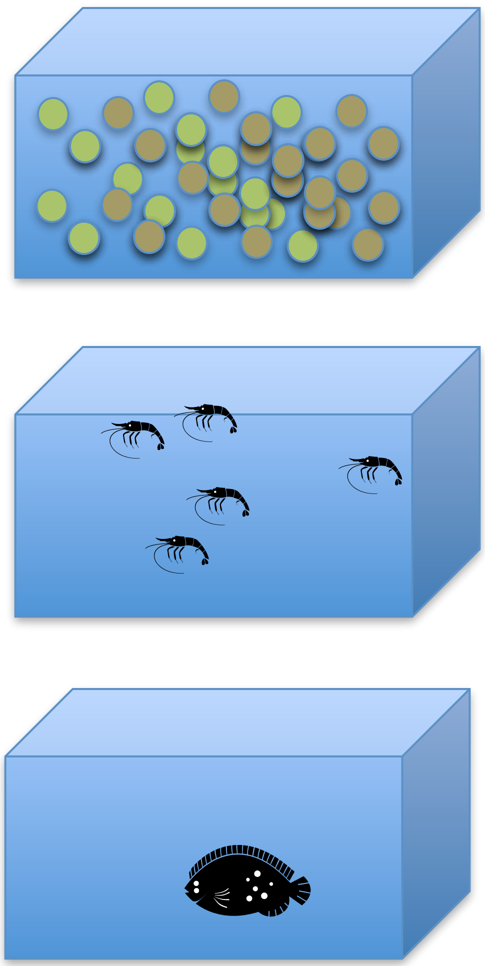
ECOLOGY & SYSTEMS

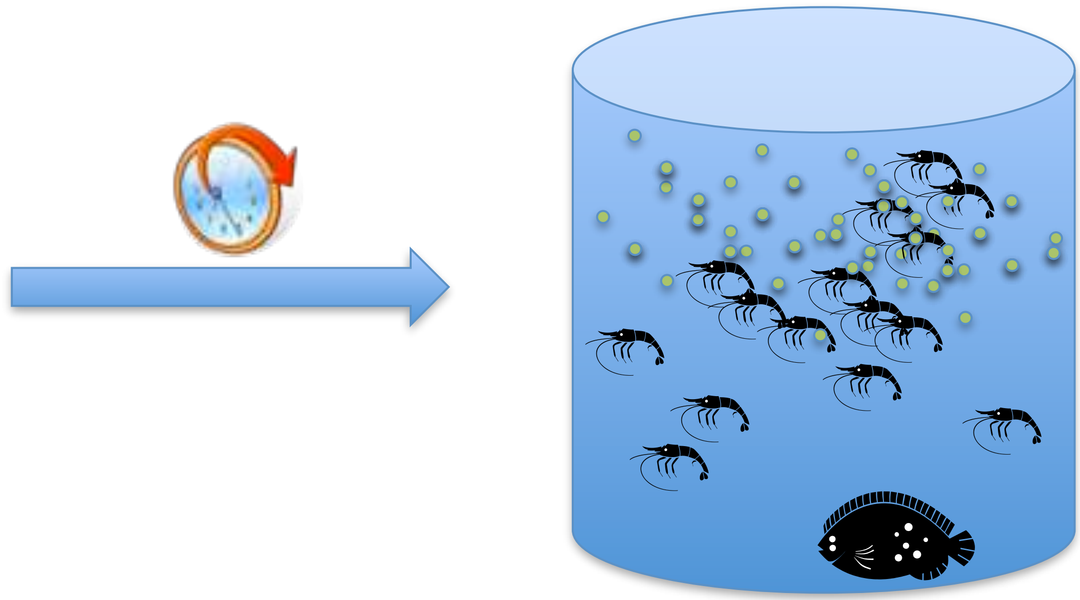
Janet Nye and Jason Grear

US EPA

Doranne Borsay Horowitz
Ruth Gutjahr-Gobell

Evaluating ecosystem effects from mesocosm studies





- **Capitalize on observation system that Jason has developed to examine behavior**
- **AED has a history of large-scale laboratory operations from historical toxicology assays**

Moose O'Donnell
Terrie Klinger

University of Washington
Friday Harbor Laboratories

Summer 2011

ECOLOGY & SYSTEMS

Graduate course: Conducting acidification research

We will offer a *graduate training course* in performing manipulative experiments at FHL in summer 2011

- 5-week Intensive Residential Training
  - To teach students technical skills, analytical chemistry, and experimental design for biological and ecological research
  - Laboratory and in-water mesocosm facilities for student use, plus opportunities for field work
  - Opportunity to evaluate different experimental approaches
  - Number and diversity of applications indicate need




Jim Palardy

Besedin, Post

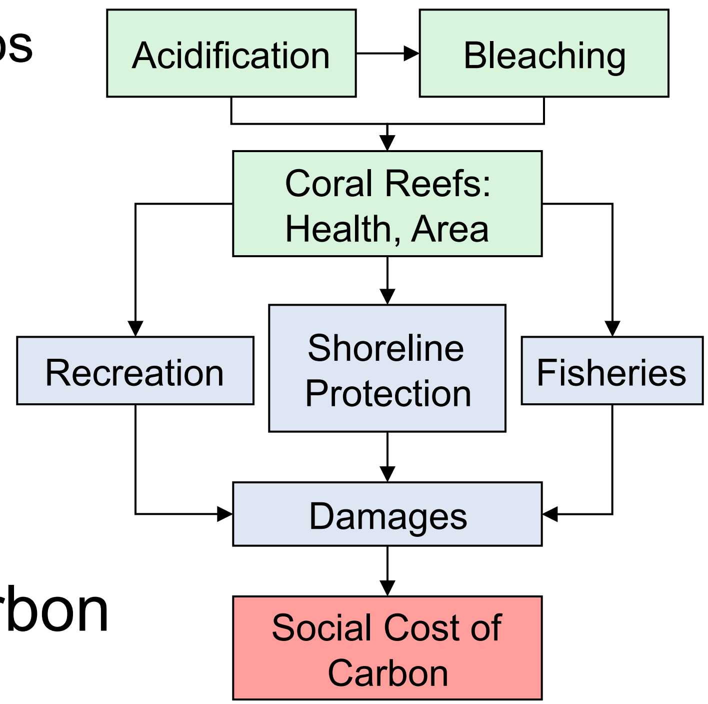
Abt Associates, Inc

Ongoing

ECOLOGY & SYSTEMS

Modeling the Economic Implications of Ocean Acidification on Coral Reefs

- Ecological Model: estimates impact of OA and warming on coral reef health for multiple climate scenarios
  - Spatially-explicit - 2010 – 2300
  - Global coverage - Multiple scenarios
- Economic Model: estimates damages from coral reef decline
  - Recreational services
  - Commercial fishing
  - Shoreline protection
- Models combined to improve estimates of the social cost of carbon



Adina Paytan

CICY Mexico

Institution

August 2010

ECOLOGY & SYSTEMS

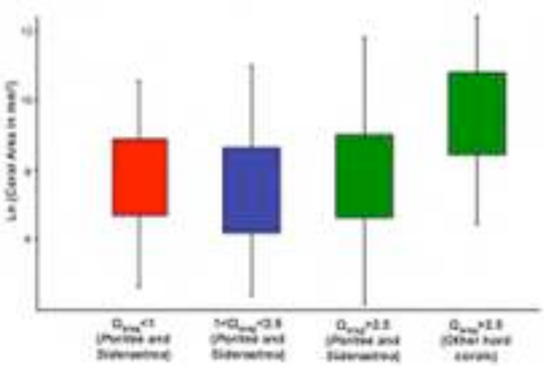
Ocean Acidification Category 2: Calcification in low saturation seawater: What can we learn from organisms in the proximity of low pH, undersaturated submarine springs?"

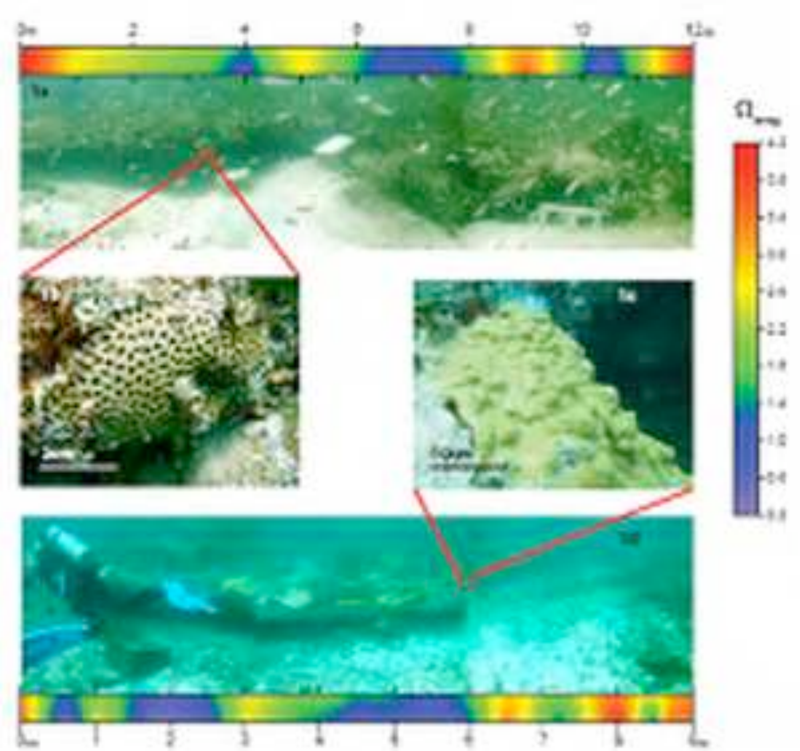
community and ecosystem responses to long term exposure to low saturation and potential interactions with nutrients and other environmental variables

- Interesting info about project

  Location – Mexico

  Early results – Some coral species calcify at low saturation but diversity and coral cover low





Nichole Price

Scripps Institution of Oceanography and
Coral Reef Ecosystem Division, NOAA

Jennifer Smith (PI), Todd Martz, Rusty Brainard

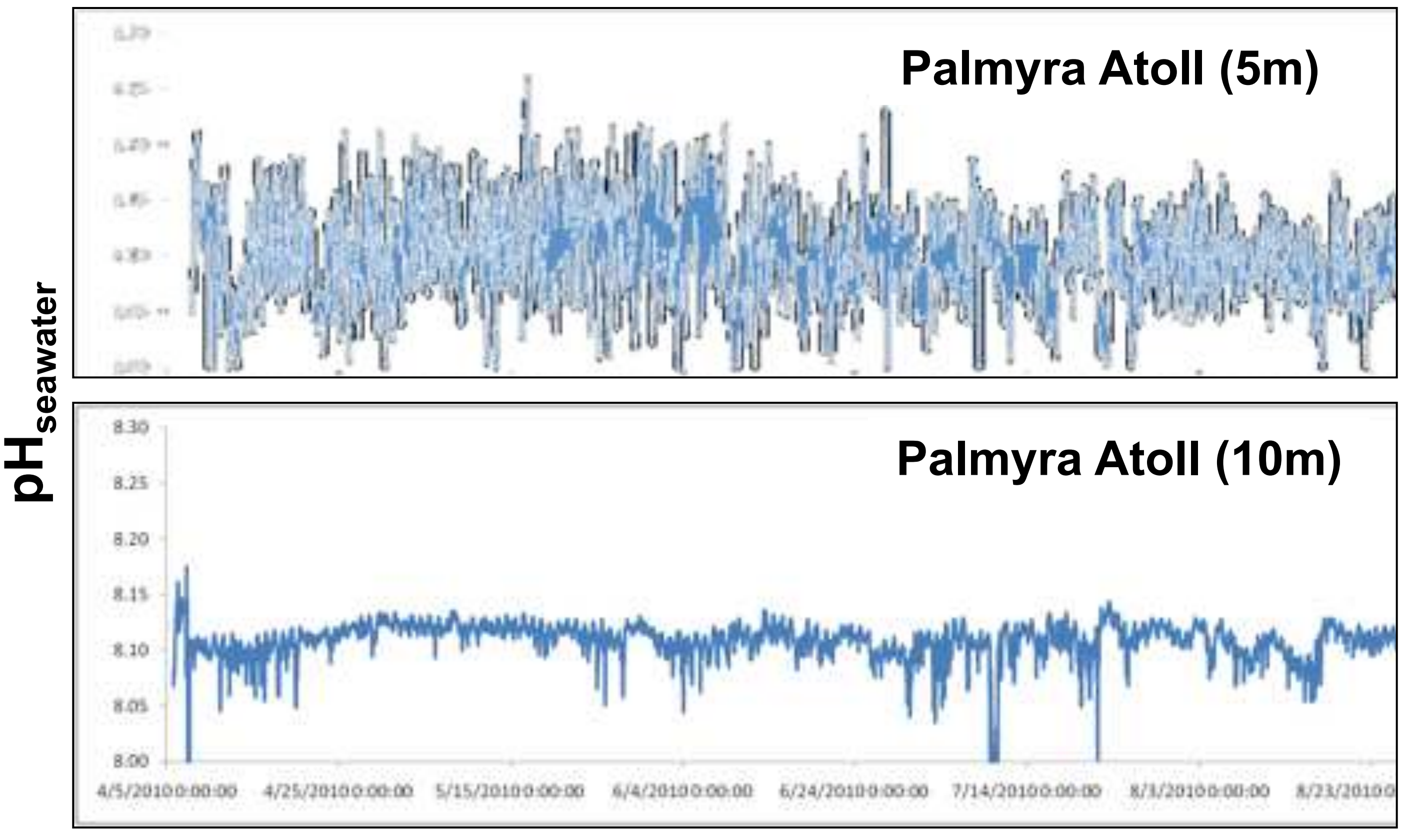
Variable sources

ECOLOGY & SYSTEMS

Spatiotemporal natural variability in calcification and seawater chemistry

Calcification-**A**cidification **U**nits and SeaFET sensors are co-located across the Pacific Remote Island Areas, the Hawaiian Archipelago, the Marianas, and American Samoa to quantify natural variability in reef accretion rates and pH.

CAU



Nichole Price

Scripps Institution of Oceanography
and San Diego State University

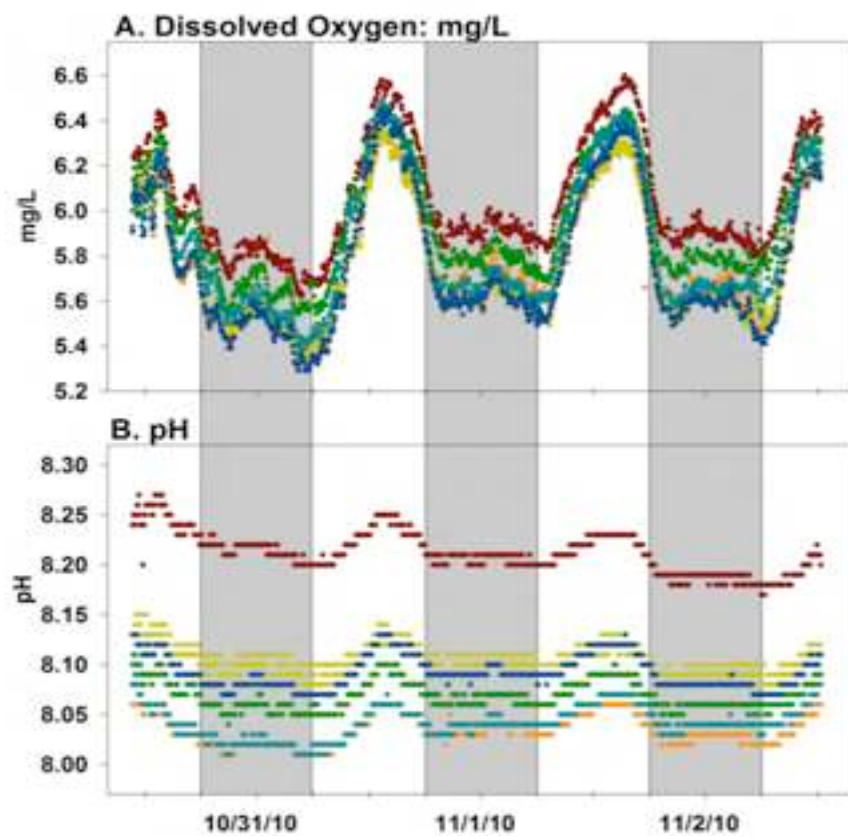
Jennifer Smith (PI), Stuart Sandin, Forest Rohwer

Variable sources

ECOLOGY & SYSTEMS

Feedbacks from Benthic Coral Reef Communities

We measured changes in seawater chemistry (pH, DO, temperature, salinity, C_T, and A_T) over 72 hrs inside enclosed replicate chambers mounted over natural benthic communities across the Northern Line Islands to determine how biology affects carbonate chemistry within boundary layers.



Tent	Coral	CCA	Macro algae	Turf
●	0	30	58	11
●	8	42	42	7
●	38	31	11	14
●	40	14	13	32
●	48	39	3	8
●	76	11	6	2

Benthic community dominated by macroalgae

Benthic community dominated by coral

Grace K. Saba

Oscar Schofield

Rutgers University

February, 2010

ECOLOGY & SYSTEMS

Effects of enhanced CO_2 on Antarctic plankton community structure and biogeochemical cycles

Determine plankton composition, rates of algal C & N uptake, carbon fixation enzyme activity, and zooplankton metabolism

- Palmer Station & WAP, Oct 2010-Mar 2011
  - ✓ 3 CO_2 mesocosm expts.
  - ✓ Antarctic krill CO_2 expts.
- Rutgers University, Mar 2011-May 2012
  - – CO_2 expts. with Antarctic algal species

Grace K. Saba

Rutgers University

Schofield, Bhattacharya, Kithill (Atmocean)

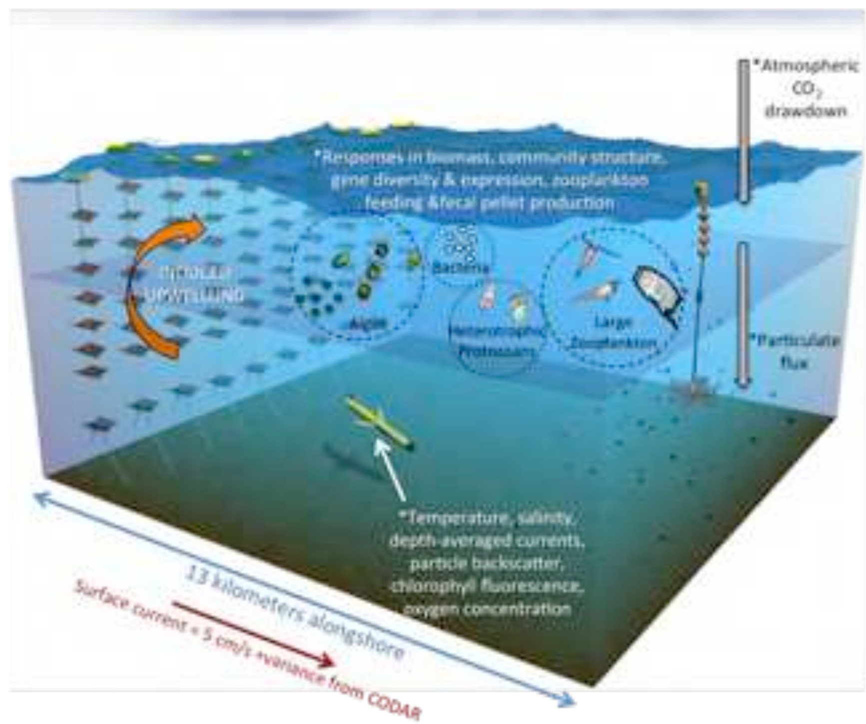
Pending

ECOLOGY & SYSTEMS

Neretic ecosystem response induced with wave-driven upwelling pumps

Examine biotic/geochemical response of microbial community to induced upwelling and quantify potential CO_2 sequestration during long-term utilization of pump technology

- Location: Mid-Atlantic Bight
- Upwelling field test
- Intensive shipboard sampling prior to and after pump installation
- Continuous monitoring via gliders and NOAA MAB OOS



Astrid Schnetzer

D. Caron, D. Hutchins, F. Fu

University of Southern California

04/01/2010

ECOLOGY & SYSTEMS

Experimental studies to understand and evaluate acclimation of marine plankton assemblages to increased CO_2 and temperature.

How do progressing ocean acidification and increasing sea surface temperature impact marine plankton community structure and community-level processes?

- Dinoflagellate and diatom-dominated communities from Southern California waters are tested in their response to changed CO_2/temperature regime in semi-continuous field incubation experiments.
- Next, dominant algal species are isolated from different ‘greenhouse’ treatments in our field experiments and tested for their ability to re-establish dominance under the same conditions in acclimated laboratory culture competition studies.

First project year:

- Field incubation with natural dinoflagellate-dominated assemblage
- Establishment of algal cultures grown at 3 different CO_2 concentration levels
- Laboratory competition trials with acclimated specimens

Tim Wootton

Cathy Pfister, Sophie McCoy

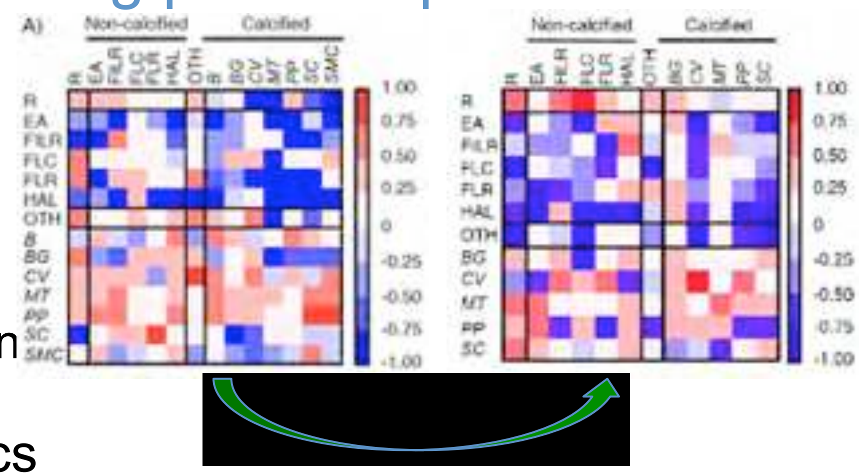
University of Chicago

June 2010 (LTREB)

ECOLOGY & SYSTEMS

Ecosystem Response to Changing pH

What is the interplay between declining pH and species interactions?



- Long-term species manipulations
  - Relationships to pH change when composition changes
  - Need to account for species interaction
- Changes in mobile consumer dynamics
  - Macrograzer decline; predators & mesograzers increase (scavenging?)
- Repeat “classic” field experiments under low pH conditions
  - Coralline competition/grazing experiments
  - Limpets-algae
  - Whelks-barnacles

BIOGEOCHEMISTRY & MODELING

Andreas J. Andersson

BIOS

Nick Bates

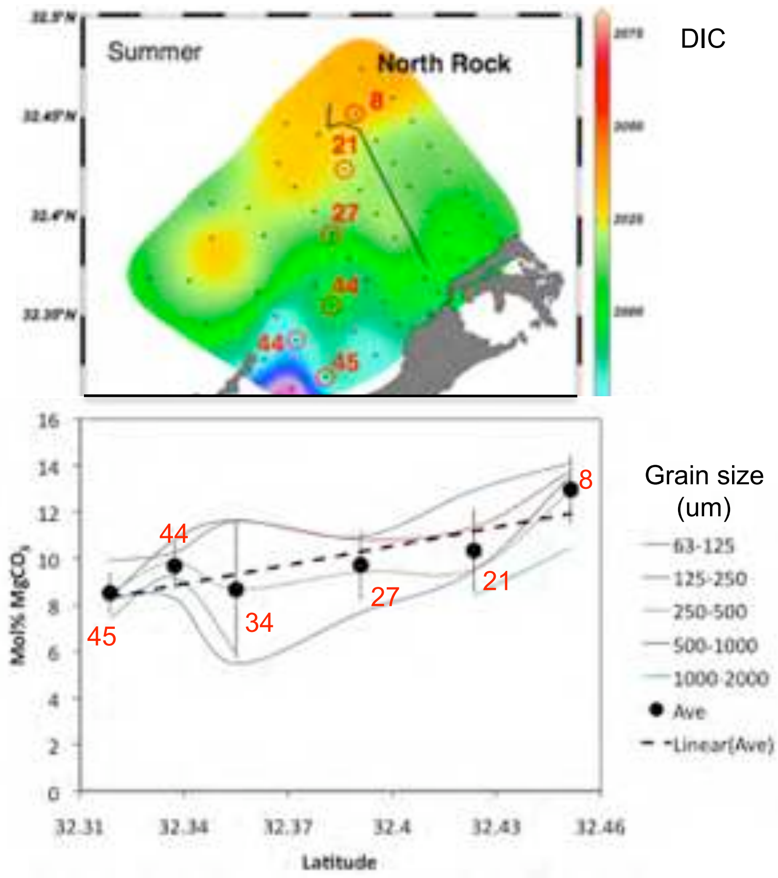
May 1, 2010

Mg-calcite mineral dynamics in natural seawater systems: relevance to oceanic uptake of anthropogenic CO_2 and ocean acidification

Improve the understanding of biogenic Mg-calcite reactivity in the natural environment

Overview

- Define CO_2-carbonic acid system (e.g., pH, $[CO_3^{2-}]$, Ω)
  - Seawater
  - Pore water
- Define Mg-calcite composition as a function of:
  - Sediment grain size
  - Grain constituents
  - pH, $[CO_3^{2-}]$, Ω



Russell E. Brainard

Charles Young (UH), Richard Feely & Simone Alin (PMEL), Dwight Gledhill (AOML)

NOAA Pacific Islands Fisheries Science Center

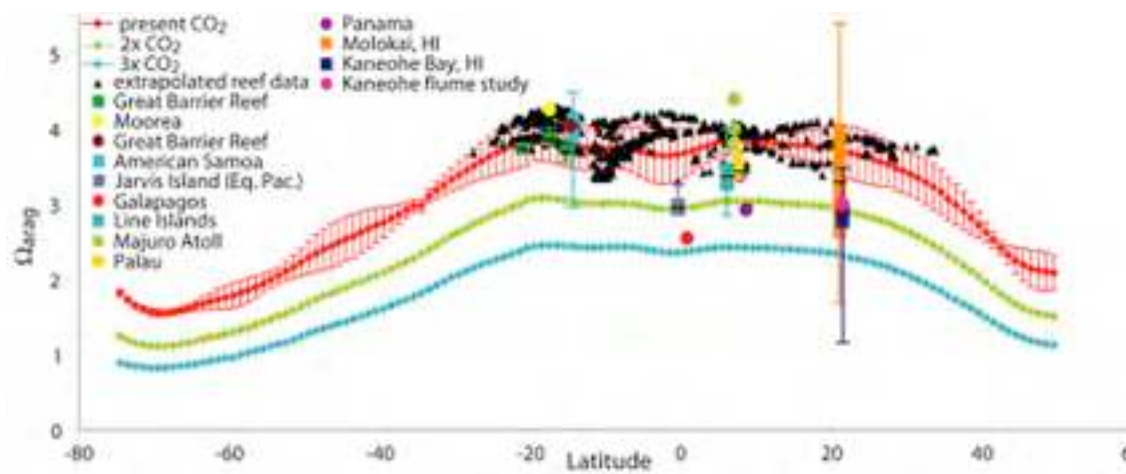
January 2006

BIOGEOCHEMISTRY & MODELING

Ocean Acidification: Spatial and temporal patterns of carbonate chemistry in the Pacific Islands

Water sampling for dissolved inorganic carbon and total alkalinity to monitor spatial patterns and temporal trends in carbonate chemistry in coral reef habitats across the Pacific.

- Systematic approaches to understand long-term spatial and temporal patterns of ocean acidification.
- Hawaii, American Samoa, Guam, CNMI, PRIA
– Upwelling islands have low omega.
- Maug caldera is acidic



BIOGEOCHEMISTRY & MODELING

Wei-Jun Cai

University of Georgia

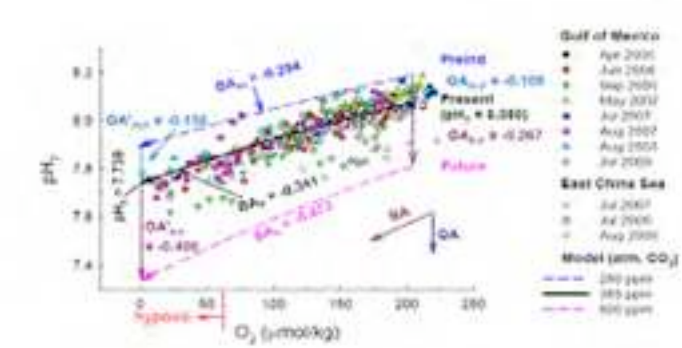
S. Lohrenz and K. Gundersen

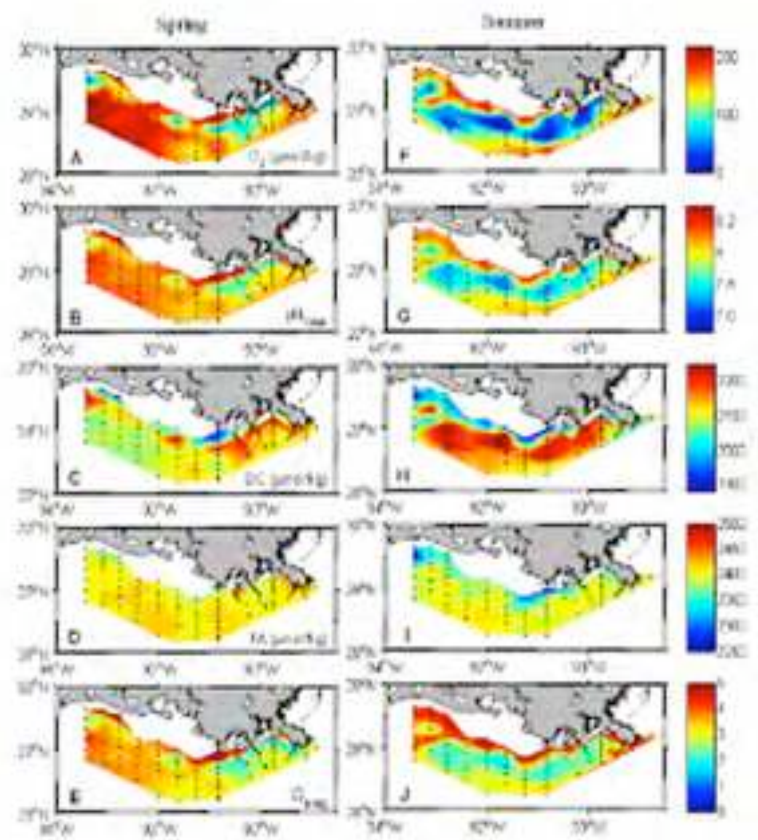
July 2007

NSF-OCE: Collaborative Research: Satellite Assessment of CO_2 Distribution, Variability and Flux and Understanding of Control Mechanisms in a River Dominated Ocean Margin

Study the synergistic effects of the double stressors, OA and eutrophication, in large river dominated coastal oceans.

- Fossil-fuel-derived CO_2 and respiration-derived CO_2 have acted in concert to lower pH greatly, as much as 0.45 units in subsurface waters under the Mississippi plume.





Wei-Jun Cai

University of Georgia

July 2010

BIOGEOCHEMISTRY & MODELING

NSF-ARC: Controls on Sea Surface pCO_2 Variability and CO_2 Uptake in the Western Arctic Ocean Margins

Study the response of pCO_2 and pH to ice melt in the basin and margins since the major ice retreat of summer 2007

- In the marginal seas (<73N), surface waters have high pH due to biological uptake
- In the southern Canada Basin(73-76N), surface waters have OA due to the uptake of atmospheric CO_2
- In the northern basin (76-88N), there is no OA in surface water due to ice-cover but pH is low in the subsurface waters due to respiration-derived CO_2.

BIOGEOCHEMISTRY & MODELING

Francis Chan

Oregon State University

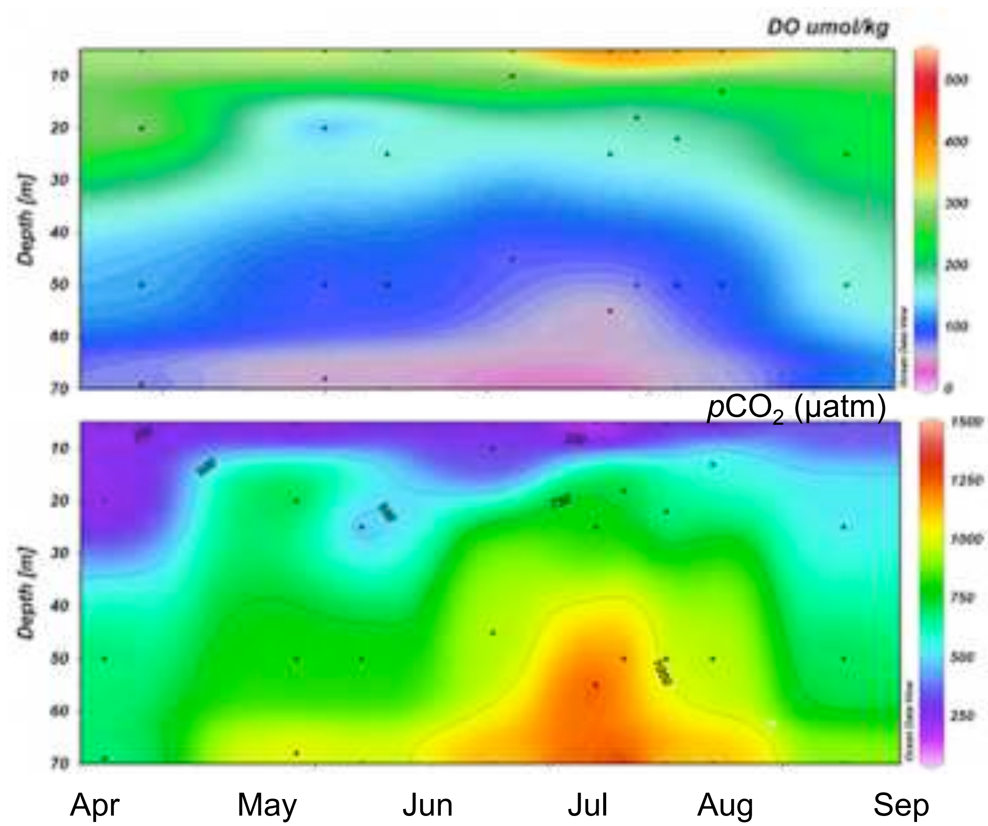
Oregon Team: Ricardo Letelier (lead PI), Jack Barth, Stephen Giovannoni, Alan Mix, Curtis Deutsch

Feb 2009

Microbial Initiative in Low Oxygen areas off Concepción and Oregon

To compare microbial assemblages and biogeochemical cycles associated with seasonal continental shelf hypoxia off Concepción and Oregon

- ❑Strong coupling between hypoxia and ocean acidification over shelf time-series station
- ❑Sequencing data to link microbial process with N-transformations along wide gradients pH and oxygen gradients



Sarah Cooley

Doney, Kite-Powell, Lucey

WHOI

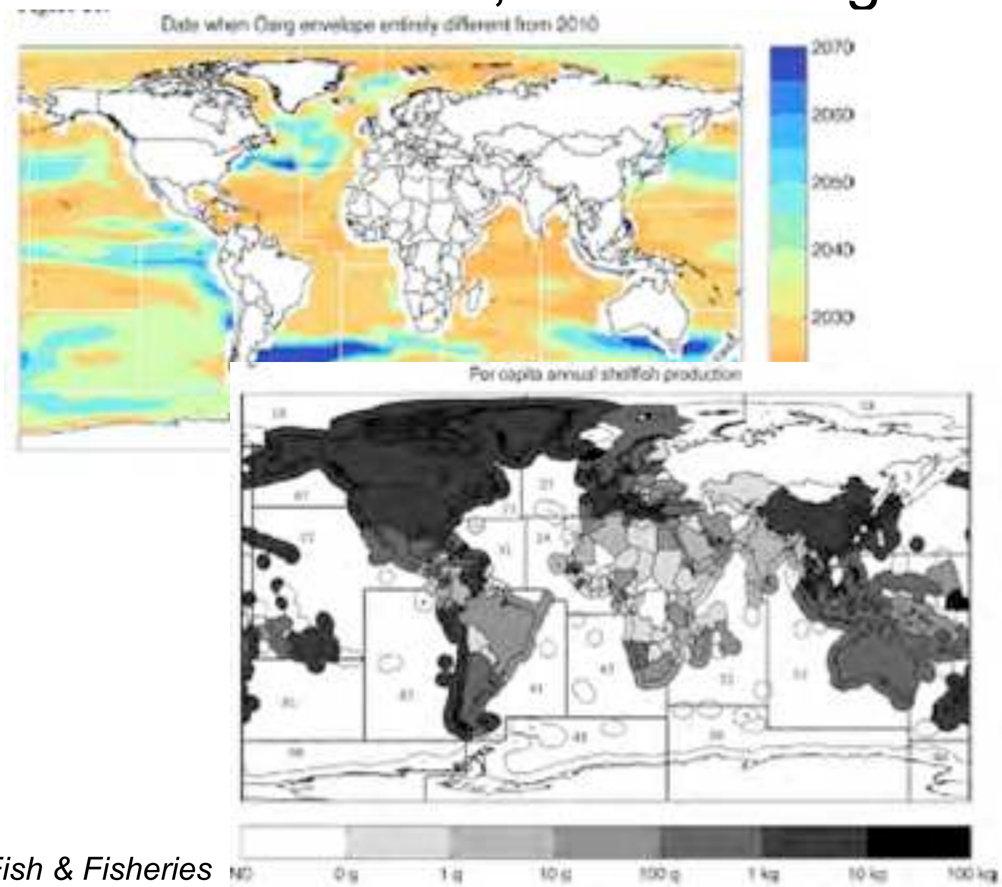
2009

BIOGEOCHEMISTRY & MODELING

Could mollusk dependence today = vulnerability tomorrow?

Use coupled model forecasts (CCSM) and fisheries harvest & nutrition data to examine current harvests, future changes.

- Low latitudes:
  - Change away from present chemistry soonest
  - Often protein shortages
  - Other envi. stressors
- Developing nations
  - Mollusks important for nutrition, income
  - Few alternatives



Cooley et al., in revision, *Fish & Fisheries*

Nathan Garcia

PI: David Hutchins

University of Southern California
March 2007- March 2012

BIOGEOCHEMISTRY & MODELING

Collaborative Research: CO_2 control of oceanic nitrogen fixation and carbon flow through diazotrophs

Examine the interactive influences of increasing CO_2 and changing temperature, irradiance, and nutrients on the N_2-fixing cyanobacteria *Trichodesmium* and *Crocosphaera*,

Poster presentation:
Combined effects of light and elevated CO_2 on growth, CO_2- and N_2 fixation rates by *Trichodesmium erythraeum* and *Crocosphaera watsonii*.

Current work:
Physiological rate responses to combined effects of elevated pCO_2 and phosphate limitation in *Crocosphaera*; combined effects of elevated pCO_2 and iron limitation in *Trichodesmium;* CO_2 response curves of diverse N_2 fixers; CO_2 effects on N_2 fixation and physiology in long term acclimated cultures.

BIOGEOCHEMISTRY & MODELING

Dwight Gledhill

Langdon, Corredor, McGillis, Piniak,
Moyer, Manzello, Sabine, Loose, et al.

NOAA, RSMAS, UPRM, WHOI,
Lamont-Doherty, USGS, et al.

October, 2008

CRCP Atlantic Ocean Acidification Test-bed

Nexus of federal and academic monitoring and research exploring the dynamics of Atlantic tropical coral reef carbonate chemistry, ecosystem response and feedback.

- Provide data rich observing environment offering a means to model CO2SYS dynamics while leveraging the support of field process investigations.
- >2 year high-resolution CO2SYS time-series, intercomparison and development of advanced techniques to monitoring coral reef community metabolism
- Carbonate budgets, community characterization and metabolism, coral growth, bioerosion studies

La Parguera, Puerto Rico

coral reef

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

USGS

BIOGEOCHEMISTRY & MODELING

David Glover

WHOI

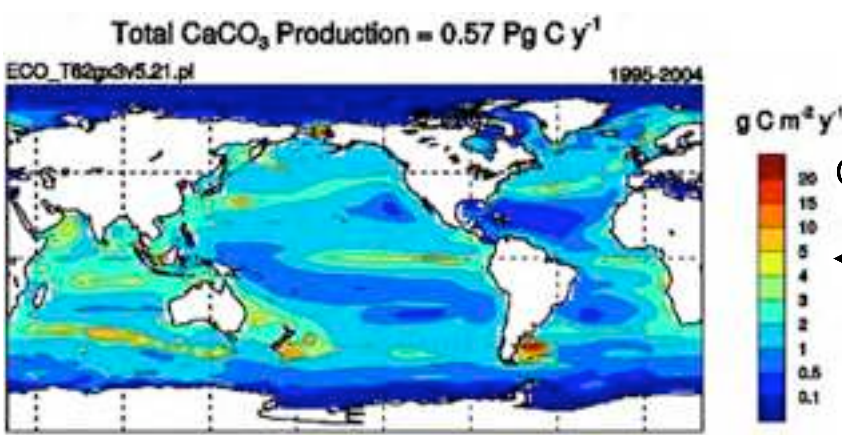
Scott Doney and Keith Lindsay

March 2011

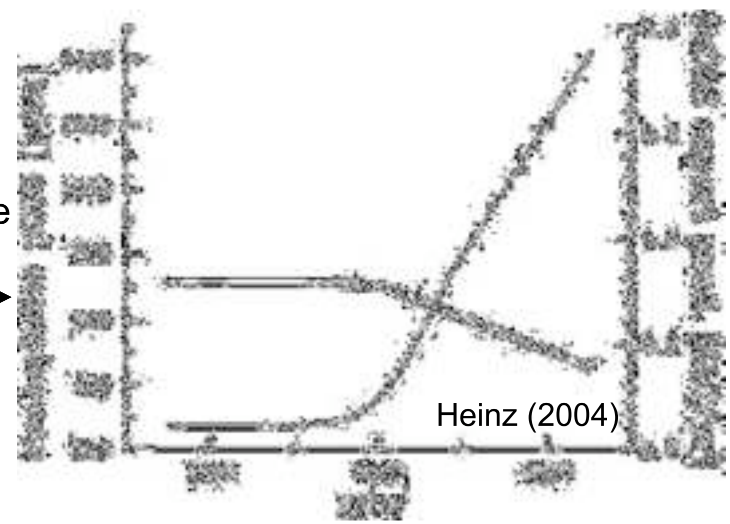
Assessing the Impact of Ocean Acidification on Marine Planktonic Calcification Using Satellite Analysis and Earth System Modeling

Better constrain the magnitude of ocean acidification and climate change impacts on marine inorganic carbon dynamics.

- Characterize the biogeographic niche for marine calcifiers with satellite and in situ data;
- Improve CESM marine ecosystem biological calcification module;
- Verify simulated planktonic calcification fields with satellite and in situ data;
- Quantify the projected calcification changes over the 21st century.



Current state of modeling ⟷



John E Joseph

Ching-Sang Chiu

Naval Postgraduate School

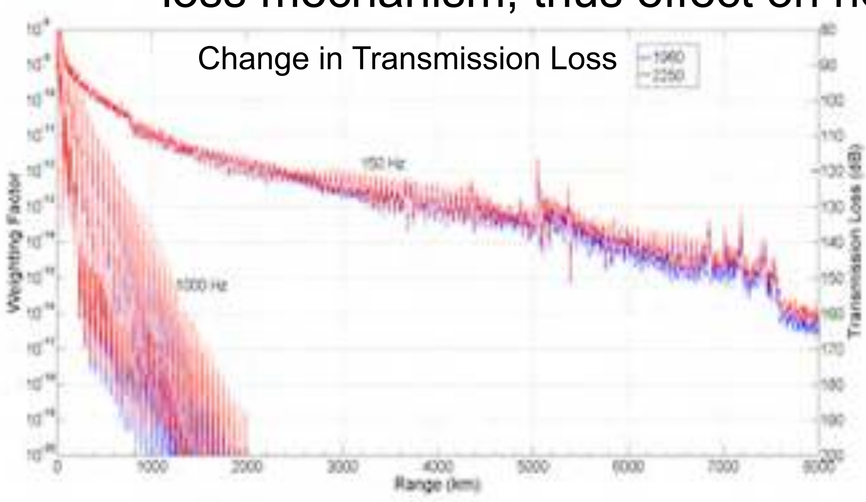
FY 2010

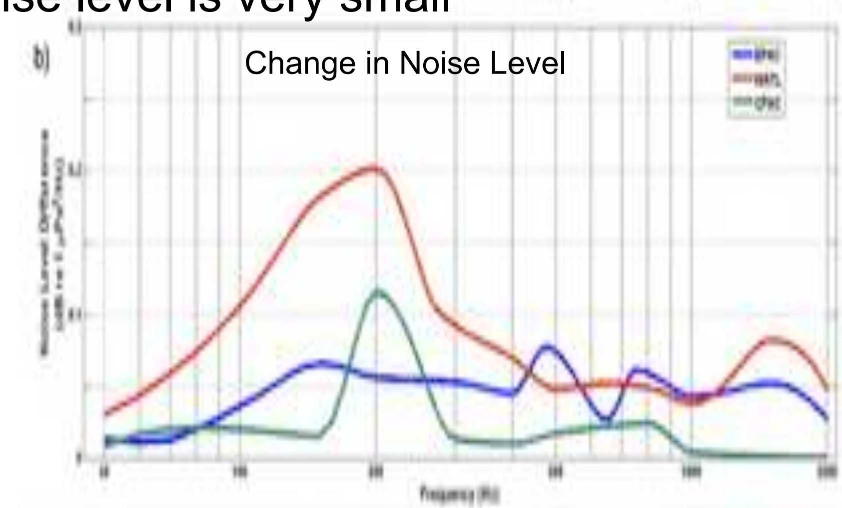
BIOGEOCHEMISTRY & MODELING

Ambient Noise Sensitivity to Ocean Acidification

Assessing the sensitivity of ambient noise to ocean acidification

- Computational Assessment
  - Realistic environment based on climatology
  - Acidification based on Caldeira and Wickett (Nature, 2003)
  - Results: pH effect on absorption is small relative to other propagation loss mechanism, thus effect on noise level is very small





BIOGEOCHEMISTRY & MODELING

Laurie Juranek

JISAO-UW/NOAA-PMEL

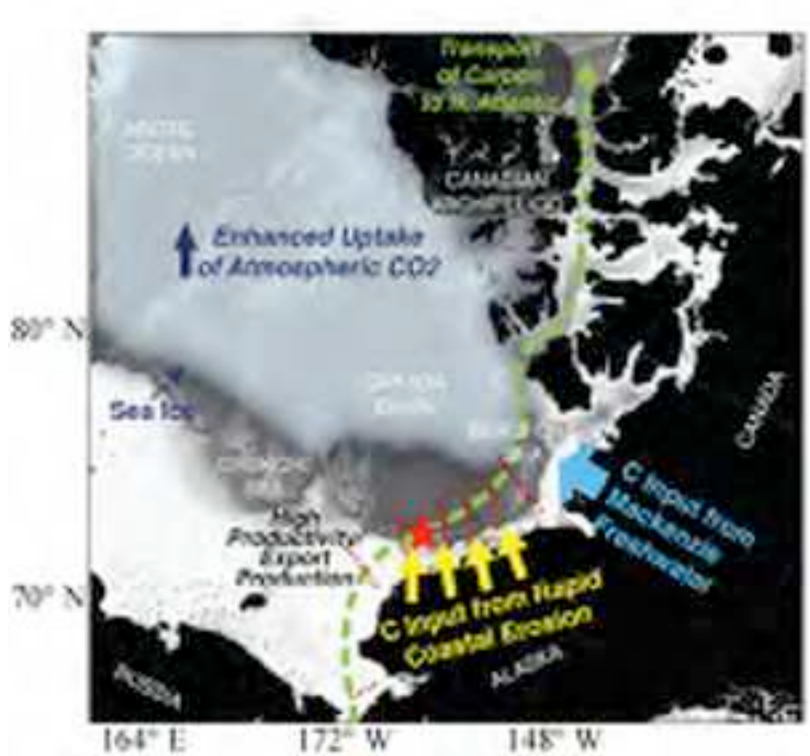
J. Mathis, R.A. Feely

January, 2011

Collaborative Research: Observation and Prediction of Ocean Acidification in the Western Arctic Ocean – Impacts of Physical and Biogeochemical Processes on Carbonate Mineral States

Analysis of sea-ice, circulation, terrestrial/riverine influences on community productivity and air-sea CO_2 flux, pH, and Ω_{arag}

- Field work to begin late summer 2011, continue through 2013:
- Discrete DIC, TA, nutrients, $^{17}\Delta$ and O_2/Ar (for community productivity), underway O_2/Ar
- Collaborations will enable concurrent observations of discrete pH and CO_3^{2-} (R. Byrne) and underway pCO_2 (Takahashi)



Cindy Lee

Stony Brook University

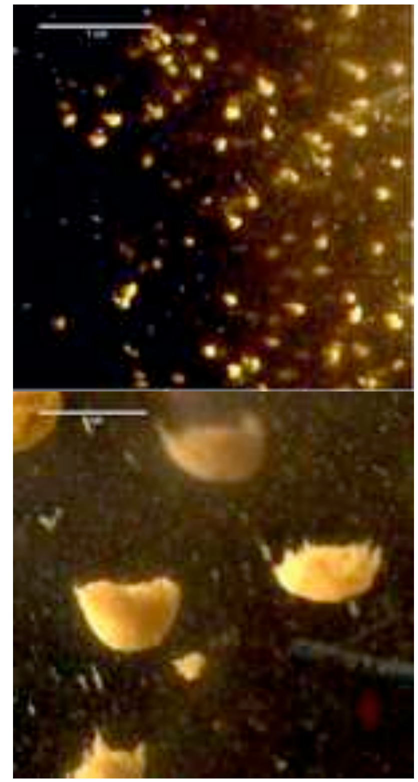
co-PI: Anja Engel

Start Date: July, 2009

BIOGEOCHEMISTRY & MODELING

Effects of ocean acidification on the formation and sinking of particle aggregates

Investigate mechanisms of aggregation of marine particles that specifically relate to organic matter-ballast mineral interactions and their sensitivity to ocean acidification.



Three hypotheses are being tested:

- 1: Gel particles enhance aggregate formation. Production of gel particles is sensitive to ocean acidification.
- 2: Biomineral ballast (particularly $CaCO_3$) is an important factor in carbon export in the ocean. Lower pH will decrease ballast-particle interactions and consequently export.
- 3. In addition to carbohydrates, gel particles also include proteins and lipids that will affect rate and mechanisms of organic matter aggregation in the ocean. The composition of gel particles in seawater will change at lower pH.

BIOGEOCHEMISTRY & MODELING

Derek Manzello

NOAA/AOML, RSMAS, NCAR, Univ. Colorado-Boulder

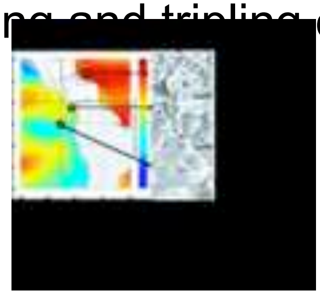
Joan A. Kleypas, David A. Budd

2005

Coral reef development in a high-CO_2 world

Coral reefs of the eastern tropical Pacific (ETP) provide a real-world example of reef growth, development, structure and function under high-CO_2, low aragonite saturation (Ω_{arag}) conditions that encompass the range of expected changes for the entire tropical surface ocean with a doubling and tripling of atmospheric CO_2.

- Interesting info about project
  - Goal: Assess coral reef structure and development across natural CO_2 gradient
  - Location: Eastern tropical Pacific, including Panamá and Galápagos Islands
  - Reef framework thickness and precipitation of $CaCO_3$ cements correlates with Ω_{arag}



Carbonate cements within the pore spaces of corals from areas with naturally different CO_2 levels (Manzello et al. 2008, *PNAS*)

Mean maximum coral reef framework thickness (m, ±std. error) from eastern tropical Pacific relative to the saturation state of aragonite, Ω_{arag}. (Manzello 2009, *Proc 11th ICRS*)

Bill Martin

WHOI

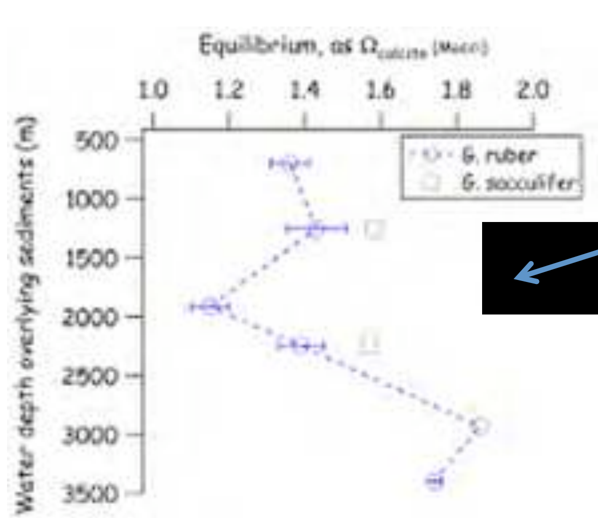
October, 2009

BIOGEOCHEMISTRY & MODELING

The Solubility of Biogenic Calcite

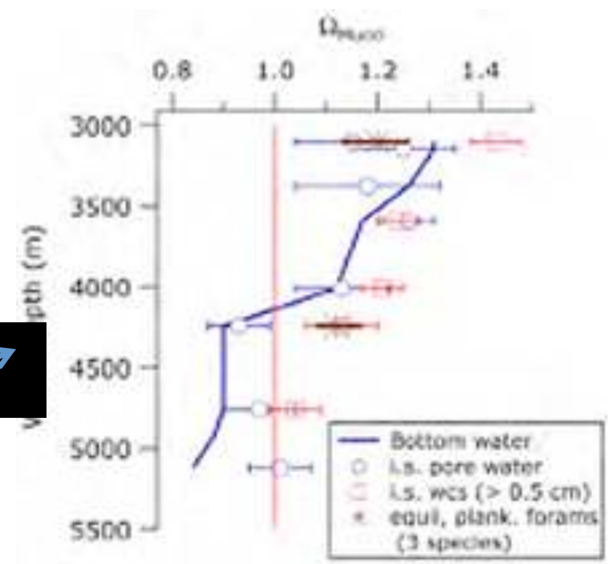
Observations of pore water CO_2 system concentrations indicate that pore waters may reach equilibrium with a carbonate phase that is more soluble than was determined by Mucci using abiogenic calcite. This project is to determine the solubility of planktonic forams collected from sediments.

Results: Our measurements of Iceland Spar calcite (abiogenic) agree with those of Mucci. We have demonstrated, using 3 species of planktonic foraminifera, that they appear to be more soluble.



Bahamas transect

Eastern tropical Atlantic



BIOGEOCHEMISTRY & MODELING

Paul McElhany & Shallin Busch

Jason Miller, Paul Williams

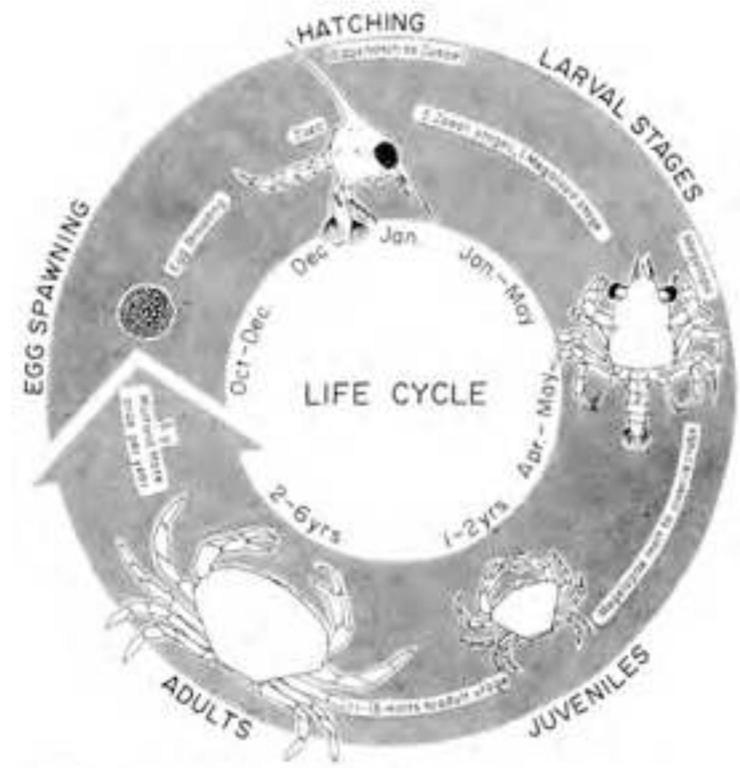
NOAA-NWFSC

Summer 2011

OA impacts on Dungeness Crab Populations: Life-cycle Based Modeling

Develop a life-cycle model for Dungeness crab that includes direct and indirect effects of OA

- Uses the Species Life-cycle Analysis Modules (SLAM) framework
- Includes direct effects of OA on crab larval development and molting based on NWFSC experiments
- Includes indirect effects of OA on crab from predicted changes in prey, predators and habitat (e.g. eelgrass)



Life-cycle of Dungeness crab

BIOGEOCHEMISTRY & MODELING

Uta Passow

Alice Alldredge

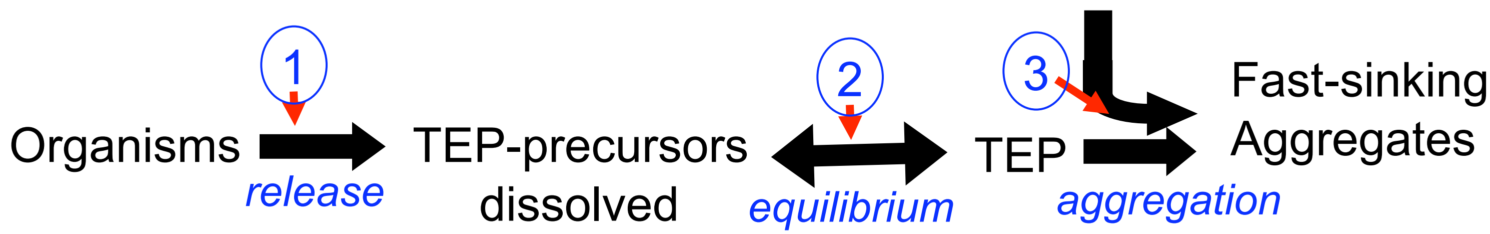
Marine Science Institute
UC Santa Barbara

October 2009

Will Ocean Acidification Diminish Particle Aggregation and Mineral Scavenging, Thus Weakening the Biological Pump?

Changes in (a) the formation of Transparent Exopolymer Particles (TEP), the gel-like particles that bind particles together, and
(b) the aggregation and carbon flux due to ocean acidification, are investigated experimentally.

OA might impact aggregation at three stages



- Steps 1 & 3: currently under investigation
- Step 2: Result: *Abiotic formation of TEP is impacted by change in pH & TA but* ***not*** *by the pH & DIC change expected in the future ocean* (see poster).

Uta Passow

Mark Brzezinski, Craig Carlson

Marine Science Institute
UC Santa Barbara

October 2010

BIOGEOCHEMISTRY & MODELING

Will high CO_2 conditions affect production, partitioning and fate of organic matter?

We will examine how increased inorganic C availability resulting from ocean acidification alters how phytoplankton partition the organic carbon fixed through photosynthesis between cellular biomass and exudates and whether CO_2-induced changes in the size and chemical composition of each pool affects the efficiency of the biological carbon pump.

We hypothesize that high CO_2 conditions

⟶ increased carbon overconsumption

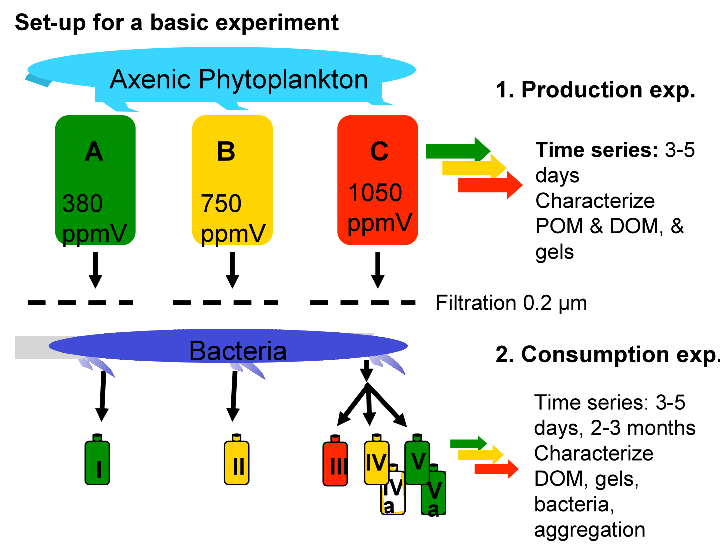
⟶ increased carbon exudation

⟶ elevated C: N and C: P in DOM

⟶ lower bioavailability of DOM

⟶ accumulation of DOM in surface waters

⟶ increase in the amount of carbon carried to depth by physical processes



Matthew Poach

Poach, Wieczorek, Chambers, Phelan

NOAA,NMFS

March, 2011

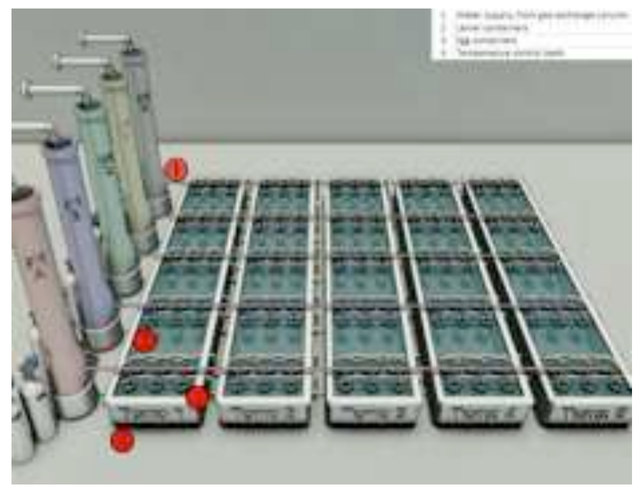
BIOGEOCHEMISTRY & MODELING

Carbon chemistry measurements associated with a controlled environment finfish experiment

Laboratory capabilities were established to measure carbon parameters from an experimental system designed to produce 5 CO_2 levels at 5 temperatures.

- Laboratory Capabilities:
  - pH by spectrophotometry
  - DIC by coulometry
  - Alkalinity by automatic titration

- Schematic of experimental system at right.



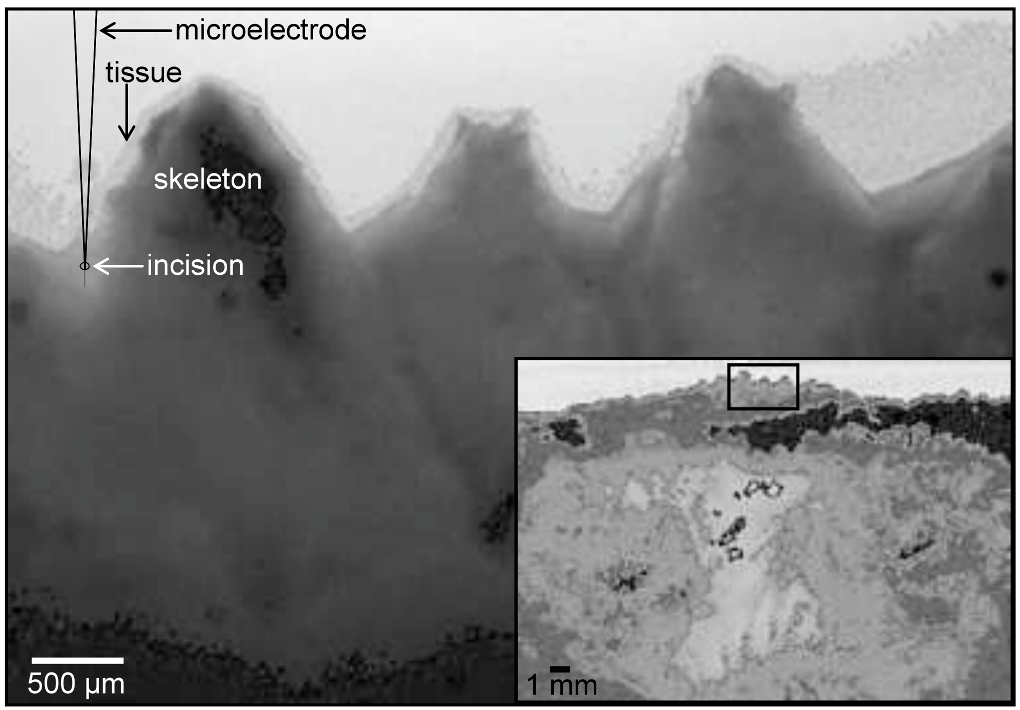
Justin B. Ries

UNC – Chapel Hill

BIOGEOCHEMISTRY & MODELING

Direct and indirect chemical analysis of the calcifying media of marine calcifiers

Using selective ion microelectrodes and chemical proxies within the shells/skeletons of marine calcifiers to estimate the composition of the media from which marine calcifiers precipitate their shells and skeletons.



BIOGEOCHEMISTRY & MODELING


E. Kwon

Jorge Sarmiento (PI)

Princeton University

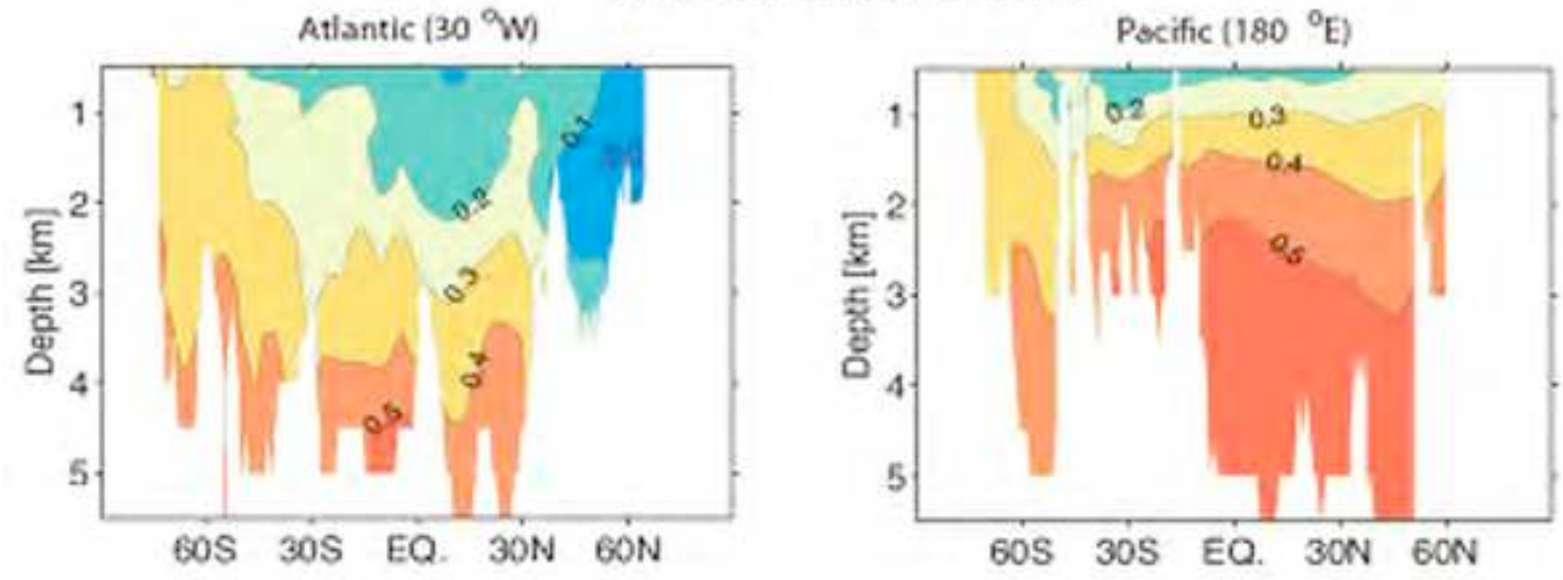
E. Kwon, J. R. Toggweiler, J. Dunne

November, 2010

Does the strength of the carbonate pump change with ocean stratification and acidification and how?

1. Optimize model formulations and parameterizations that represent the carbonate pump using a wide range of observations
2. Study the present-day operation of the carbonate pump and its interaction with climate change
3. Quantify the uncertainty in our prediction of the future response of the carbonate pump to ocean acidification and stratification

Ratio of C_{carb} to C_{soft}



BIOGEOCHEMISTRY & MODELING

Richard E. Zeebe SOEST, Univ. Hawaii

03/01/2008

Early Detection of Ocean Acidification Effects on Marine Calcification and Deep-Sea Carbonate Dissolution

Publications:

Zeebe, R. E., J. C. Zachos, K. Caldeira, and T. Tyrrell, "Oceans: Carbon Emissions and Acidification", *Science* (Perspectives), p. 51, vol. 321 (2008).

Ilyina, T., Zeebe, R.E., Maier-Reimer, E., Heinze, C., "Early Detection of Ocean Acidification Effects on Marine Calcification", *Global Biogeochemical Cycles* (2009).

Ilyina, T., Zeebe, R.E., Brewer, P.G., "Future ocean increasingly transparent to low-frequency sound owing to carbon dioxide emissions“, *Nature Geoscience* (2010).

Julie Reichert

EPA-ORISE Fellow

July 2010

FEDERAL PROGRAM

Ocean Acidification and the Clean Water Act 303(d) Program

Working on efforts to help States monitor and assess ocean acidification (OA).

- November 15, 2010: EPA issued memorandum on 303(d), 305(b), and 314 integrated reporting and listing decisions related to OA.
  - http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/oa_memo_nov2010.cfm
- Current efforts:
  - Identify and track OA-related monitoring and research.
  - Investigate methodologies that provide data on past and present OA-related assessment parameters (e.g., marine pH, aragonite saturation).
- Future plans:
  - Use climate models combined with watershed models to estimate carbon deposition to assist with future OA assessment.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

FEDERAL PROGRAM

Christine Ruf

US EPA

April 2009

Ocean Acidification and the Clean Water Act 303(d) Program

- Working to develop tools and methods to assess OA impacts and ultimately develop "carbon" pollution plans (TMDLs).
- EPA OW Office issued 11/15/2010 Memo describing how States and EPA Regions can move forward where info exists to assess coastal waters for OA water quality impairments.
- EPA has committed to developing additional guidance when future OA research provides the basis for improved monitoring and assessment methods, including significant Interagency Federal efforts.
- Working with EPA Air & ORD Office to apply national climate models to predict the water quality pollutant consequences of carbon-driven precipitation and temperature changes at the watershed scale; hoping to include OA modeling and impacts in the future.
  - http://water.epa.gov/lawsregs/lawsguidance/cwa/ tmdl/ oa_memo_nov2010.cfm

Andrew Dickson

UC San Diego

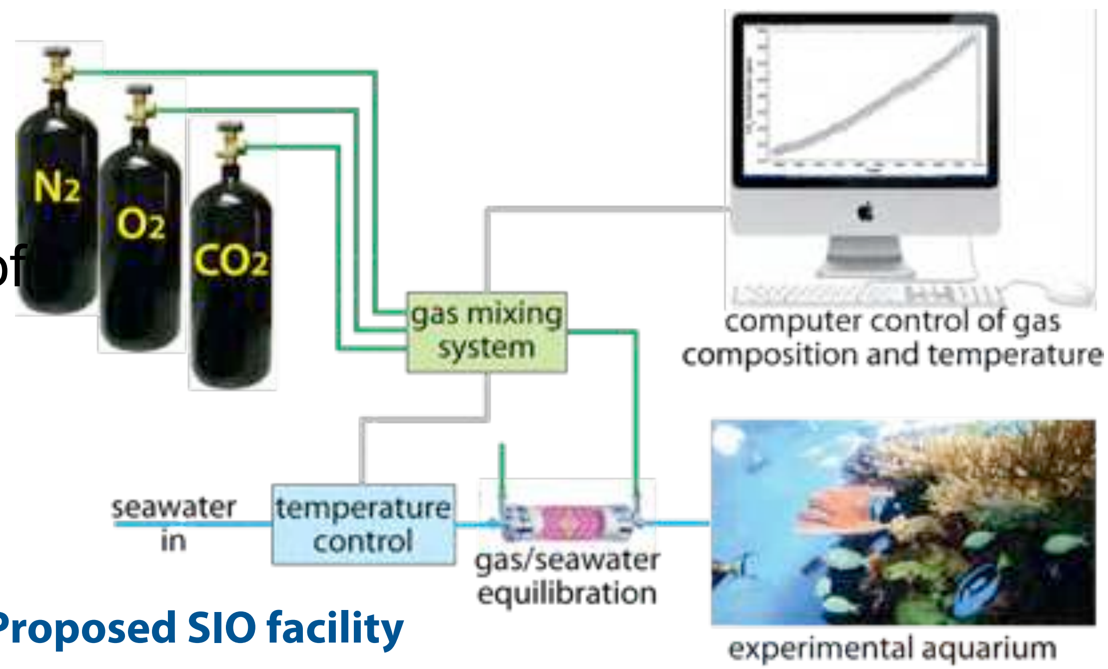
January 2011

FACILTIES

MRI: Development of instrumentation to control seawater composition for ocean acidification research.

Goal: Provide a high degree of control over *T*, *p*(CO_2), and *p*(O_2) in seawater that is being used to grow organisms for ocean acidification experiments

- ✓ Design and test system for control of gas composition
- ✓ Test use of membrane equilbrator for control of seawater composition
- Build and test single tank prototype system
- Scale up to full system



Proposed SIO facility

Gretchen Hofmann

UC Santa Barbara

August 2007

Portable CO_2 System for the culturing of marine invertebrate larvae

FACILTIES

Goal: To raise larval marine invertebrates using 'best practices' in larval culturing while also controlling CO_2 levels in a flow-through system. Can be used at home or away!

Funded by a supplement to NSF grant OCE-0425107 to GEH

- ✓ System has been used in the Antarctic (Crary labs-McMurdo Station) and in Moorea
- ✓ On-site seawater chemistry facilitates monitoring of experimental conditions
- ✓ Methods paper published

Fangue, N.A., M.J. O'Donnell, M.A. Sewell, P.G. Matson, A.C. MacPherson and G.E. Hofmann (2010) A laboratory-based experimental system for the study of ocean acidification effects on marine invertebrate larvae. *Limnol. Oceanogr.: Methods* 8: 441-452

Culture system set up in Crary Labs aquarium room, McMurdo Station, Antarctica. Prof. Mary Sewell (L) & Dr. Pauline Yu (R)

James W. Murray

University of Washington

March 2008

Ken Sebens, Bob Morris, Robin Kodner, Evelyn Lessard
Terrie Klinger, Michael O'Donnell, Emily Carrington

FHL Ocean Acidification Experimental Facility

FACILTIES

A new experimental facility has been constructed at UW Friday Harbor Laboratories (FHL)

- This facility includes the capability for experimental studies of small-scale single organism studies as well as multi-species food-web interactions. Both temperature and CO_2 levels can be manipulated. The facility includes a complete carbonate system analytical lab.
  - Our goal is to characterize biological and ecological response to increasing acidification and temperature
  - The first mesocosm experiment is planned for June 2011 in conjunction with a FHL Summer Course on Ocean Acidification

James W. Murray

University of Washington

March 2008

Ken Sebens, Bob Morris, Robin Kodner, Evelyn Lessard
Terrie Klinger, Michael O'Donnell, Emily Carrington

FHL Ocean Acidification Experimental Facility

FACILTIES

National Science Foundation - FSML Program

Kenneth P. Sebens, Terrie Klinger, James Murray, Emily Carrington, Michael O' Donnell, Sarah Gilman

UW Seattle & UW Friday Harbor Labs

James W. Murray

University of Washington

March 2008

Ken Sebens, Bob Morris, Robin Kodner, Evelyn Lessard
Terrie Klinger, Michael O'Donnell, Emily Carrington

FHL Ocean Acidification Experimental Facility

FACILTIES

The Ocean in a High-CO_2 World
Ocean Acidification
Third Symposium • Monterey • California • 24-27 September • 2012

- **Ulf Riebesell (Germany), Chair**
- **Claire Armstrong (Norway)**
- **Peter Brewer (USA)**
- **Ken Denman (Canada)**
- **Richard Feely (USA)**
- **Kunshan Gao (China-Beijing)**
- **Jean-Pierre Gattuso (France)**
- **Dan Laffoley (UK)**
- **Yukihiro Nojiri (Japan)**
- **James Orr (France)**
- **Hans-Otto Poertner (Germany)**
- **Carlos Eduardo Rezende (Brazil)**
- **Daniela Schmidt (UK)**
- **Anya Waite (Australia)**

International Planning Committee

The Ocean in a High-CO_2 World

Ocean Acidification

Third Symposium • Monterey • California • 24-27 September • 2012

Sept. 23 (Sunday)	**Sept. 24 (Monday)**	**Sept. 25 (Tuesday)**	**Sept. 26 (Wednesday)**	**Sept. 27 (Thursday) Policy Day**
	Plenary	Plenary	Plenary	Plenary
	Break	Break	Break	Break
	Parallel Sessions	Parallel Sessions	Parallel Sessions	Plenary
	Lunch	Lunch	Lunch	Lunch
Registration, poster set up and ice- breaker reception	Parallel Sessions	Parallel Sessions	Parallel Sessions	
	Break	Break	Break	
	Parallel Sessions	Parallel Sessions	Parallel Sessions	
	Poster Session	Poster Session	Dinner at Aquarium	

The Ocean in a High-CO_2 World

Ocean Acidification

Third Symposium • Monterey • California • 24-27 September • 2012

PLENARY PRESENTATION TOPICS

- The History of Ocean Acidification Science
- Changes in ocean carbonate chemistry since the Industrial Revolution
- Rates of change of ocean acidification: Insights from the paleorecord
- Interactions of ocean acidification with physical climate change
- Responses of marine organisms and ecosystems to multiple environmental stressors (ocean acidification, hypoxia, temperature, UV, etc.)
- Acclimation and adaption to ocean acidification: Genomics, physiology, and behavior
- Ecosystem change and resilience in response to ocean acidification
- Biogeochemical consequences of ocean acidification and feedbacks to the Earth system
- Understanding the economics of ocean acidification
- Policy and governance in the context of ocean acidification: Implications, solutions, and barriers
- Impacts of ocean acidification on foodwebs and fisheries

The Ocean in a High-CO_2 World

Ocean Acidification

Third Symposium • Monterey • California • 24-27 September • 2012

PARALLEL PRESENTATION TOPICS

- Detection and attribution of ocean acidification changes
- Effects of ocean acidification on nutrient and metal speciation
- New developments in measuring and observing ocean acidification and its effects
- Regional impacts of ocean acidification
- Effects of ocean acidification on calcifying organisms
- New concerns in ocean acidification research

Seventh EGU Alexander von Humboldt International Conference on Ocean acidification: consequences for marine ecosystems and society

Park Royal Penang Resort
Penang, Malaysia, June 20-24, 2011

Conference homepage:
www.meetings.copernicus.org/avh7

Abstract submission deadline: 3/15/2011

Topics:
Ocean acidification and the marine ecosystem
Ocean acidification and society and politics
Ocean acidification and climate engineering
Outreach