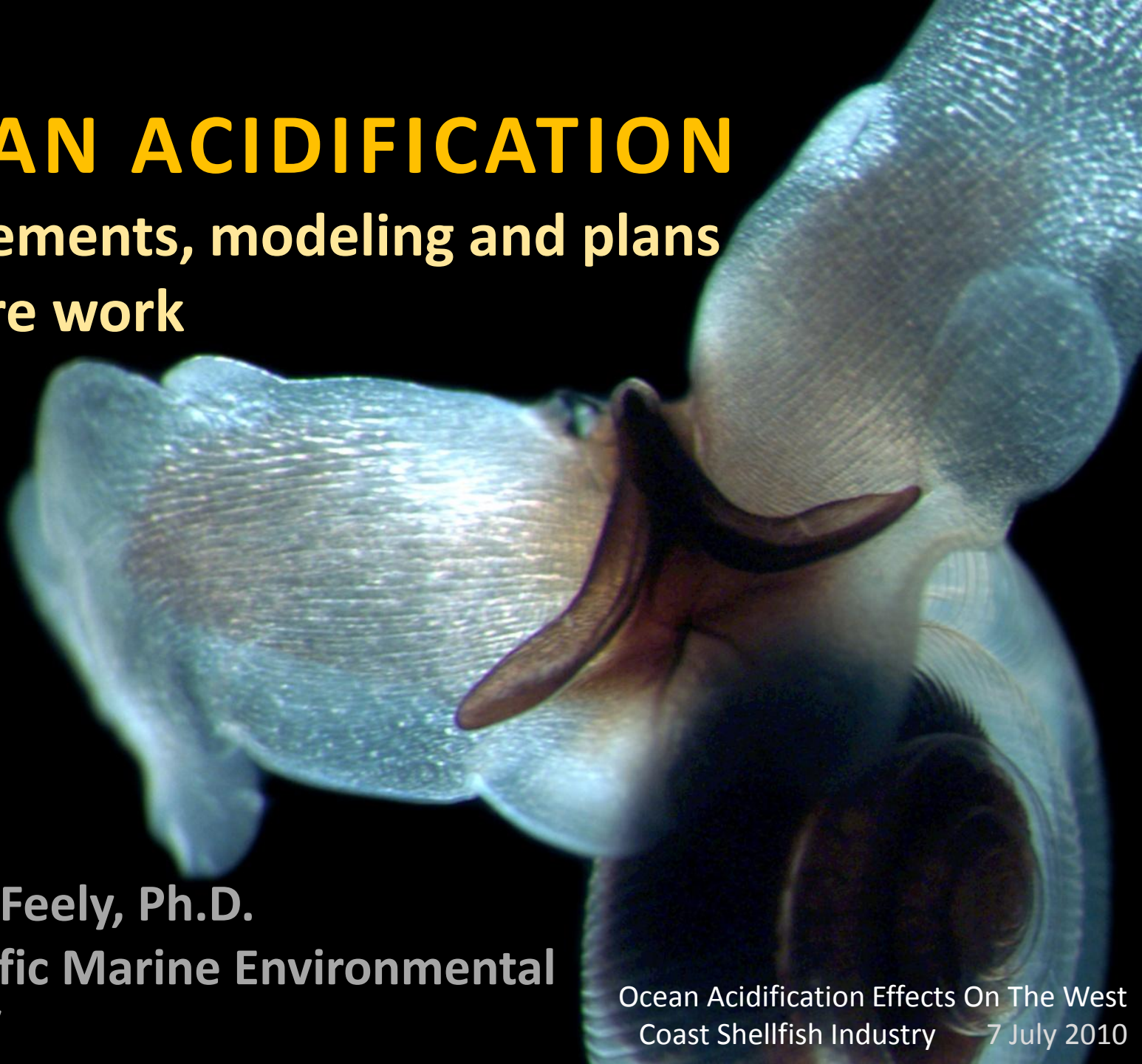
OCEAN ACIDIFICATION

Measurements, modeling and plans for future work



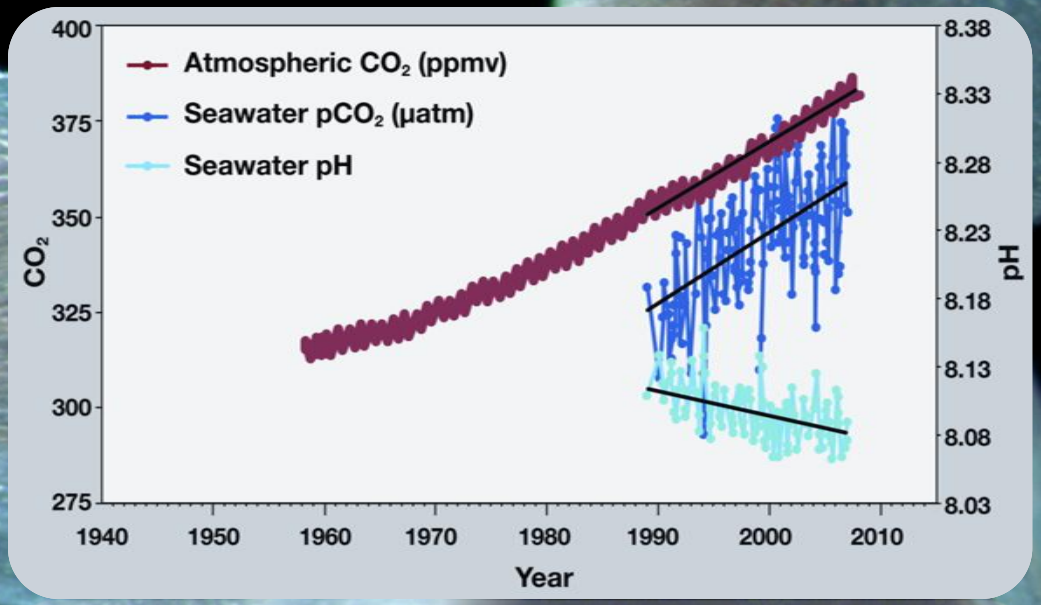
Richard A. Feely, Ph.D.

NOAA Pacific Marine Environmental Laboratory

Ocean Acidification Effects On The West Coast Shellfish Industry 7 July 2010

OCEAN ACIDIFICATION

Measurements, modeling and plans for future work



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Ocean Acidification Effects On The West Coast Shellfish Industry 7 July 2010

OCEAN ACIDIFICATION

Measurements, modeling and plans for future work

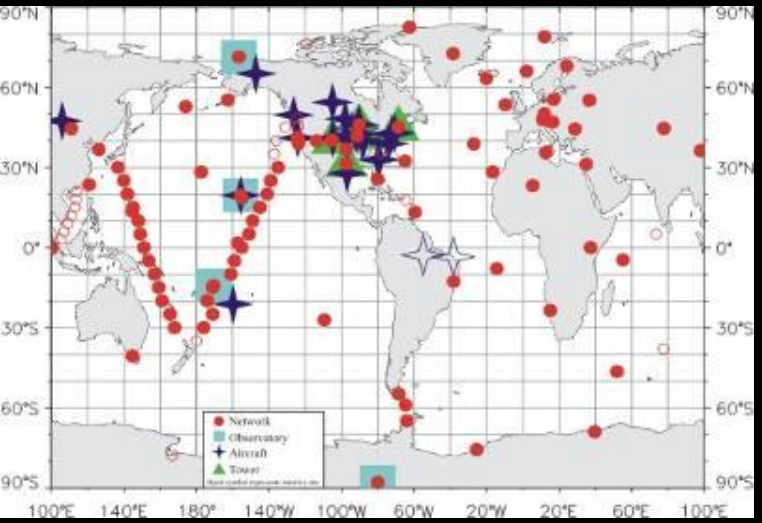
Outline

1. Overview of ocean acidification science
2. Measurements and models on the West Coast
3. Where do we go from here?

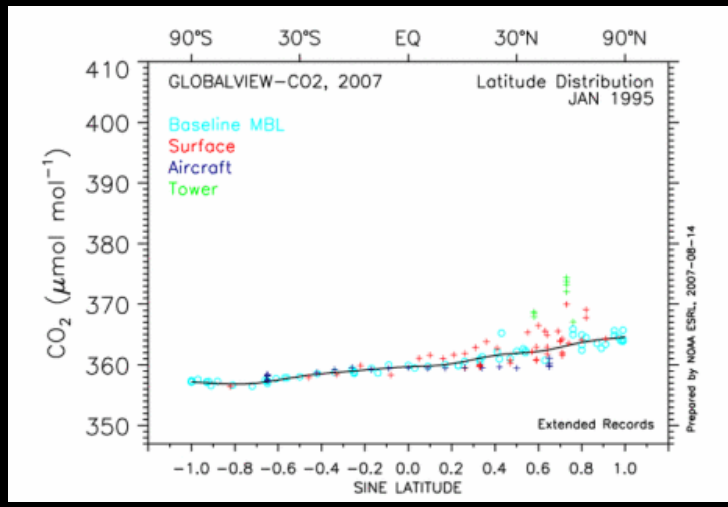
Richard A. Feely, Ph.D.
NOAA Pacific Marine Environmental Laboratory

Ocean Acidification Effects On The West Coast Shellfish Industry 7 July 2010

Atmospheric CO_2 Record



NOAA Earth Systems Research Laboratory, Global Monitoring Division Global CO_2 Monitoring Network



Cumulative carbon sources and sinks over the last two centuries

SOURCES

Land-use change
160 Pg C
(31%)

Fossil emission
348 Pg C
(69%)

SINKS

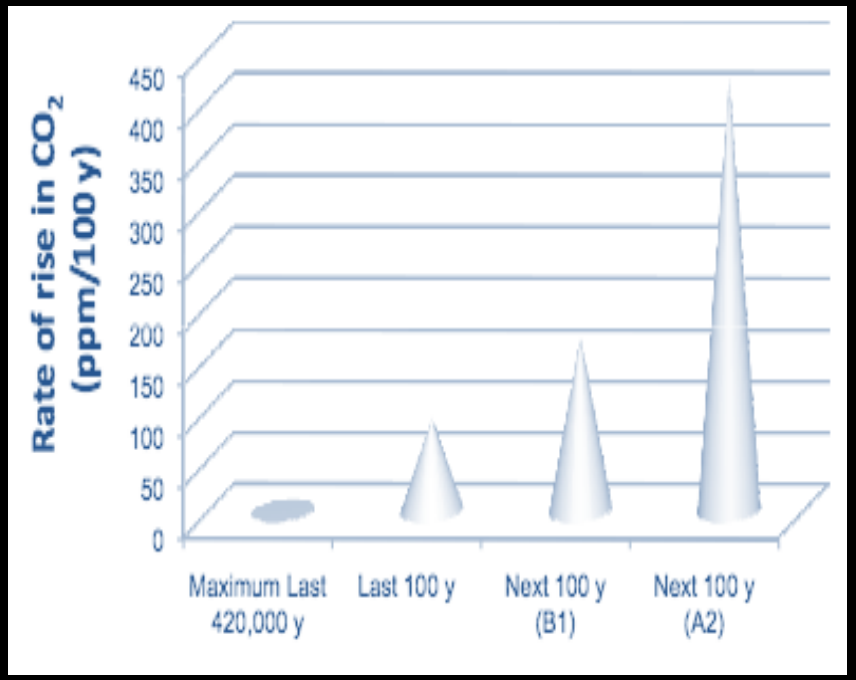
Atmospheric accumulation
234 Pg C
(46%)

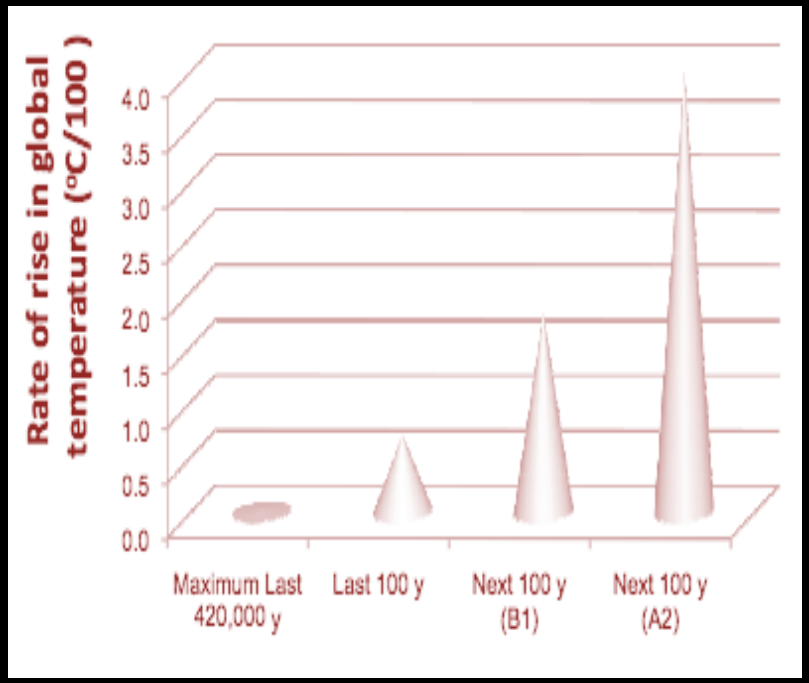
Terrestrial sink
147 Pg C
(29%)

Ocean sink
127 Pg C
(25%)

Global Carbon Project (2008) Carbon Budget and trends 2007, www.globalcarbonproject.org, 26 September 2008

Rates of increase are important





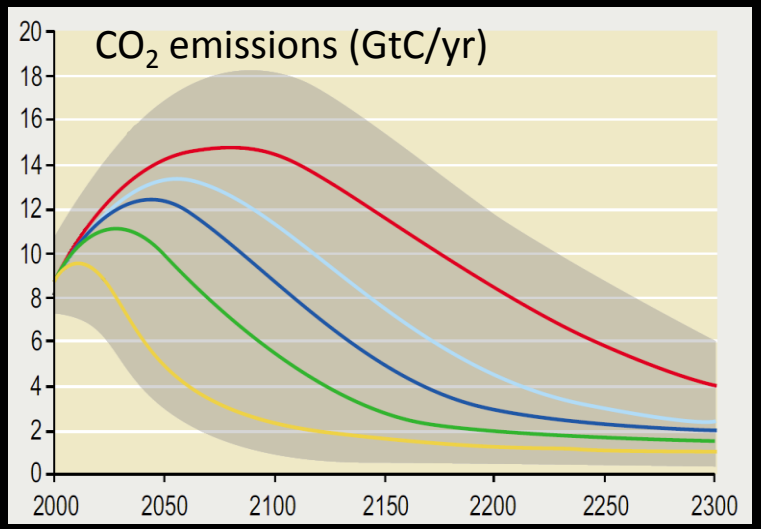
atmospheric CO_2

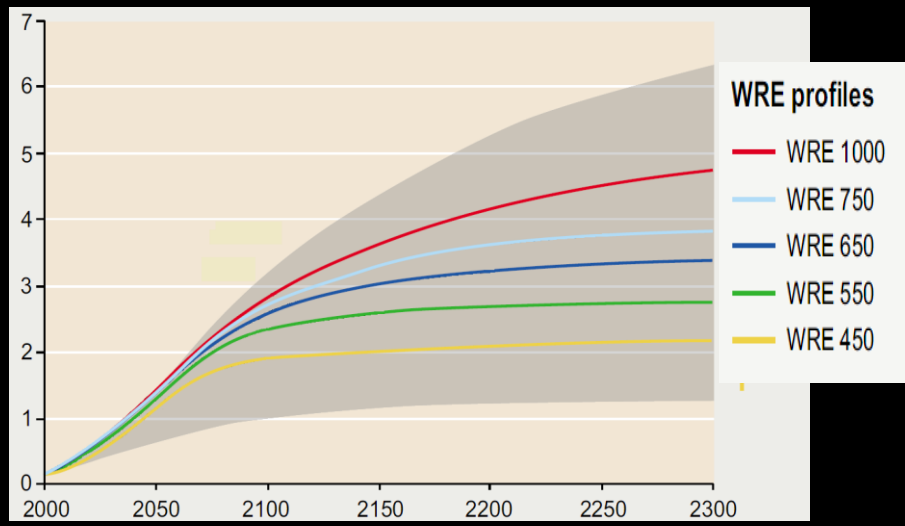
global temperature

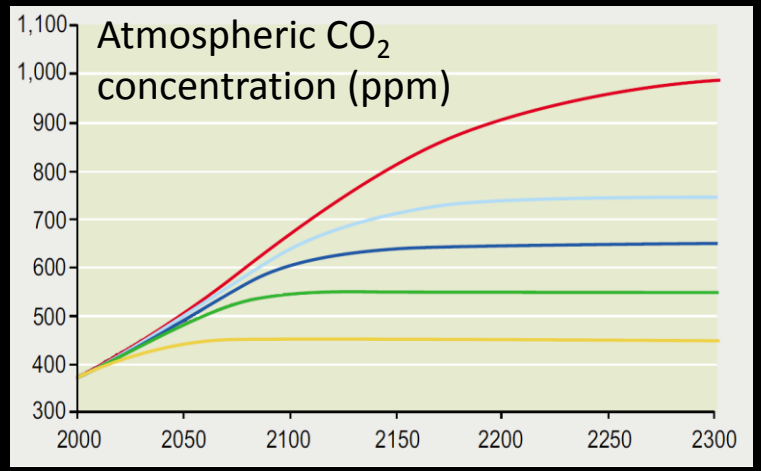
Hoegh-Guldberg *et al*. 2007, *Science*

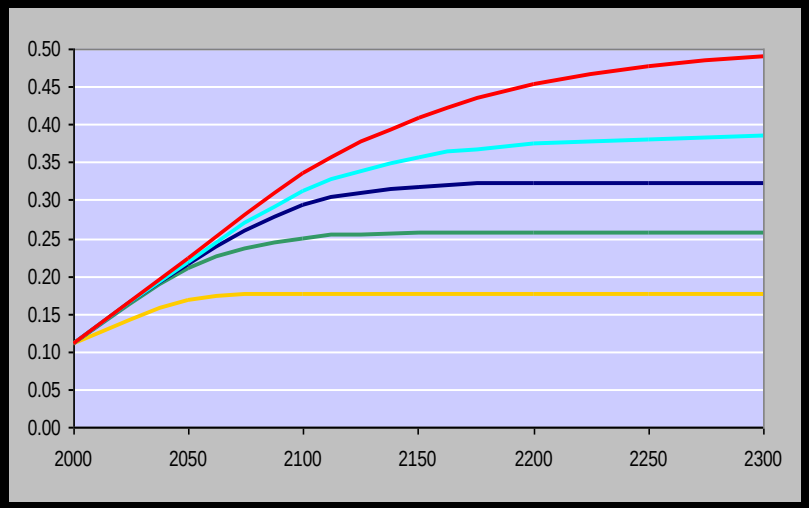
Ocean CO_2 Chemistry

IPCC TAR Emission Profiles from Pre-Industrial Levels







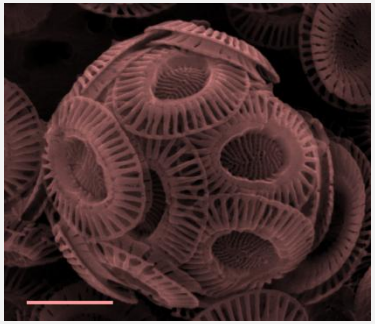


Turley (2006)

Drivers for a change in energy policy

Calcium Carbonate Saturation State

$$CO_2 + CO_3^{2-} + H_2O \Leftrightarrow 2HCO_3^-$$



Saturation State

$$\Omega_{phase} = \frac{[Ca^{2+}][CO_3^{2-}]}{K^*_{sp,phase}}$$

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

calcium carbonate calcium carbonate

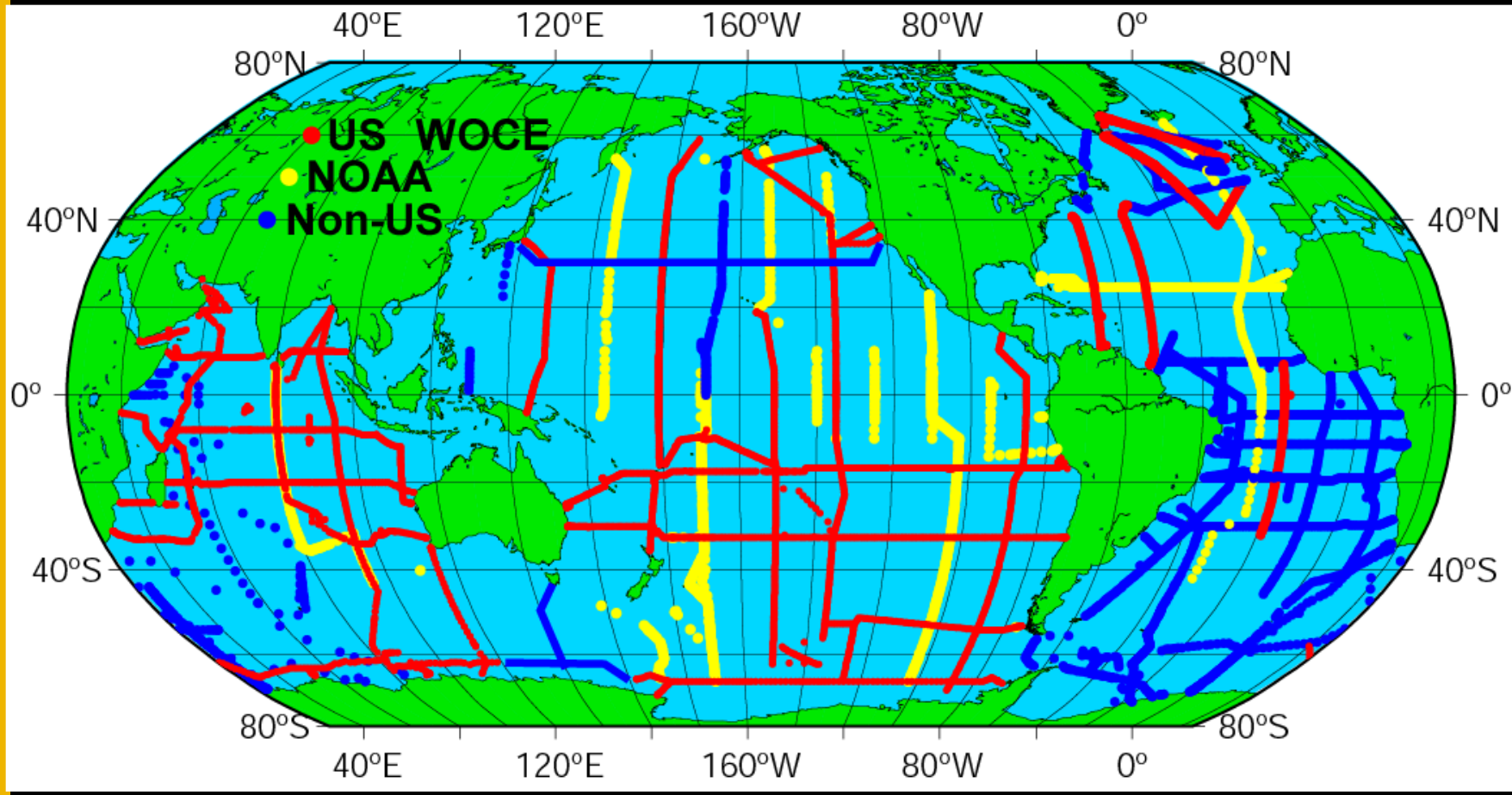
$\Omega > 1 =$ *precipitation*

$\Omega = 1 =$ *equilibrium*

$\Omega < 1 =$ *dissolution*

Ocean CO_2 Chemistry

Field Observations



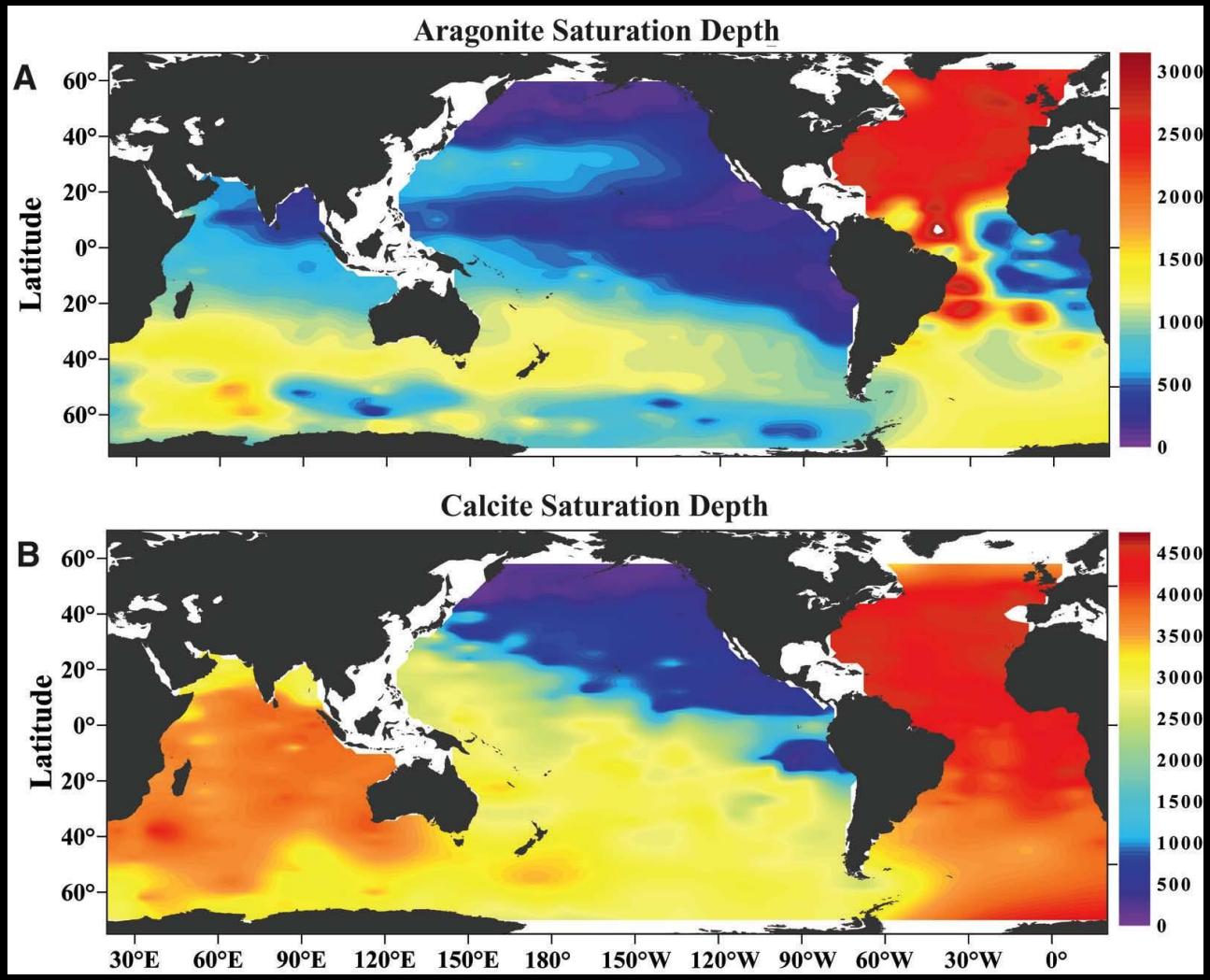
WOCE/JGOFS/OACES Global CO_2 Survey

~72,000 sample locations collected in the 1990s

DIC ± 2 μmol kg^{-1}
TA ± 4 μmol kg^{-1}

Sabine *et al*. (2004)

Observed aragonite & calcite saturation depths



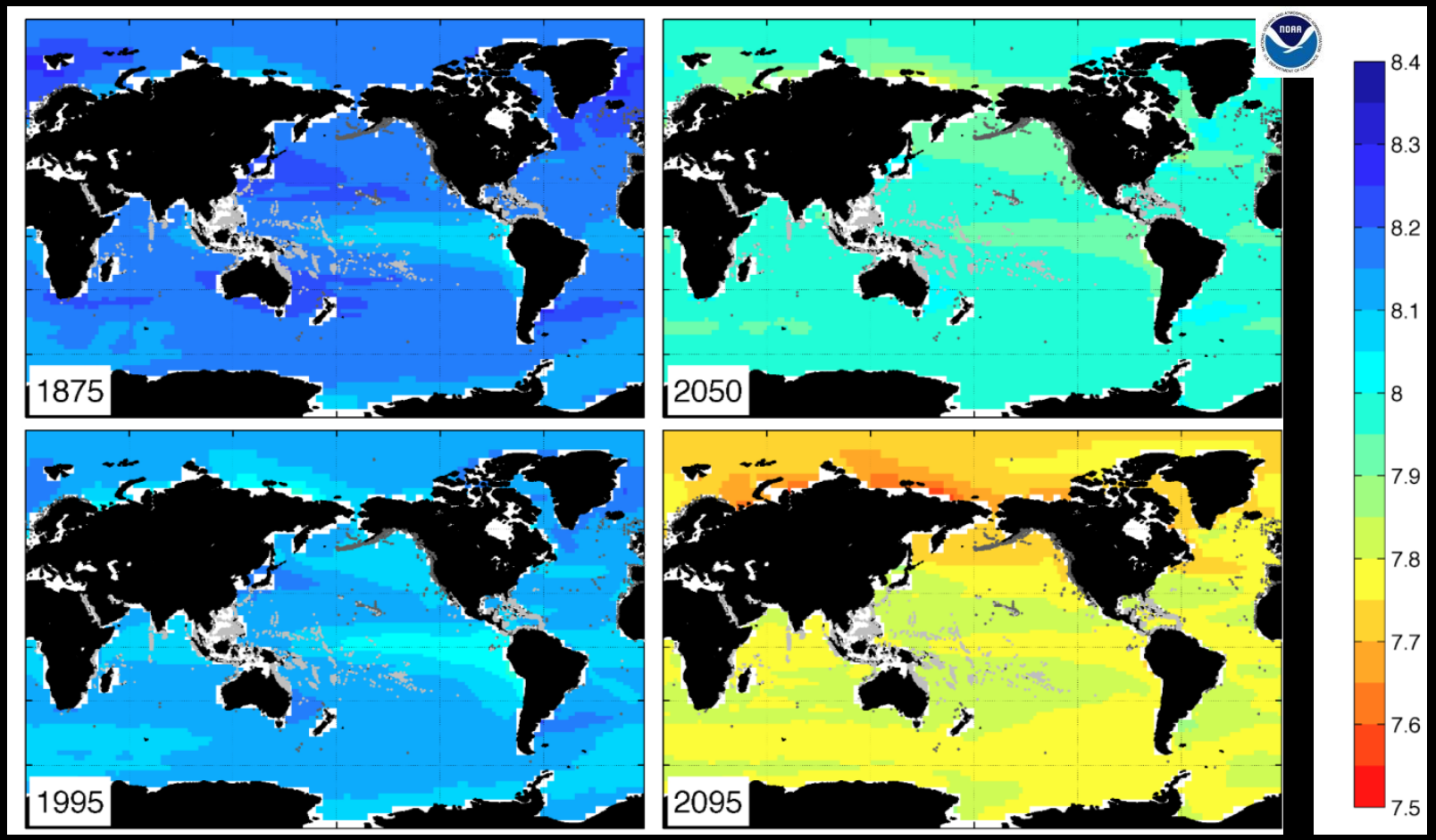
Feely *et al.* (2004)

The ***aragonite saturation state*** migrates towards the surface at the rate of 1-2 m yr^{-1}, depending on location.

Projections

pH distribution in surface waters

from the NCAR CCSM3 model projections using the IPCC A2 CO_2 Emission Scenarios



- warm water corals
- deep water corals

Feely, Doney and Cooley, *Oceanography* (2009)

Potential impacts: marine organisms & ecosystems

- Reduced calcification rates
- Significant shift in key nutrient and trace element speciation
- Shift in phytoplankton diversity
- Reduced growth, production and life span of adults, juveniles & larvae
- Reduced tolerance to other environmental fluctuations

- Changes to:
  - Fitness and survival
  - Species biogeography
  - Key biogeochemical cycles
  - Food webs
- Reduced:
  - Sound Absorption
  - Homing Ability
  - Recruitment and Settlement

Changes to ecosystems & their services

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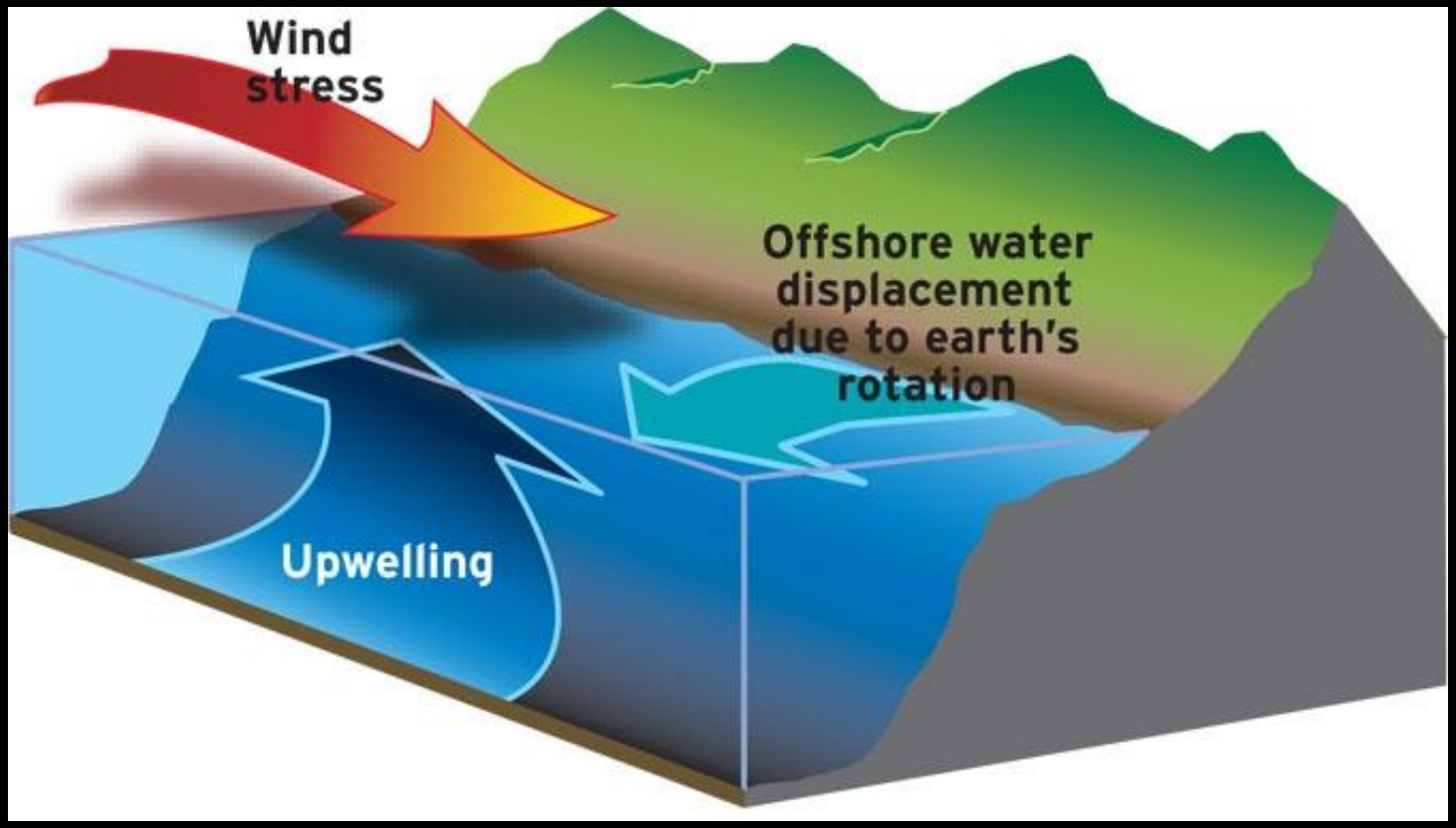
  - Homing Ability
  - Recruitment and Settlement

Uncertainties great
RESEARCH REQUIRED

Changes to ecosystems & their services

Projections

Natural processes that could accelerate the ocean acidification of coastal waters



brings high CO_2, low pH, low Ω, low O_2 water to surface

Coastal Upwelling

The source of the upwelled water takes a long time to get here.

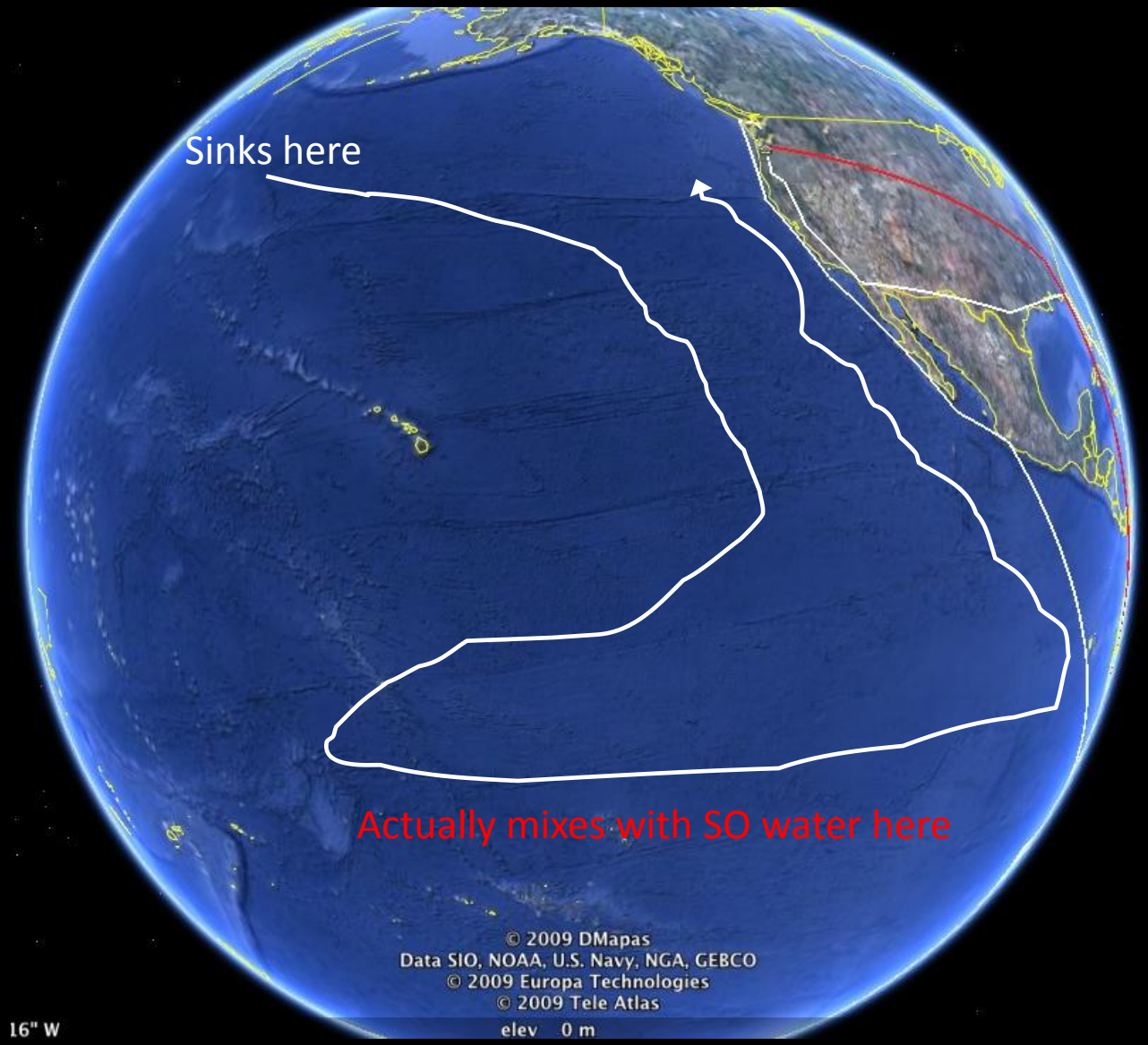
Water takes a circuitous path to upwelling centers.

Takes decades (3-5?) to get here.

Water gets as deep as ~500m along its route.

During its entire transit, metabolic processes add CO_2.

Provided by Burke Hales, OSU



NACP West Coast Survey Cruise

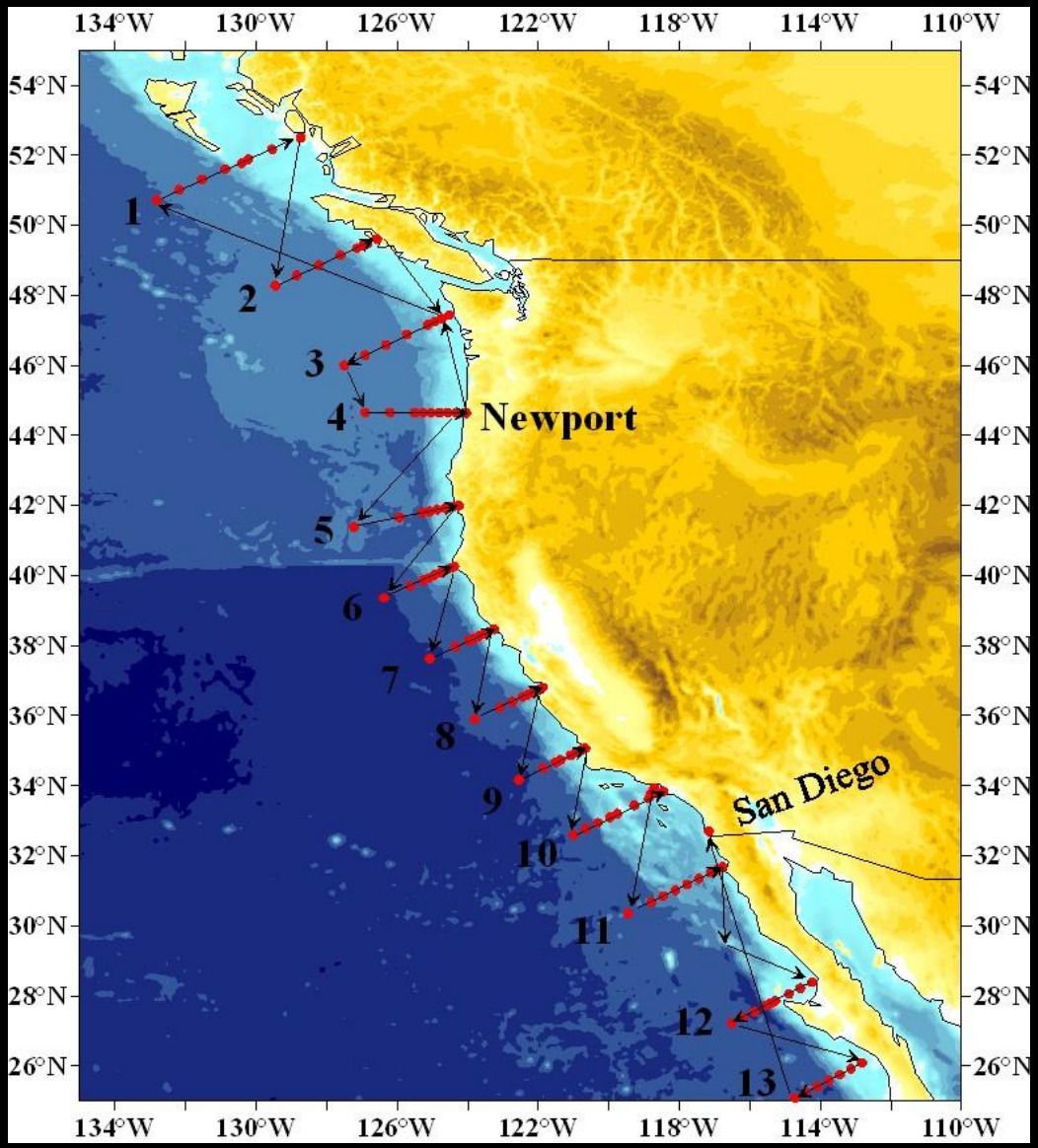
11 May – 14 June 2007

Newport

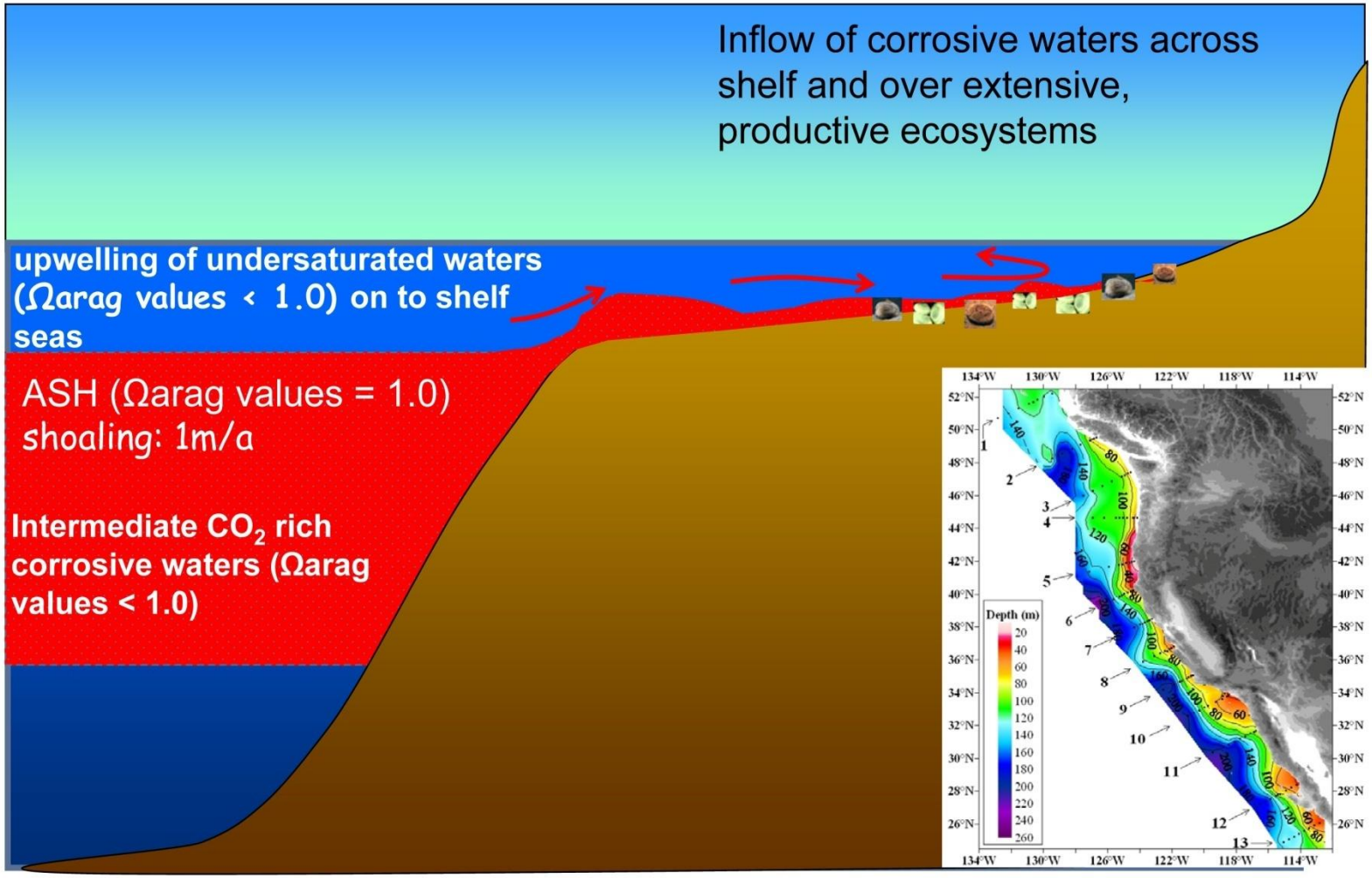
Aberdeen

MBARI

UCLA



Seasonal invasion of corrosive waters on west coast North America

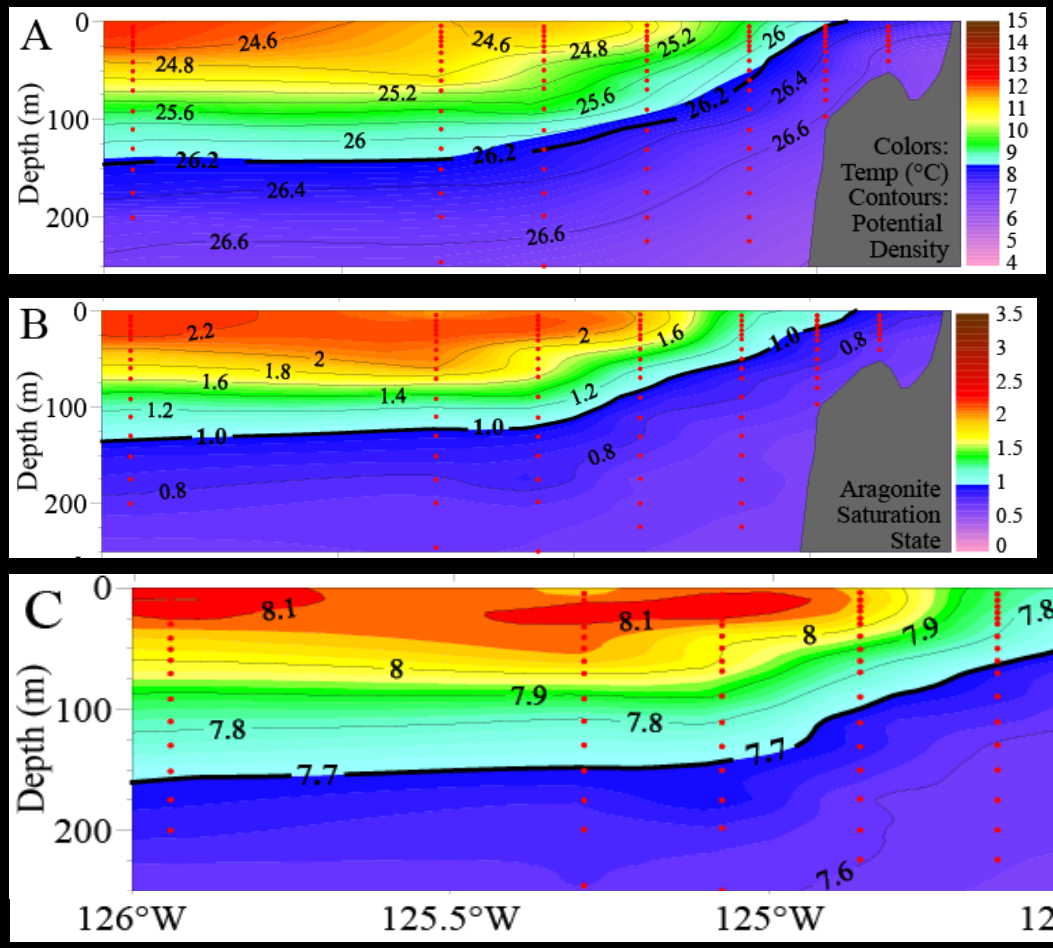


Schematic by C. Turley

Feely et al. Science (2008)

NACP West Coast Survey Cruise

11 May – 14 June 2007



Vertical sections from Line 5 (Pt. St. George, California)

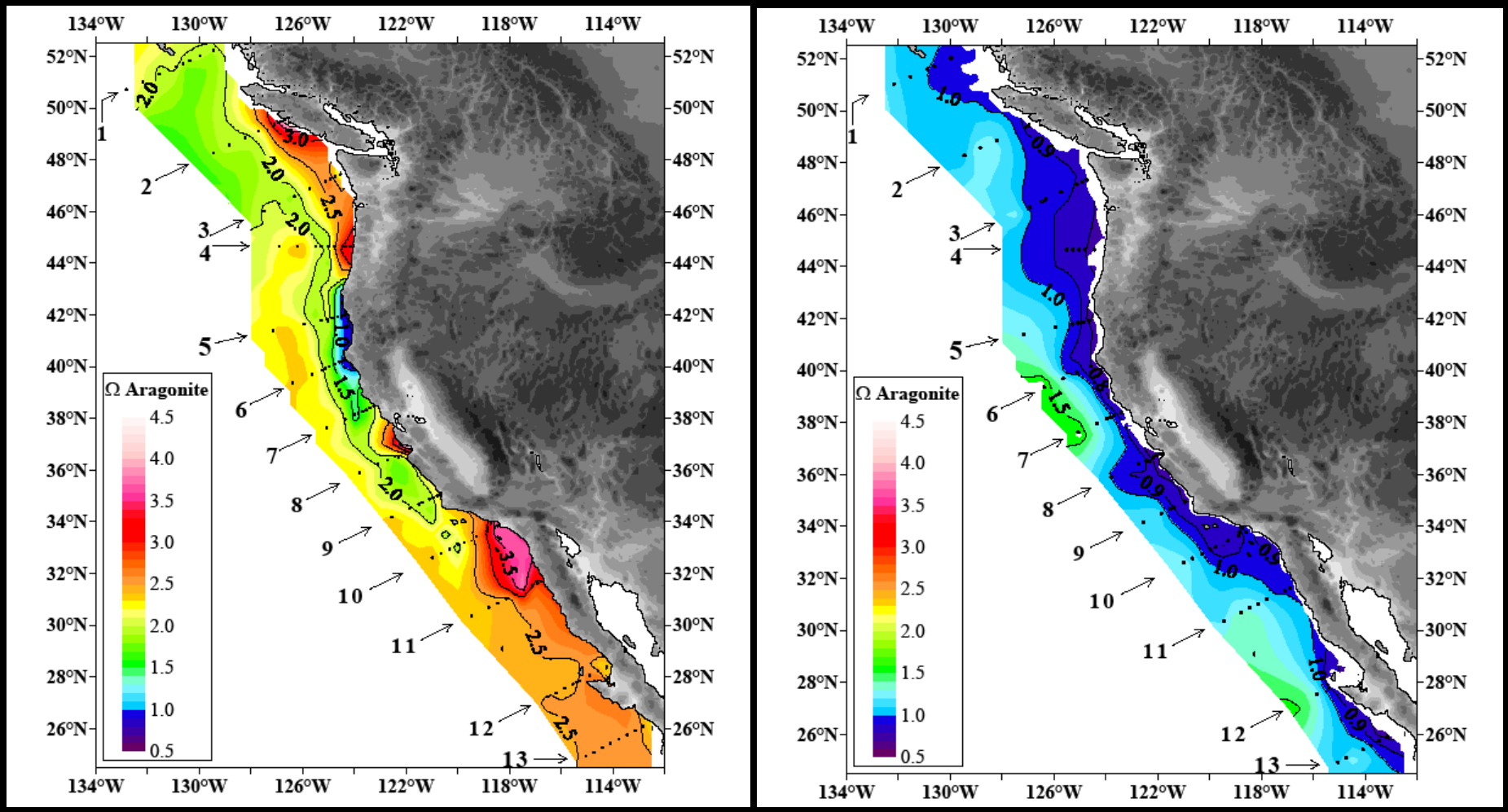
Feely *et al.* (2008)

sample locations

The 'ocean acidified' corrosive water was upwelled from depths of 150-200 m onto the shelf and outcropped at the surface near the coast.

North American Carbon Program

Continental carbon budgets, dynamics, processes & management

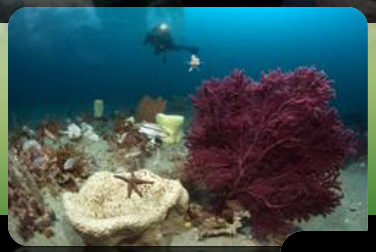


Aragonite saturation state in west coast waters

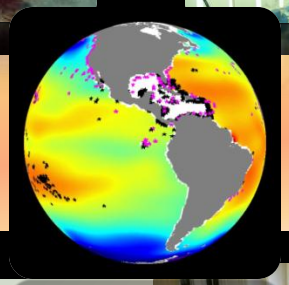
NOAA OA Research Implementation Plan

Monitor trends

Ecosystem responses



Model changes & responses



Develop adaptation strategies

Conduct education and outreach

Science-based guidance

Hypotheses

Rates and magnitudes of ocean acidification will vary.

Ocean acidification will change ecosystem structure, function, & biodiversity.

Species-specific vulnerabilities will differ at regional and local scales.

Themes

1 Monitor

2 Assess

3 Forecast

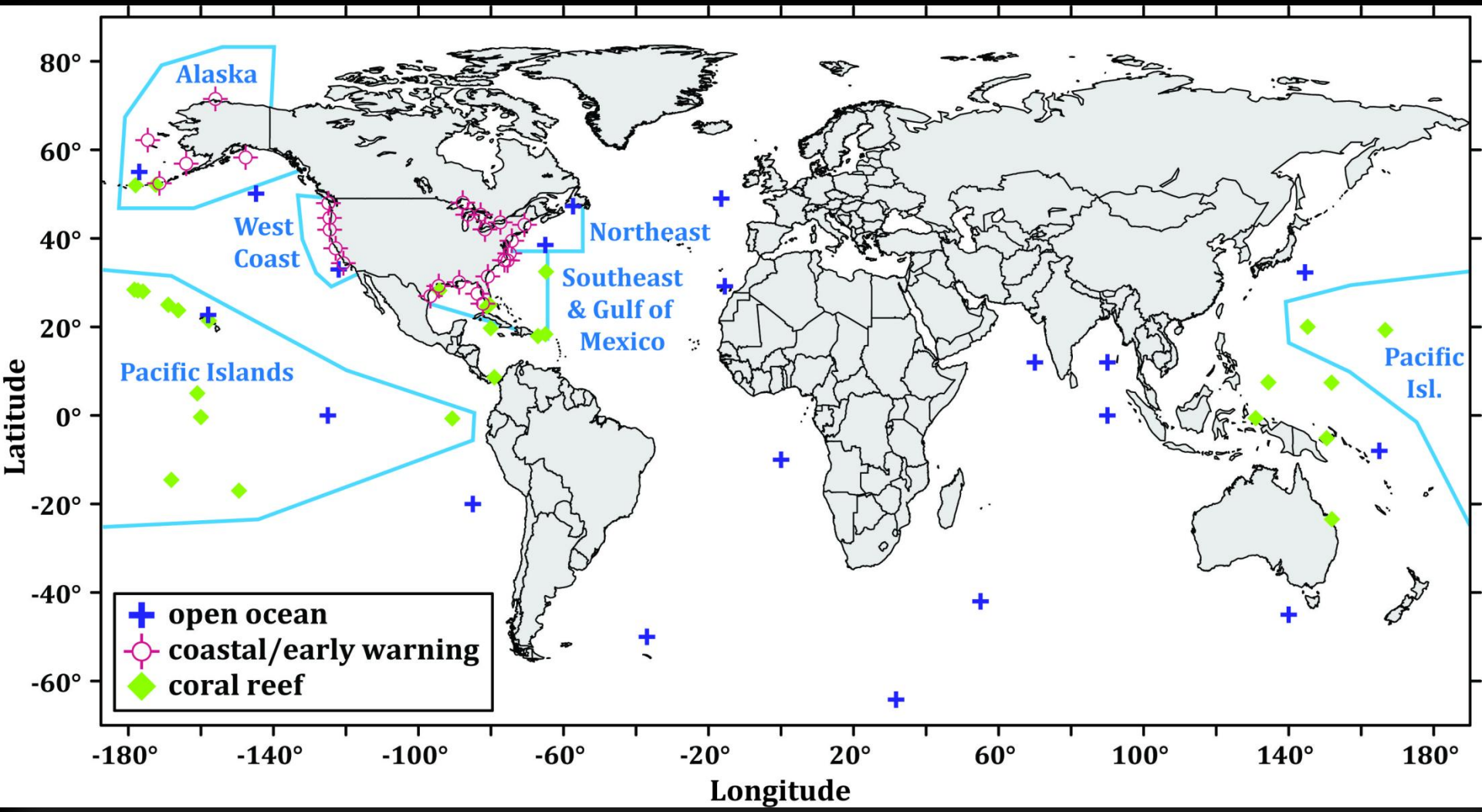
4 Manage

5 Synthesize

6 Engage

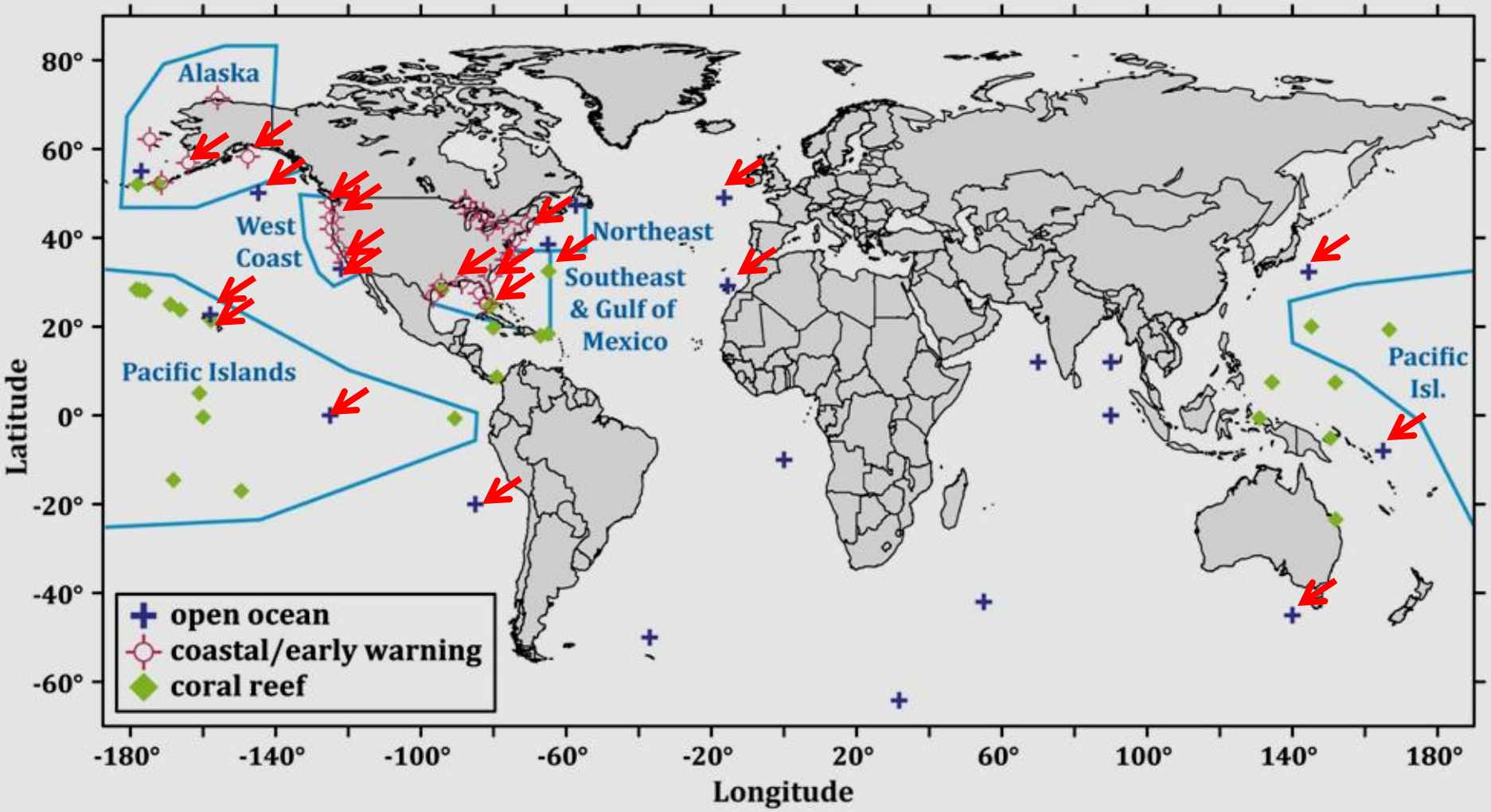
Global monitoring

Ocean Carbon Observatory Network



Leveraging

Adding sensors to existing moorings

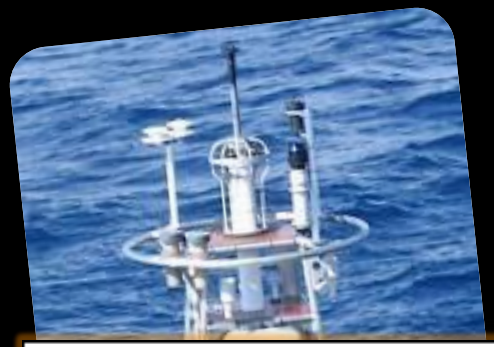


Existing (as of FY10) CO_2 moorings maintained by NOAA and/or partners

2007 – 1st OA mooring in Gulf of Alaska at Papa Station

Importance of Moorings

Preliminary results show a clear *seasonal trend* in pH and a strong correlation with pCO_2



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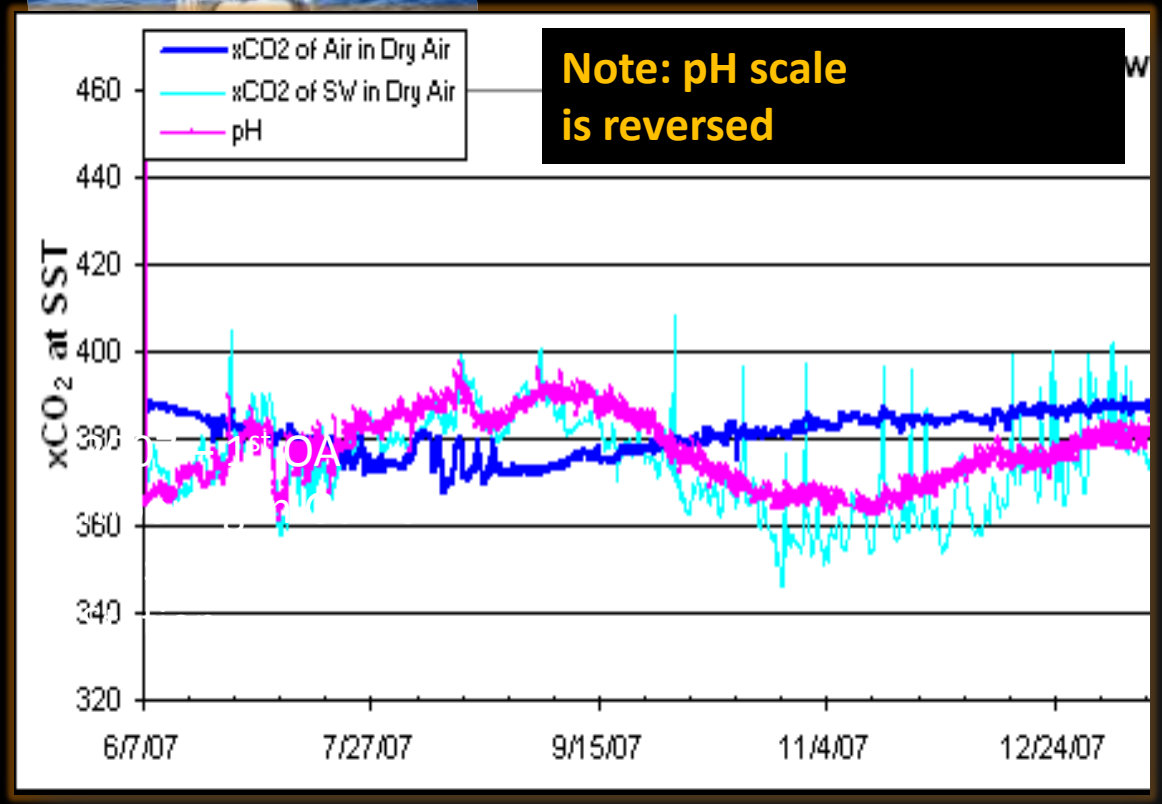
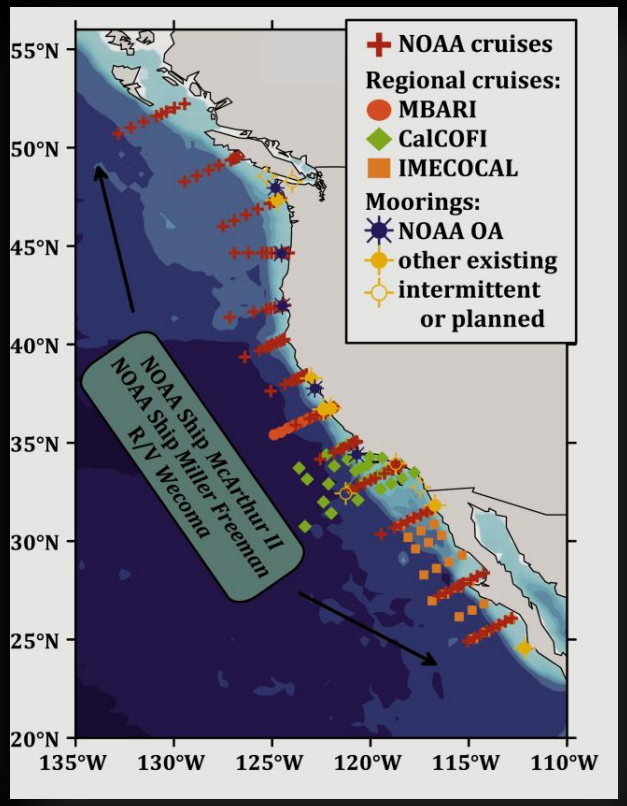
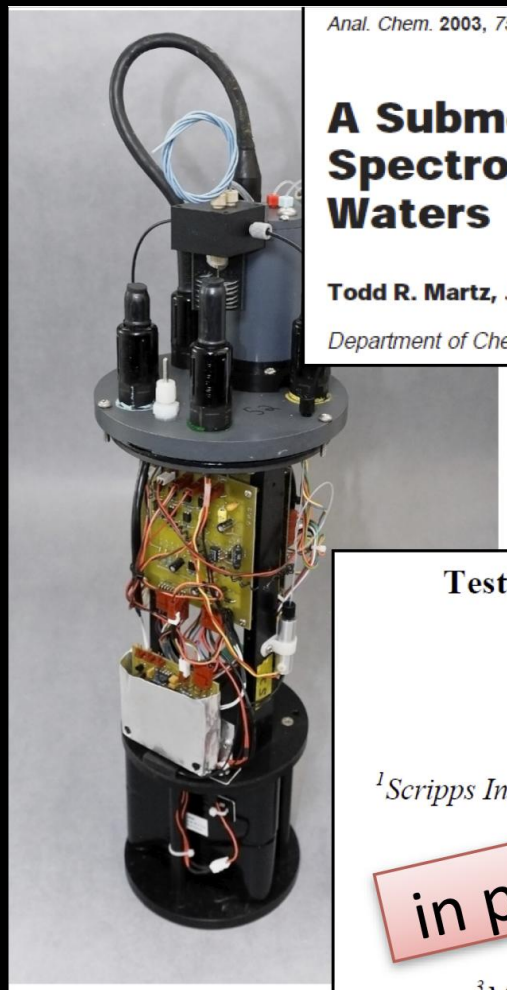




Collaboration and coordination across international, federal and state agencies is vital.

An Ocean Acidification Observational Network

What tools do we have to address ocean acidification?



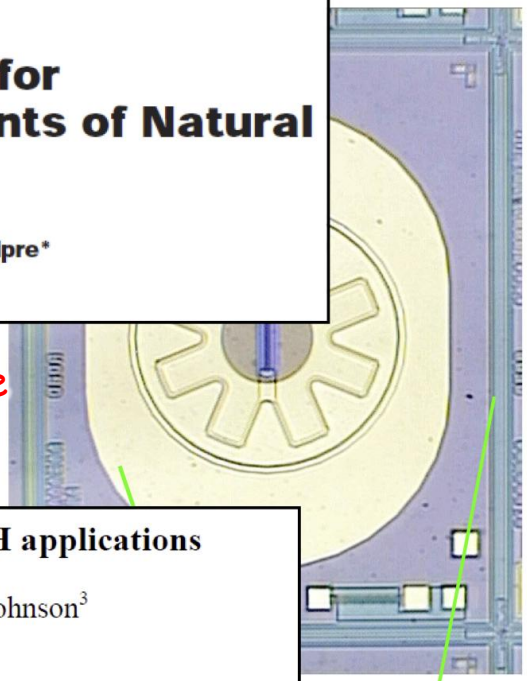
Anal. Chem. **2003**, *75*, 1844–1850

A Submersible Autonomous Sensor for Spectrophotometric pH Measurements of Natural Waters

Todd R. Martz, Jeffrey J. Carr, Craig R. French, and Michael D. DeGrandpre*

Department of Chemistry, The University of Montana, Missoula, Montana 59812

Honeywell Durafet Ion Sensitive Field Effect Transistor



Testing the Honeywell Durafet® for seawater pH applications

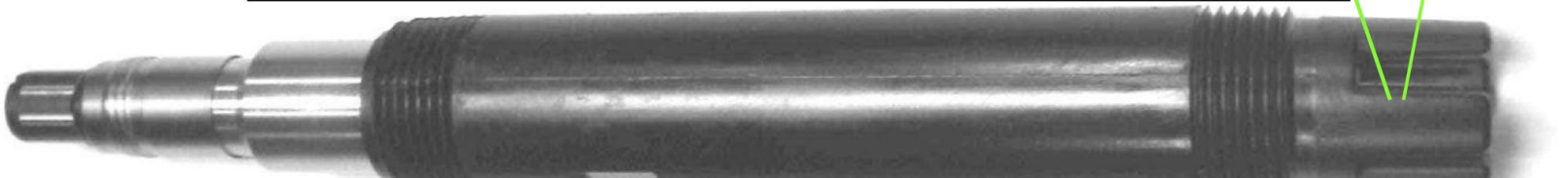
Todd R. Martz[1], James G. Connery[2], Kenneth S. Johnson[3]

[1]*Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, 92093*

[2]*215 E. Welsh Road, Maple Glen, PA, 19002*

[3]*Monterey Bay Aquarium Research Institute, Moss Landing, CA, 95039*

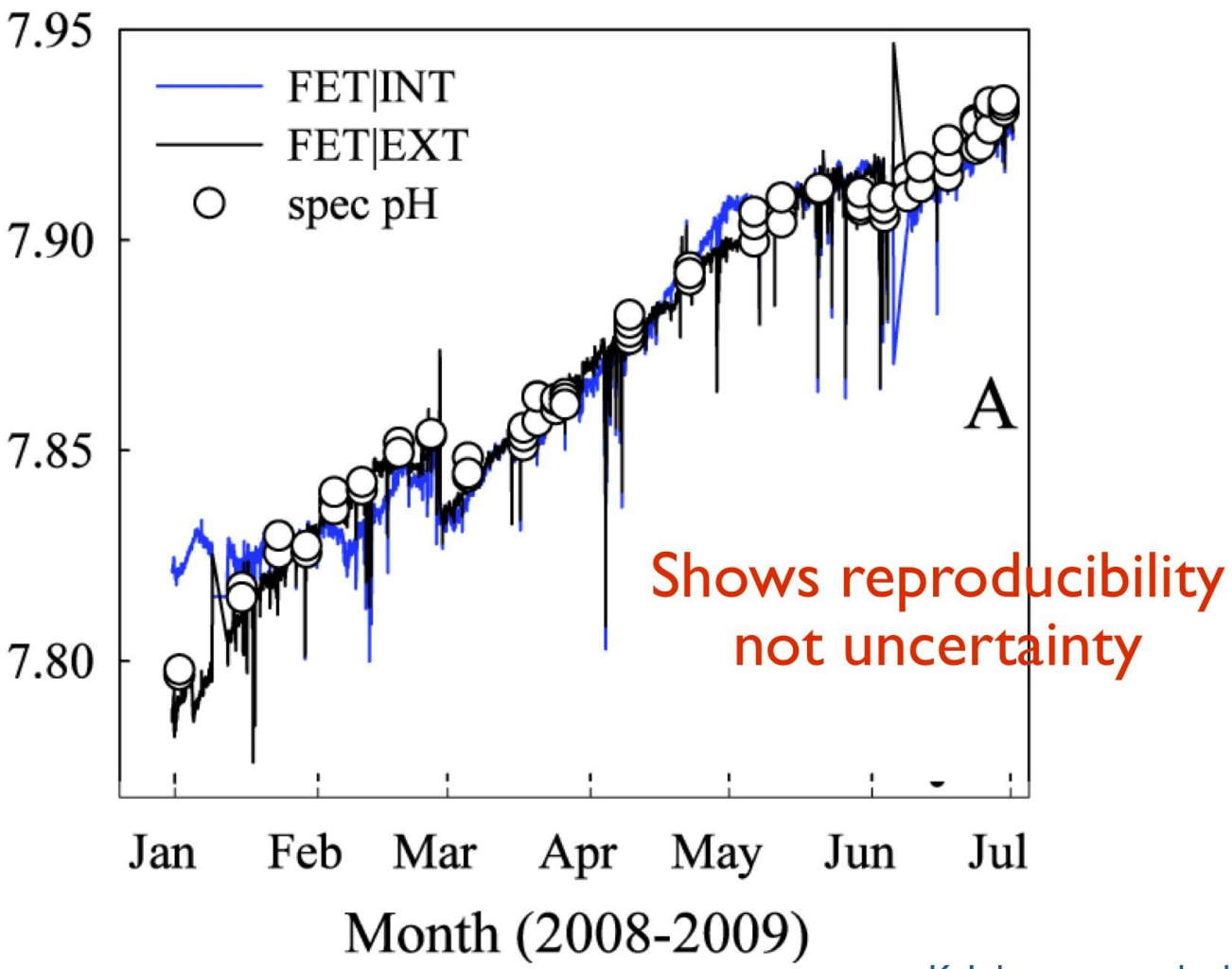
in prep.



An Ocean Acidification Observational Network

What tools do we have to address ocean acidification?

6 months of pH data from MBARI test tank



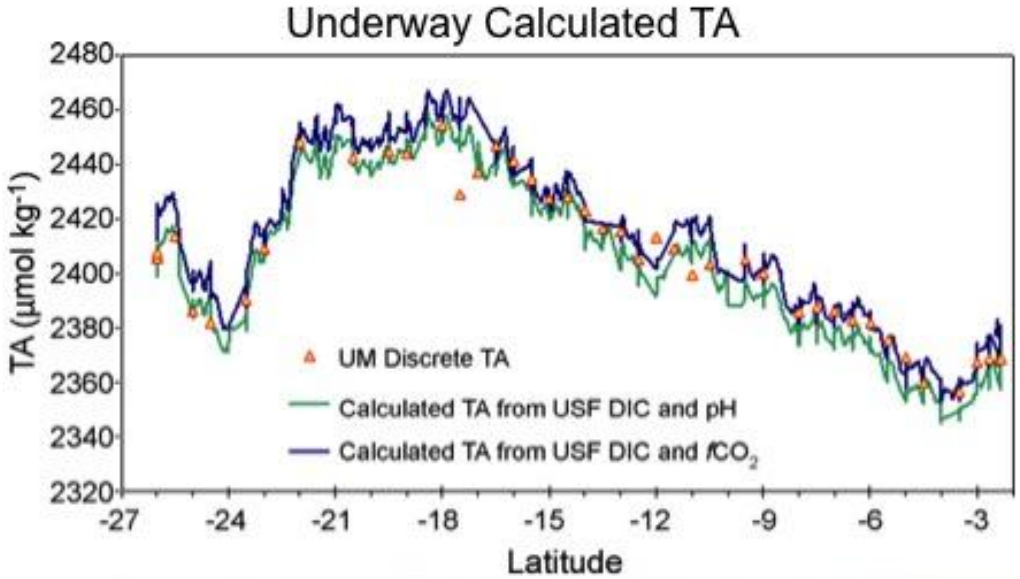
Shows reproducibility not uncertainty

K. Johnson, unpub. data

An Ocean Acidification Observational Network

What tools do we have to address ocean acidification?

Shipboard TA Determination Using MICA



UNIVERSITY OF SOUTH FLORIDA

SRI International

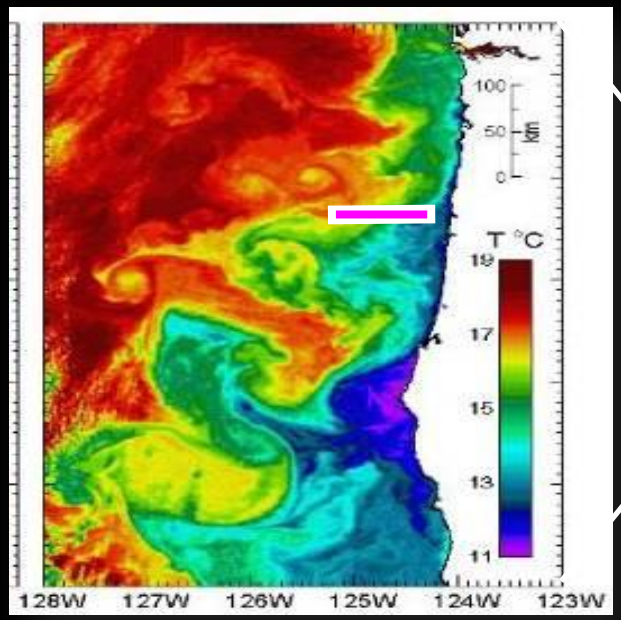
Innovating Technology

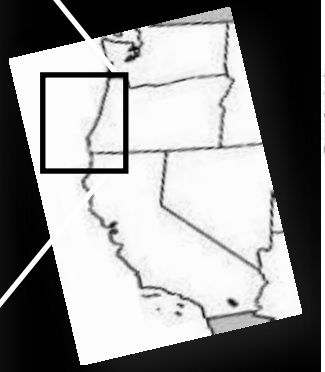
Autonomous Underwater Gliders

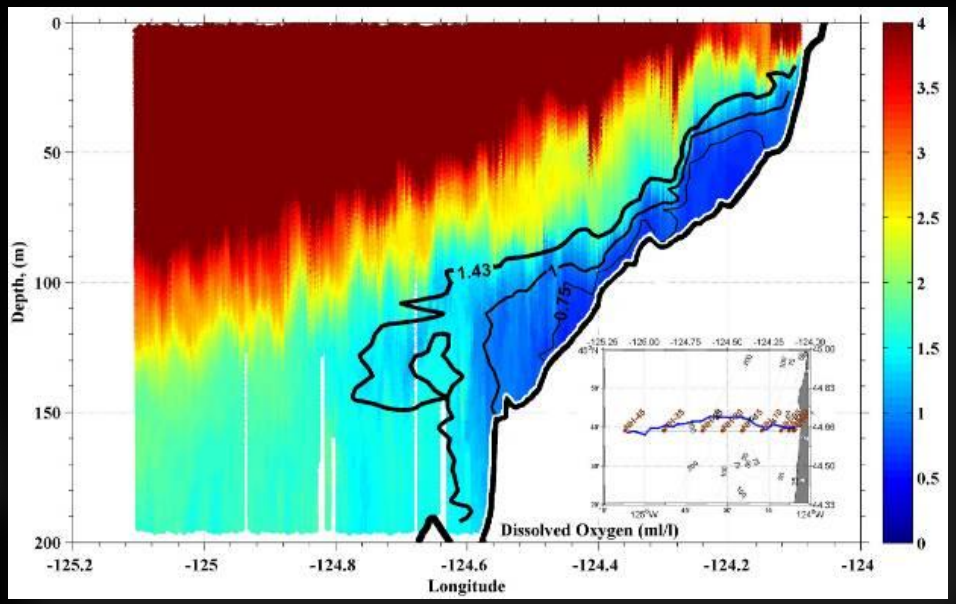
High resolution data

Innovating Technology

Autonomous Underwater Gliders







CTD
dissolved oxygen
chlorophyll fluorescence
CDOM fluorescence
light backscatter

cross-margin transect twice per week since April 2006

High resolution data

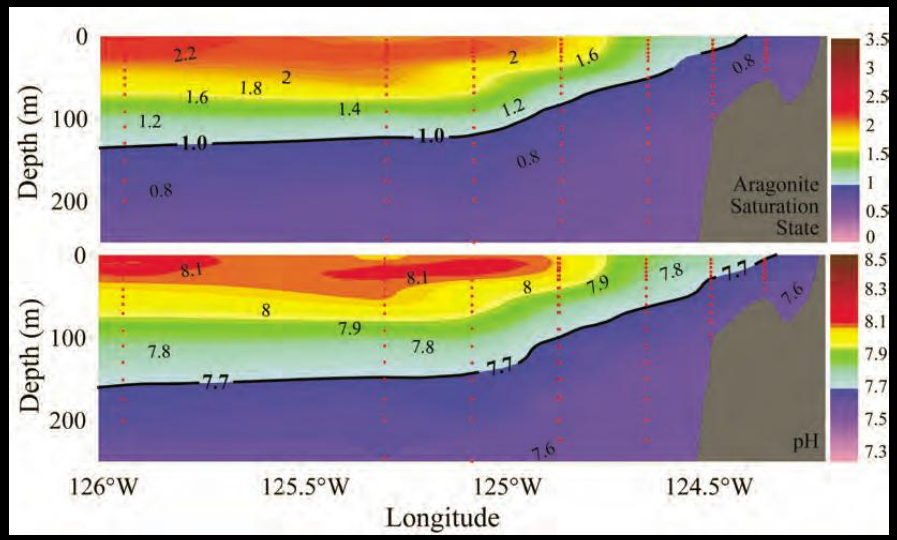
An Ocean Acidification Observational Network

How do we set up an observational network for ocean acidification?

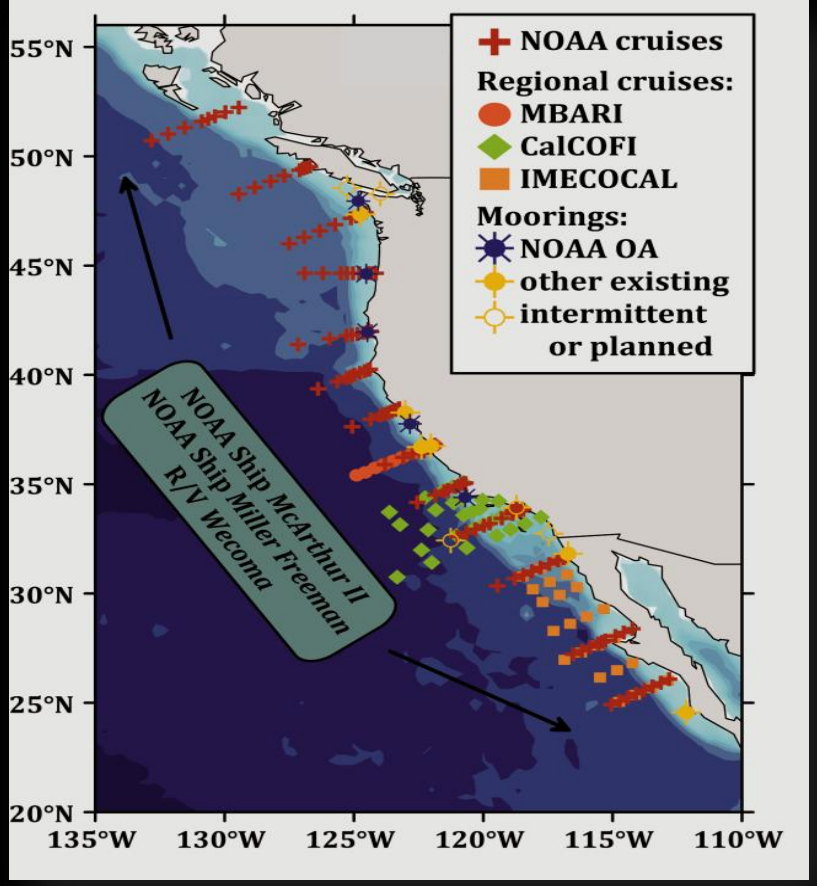
Plans for a west-coast ocean acidity observing system

- Consortium of partner institutions operating moorings
- Standardized sensor suite
- Near real-time data transmission
- Uniform data management infrastructure and public data availability
- Mooring data synthesized with models and other relevant coastal data
- Data will be used to inform laboratory studies

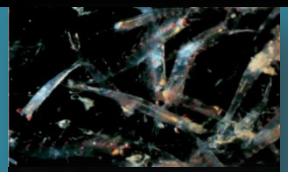
West Coast Region



Aragonite saturation state off northern California coast, Sept. 2008



Organisms of Near-Term Focus



Zooplankton

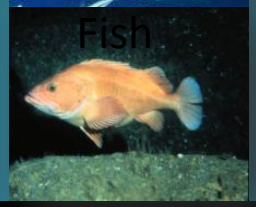
Geoduck

Pacific oyster

Deep sea coral

Dungeness crab

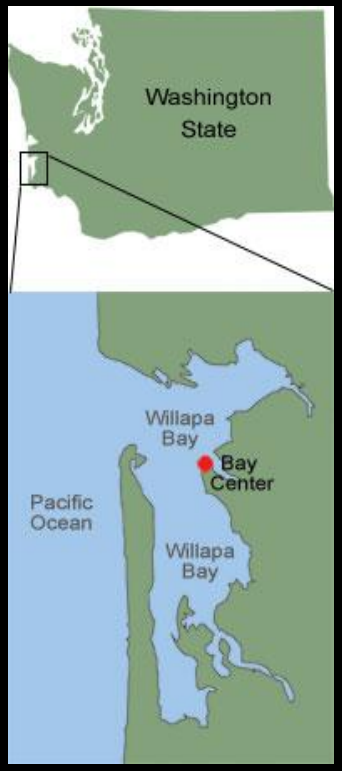
Sea urchins



Fish

"Early warning" system will provide real-time, local data

Pacific Northwest *oyster emergency*



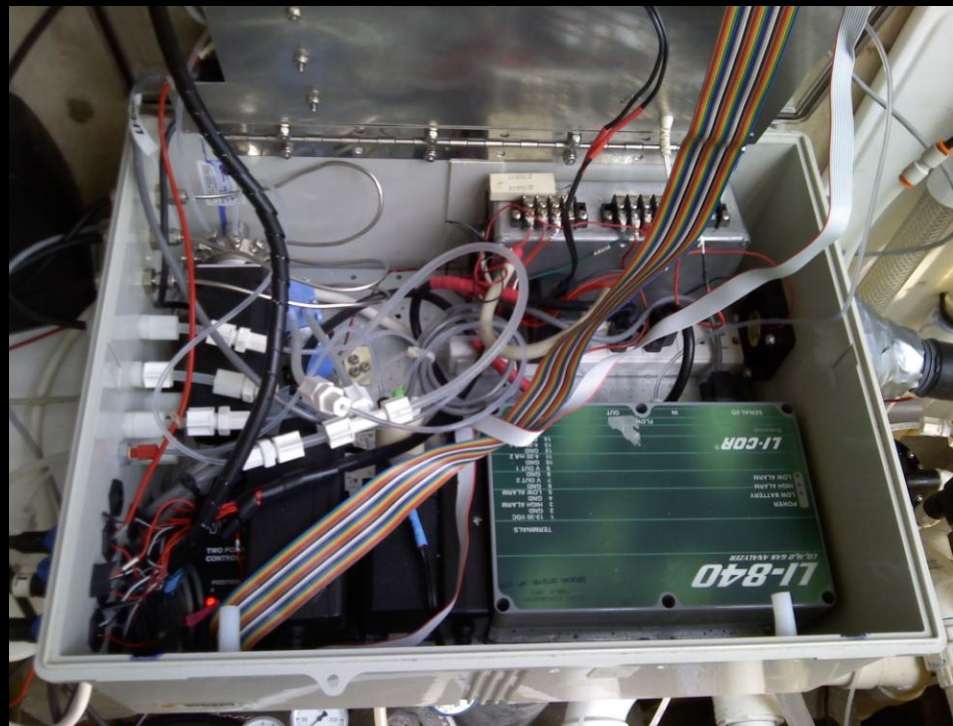
Crasostrea gigas, 'Pacific' 'giant' or 'Japanese' oyster, native to western Pacific. Introduced to E. Pacific ~1900, basis of commercial oyster industry in PNW.

Willapa Bay seed crisis

- **Failure of larval oyster recruitments in recent years**
- **Commercial oyster hatchery failures threatens $100M industry (3000 Jobs)**
- ***Low pH "upwelled" waters a possible leading factor in failures***

Larval oyster may be "canary in goldmine" for near-shore acidification?

Coastal upwelling linked to *high mortality events*



OSU scientists are now measuring realtime S, T, O_2, pH, pCO_2 at the hatchery and in the bay.

Photo courtesy of Jesse Vance and Burke Hales

Conclusions

Since the beginning of the industrial age surface ocean pH (~0.1), carbonate ion concentrations (~16%), and aragonite and calcite saturation states (~16%) have been decreasing *because of the uptake of anthropogenic CO_2* by the oceans, i.e., ocean acidification. By the end of this century pH could have a further decrease by as much as 0.3-0.4 pH units.

An *observational network* for ocean acidification is under development for the West Coast.

Modeling studies need to be expanded into coastal regions.

Coordination of data reporting needs to be be developed and integrated with the models.