A National Ocean Observing System for Ocean Acidification

Dr. Richard A. Feely

Pacific Marine Environmental Laboratory

Seattle, Washington USA

OCB-OA PI Workshop, WHOI, March 22, 2011

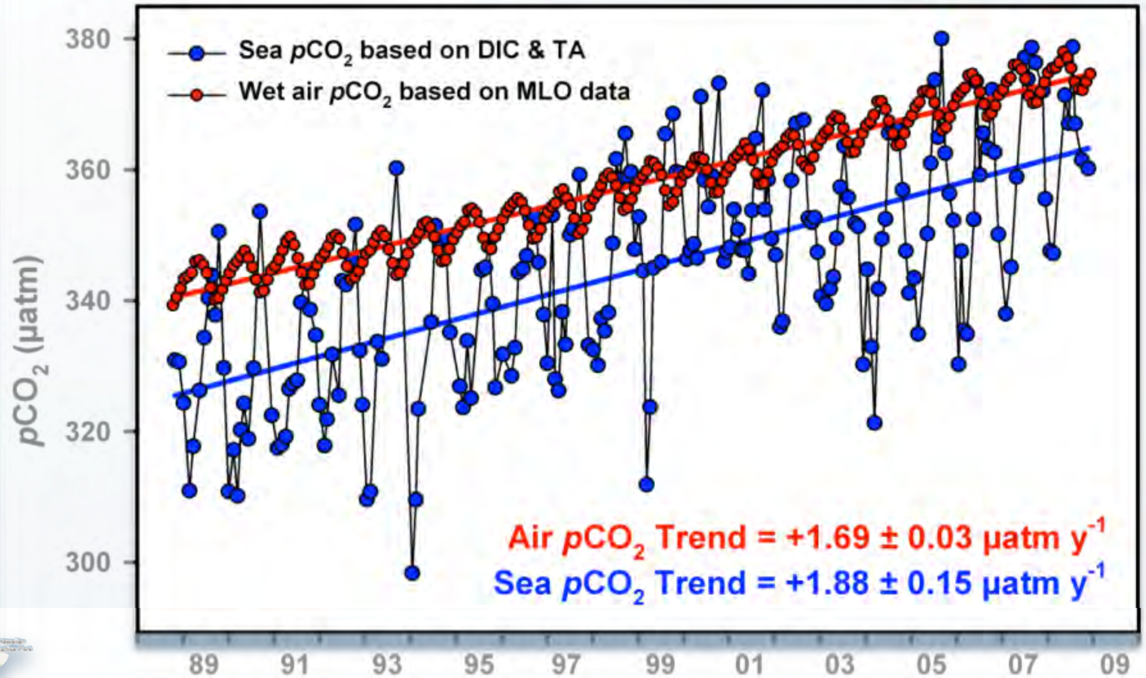
Outline:

Developing a National Ocean Acidification Observing System for:

- High- and Low Latitude Pelagic Oceans
- Coastal Ocean Including Estuaries
- Coral Reefs Regions

Acknowledgements:
C. Sabine (PMEL), L. Juranek (PMEL), S. Alin (PMEL), R. Wanninkhof (AOML),
K. Shamberger (PMEL), U. Send (SIO), J. Newton (UW), S. Doney (WHOI),
S. Cooley (WHOI), D. Gledhill (AOML)

Carbon Changes at the Hawaii Ocean Time-series (HOT) site

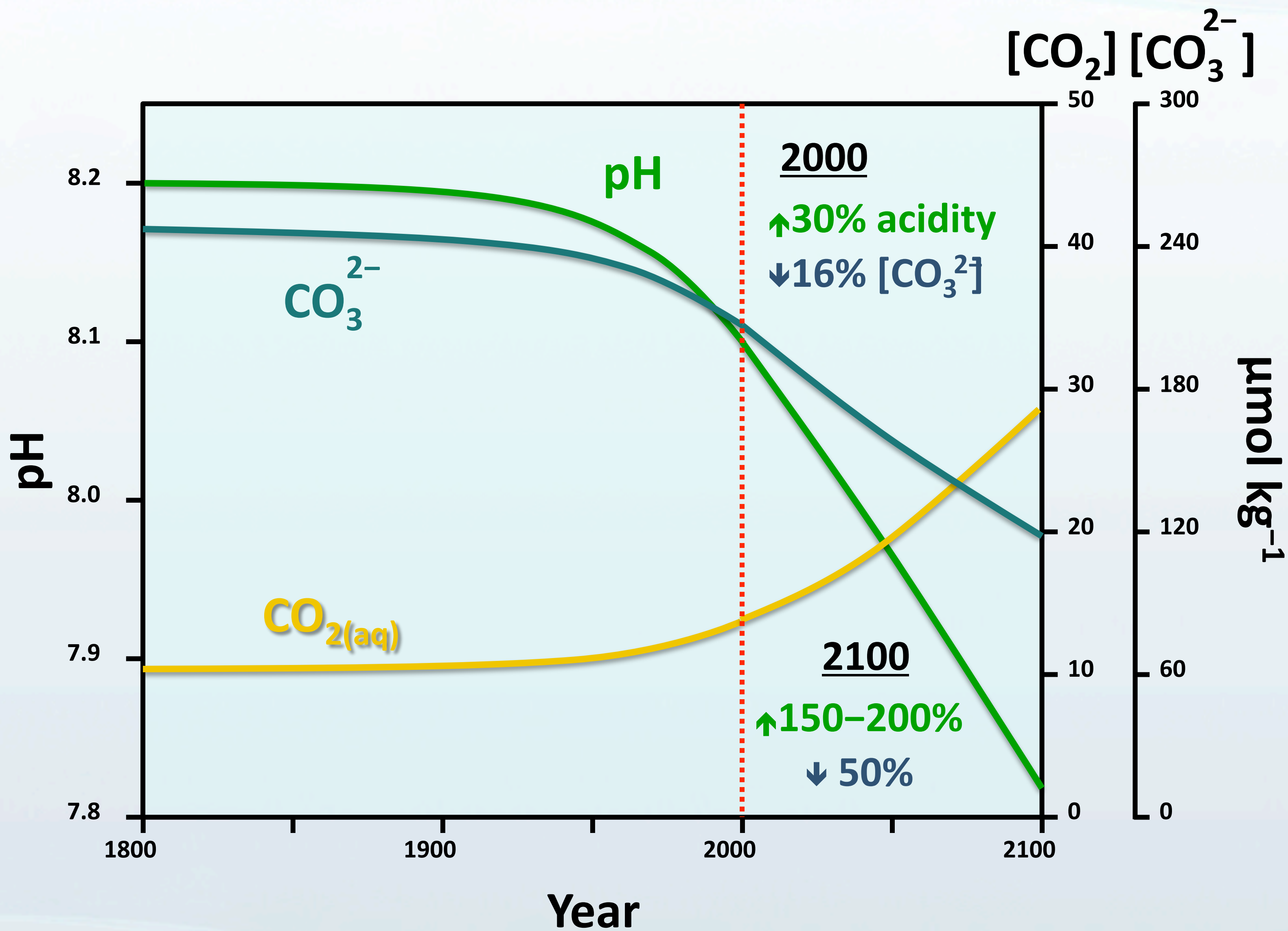


Surface water pCO_2 is increasing at about the same rate as atmosphere

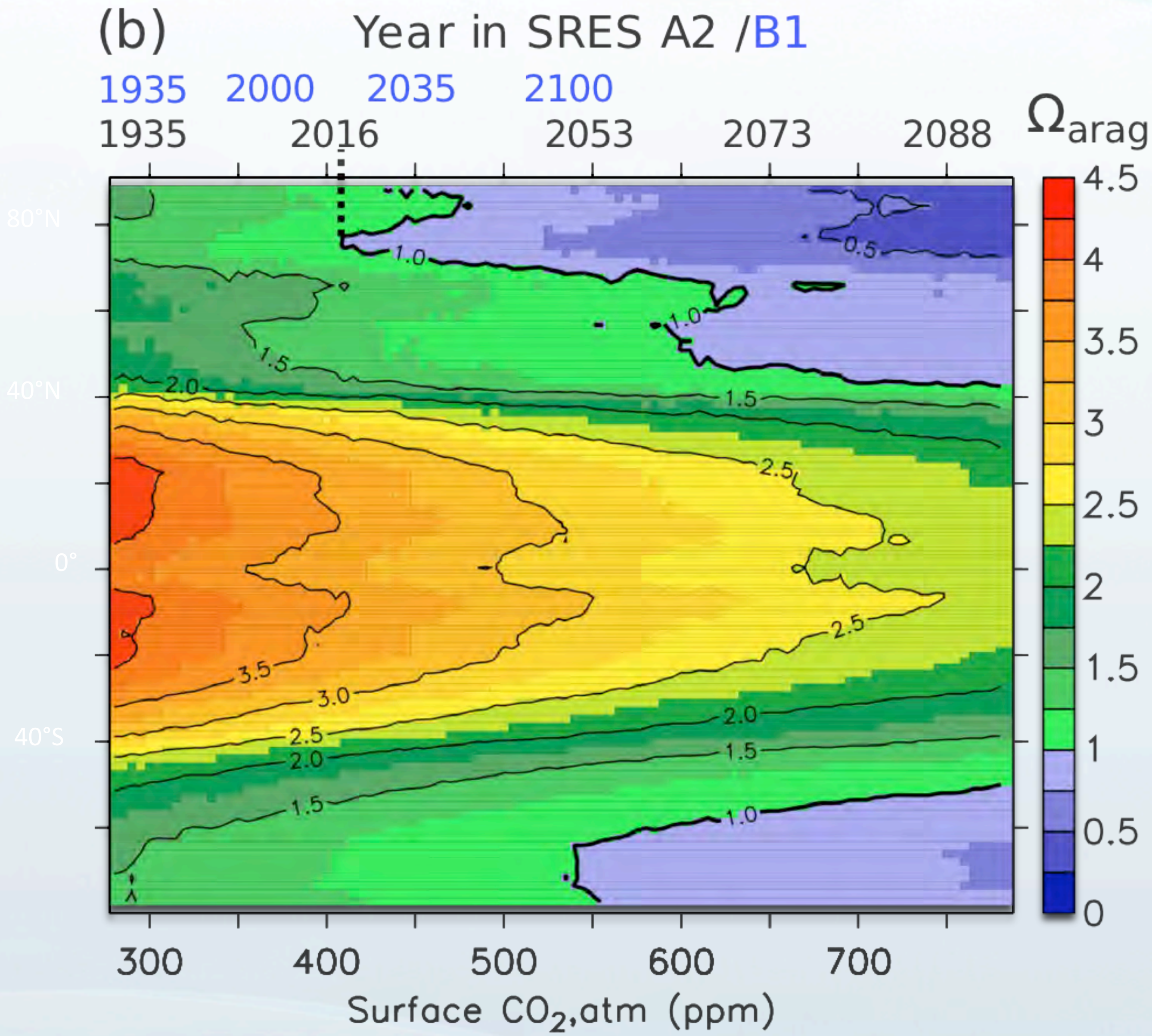
We see a commensurate decrease in pH with the rise in surface water pCO_2

Doney, Science 2010
Dore et al., PNAS 2009

Historical & Future OA Trajectory



Wolf-Gladrow et al. (1999)



Change in Aragonite Saturation with CO_2

- Saturation state declines across all latitudes
- Undersaturated conditions appear for aragonite in high latitudes

Steinacher et al., Biogeosci., 2009

FOARAM Act

Subtitle D – Federal Ocean Acidification Research and Monitoring Act of 2009

SEC 12401.SHORT TITLE

This subtitle may be cited as “Federal Ocean Acidification Research and Monitoring Act of 2009” or the “FOARAM Act”.

SEC 12402.PURPOSE

(a) Purposes – The purposes of this subtitle are to provide for –

(1) development and coordination of the comprehensive interagency plan to–

(A) monitor and conduct research on the processes and consequences of ocean acidification on marine organisms and ecosystems; and

(B) establish an interagency research and monitoring program on ocean acidification;

(2) establishment of an ocean acidification program within the National Oceanic and Atmospheric Administration;

(3) assessment and consideration of regional and national ecosystem and socioeconomic impacts of increased ocean acidification; and

(4) research adaptation strategies and techniques for effectively conserving marine ecosystems as they cope with increased ocean acidification.

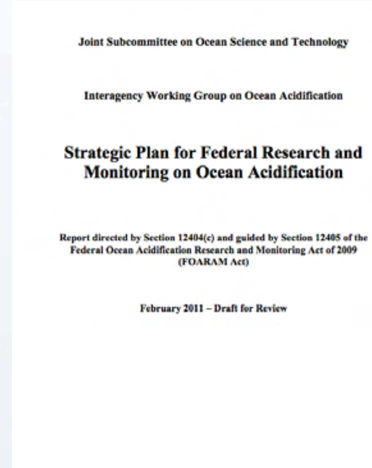
Interagency Working Group on Ocean Acidification (IWG-OA)

- Ned Cyr, NOAA (Chair)
- Libby Jewett, NOAA
- Richard Feely, NOAA
- Chris Sabine, NOAA
- Kenric Osgood, NOAA
- Phil Taylor, NSF (Vice-Chair)
- Paula Bontempi, NASA
- Chris Moore, EPA
- Erin Seney, NOAA
- Bill Fisher, EPA
- Jennie Dean, Navy
- Mary Boatman, BOEMRE
- Lisa Robbins, USGS
- Bret Wolfe, USFWS
- Adriana Muir, DOS

Strategic Plan for Federal Research and Monitoring

- Establishes 10-yr goals and priorities for federal OA research
- Describes federal agencies' :
  - roles
  - Budget requirements
- Considers reports from agencies, NRC, ORRAP

  OA Task Force, other entities
- Recommendations for international coordination
- Identifies and prioritizes existing and required observing systems for OA and its impacts
- Includes an outreach and data exchange program with stakeholders
- Describes specific activities to be undertaken in 7 themes

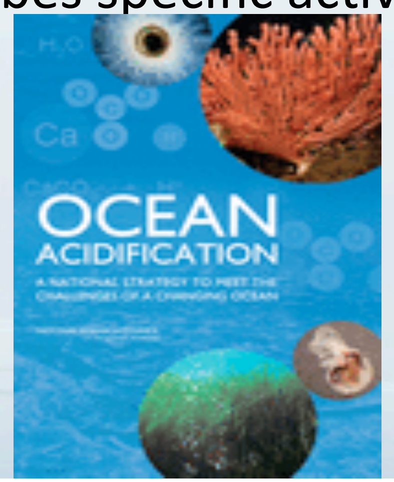

Joint Subcommittee on Ocean Science and Technology

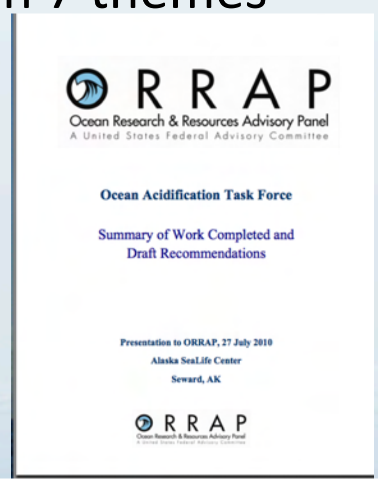
Interagency Working Group on Ocean Acidification

Strategic Plan for Federal Research and Monitoring on Ocean Acidification

Report directed by Section 12404(c) and guided by Section 12405 of the Federal Ocean Acidification Research and Monitoring Act of 2009 (FOARAM Act)

February 2011 – Draft for Review




ORRAP
Ocean Research & Resources Advisory Panel
A United States Federal Advisory Committee

Ocean Acidification Task Force

Summary of Work Completed and Draft Recommendations

Presentation to ORRAP, 27 July 2010
Alaska SeaLife Center
Seward, AK

ORRAP

What existing resources can we use to monitor ocean acidification in the global ocean?

- The OceanObs'09 Conference brought together more than 600 scientists from 36 nations, supported by 99 Community White Papers and 47 Plenary Papers, to build a **common vision for the provision of routine and sustained global information on the marine environment sufficient to meet society's needs** for describing, understanding and forecasting marine variability (including physical, biogeochemical, ecosystems and living marine resources), weather, seasonal to decadal climate variability, climate change, sustainable management of living marine resources, and assessment of longer term trends.

- **TOWARDS AN INTEGRATED GLOBAL OBSERVING SYSTEM: IN-SITU OBSERVATIONS**

Uwe Send, Peter Burkill, Nicolas Gruber, Gregory C. Johnson, Arne Körtzinger, Tony Koslow, Ron O'Dor, Steve Rintoul, Dean Roemmich, Susan Wijffels

- **TOWARDS AN INTEGRATED GLOBAL OCEAN ACIDIFICATION OBSERVATION NETWORK**

M. Debora Iglesias-Rodriguez, Kenneth R.N. Anthony, Jella Bijma, Andrew G. Dickson, Scott C. Doney, Victoria J. Fabry, Richard A. Feely, Jean-Pierre Gattuso, Kitack Lee, Ulf Riebesell, Toshiro Saino and Carol Turley

- **TOWARD AN INTEGRATED OBSERVING SYSTEM FOR OCEAN CARBON AND BIOGEOCHEMISTRY AT A TIME OF CHANGE**

Nicolas Gruber, Arne Körtzinger, Alberto Borges, Hervé Claustre, Scott C. Doney, Richard A. Feely, Maria Hood, Masao Ishii, Alexander Kozyr, Pedro Monteiro, Yukihiro Nojiri, Christopher L. Sabine, Ute Schuster, Douglas W.R. Wallace, and Rik Wanninkhof

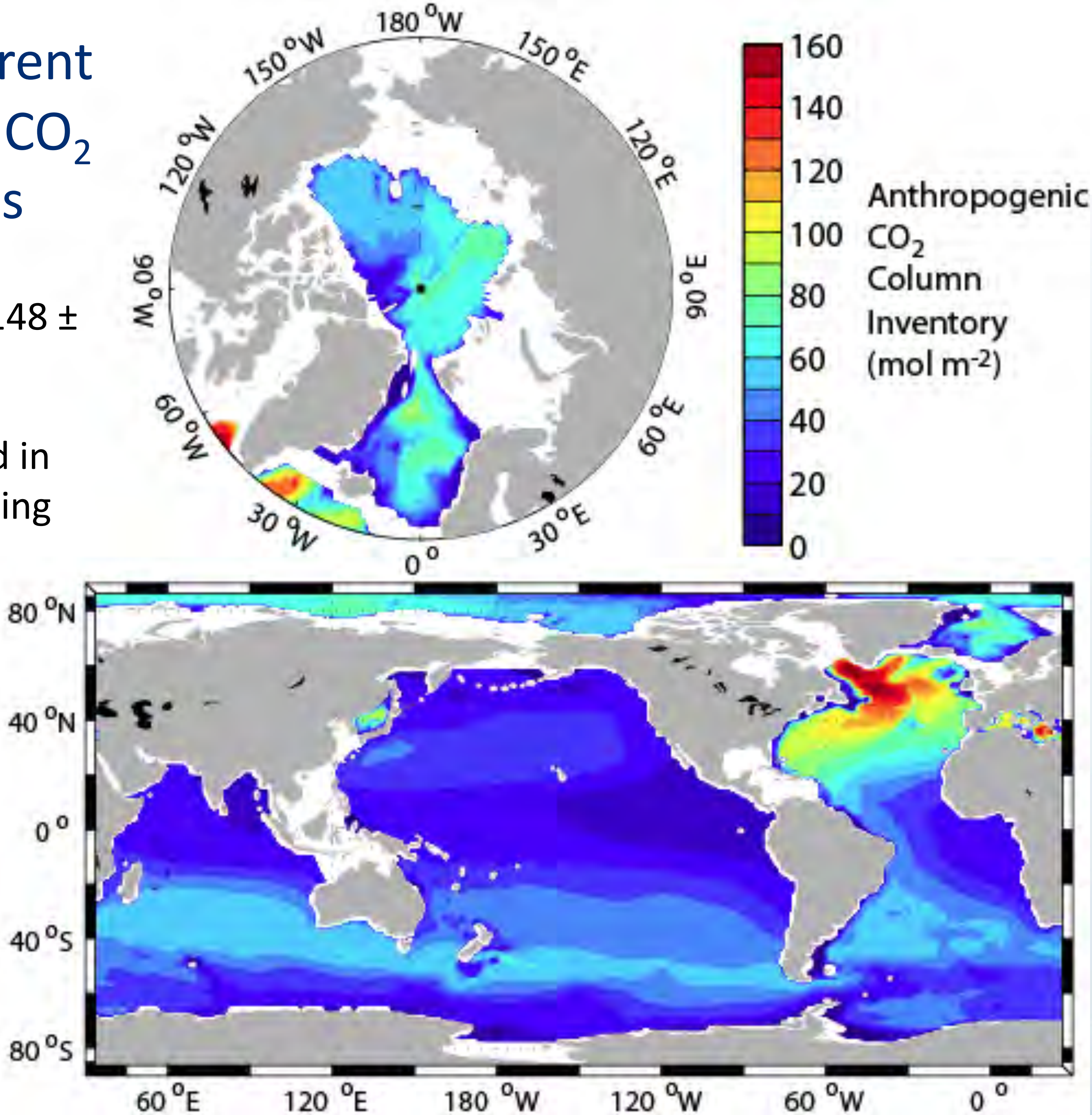
What existing resources can we use to monitor ocean acidification in the pelagic ocean?

Estimate of current Anthropogenic CO_2 Distributions

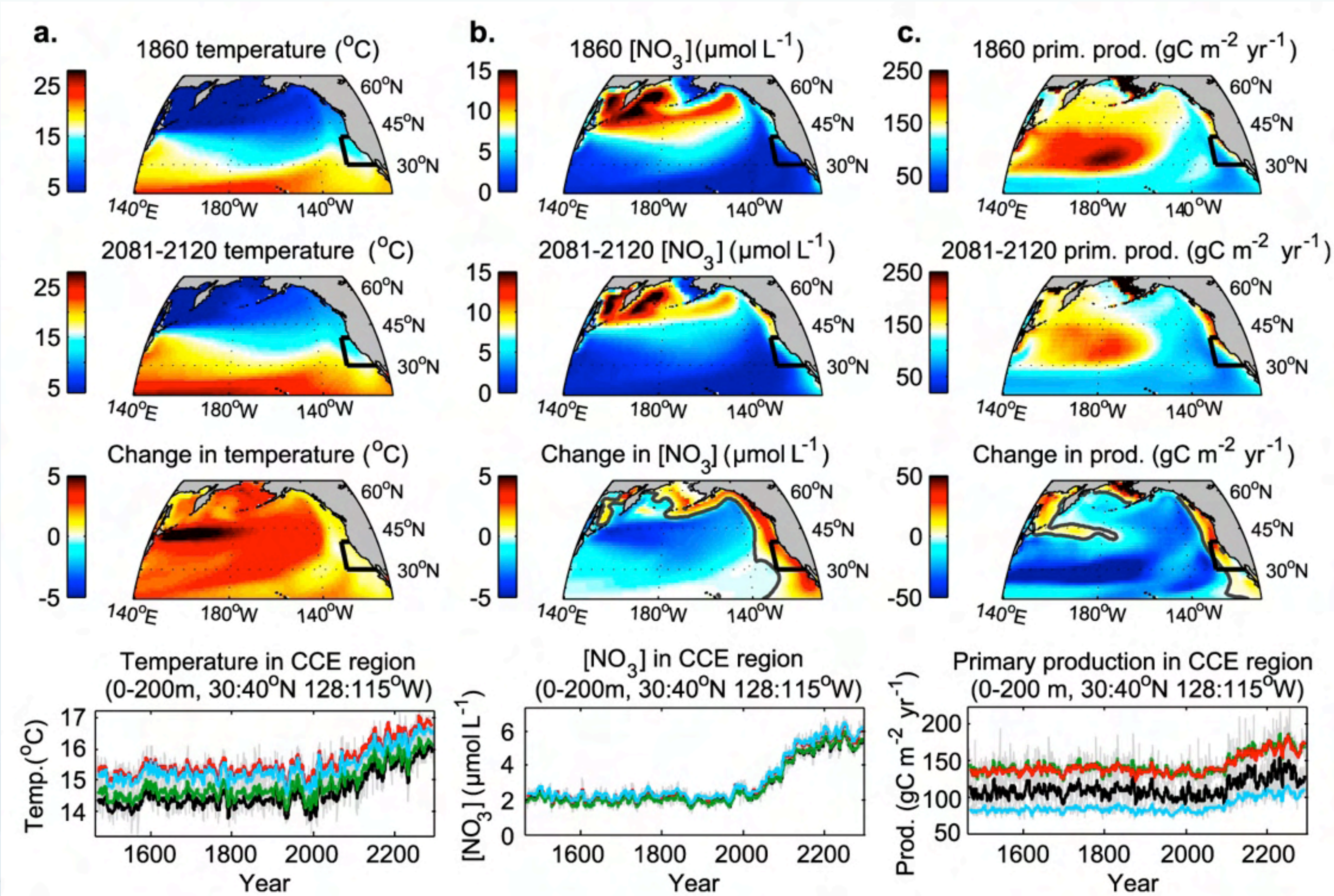
Total 2008 Inventory: 148 ± 27 Pg C

~ 6% (8.2 Pg C) stored in Marginal Seas (including the Arctic)

From: the global Ocean excluding the marginal seas (Khatiwala et al., 2009), 140 ± 25 Pg C; Arctic Ocean (Tanhua et al., 2009) 2.6 – 3.4 Pg C; the Nordic Seas (Olsen et al., 2010) 1.0 – 1.5 Pg C; the Mediterranean Sea (Schneider et al., 2010) 1.5 – 2.4 Pg C; the East Sea (Sea of Japan) (Park et al., 2006) 0.40 ± 0.06 Pg C.

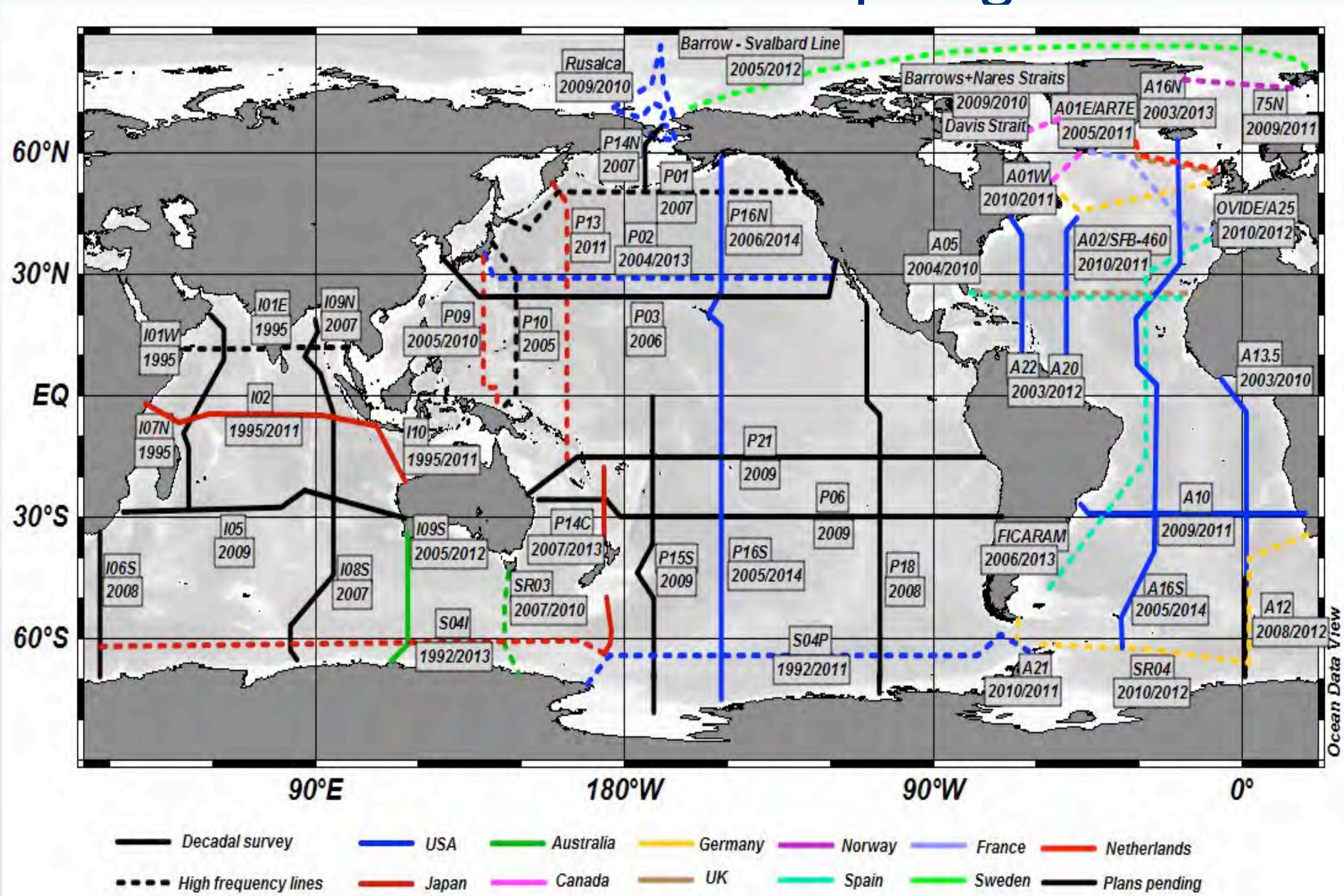


What are the unique oceanographic concerns about ocean acidification in the pelagic ocean?



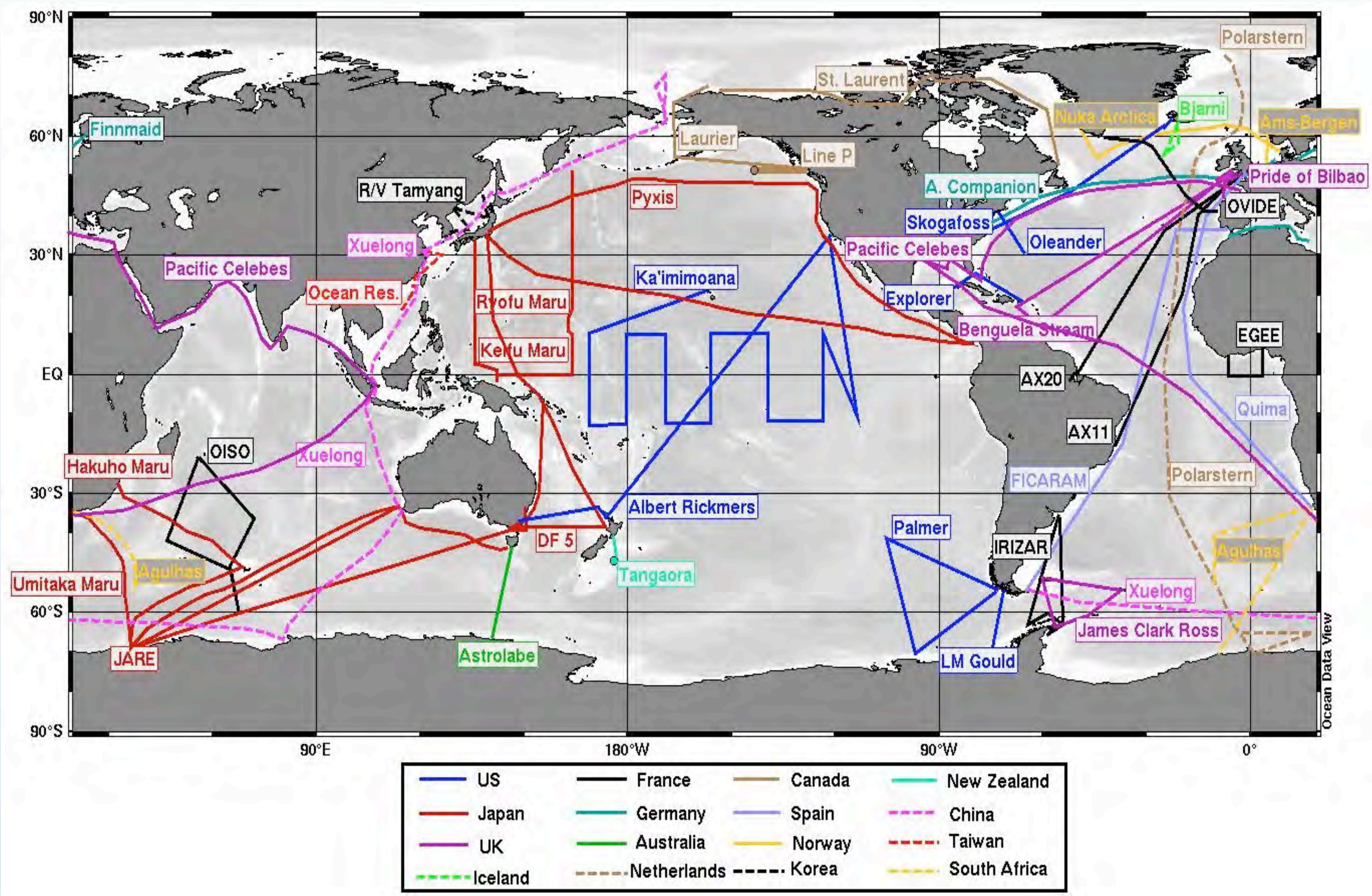
Rykaczewski and Dunne, GRL (2010)

What existing resources can we use to monitor ocean acidification in the pelagic ocean?



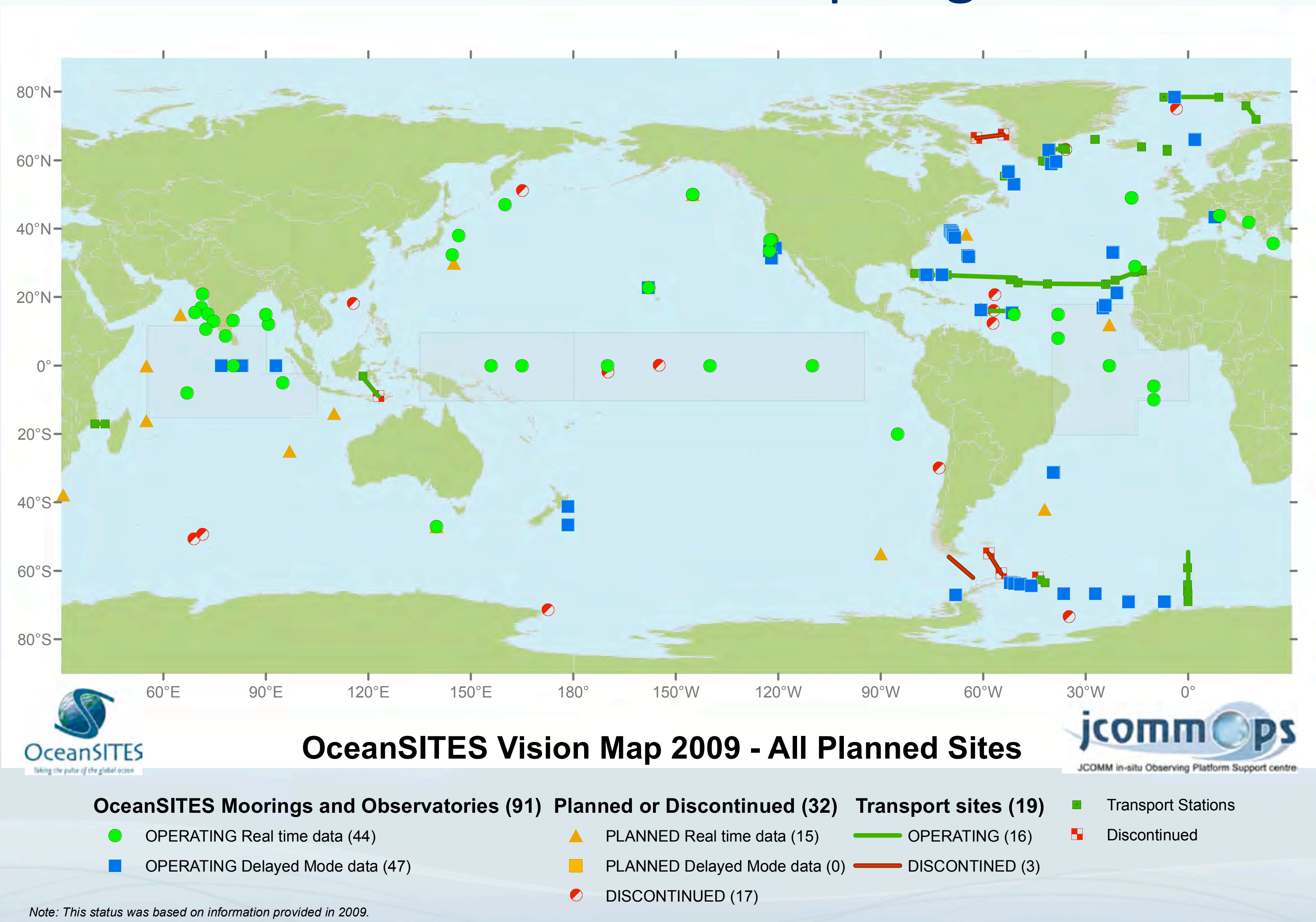
Planned CLIVAR/CO_2 Repeat Hydrography surveys and high-frequency lines for carbon and ocean acidification measurements

What existing resources can we use to monitor ocean acidification in the pelagic ocean?



Planned underway VOS surveys for surface ocean measurements of pCO_2 and other chemical and biological parameters

What existing resources can we use to monitor ocean acidification in the pelagic ocean?



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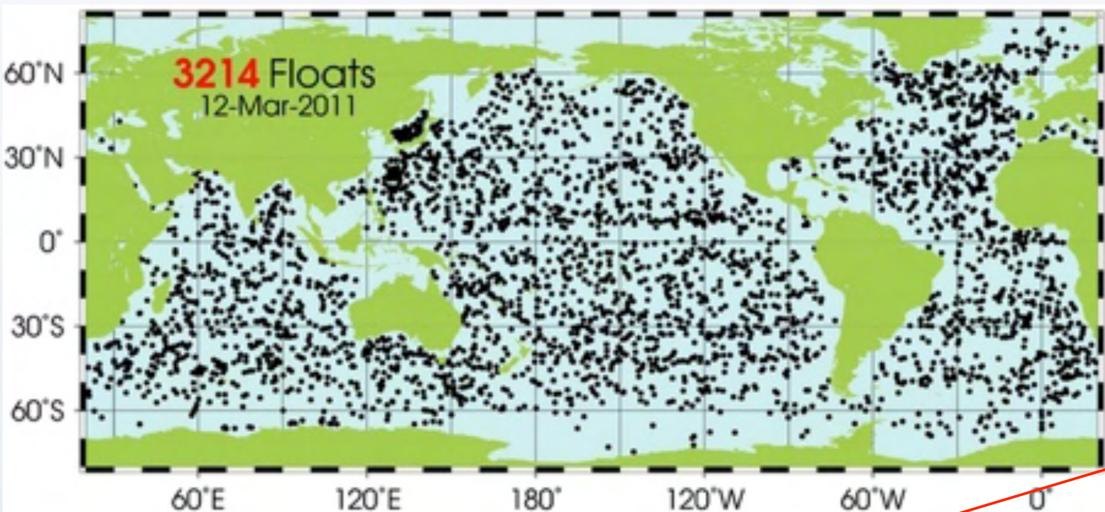
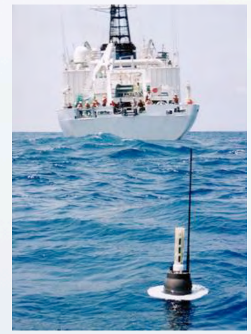
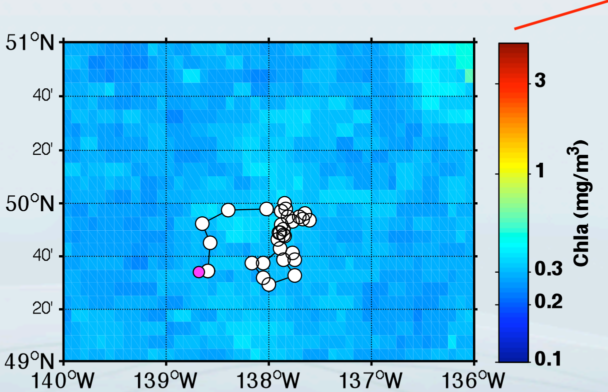
Argo – part integrated Global Observation Strategy

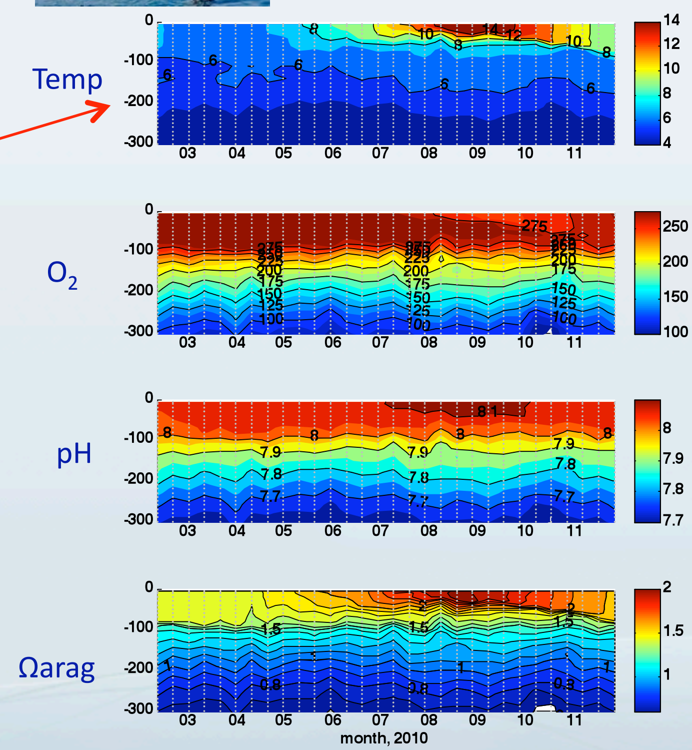




Juranek et al - Empirical algorithms to predict pH, Ω from hydrographic data



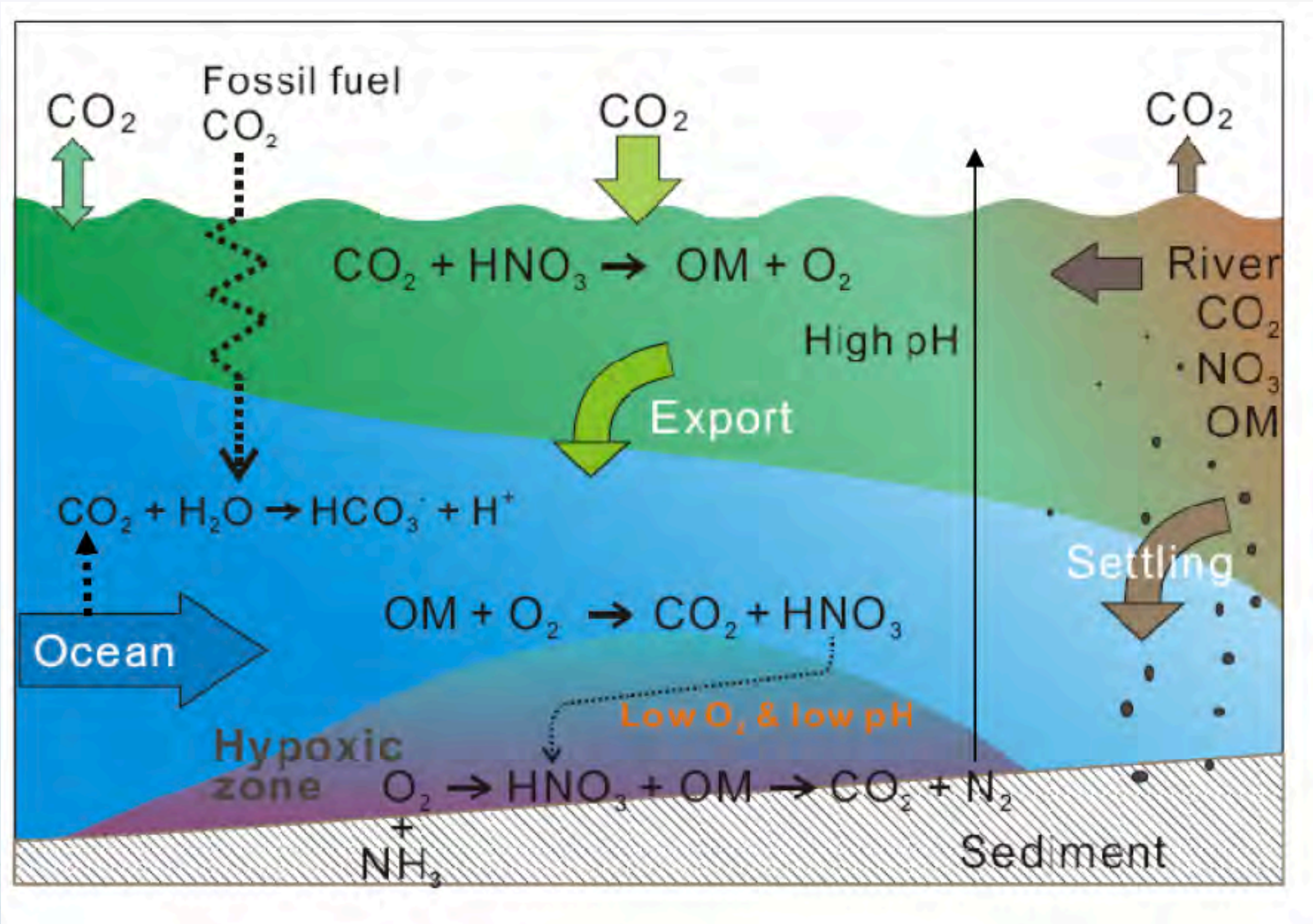
Allows low-cost monitoring of carbon system parameters in areas of interest from profiling floats and AUVs



What are the unique oceanographic concerns about ocean acidification in the coastal ocean?

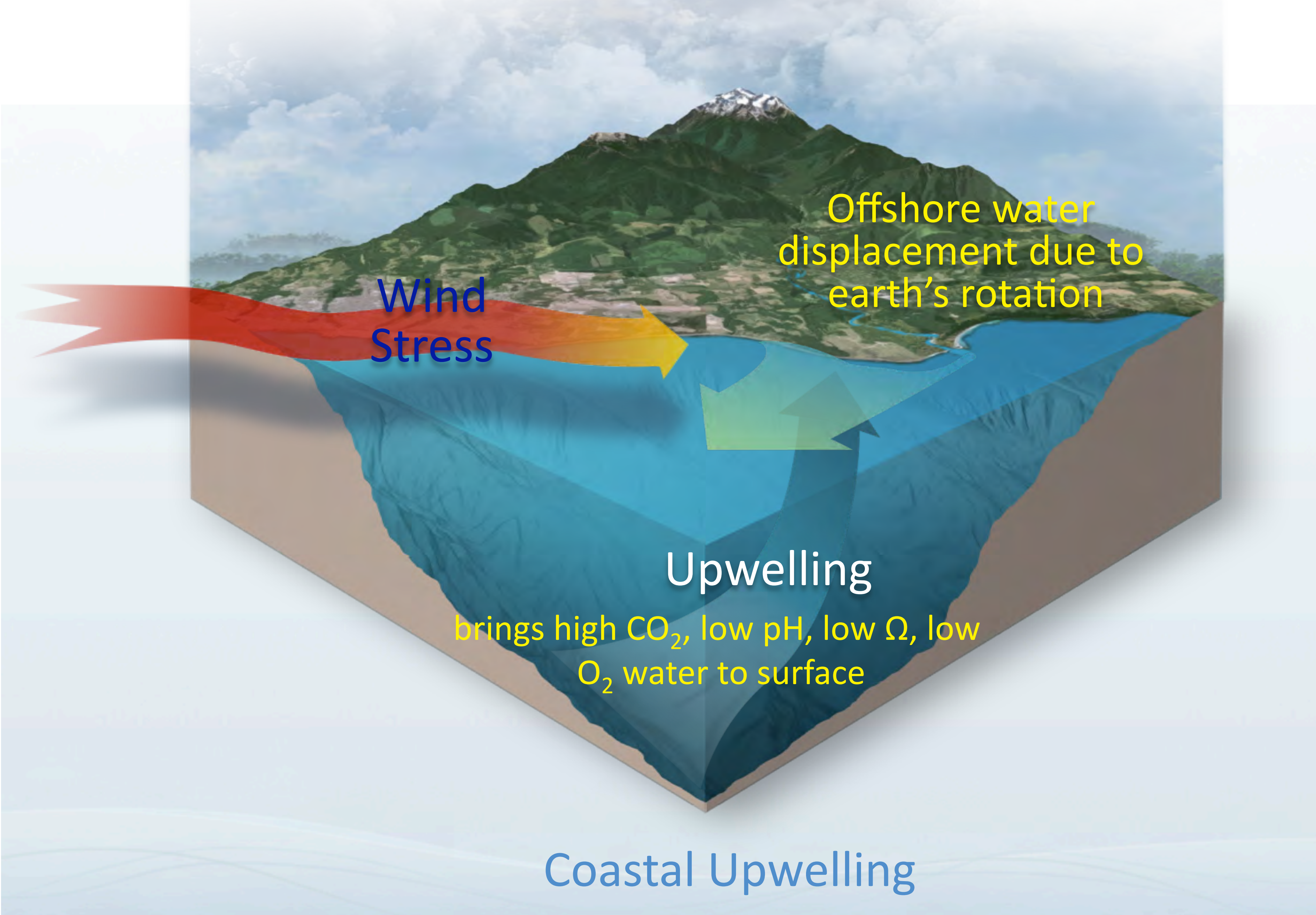
What are the unique oceanographic concerns about ocean acidification in the coastal ocean?

Focus is on regions where changes in water column inorganic carbon dynamics are significant compared to the anthropogenic CO_2 (C_{anthro}) input with respect to the pCO_2, CO_3^{2-}, pH and Ω.



Lohrenz et al.

Natural processes can accelerate acidification in coastal waters



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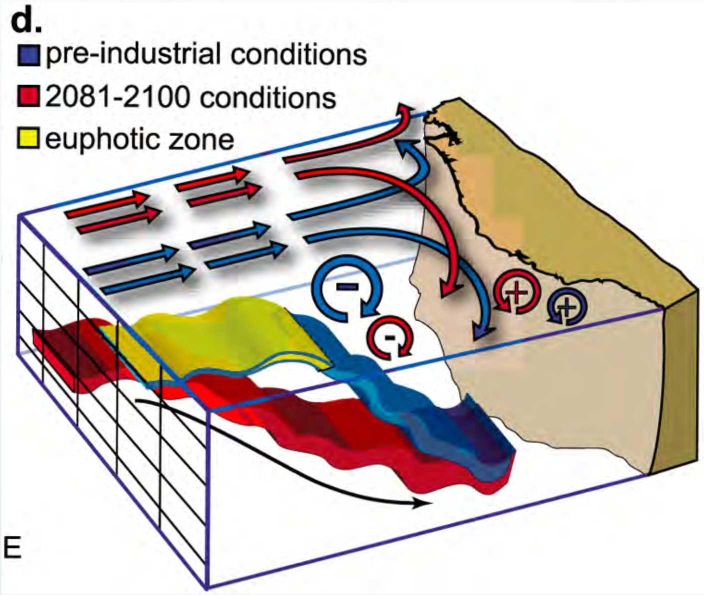
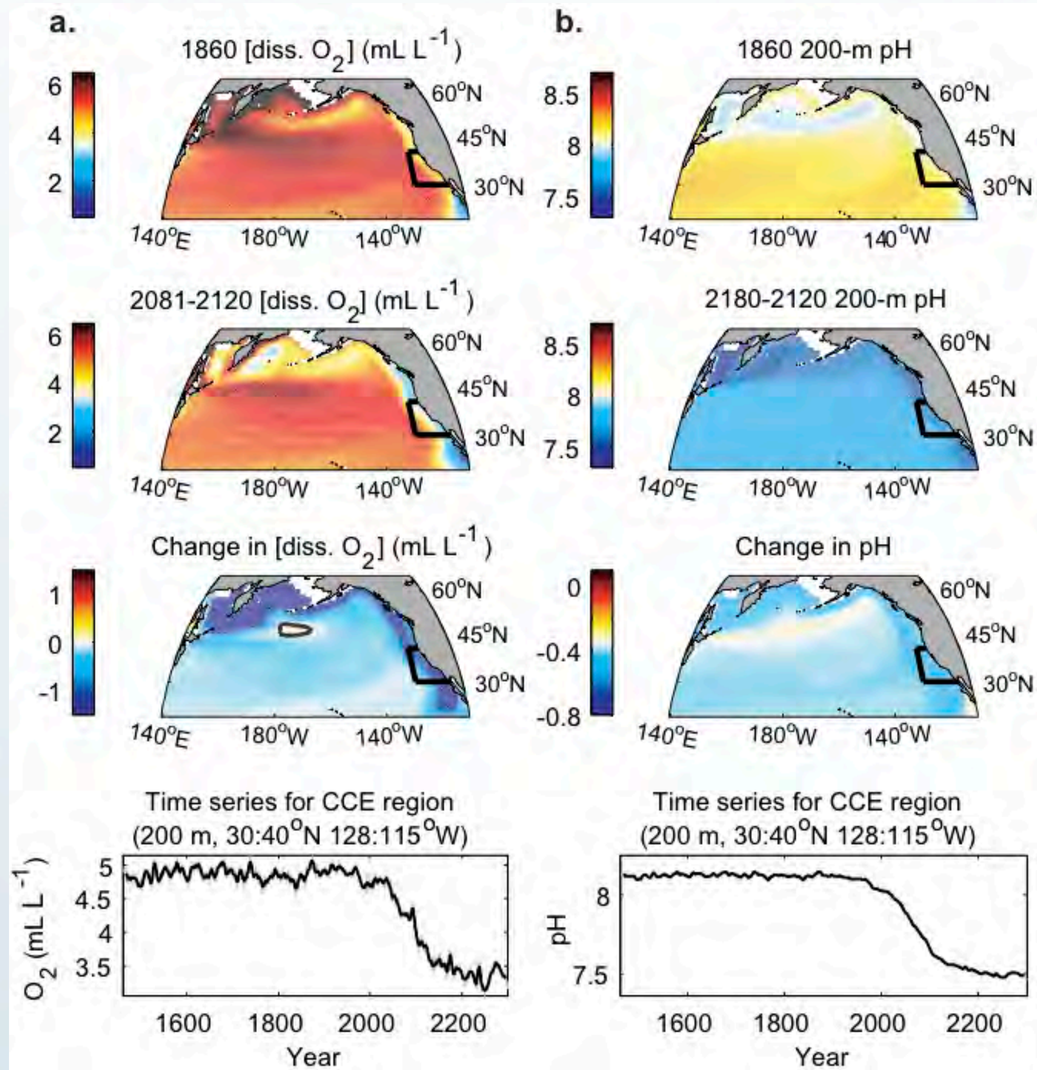




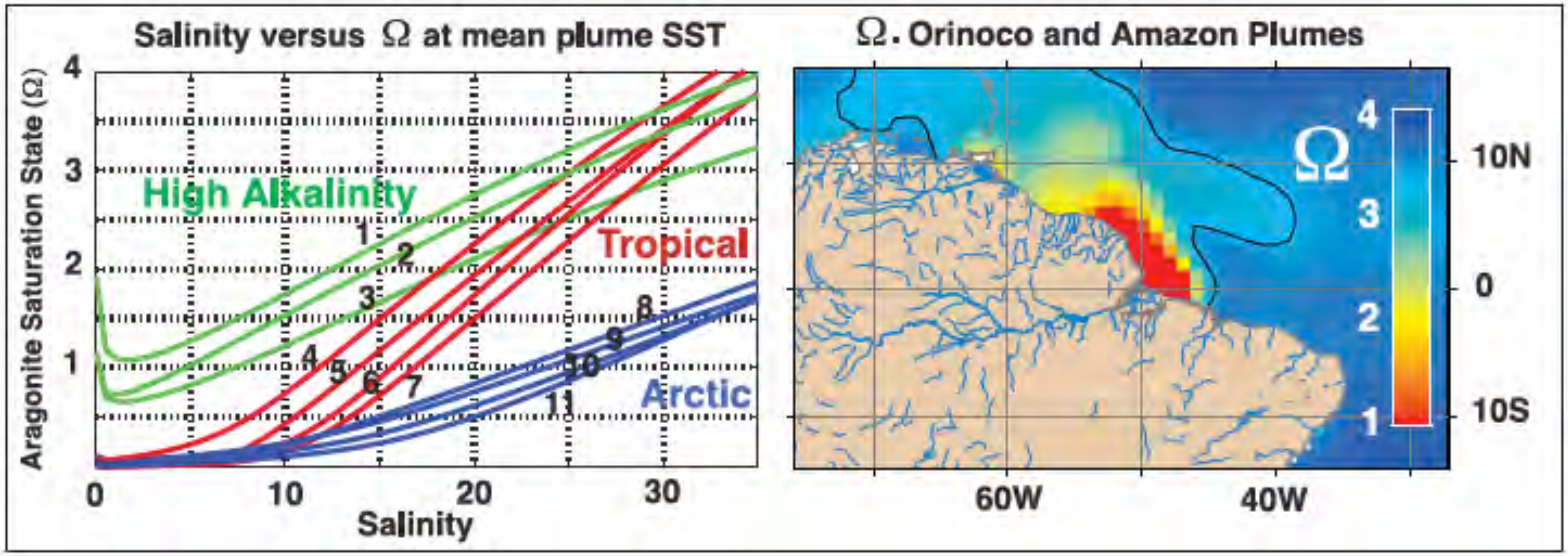
The model projects increases in nitrate supply and productivity in the CCE during the 21st century despite increases in stratification and limited change in wind-driven upwelling. The increased nitrate supply to enrichment of deep source waters entering the CCE results from decreased ventilation of the North Pacific. Decreases in dissolved oxygen concentration and increasing acidification accompany projected increases in nitrate.

Rykaczewski and Dunne, GRL (2010)

What are the unique oceanographic concerns about ocean acidification in the coastal ocean?

Riverine Input

Function of temperature and TA of river with low TA and high pCO_2 lead to low Ω



Salisbury et al. 2008 EOS

What existing resources can we use to monitor ocean acidification in the coastal ocean?

What existing resources can we use to monitor ocean acidification in the coastal ocean?

- Integrated Ocean Observing System (IOOS)
- Ocean Observatories Initiative (OOI)
- Long-Term Ecological Research (LTER)
- National Marine Sanctuary Program (NMSP)
- National Estuarine Research Reserve System (NERRS)
- National Estuary Program (NEP)
- NOAA Coral Reef Conservation Program (CRCP)
- National Park Service Inventory and Monitoring Program
- National Wildlife Refuge System Inventory and Monitoring Program (NWRS)
- National Association of Marine Laboratories (NAML)

What existing resources can we use to monitor ocean acidification in the coastal ocean?

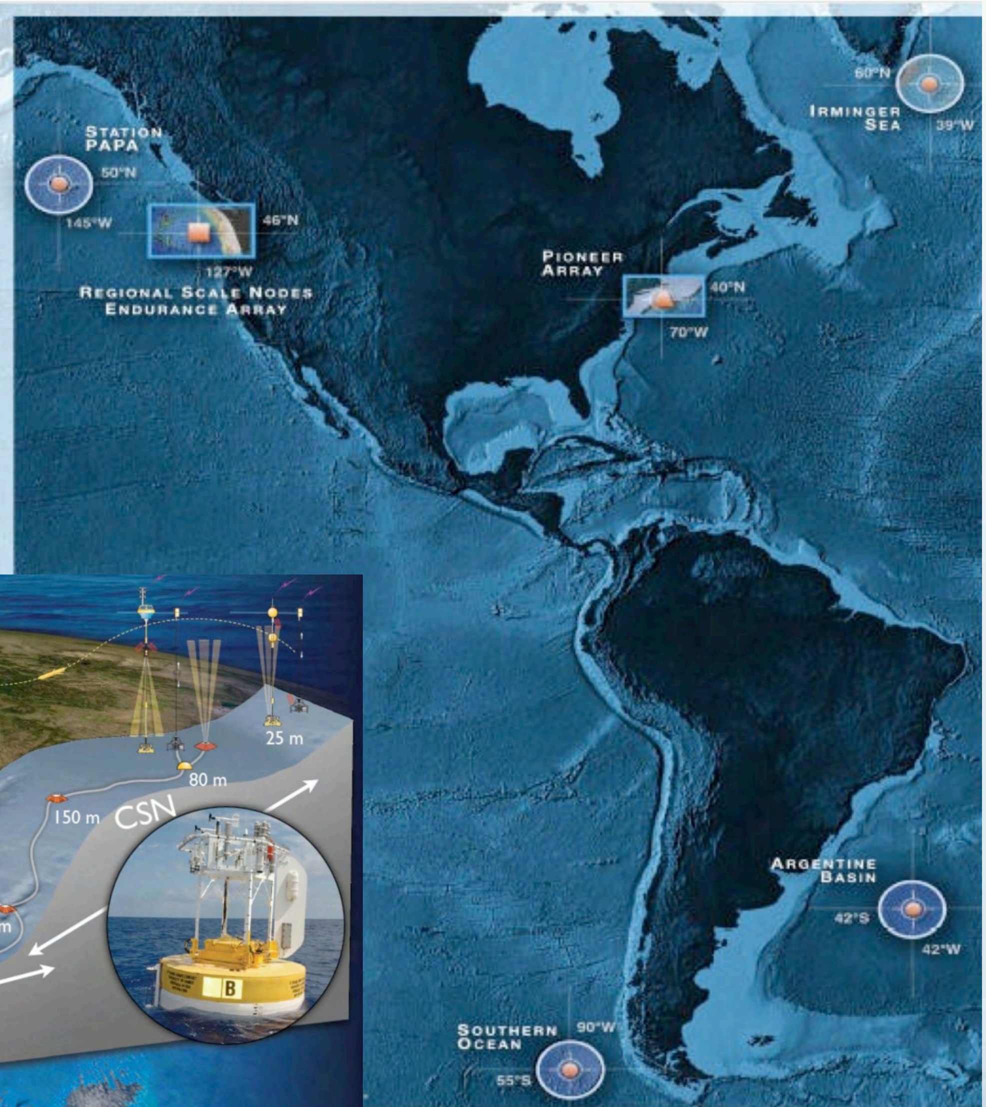
Ocean Observatories Initiative (OOI)

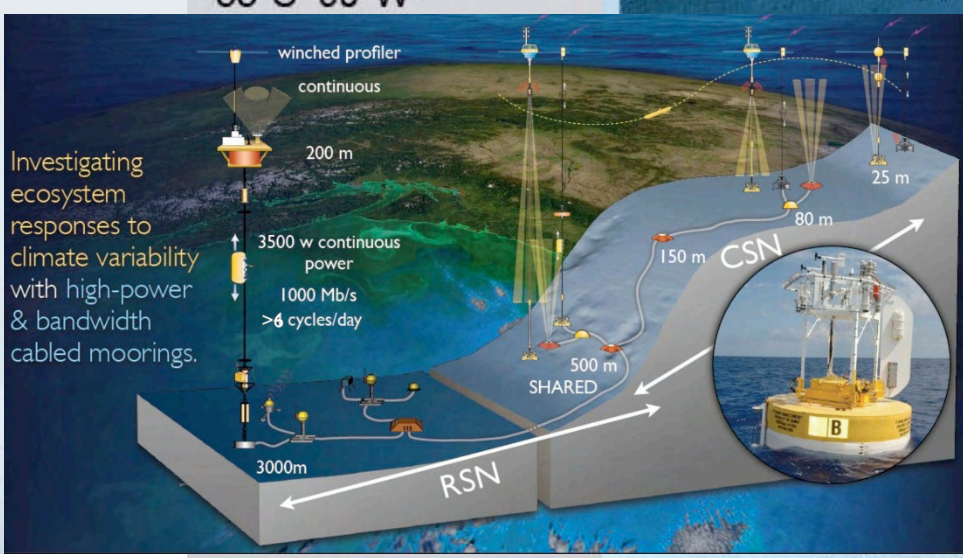
PAPA
50°N 145°W
(joint with PMEL)

Irminger Sea
60°N 39°W

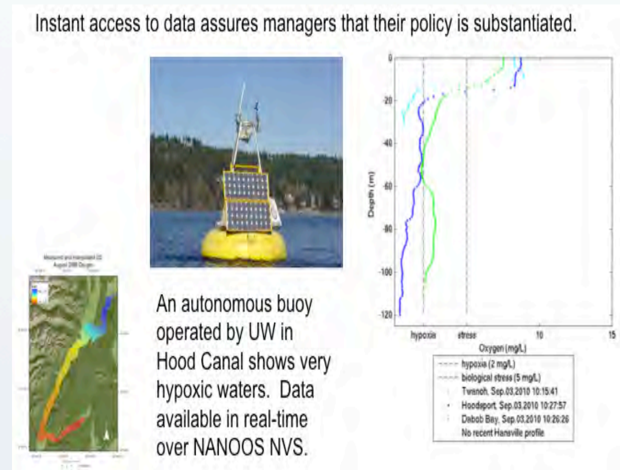
Argentine Basin
42°S 42°W

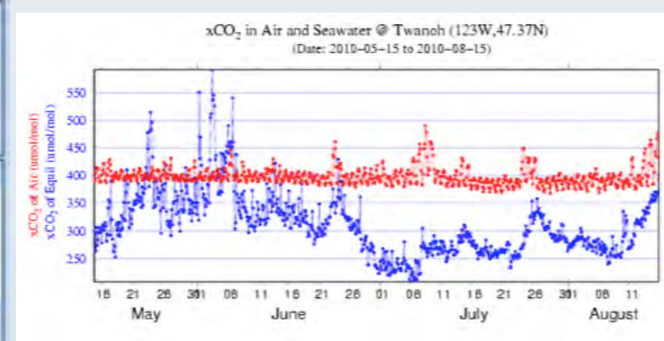
SE Pacific
55°S 90°W





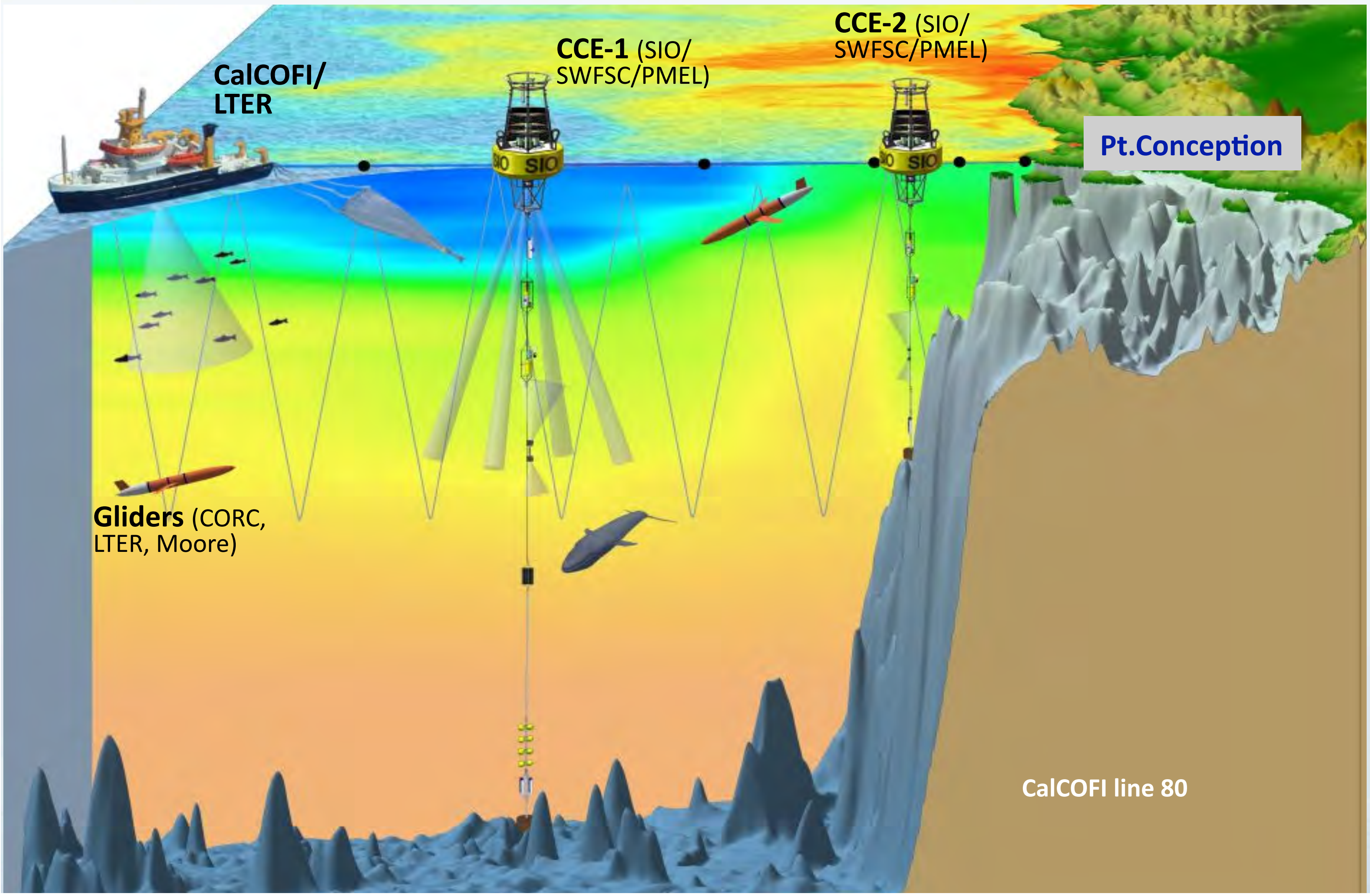
What existing resources can we use to monitor ocean acidification in the coastal ocean?





The power of CCE1/2 comes from the context of other measurements

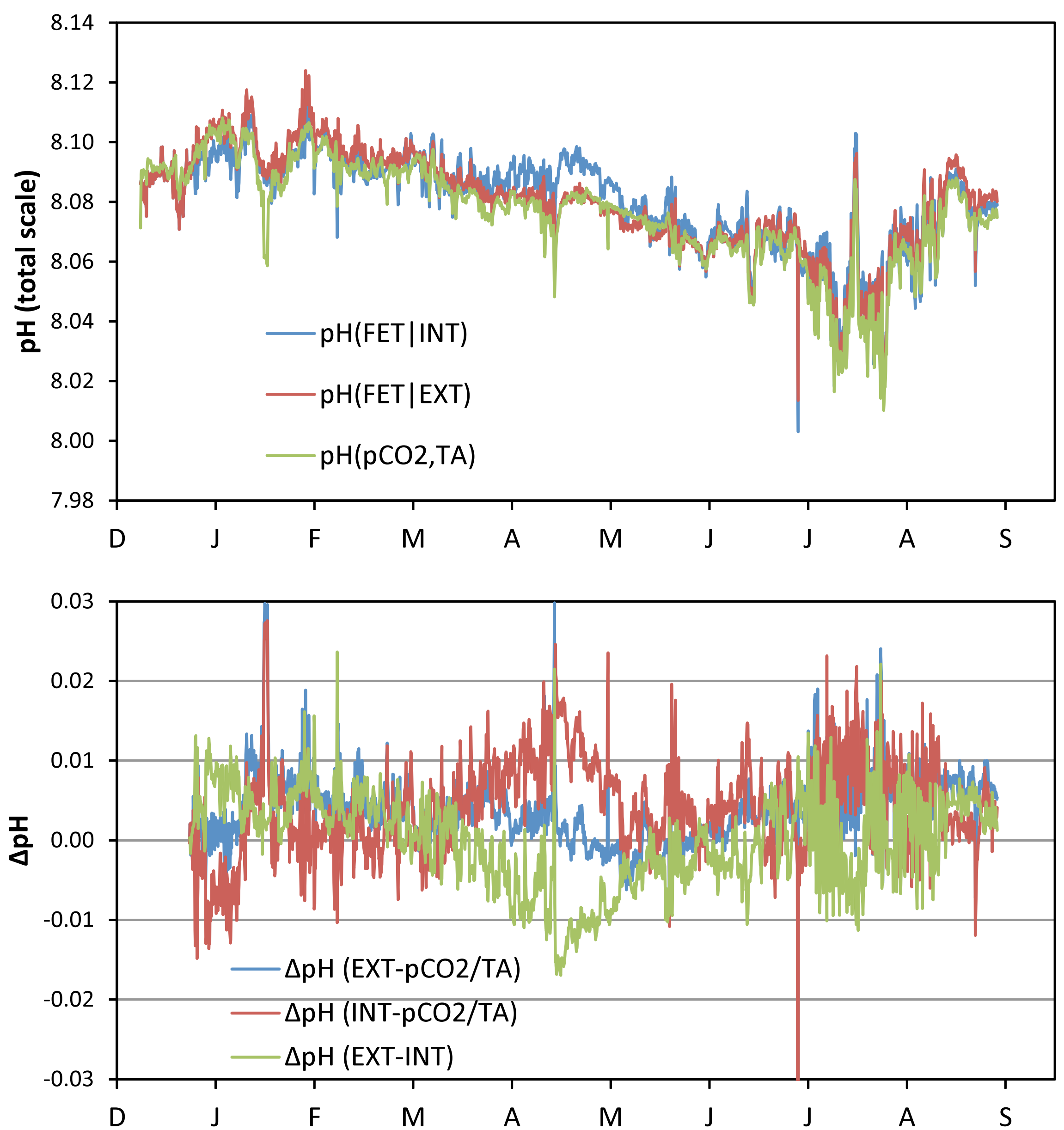
- Ships sample many variables and provide ground truth
- Gliders provide cross-shelf sampling with a few variables
- Moorings give full time sampling of a wide range of variables



Chlorophyll shown on surface; salinity on cross-section

Figure provided by U. Send, M. Ohman, SIO

CCE-1 surface pH (Jan – Sept.) 2010



pH measured using a modified Honeywell Durafet and estimated from pCO_2 using TA = f(S,T) provided by Simone Alin (PMEL).

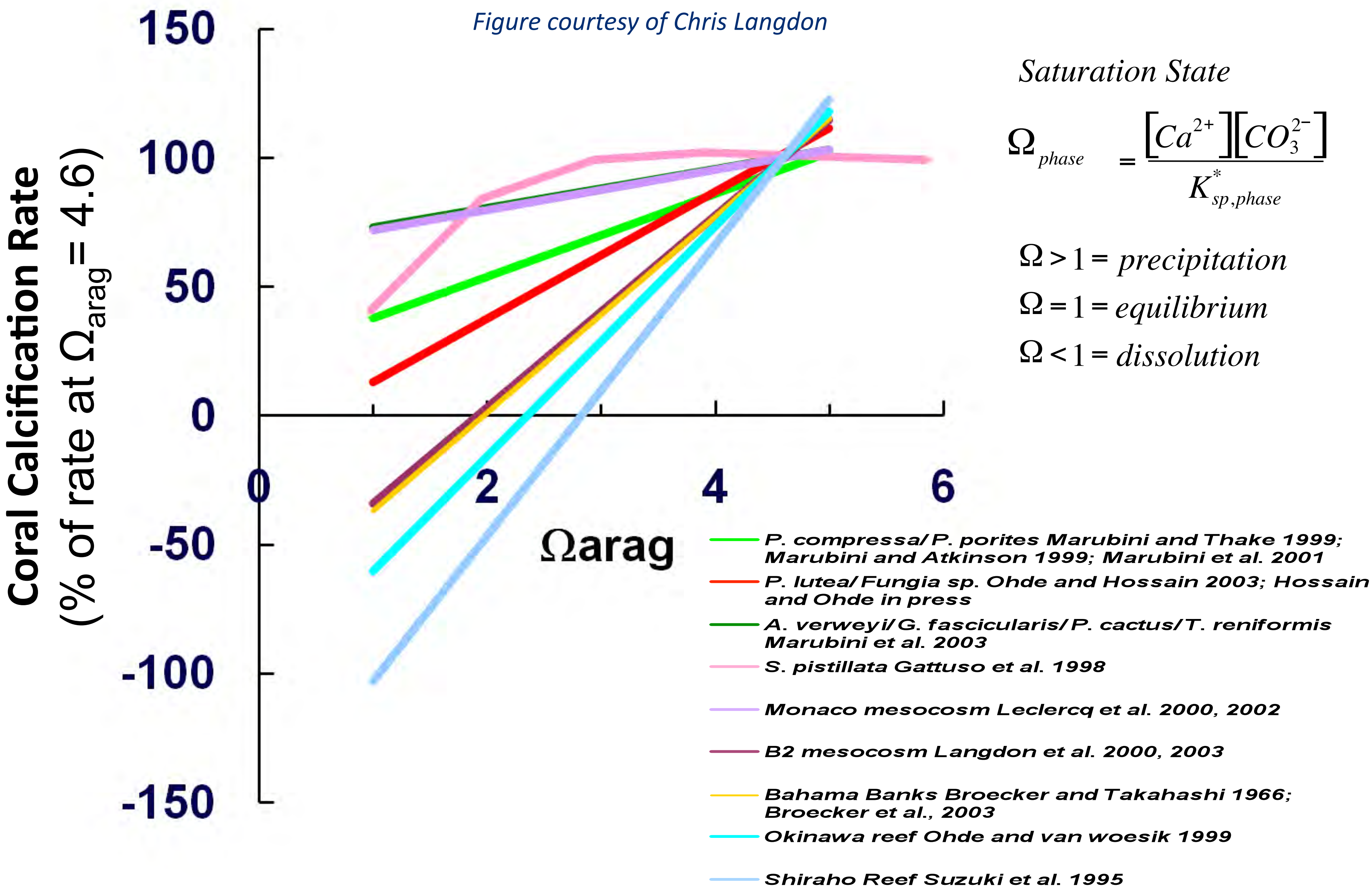
Examining the agreement between the three different pH values provides a useful QC on sensor data.

Figure provided by T. Martz, U. Send, M. Ohman, SIO

What are the unique oceanographic concerns about ocean acidification in coral reefs?

Corals show a strong response to high CO_2/ low saturation state

Figure courtesy of Chris Langdon



Saturation State

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

$\Omega > 1 = \textit{precipitation}$

$\Omega = 1 = \textit{equilibrium}$

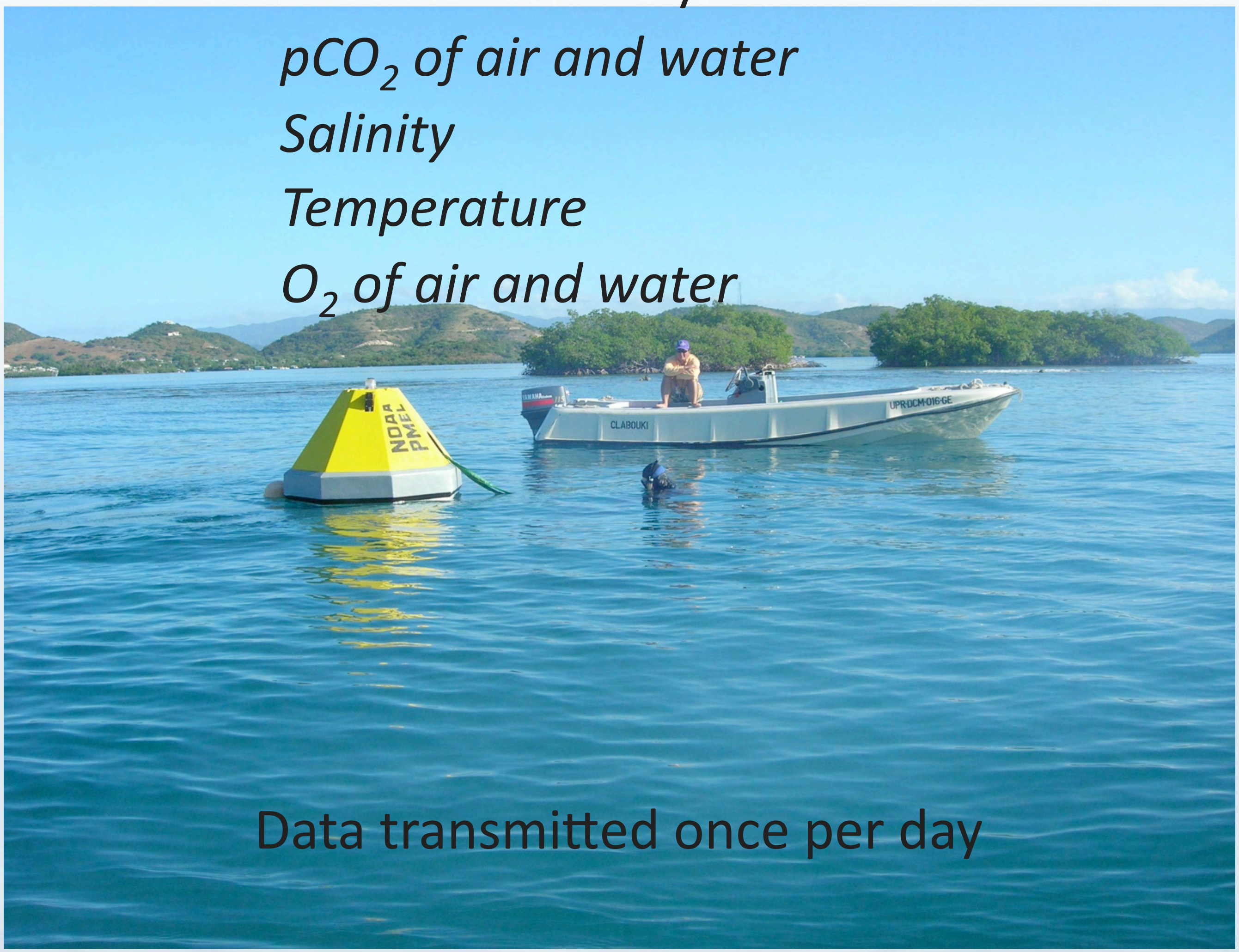
$\Omega < 1 = \textit{dissolution}$

What existing resources can we use to monitor ocean acidification in the coral reefs?

Enrique Reef, Puerto Rico

Deployed December 2009 - 2011

Measurements every three hours:



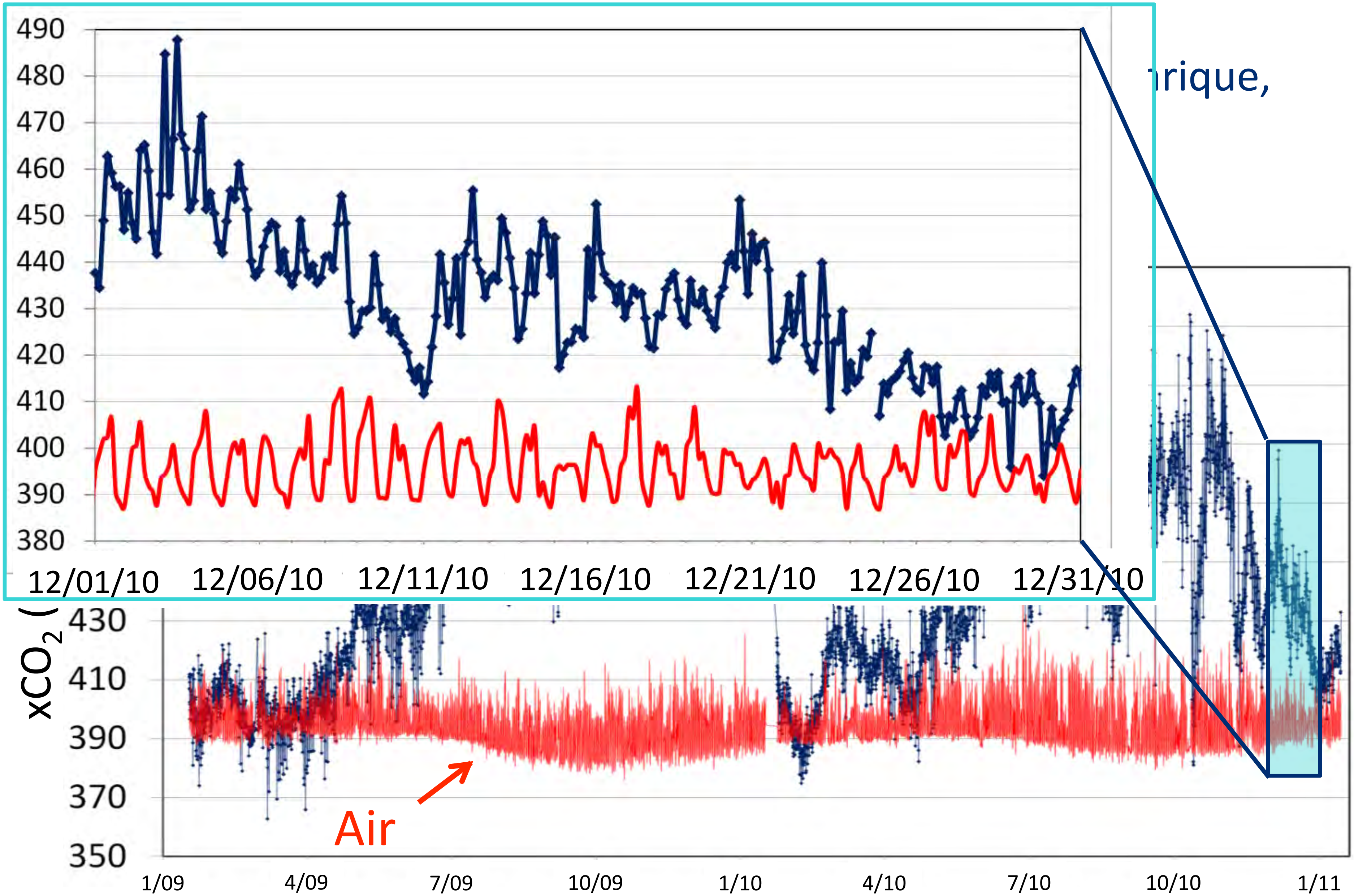
pCO_2 of air and water

Salinity

Temperature

O_2 of air and water

Data transmitted once per day



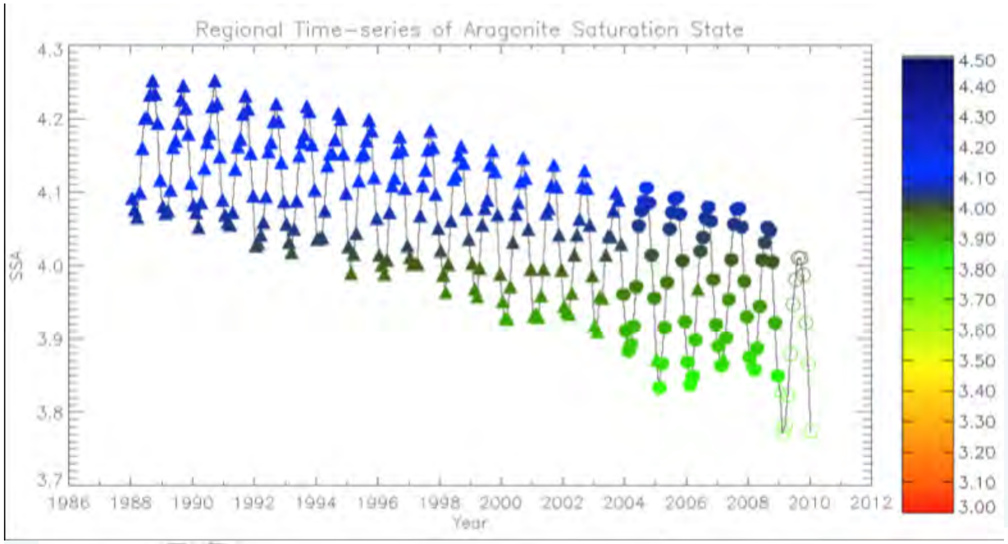
Marine Sciences, UPRM

UNIVERSITY OF MIAMI RSMAS ROSENSTIEL SCHOOL OF MARINE & ATMOSPHERIC SCIENCE

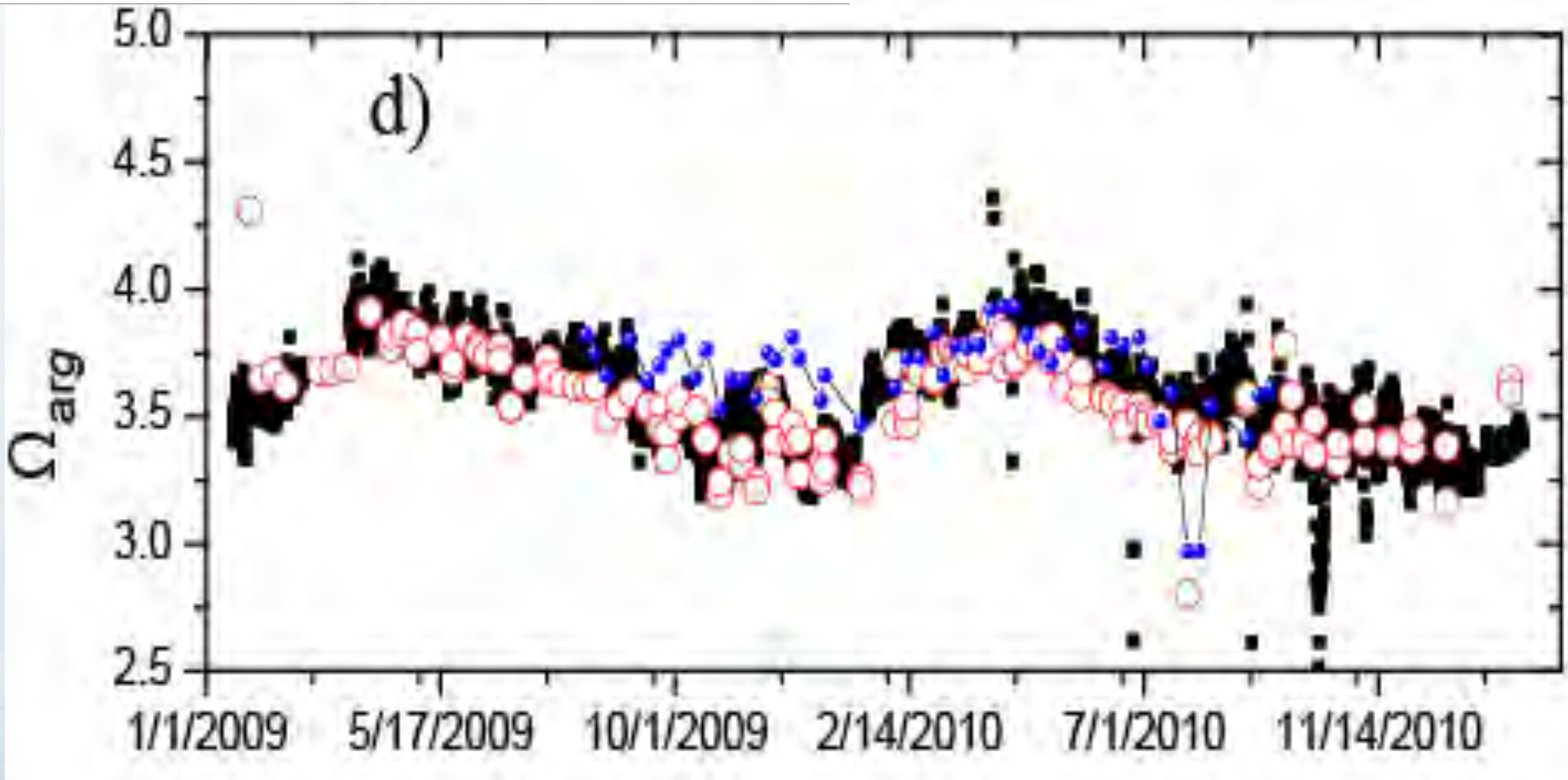
USGS science for a changing world

NOAA

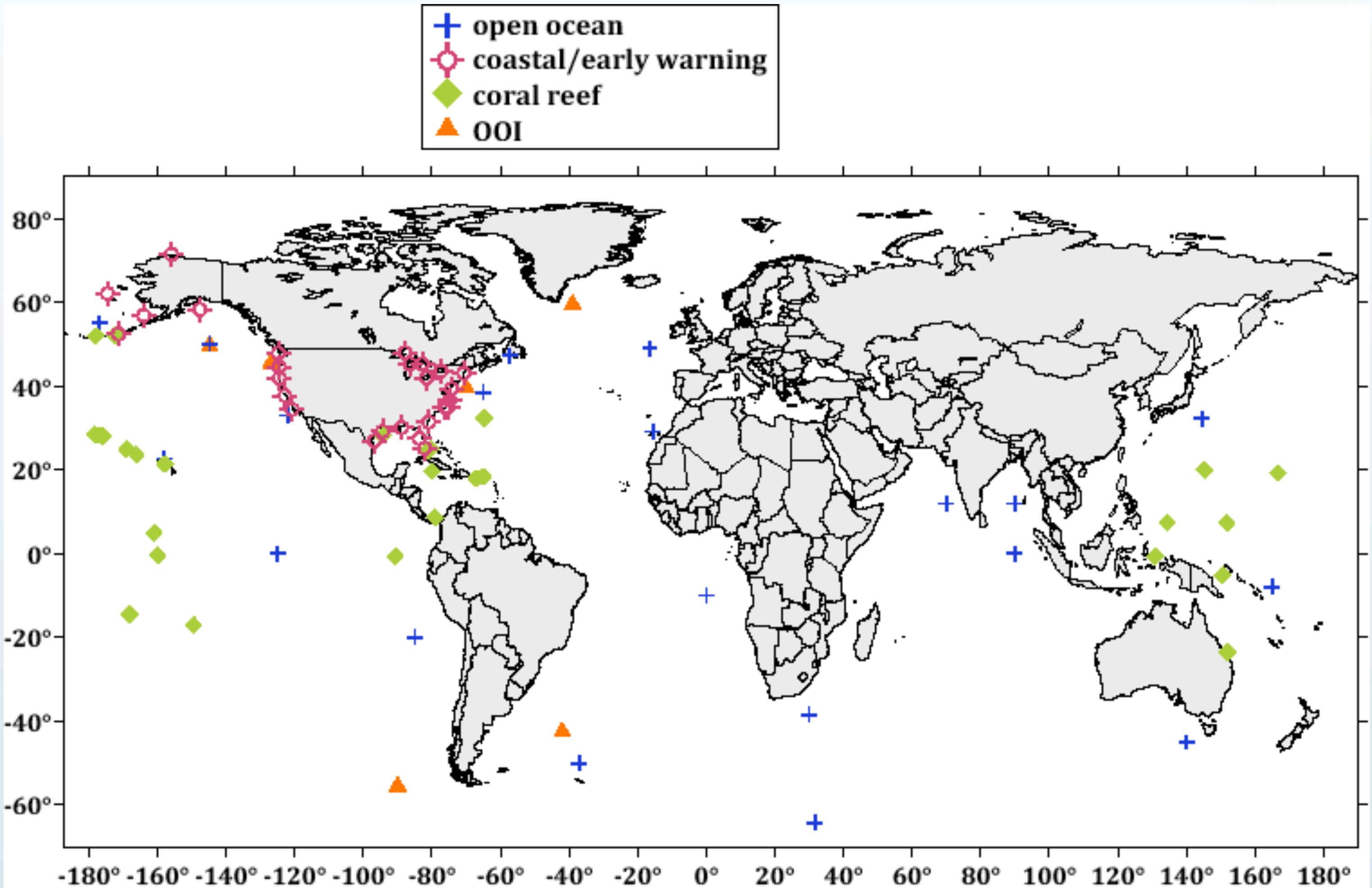
NOAA coral reef CONSERVATION PROGRAM



Discrete measurements from J. Corredor's lab show aragonite saturation state variability at Enrique Reef is roughly twice the amplitude of the empirical model



What existing resources can we use to monitor ocean acidification in the global oceans?



Possible United States carbon and acidification monitoring sites in open-ocean, coastal ocean, and coral reef regions for time-series measurements and process studies

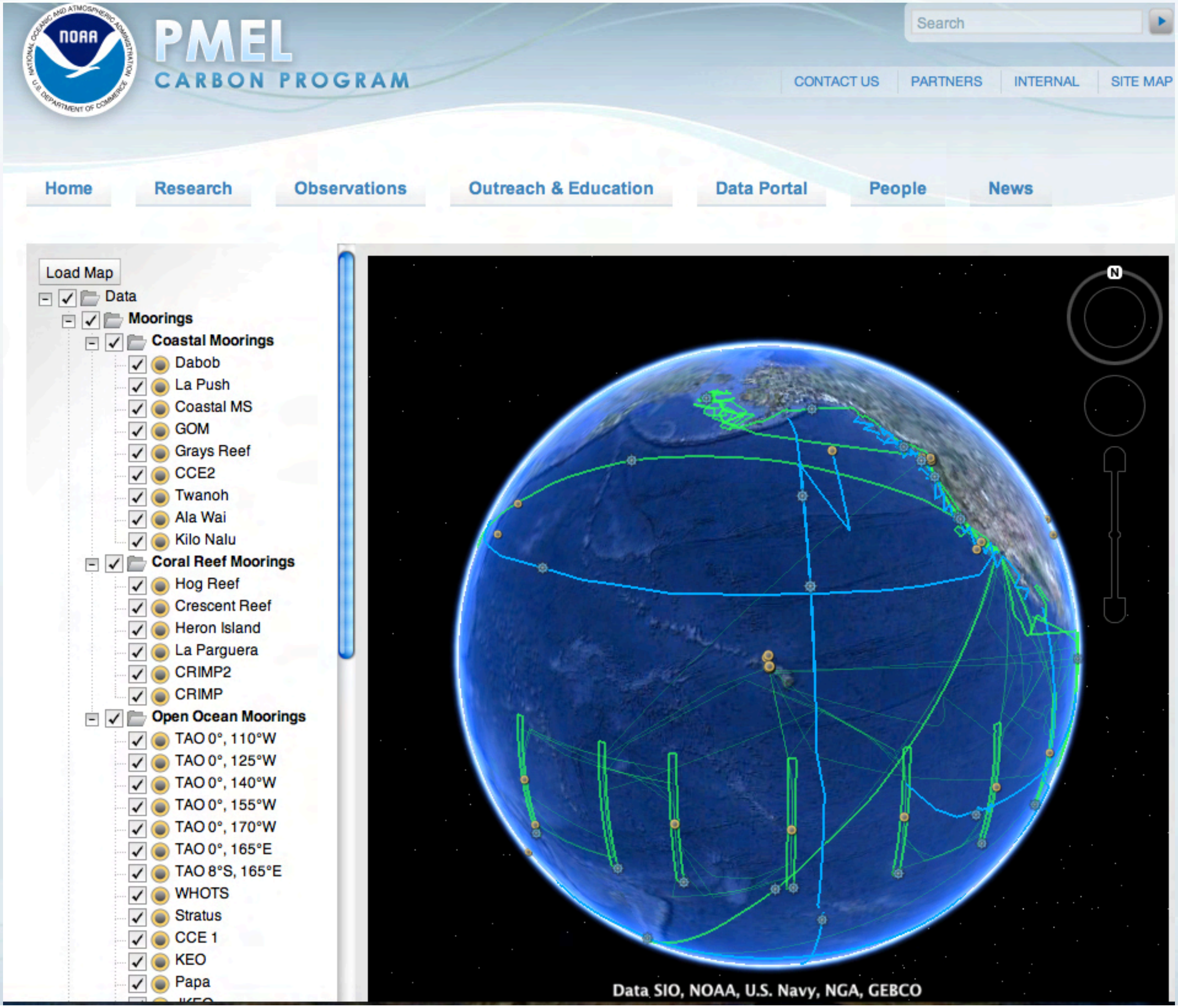
Next Steps….

1. Develop a national ocean acidification observing system implementation plan with clear priorities and strict metrics following the “Ocean Acidification Best Practices” guidelines with verification where possible;

2. Define physical, chemical and biological parameters to be measured for various platforms;

3. Develop integrated data management and data exchange system with open access to real-time data; and

Next Steps….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Coastal MS
GOM
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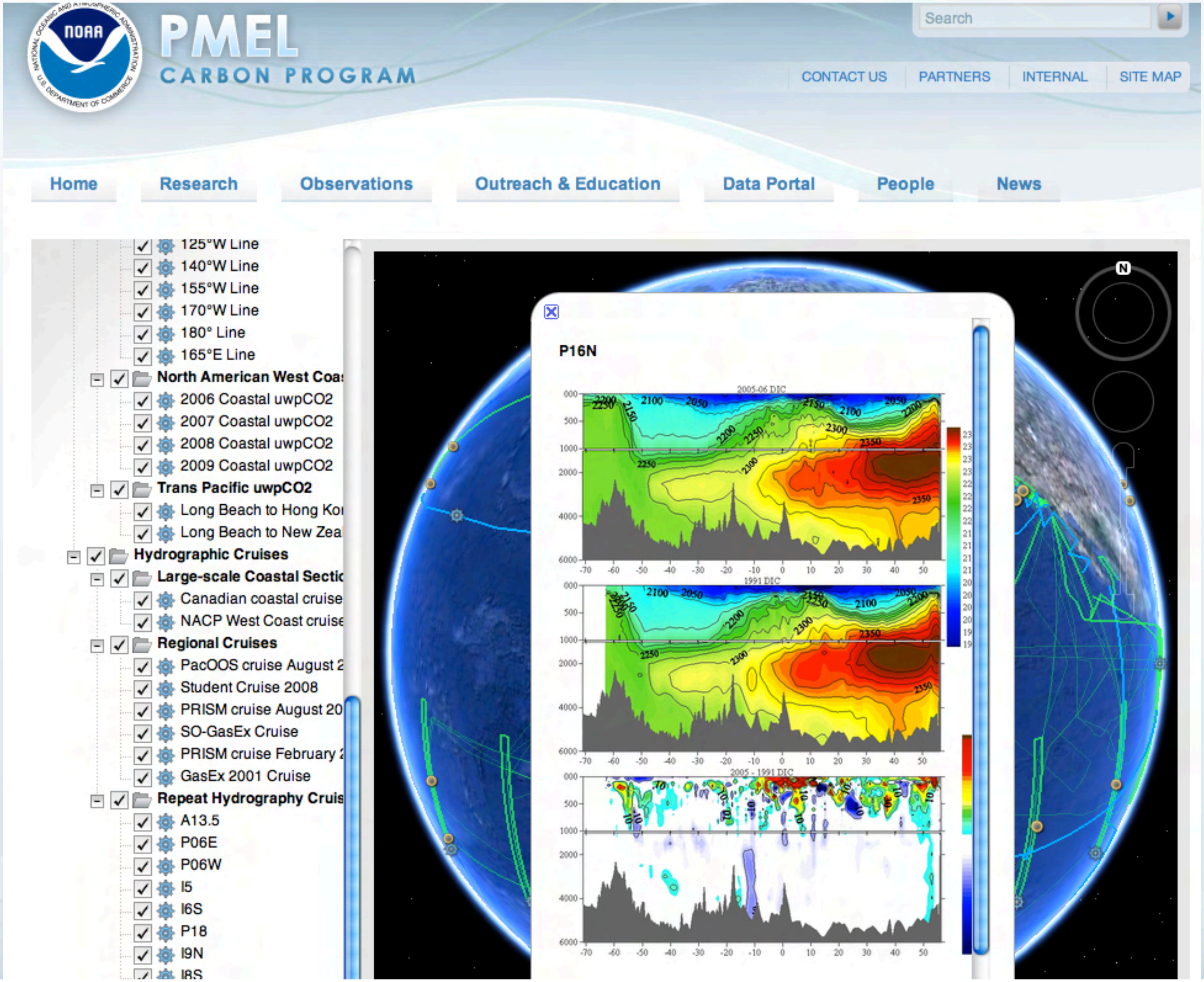
CCE2
Twanoh
Ala Wai
Kilo Nalu
Coral Reef Moorings
Hog Reef
Crescent Reef
Heron Island
La Parguera
CRIMP2
CRIMP
Open Ocean Moorings
TAO 0°, 110°W
TAO 0°, 125°W
TAO 0°, 140°W
TAO 0°, 155°W
TAO 0°, 170°W
TAO 0°, 165°E
TAO 8°S, 165°E
WHOTS
Stratus
CCE 1
KEO
Papa
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Next Steps….



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155°W Line
170°W Line
180° Line
165°E Line
North American West Coa
2006 Coastal uwpCO2
2007 Coastal uwpCO2
2008 Coastal uwpCO2
2009 Coastal uwpCO2
Trans Pacific uwpCO2
Long Beach to Hong Ko
Long Beach to New Zea
Hydrographic Cruises
Large-scale Coastal Sectio
Canadian coastal cruise
NACP West Coast cruise
Regional Cruises
PacOOS cruise August 2
Student Cruise 2008
PRISM cruise August 20
SO-GasEx Cruise
PRISM cruise February 2
GasEx 2001 Cruise
Repeat Hydrography Cruis
A13.5
P06E
P06W
I5
I6S
P18
I9N
I8S
P16N
2005-06 DIC
1991 DIC
2005 - 1991 DIC

Next Steps….

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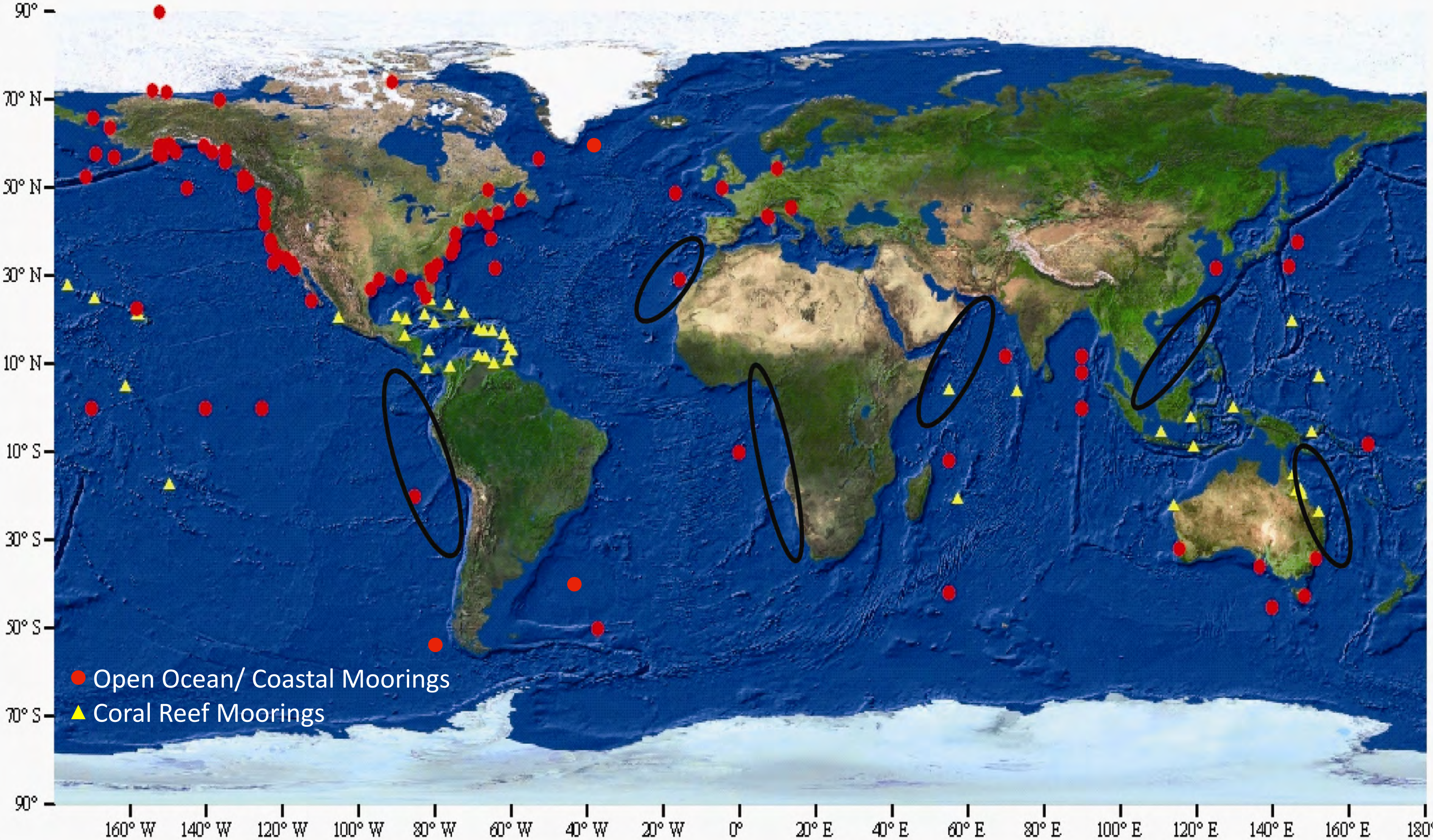
2. Define physical, chemical and biological parameters to be measured for various platforms;

3. Develop integrated data management and data exchange system with open access to real-time data; and

4. Coordinate national observing system with the international community.

An International Ocean Acidification Observing Network



from Iglesias-Rodriguez et al., 2010

Next Steps….

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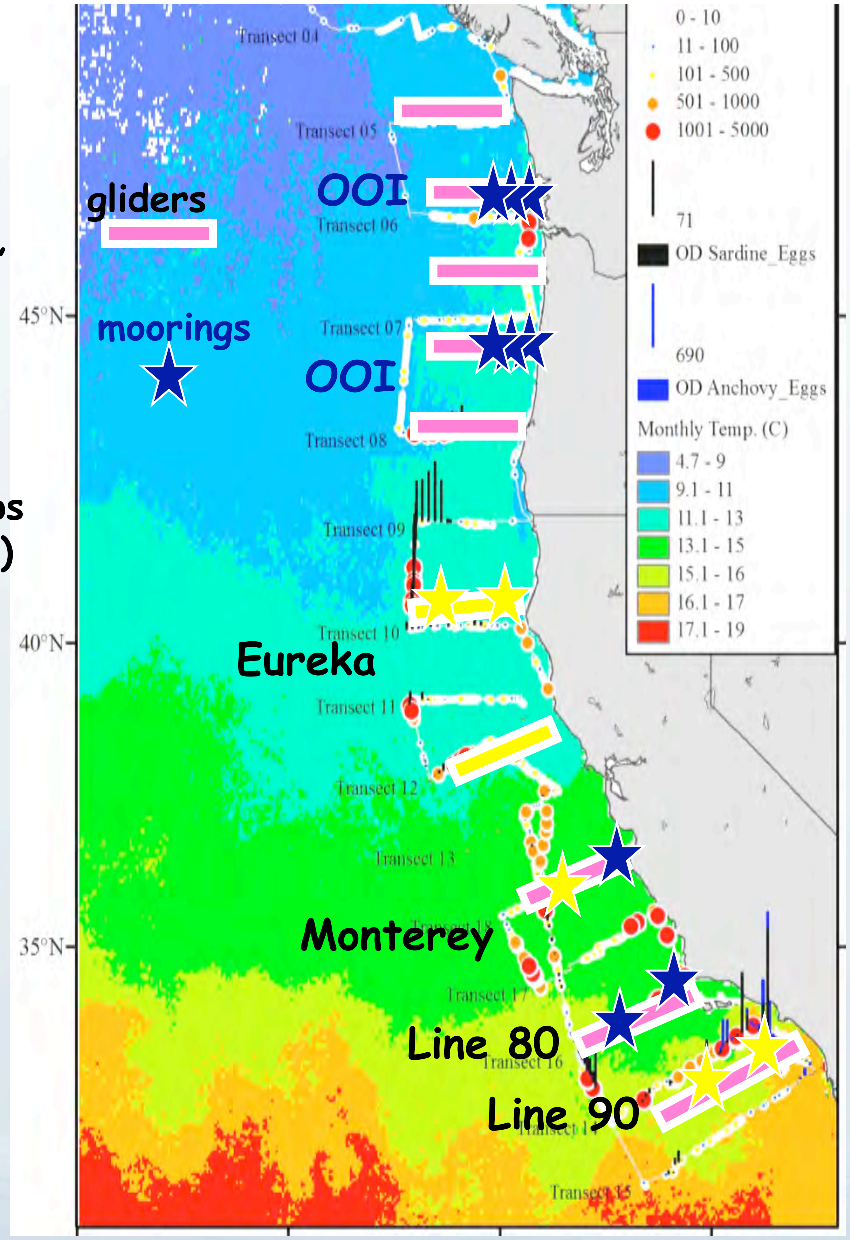
4. Coordinate national observing system with the international community.

Example integrated California Current observing system – existing and missing pieces

Regular ship surveys exist for in-situ sampling: NOAA stock assessment, NOAA acidification surveys, CalCOFI cruises, etc.

Can achieve "full CCE coverage" by merging this with autonomous systems to fill spatial and temporal gaps (and for cost-effectiveness)



Much is already in place

- all ship surveys
- 3 glider lines (CORC)
- CCE-1/2 and MBARI moorings
- coming OOI glider sections and moorings

Need only small increment to complete a comprehensive system (example in yellow):

- 2-3 glider lines
- 4-5 ecosystem moorings

Main lack: coordination of all observing assets/plans between NOAA NMFS, NOAA climate, regional OOS, NSF, etc, and integrated analysis and modelling.

NOAA