Diversity of Calcifiers

SCRIPPS INSTITUTION OF OCEANOGRAPHY

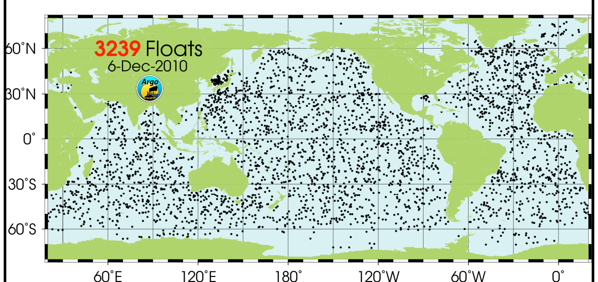
UC San Diego

Critical Needs in the Race to Observe Ocean Acidification

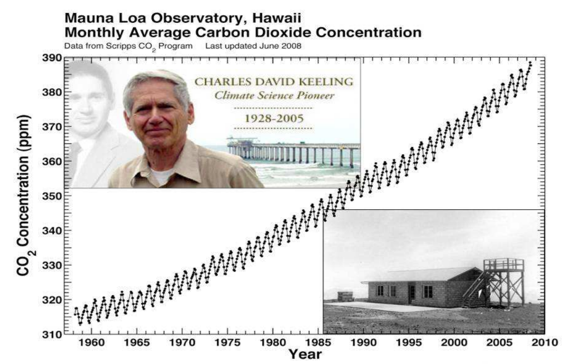
Tony Haymet

December 6, 2010 COP-16 Cancun

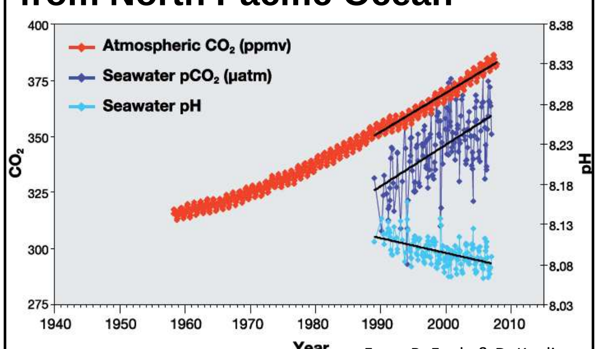
Robot Positions 06 Dec 2010



26 nations contribute; data available to all
www.argo.ucsd.edu



CO_2 and pH "time series" data from North Pacific Ocean



From R. Feely & D. Keeling

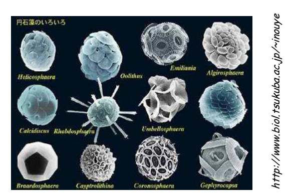
Ocean Acidification

Since about 1850, the CO_2 chemistry of the oceans has been changing because of the uptake of anthropogenic CO_2 by the oceans.

- Decrease in pH of about 0.1 over the last two centuries; a projected decrease of 0.4 by 2100
- Today's ocean has undergone a 30% increase in acidity and a decrease in carbonate ion concentration of about 20%

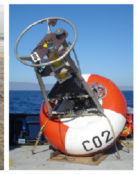
These changes in pH and carbonate chemistry may have profound impacts on many open ocean and coastal marine ecosystems.

Coral



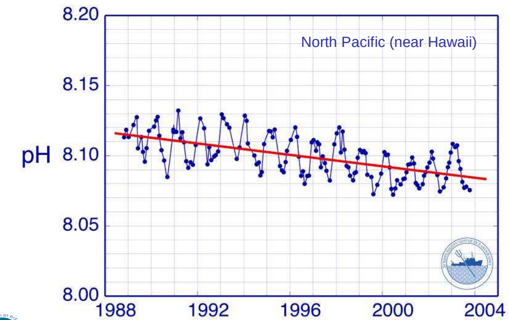
Calcareous Plankton

Observing Ocean Acidification

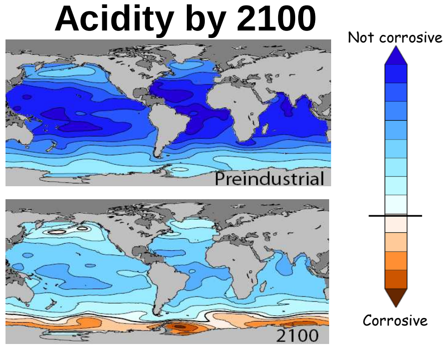


Photos: (top sequence) David Liittschwager, National Geographic Stock; (right) Mark Ohman

Declining Ocean pH

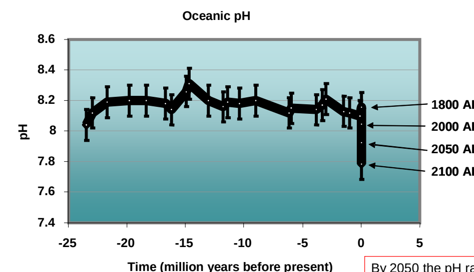


Projected Changes in Ocean Acidity by 2100



Polar & some subpolar regions become corrosive (aragonite saturation < 1.0; pH < 7.75) as early as 2050 *Fabry et al. (2008)*

At current rate we soon reach levels of ocean acidity (pH) not seen for 44 m yr



Past (from Pearson and Palmer, 2000) and predicted (from Turley et al., 2005) variability of marine pH. Future predictions are model derived values based on IPCC mean scenarios. The error bars indicate the likely seasonal scale variability in pH.

By 2050 the pH range will be discrete from the entire pre-industrial pH range. We will be in unknown territory.

CO_2-induced seawater acidification: Simple chemistry

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad H^+ + HCO_3^-$$

$$H^+ + CO_3^{2-} \rightarrow HCO_3^-$$

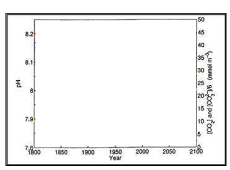
$$CO_2 + CO_3^{2-} + H_2O \Leftrightarrow 2HCO_3^-$$

Skirrow & Whitfield (1975)

The evolving chemistry of surface sea water under "Business as Usual"

Time	pCO_2	Total CO_2	pH	HCO_3^-	CO_3^{2-}	H_2CO_3
yr.	μatm	μmol kg^{-1}		μmol kg^{-1}	μmol kg^{-1}	μmol kg^{-1}
1800	280	2017	8.191	1789	217	10.5
1996	360	2067	8.101	1869	184	13.5
2020	440	2105	8.028	1928	161	16.5
2040	510	2131	7.972	1968	144	19.1
2060	600	2158	7.911	2008	128	22.5
2080	700	2182	7.851	2043	113	26.2
2100	850	2212	7.775	2083	97	31.8

Brewer (1997)



Wolf-Gladrow, Riebesell, Burkhardt, Bijma (1999)

Calcification/carbonate dissolution

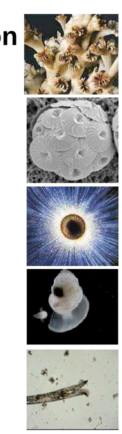
$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \qquad \Omega > 1$$

$$Ca^{2+} + CO_3^{2-} \leftarrow CaCO_3 \qquad \Omega < 1$$

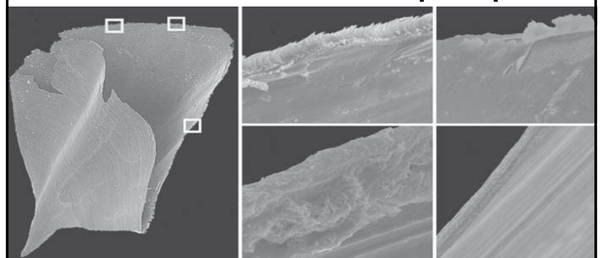
Saturation State

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

$$\Omega > 1 = \textit{precipitation}$$
$$\Omega = 1 = \textit{equilibrium}$$
$$\Omega < 1 = \textit{dissolution}$$



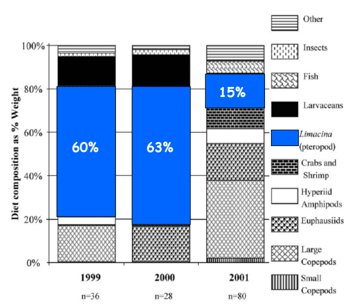
Biological impact of increasing acidity: Shell dissolution in a live pteropod



NATURE **437**, 29 Sept 2005
J.C. Orr, …Richard Matear,…

- Shell from a live pteropod, Clio pyramidata, collected from the subarctic Pacific and kept in water undersaturated with respect to aragonite for 48 h. The whole shell (a) has superimposed white rectangles that indicate three magnified areas: the shell surface (b), which reveals etch pits from dissolution and resulting exposure of aragonitic rods; the prismatic layer (c), which has begun to peel back, increasing the surface area over which dissolution occurs; and the aperture region (d), which reveals advanced shell dissolution when compared to a typical C. pyramidata shell not exposed to undersaturated conditions (e).

Food Web Impacts: Diet of Juvenile Pink Salmon

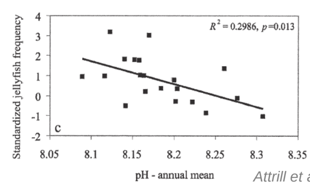


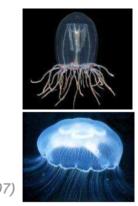
Diet highly variable among years

High salmon survival associated with feeding on non-crustacean zooplankton during critical period in August

Armstrong et al., 2005; Beauchamp, unpubl.

Increasing occurrence of jellyfish correlated with pH decrease

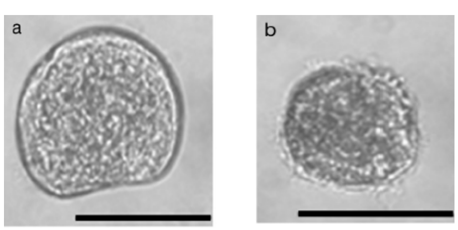




Attrill et al. (2007)

- Frequency (presence/absence) of nematocysts in Continuous Plankton Recorder samples from 1958-2000
- Significant correlation between reduced pH and increased jellyfish occurrence
- Mechanism unknown – may be associated with 1980's regime shift in North Sea
- Suggest that jellyfish occurrence will increase over the next century as pH values decrease
- Major adverse implications for marine ecosystems & fisheries

Oyster larvae: Abnormal or no calcification in corrosive seawater



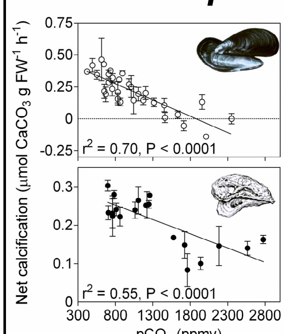
Normal seawater

Corrosive seawater

Oyster larvae did not form larval shells in corrosive seawater

Kurihara et al. (2007)

Response of mussels & oysters to elevated pCO_2



Decrease in calcification rates observed for the 2 species: *Mytilus edulis* & *Crassostrea gigas*

At pCO_2 740 ppmv

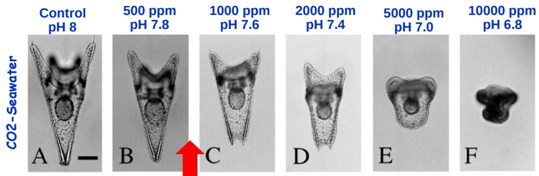
•25% decrease in calcification for mussel

•10% decrease in calcification for oysters

)

Gazeau et al. (2007)

Sea urchins: Impacts of increased CO_2 on development of larval stages

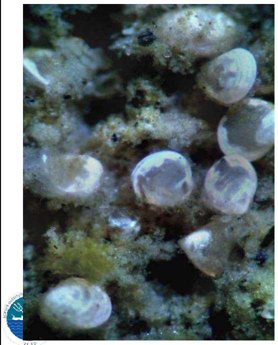


pH of upwelled corrosive water off California (pH = 7.76)

- Malformed larval stages at high CO_2 and low pH
- Unable to calcify calcium carbonate skeletal rods at high CO_2 and low pH

Kurihara & Shirayama (2004)

Clams – early life stages can also be sensitive to carbonate chemistry



Hard shell clam *Mercenaria*

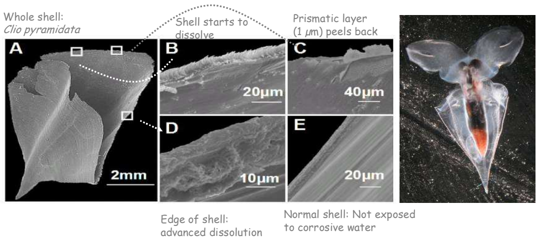
- Common in soft bottom habitats

Used newly settled clams

- Size 0.3 mm
- Massive dissolution within 24 h in corrosive (i.e., undersaturated water); shell gone within 2 weeks

Green et al. (2004)

Shells of living pteropods (plankton – food for salmon & and other marine life) begin to dissolve at elevated CO_2 levels



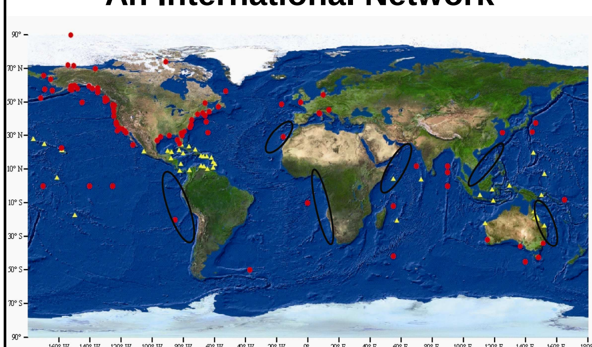
- Food source for marine predators including salmon, pollack
- Integral component of food webs in polar & subpolar regions

Orr et al. (2005)

A Path Forward

- We know enough to act: reduce CO2
- To know precisely which commercial fisheries (& marine ecosystems) will be affected first…
- International measurement network: CO2 as function of time and depth, available for all
  - Corals
  - high latitudes, coastal, & open ocean
- Communal facilities for live organism studies
- Integrated Modeling "from CO2 to fish"

An International Network



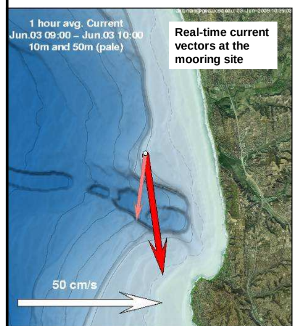
From Feely et al (2010)

'Baja to BC" Test bed

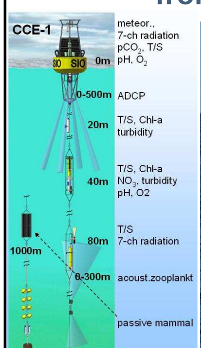
- The groups already cooperate
- "Baja to BC" West Coast is one example which urgently needs ocean acidification observing system
- CO_2 observations will tell us where & when to look for biological effects
- Community experimental facility to test impacts on commercially & ecologically important species

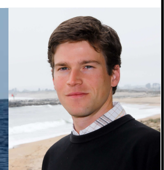
Multi-disciplinary real-time mooring 6km off La Jolla

Wind, full water-column currents&temp, 1m&35m T,S,O_2,Chl, surface nutrients

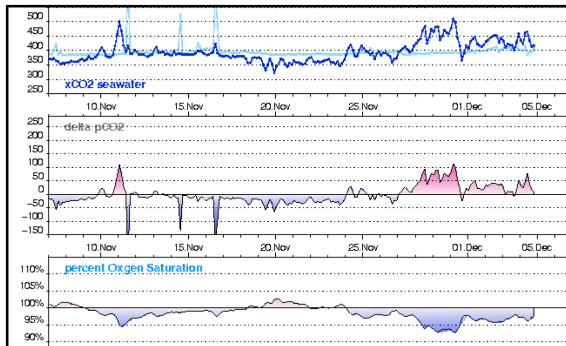


In-Situ Measurements from Fixed Moorings





Images: Uwe Send

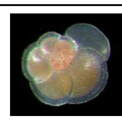


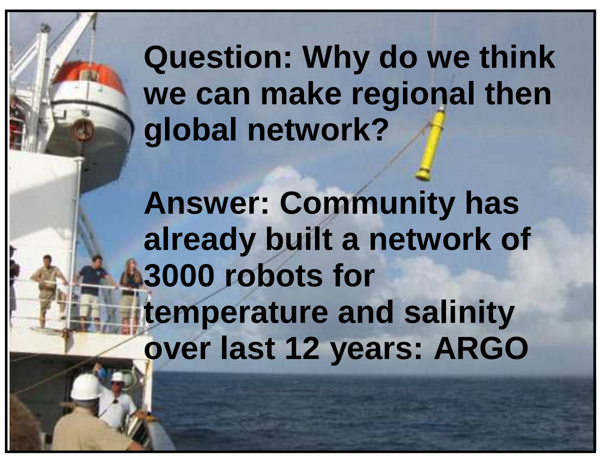
mooring.ucsd.edu

Ocean CO2 data from today

Critical Research Needs & Challenges

- Standardized measurement protocols and data reporting guidelines (calcification rates, manipulation of seawater CO_2 system, dissolution, respiration)
- Autonomous systems for measurement of an additional parameters of the seawater CO_2 system
- Methods to investigate *in situ* response of organisms that are difficult to maintain in the lab (e.g., foraminfera, pteropods, squid)
- Methods to identify effects of chronic exposure to elevated pCO_2
- Address questions of species adaptation over timescales of decades





Question: Why do we think we can make regional then global network?

Answer: Community has already built a network of 3000 robots for temperature and salinity over last 12 years: ARGO

Argo Floats

Davis and Roemmich with a float “robot”

ROBOTS

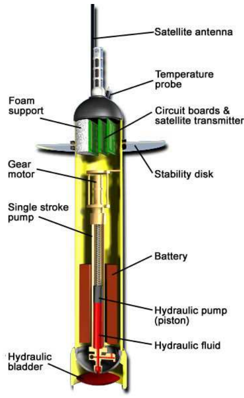
Depth

Temperature

Salinity

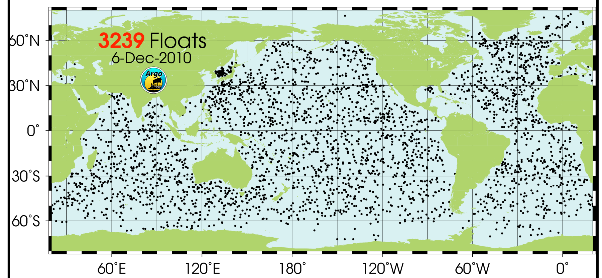
Need to be Extended to

Dissolved Gasses & biology



A profiling Argo float

Robot Positions 06 Dec 2010



26 nations contribute; data available to all
www.argo.ucsd.edu

Climate Ocean Observations

A Lesson from Argo

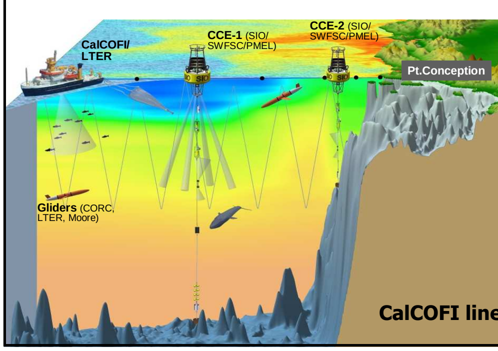
- One proven route to an operational International network
- 1. Scientists do it first
- 2. Collect the data to “make the case”
- 3. Agencies and formal structures use that case to complete the network & make it “sustained”
- 4. “Light touch” open network structure survives the transition (much to the delight of scientists..)

One Path Forward

- International measurement network: CO_2 as function of time and depth, available for all
  - high latitudes, coastal, open ocean & corals
- Communal facilities for live organism studies – what is waiting for us? How long do we have?
- Integrated Modeling “from CO_2 to fish”
- Addressing Agency overload and “unfunded mandates”
- Economists, Social scientists, and marketing: avoiding the mistakes of CO_2 “heat”

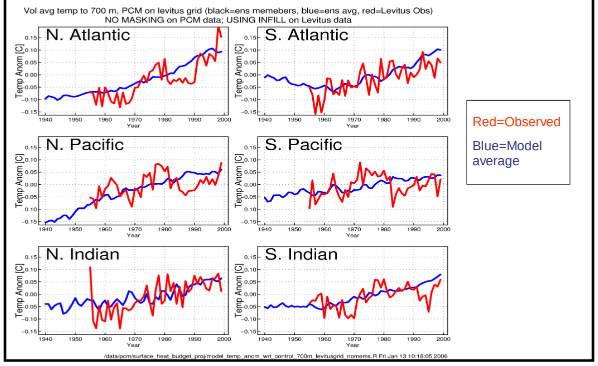
The power of CCE1/2 comes from the context of other measurements

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



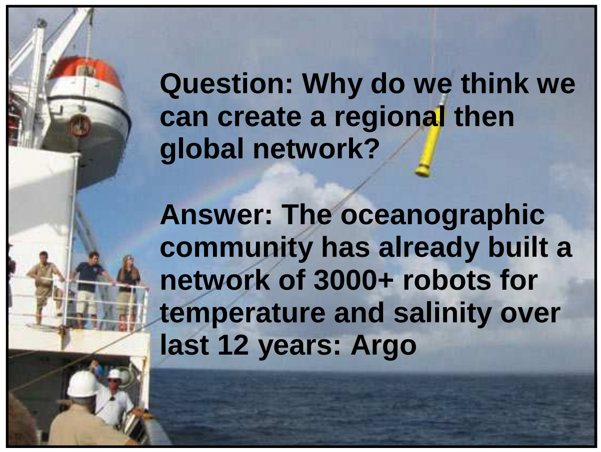
Chlorophyll shown on surface; salinity on cross-section

Ocean Temperature Increase: measured 0-700m



One Path Forward

- International measurement network: CO2 as function of time and depth, available for all
  - high latitudes, coastal, open ocean & corals
- Communal facilities for live organism studies – what is waiting for us? How long do we have?
- Integrated Modeling "from CO2 to fish"
- Addressing Agency overload and "unfunded mandates"
- Economists, Social scientists, and marketing: avoiding the mistakes of CO2 "heat"



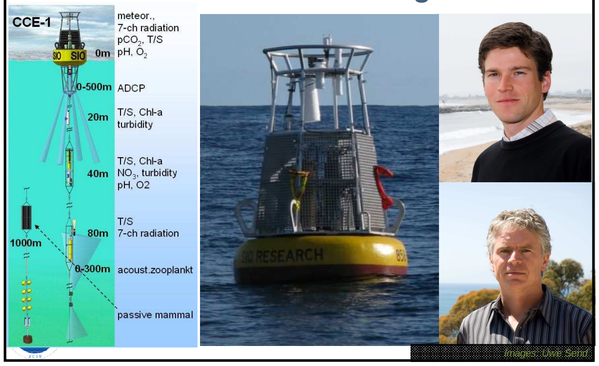
A Lesson from Argo

- One proven route to an operational International network
- 1. Scientists do it first
- 2. Collect the data to "make the case"
- 3. Agencies and formal structures use that case to complete the network & make it "sustained"
- 4. "Light touch" open network structure survives the transition (much to the delight of scientists..)

'Baja to BC" Test bed

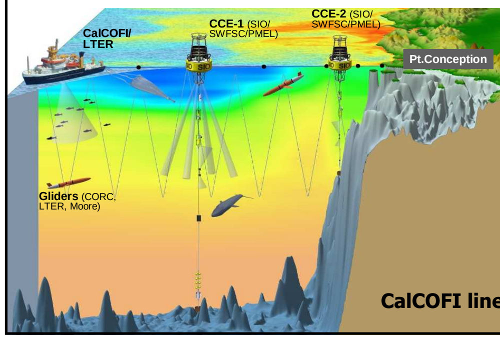
- The groups already cooperate
- "Baja to BC" West Coast is one example which urgently needs ocean acidification observing system
- CO_2 observations will tell us where & when to look for biological effects
- Community experimental facility to test impacts on commercially & ecologically important species

In-Situ Measurements from Fixed Moorings

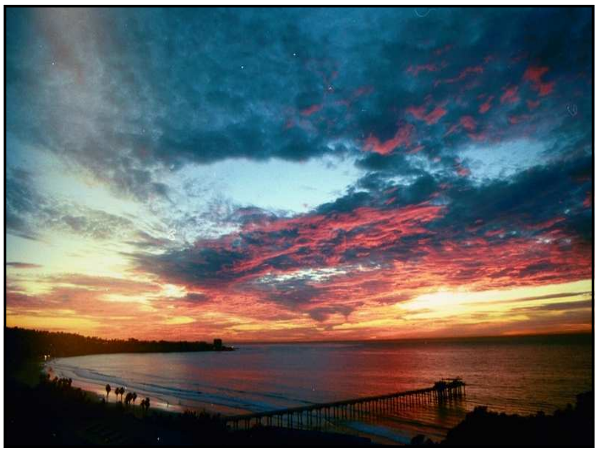


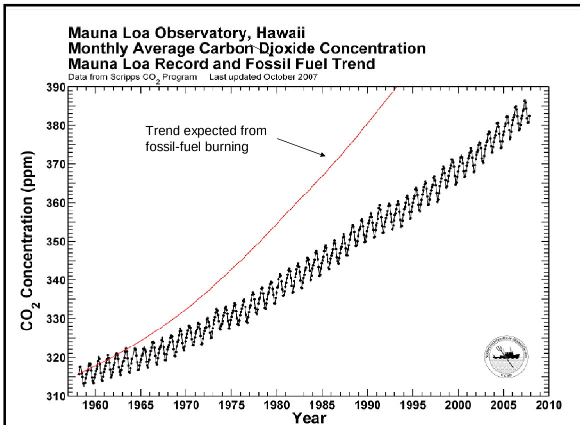
The power of CCE1/2 comes from the context of other measurements

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



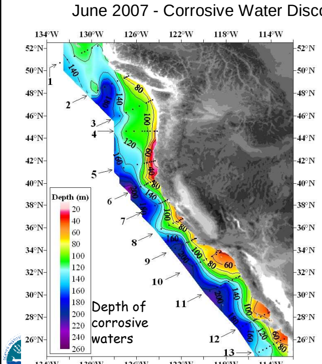
Chlorophyll shown on surface; salinity on cross-section





Ocean Acidification…The California Problem

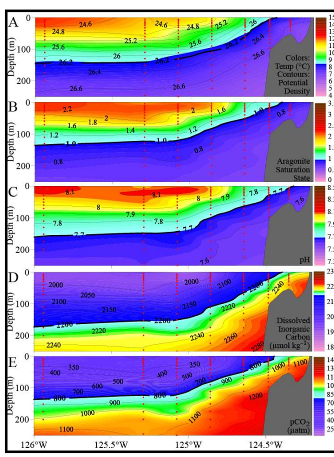
June 2007 - Corrosive Water Discovered Off California Coast



Distribution of the depths of the corrosive water (aragonite saturation < 1.0; pH < 7.75) on the continental shelf of west coast from Queen Charlotte Sound, Canada to San Gregorio Baja California Sur, Mexico.

On transect line 5 – near Trinidad Head, CA - the corrosive water reaches all the way to the surface in the waters near the coast.

Feely et al. (2008)



Upwelling-Induced Acidification of the Continental Shelf

Feely Sceince May 2008
Vertical sections from Line 5
(Pt. St. George, California)

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

Evidence of corrosive water caused by the ocean's absorption of carbon dioxide (CO2) was found less than 20 miles off of the west coast of Mexico this summer. This was the first time corrosive acidified ocean water has been identified on the continental shelf of western North America.. evidence for corrosive low pH seawater in the bottom waters as depicted by Ωarag values < 1.0 and pH values < 7.75.

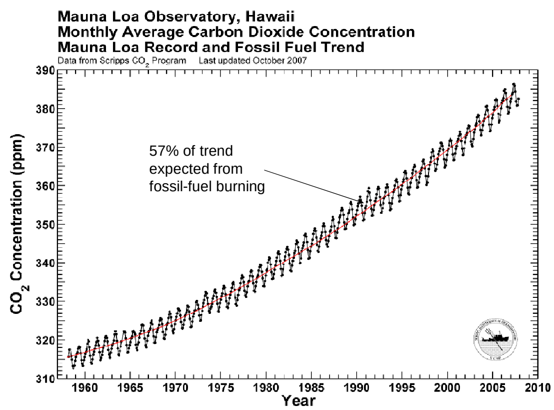
Red dots represent sample locations.

Feely's Conclusions

- Uptake of anthropogenic carbon dioxide in the North Pacific induces a 1 m yr^{-1} shoaling of the aragonite saturation horizon.
- Seasonal coastal upwelling of undersaturated water with respect to aragonite extends throughout the continental shelf region from southern Canada to northern Mexico.
- Possible responses of ecosystems are speculative but could involve changes in species composition & abundances - could affect food webs, biogeochemical cycles.

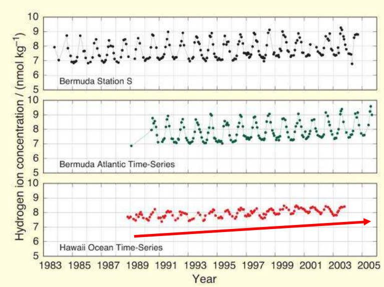
Immediate Needs for the US West Coast

- Urgent need to develop US west coast ocean acidification observing system
- West coast network of CO_2 observations will tell us where & when to look for biological effects
- Urgent need for experimental facility to test impacts on commercially and ecologically important species



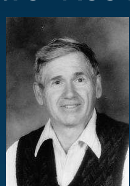
Changes in hydrogen ion concentration at the Bermuda and Hawaii Time-Series Stations resulting from the increase in atmospheric CO_2

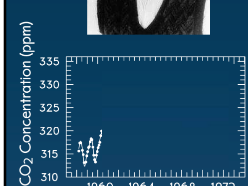
1850
$H^+ = 6.5$
nmol kg^{-1}



SCRIPPS CO_2 PROGRAM

Dave Keeling - Scripps 1957-2005

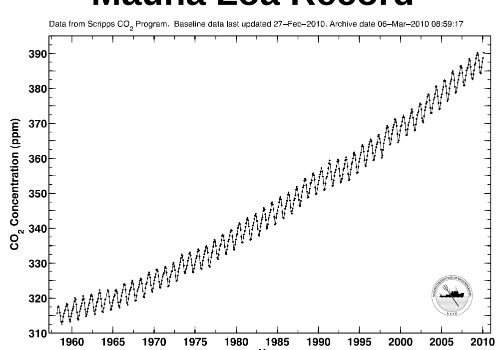




- *Charles David Keeling (1928-2005)*

Image credit: Publication of the National Oceanic & Atmospheric Administration (NOAA), NOAA Central Library;
Photo Date: 1982 February; Photographer: Commander John Bortniak, NOAA Corps (ret.)

Mauna Loa Record



Los Angeles Times

A warning from the sea

Oyster 'seeds' are dying as Pacific Coast waters grow warmer.

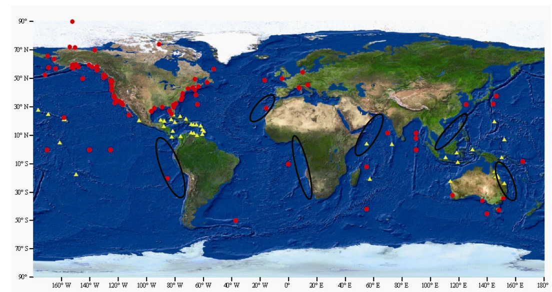
By Kenneth R. Weiss, Los Angeles Times Staff Writer
July 13, 2008

Oyster farming

Source: Pacific Coast Shellfish Growers Assn.
Graphics reporting by Kenneth R. Weiss

- Number 1 aquacultured crop in the world
- $3 billion industry
- Oysters are cultivated all along west coast (see map)
- Larval oysters dying – may be a result of warming temperature, bacteria, low oxygen and low pH
- West coast shellfish industry is at risk
- Without oysters & other filter feeding molluscs, estuaries may have more algal blooms & decreased water quality in future

Parallel steps: An International Network



From Feely et al (2010)

Ocean Acidification Becomes Warming's 'Evil Twin' at COP15

Photos: Scripps Oceanography