OCEAN ACIDIFICATION
Measurements, modeling and plans for future work

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NOAA Pacific Marine Environmental Laboratory

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

1. Overview of ocean acidification science
2. Measurements and models on the West Coast
3. Where do we go from here?
Atmospheric CO$_2$ Record

Mauna Loa Observatory

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%)

Rates of increase are important

atmospheric CO$_2$

global temperature

Hoegh-Guldberg et al. 2007, Science
IPCC TAR Emission Profiles from Pre-Industrial Levels

Drivers for a change in energy policy

Ocean CO₂ Chemistry

Turley (2006)
Calcium Carbonate Saturation State

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

\[ Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \]

Saturation State

\[ \Omega_{phase} = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp,phase}} \]

- \( \Omega > 1 \) = precipitation
- \( \Omega = 1 \) = equilibrium
- \( \Omega < 1 \) = dissolution
Field Observations

WOCE/JGOFS/OACES Global CO$_2$ Survey

~72,000 sample locations collected in the 1990s

DIC $\pm$ 2 $\mu$mol kg$^{-1}$
TA $\pm$ 4 $\mu$mol kg$^{-1}$

Sabine et al. (2004)
The aragonite saturation state migrates towards the surface at the rate of 1-2 m yr$^{-1}$, depending on location.
pH distribution in surface waters from the NCAR CCSM3 model projections using the IPCC A2 CO₂ 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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Changes to ecosystems & their services

Uncertainties great research required
Natural processes that could accelerate the ocean acidification of coastal waters

Coastal upwelling

brings high CO₂, low pH, low Ω, low O₂ water to surface
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

Actually mixes with SO water here
NACP West Coast Survey Cruise

11 May – 14 June 2007

Newport

Aberdeen

MBARI

UCLA
Seasonal invasion of corrosive waters on west coast North America

Inflow of corrosive waters across shelf and over extensive, productive ecosystems

upwelling of undersaturated waters ($\Omega_{\text{arag}}$ values $< 1.0$) onto shelf seas

ASH ($\Omega_{\text{arag}}$ values $= 1.0$) shoaling: 1m/a

Intermediate CO$_2$ rich corrosive waters ($\Omega_{\text{arag}}$ values $< 1.0$)

Schematic by C. Turley

Feely et al. Science (2008)
The ‘ocean acidified’ corrosive water was upwelled from depths of 150-200 m onto the shelf and outcropped at the surface near the coast.
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

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
Importance of Moorings

Preliminary results show a clear *seasonal trend* in pH and a strong correlation with pCO$_2$.
**Importance of Moorings**

Preliminary results show a clear *seasonal trend* in pH and a strong correlation with pCO$_2$.

**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?

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

Testing the Honeywell Durafet® for seawater pH applications

Todd R. Martz¹, James G. Connery², Kenneth S. Johnson³

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

²215 E. Welsh Road, Maple Glen, PA, 19002

³Monterey Bay Aquarium Research Institute, Moss Landing, CA, 95039

Honeywell Durafet Ion Sensitive Field Effect Transistor
An Ocean Acidification Observational Network
What tools do we have to address ocean acidification?

6 months of pH data from MBARI test tank

- FET|INT
- FET|EXT
- spec pH

Shows reproducibility not uncertainty

Month (2008-2009)

K. Johnson, unpub. data
An Ocean Acidification Observational Network

What tools do we have to address ocean acidification?

Shipboard TA Determination Using MICA

Underway Calculated TA

Latitude

TA (µmol kg⁻¹)

-27 -24 -21 -18 -15 -12 -9 -6 -3

UM Discrete TA
Calculated TA from USF DIC and pH
Calculated TA from USF DIC and f/CO₂

SRI International
Innovating Technology

Autonomous Underwater Gliders

High resolution data
Autonomous Underwater Gliders

Innovating Technology

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
- Pacific oyster
- Deep sea coral
- Dungeness crab
- Geoduck
- Sea urchins
- Fish

“Early warning” system will provide real-time, local data
Pacific Northwest *oyster emergency*

**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*

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

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 developed and integrated with the models.