Climate change impacts on the marine and coastal environment

Francisco Chavez
Senior Scientist
Monterey Bay Aquarium Research Institute (MBARI)
Regional Seas November 2008
Implications for marine governance

- Climate and global change are a given
- Large uncertainty regarding impacts
- Management needs to change from a year to year to a decade to decade horizon (a huge political problem)
- Full scale advocacy for emission reductions
- But by itself not enough, need to adapt and mitigate
- Mitigation strategies need to be carefully evaluated
Continued

• Ocean information severely lacking (a few long term sites in ocean, hundreds on land)

• Leads to decisions made out of fear or ignorance, not very satisfying for a scientist

• Urgent need to improve observations and build support systems for long-term decisions
What is Climate Change?

- Scientists typically define it to include any change in climate, be it due to nature or man, on any scale (e.g. interannual to centennial or longer)
What about Global Change?

- Here defined as any environmental change associated with human activity
- The most debated is global warming but there are many others such as ocean acidification, pollution (nutrients, metals, etc.), overfishing, etc.
The role of the ocean in moderating the atmospheric CO₂ increase has been recognized (by scientists) for a very long time. Revelle and Suess (1957) first explicitly calculated the partitioning of CO₂ released to the atmosphere between air and sea and estimated that ~ 40% of the gas would quickly be absorbed by the surface ocean, with the remainder building up in the atmosphere and changing climate.

While the climate impacts of increasing atmospheric CO₂ levels have received great attention, the direct effects of the enormous CO₂ enrichment of the upper ocean have had little discussion. That is about to change, for ocean chemistry is being altered on a scale not seen for millions of years, and there are very basic questions on the impact on ecosystems and biogeochemical cycles to which we simply do not yet have answers. The oceanic invasion rate of fossil fuel CO₂ is now over 1 million tons CO₂ per hour.

Ocean Acidification

The role of the ocean in moderating the atmospheric CO₂ increase has been recognized (by scientists) for a very long time. Revelle and Suess (1957) first explicitly calculated the partitioning of CO₂ released to the atmosphere between air and sea and estimated that ~ 40% of the gas would quickly be absorbed by the surface ocean, with the remainder building up in the atmosphere and changing climate.

While the climate impacts of increasing atmospheric CO₂ levels have received great attention, the direct effects of the enormous CO₂ enrichment of the upper ocean have had little discussion. That is about to change, for ocean chemistry is being altered on a scale not seen for millions of years, and there are very basic questions on the impact on ecosystems and biogeochemical cycles to which we simply do not yet have answers. The oceanic invasion rate of fossil fuel CO₂ is now over 1 million tons CO₂ per hour.
During the 3 days of the meeting, the ocean will have absorbed almost 100 million tons of CO$_2$. 
Parameters

- Partial pressure of CO$_2$ and pH
- Temperature
- Chlorophyll/productivity (and some species)
- Oxygen
Ocean Acidification is Happening Now and is Measurable ……

- CO₂ in oceans increases with increasing atmospheric CO₂: this is certain!

Observed trends indicate possible impacts already emerging in:

- Shell weight decrease with time in Pteropods, Foraminifera and Brachiopods
- Reduced calcification in coral reefs from GBR over last 2 decades

Atlantic - BATS
Monterey Bay, California, coastal regions much more variable.
The Ocean Acidification Timeline ……

While climate change has uncertainty, these geochemical changes are highly predictable.

Oceans are an important reservoir for CO₂ with c. 30% of CO₂ produced from fossil fuel burning & land-use change taken up by oceans (Sabine et al. 2004 Science) – effectively buffering climate change.

CO₂ produced by humans is predicted to decrease surface ocean pH by 0.4 +/- 0.1 depending on scenario by 2100.

pH has already changed by 0.1 in surface waters due to absorption of anthropogenic CO₂ - equivalent to 30% increase in acidity.

Learning From the Past – Are There Clues to Future Impacts?

Mass extinctions linked to previous ocean acidification events

Takes millions of years to recover

"Today is a rare event in the history of the World"
There could be many biological impacts but the most obvious is on organisms with calcareous or aragonitic shells, these include:

- Corals
- Coccolithophorids
- Pteropods – apparently the preferred first food of pink salmon
But what about Climate Change?

- Where are we on long term changes in the ocean?
- What are the sources of natural variability?
- What will the future bring? Uncertainty!
Natural Versus Anthropogenic Climate Change

- Natural cycles fluctuate between two or more states, typically warm versus cold.
- Anthropogenic unidirectional unless measures are taken to reverse trend (Hudson estuary example of reversal).
- Natural and anthropogenic may interact differently and unpredictably (warm PDO, global warming, cool PDO, global warming).
Two Primary States

Change

Variability

Chavez et al. 2008
It is a familiar story

El Niño

La Niña

El Viejo

La Vieja

Once ever 3-8 years

Once ever 25-40 years
Record cold temperatures during 2008

Temperature Anomalies at the M1 Mooring, Monterey Bay California

Note: 60 point moving average applied to daily averaged values.
Monterey Bay Aquarium Research Institute
Contact: rako@mbari.org

Updated: 23-Jun-2008
Part of a larger spatial scale trend

Effects will not be uniformly distributed

Chavez et al. 2008
Global warming reversed?
Are oxygen levels in Monterey Bay responding to increased productivity during La Vieja or are there other processes at play?
Greening correlated with cooling and increase of nutrients at depth

Monterey Bay Temperature at Depth

Monterey Bay Nitrate at Depth

Monterey Bay Surface Chlorophyll

1984 to 2005

Patterns consistent in many time series

Monterey Bay chlorophyll

Southern California chlorophyll

Peru chlorophyll

San Francisco Bay chlorophyll

Monterey Bay Time Series
- El Niños during 92-93 and 97-98
- Transition from El Viejo to La Vieja
- The age of dinoflagellates?
How will a warmer world change atmospheric forcing and ocean circulation and productivity? First guesses

• It may drive stronger coastal upwelling by increasing the land sea temperature gradient

• It may weaken the trade winds by weakening the high to low latitude temperature gradient
Will Ocean Productivity Increase due to Warming? Predictions are ....

Will this be passed on to higher trophic levels?  
Will this draw down more CO₂ or less?
Longer Centennial changes
We can learn from the sediments

And the oxygen story

Gutierrez et al. - Paleopeces
Summary, during Little Ice Age ocean off Peru high oxygen (low fish), low oxygen (high fish) after
The low oxygen expanded southward in to Chile, what about the recent record (~50 years)

- California
- Peru
Long-Term Trends in Dissolved Oxygen off California

-2.1 μmol/kg/y

ΔZ_{mean} = -41 m  ΔZ_{max} = -92 m

Expansion of Low-Oxygen Habitat
In situ oceanographic data off Peru shows that ocean losing nitrate (oxygen is zero so nitrate electron donor) and increasing productivity
Stramma et al in Science on expanding low oxygen
It appears as if the tropical (eastern Pacific) low oxygen regions reformed after the Little Ice Age and continue to expand (and increase in productivity?) today.

Are there biological indicators of this expansion?
The Hake off Peru has retreated and gotten more concentrated

1966-1977
1978-1987
1988-1995
1996-2001

Hake in Ecuador

Index of Hake concentration
Post 1997/98 expansion of *Dosidicus gigas* range

**JUMBO FLYING SQUID LANDINGS 1980 - 2000**

- Tons: 0, 2000, 4000, 6000, 8000, 10000, 12000, 14000, 16000, 18000, 20000

---

**Tracy Arm (Sitka), AK**
- July 2005

**Outer Coast, BC**
- Sept. 2005

**La Jolla Cove, CA**
- July 2002

---

**The Carmel Pine Cone**

**Rescues struggle to save amazing giant squid**

Little-known candidates reveal views on water

---

**1998+ Monterey Canyon**

**2002-3 La Jolla to Menocino**

**1970+ Guaymas Basin**

---

**Tropic of Cancer**
Summary

- Low oxygen in eastern Pacific as we know today reformed after the Little Ice Age
- Expansion continues today?
- Low oxygen = low pH
- Anthropogenic influences pushing in the same direction (i.e. warming, stratification reducing ventilation, CO2 absorption < pH)
- Peru and Chile, a window into the future?
More conclusions

• Sixty four thousand million billion dollar (euro?) question: are changes natural or human-induced?
• Only matters if can be used to pressure governments into reducing emissions
• We have to deal with the consequences irrespective of driver
• New coupled observation, modeling and decision support systems required
Observations

Basic Ecosystem Rules

Model

Management Practice
Adaptation and mitigation

• Reduce emissions

• Change marine use strategies – e.g. aquaculture vs. fishing

• Geoengineering options – “Neutralize” ocean, ocean fertilization

• New coupled observation, modeling and decision support systems required to decide which options are better
Known and unknowns

• No doubt ocean will be more acidic
• Consequences uncertain
• On the decade scale world will be warmer
• Complex development/consequences uncertain
• Reducing emissions needed but will not solve problem
• Adaptation and mitigation will be needed