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

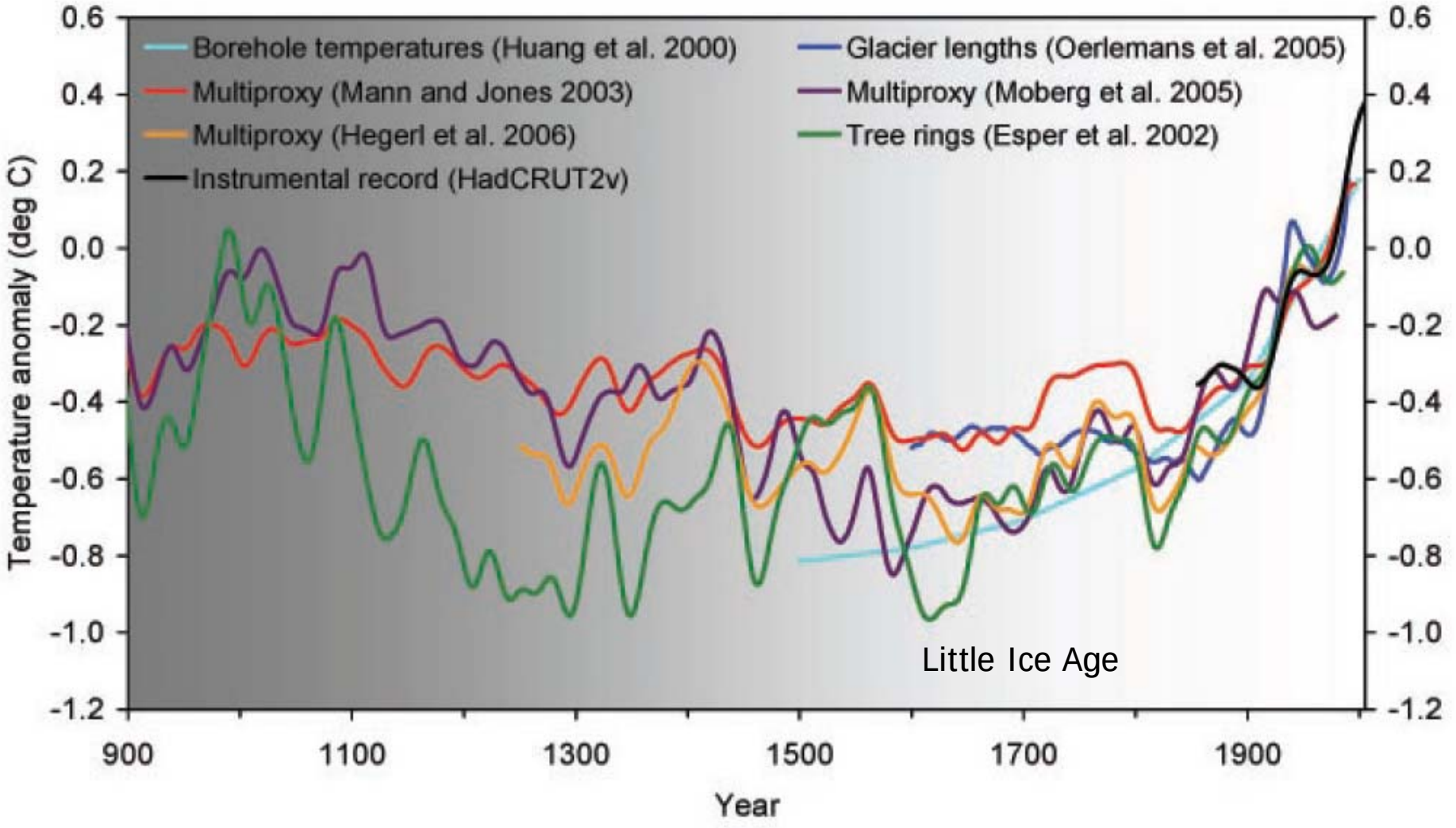
Continued

- 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)

US National Academies Report 2006



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.

Ocean Acidification

The role of the ocean in moderating the atmospheric CO_2 increase has been recognized (by scientists) for a very long time. Revelle and Suess (1957) first explicitly calculated the partitioning of CO_2 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 CO_2 levels have received great attention, the direct effects of the enormous CO_2 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 CO_2 is now over 1 million tons CO_2 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 ……

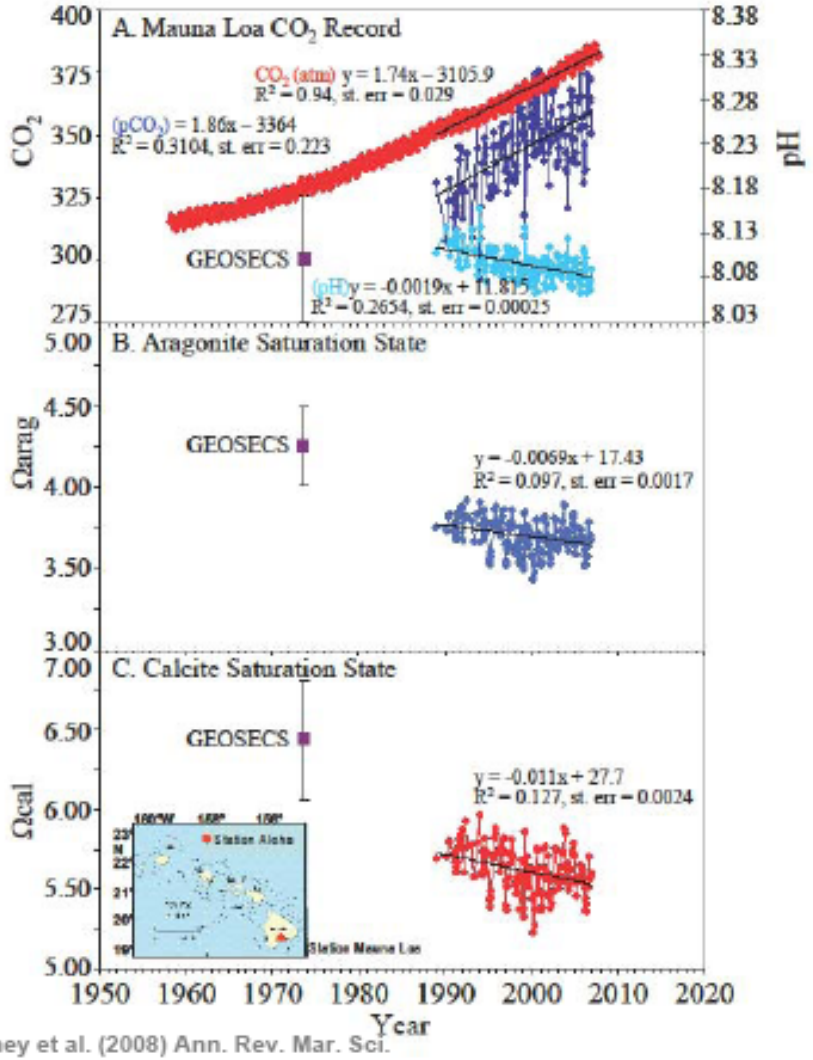
- CO_2 in oceans increases with increasing atmospheric CO_2: this is certain!

Observed trends indicate possible impacts already emerging in:

- Shell weight decrease with time in Pteropods, Foraminifera and Brachiopods

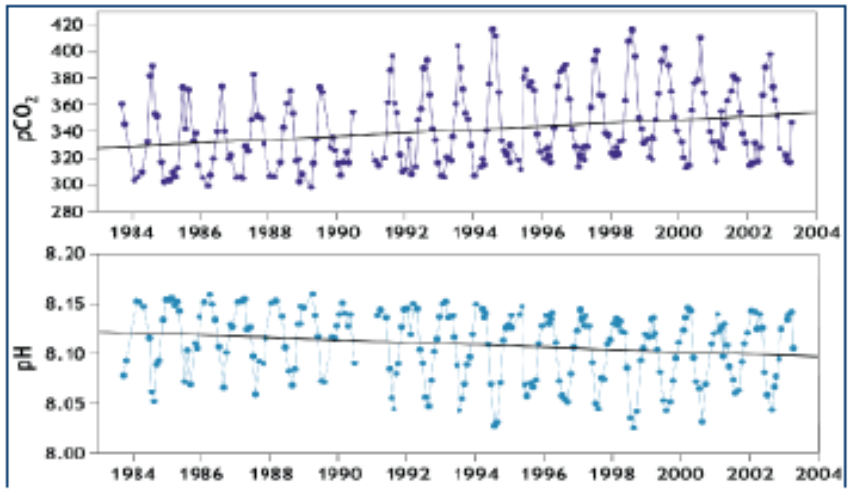
- Reduced calcification in coral reefs from GBR over last 2 decades

Pacific - HOTS

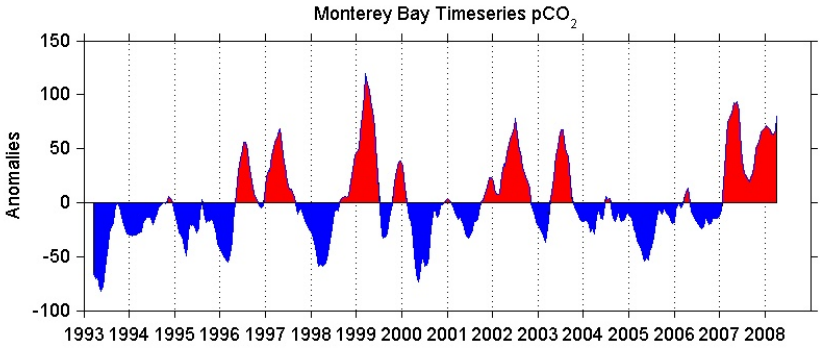


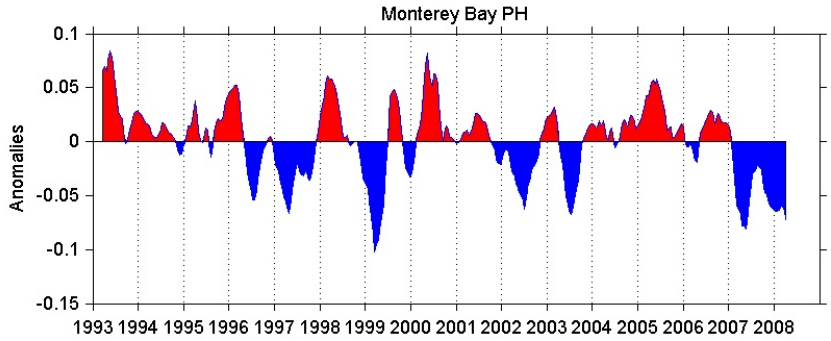
Doney et al. (2008) Ann. Rev. Mar. Sci.

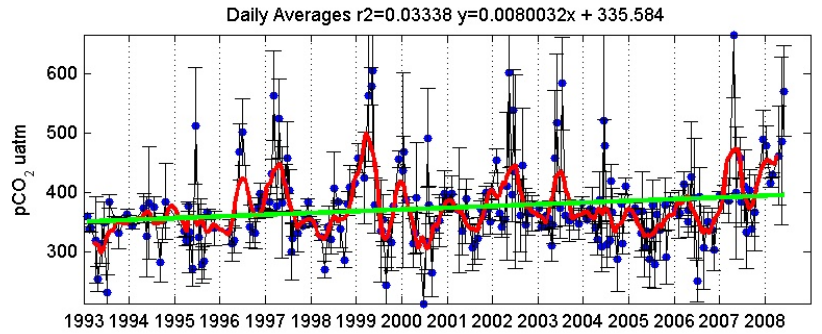
Atlantic - BATS

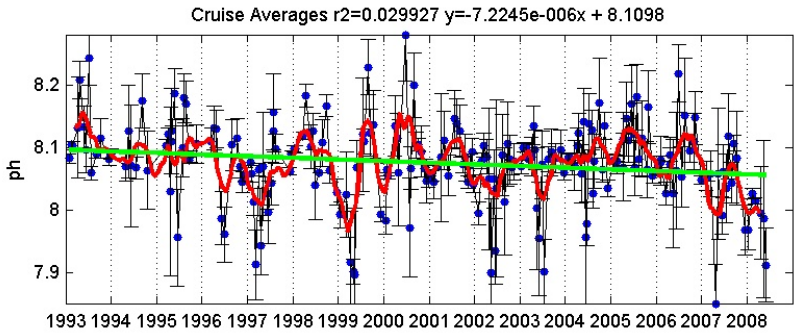


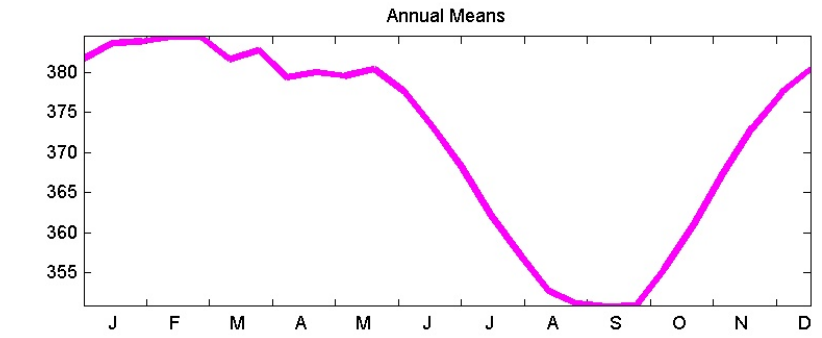
Monterey Bay, California, coastal regions much more variable

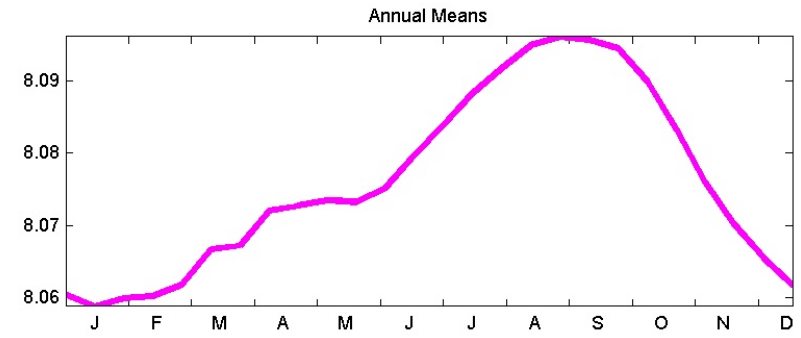


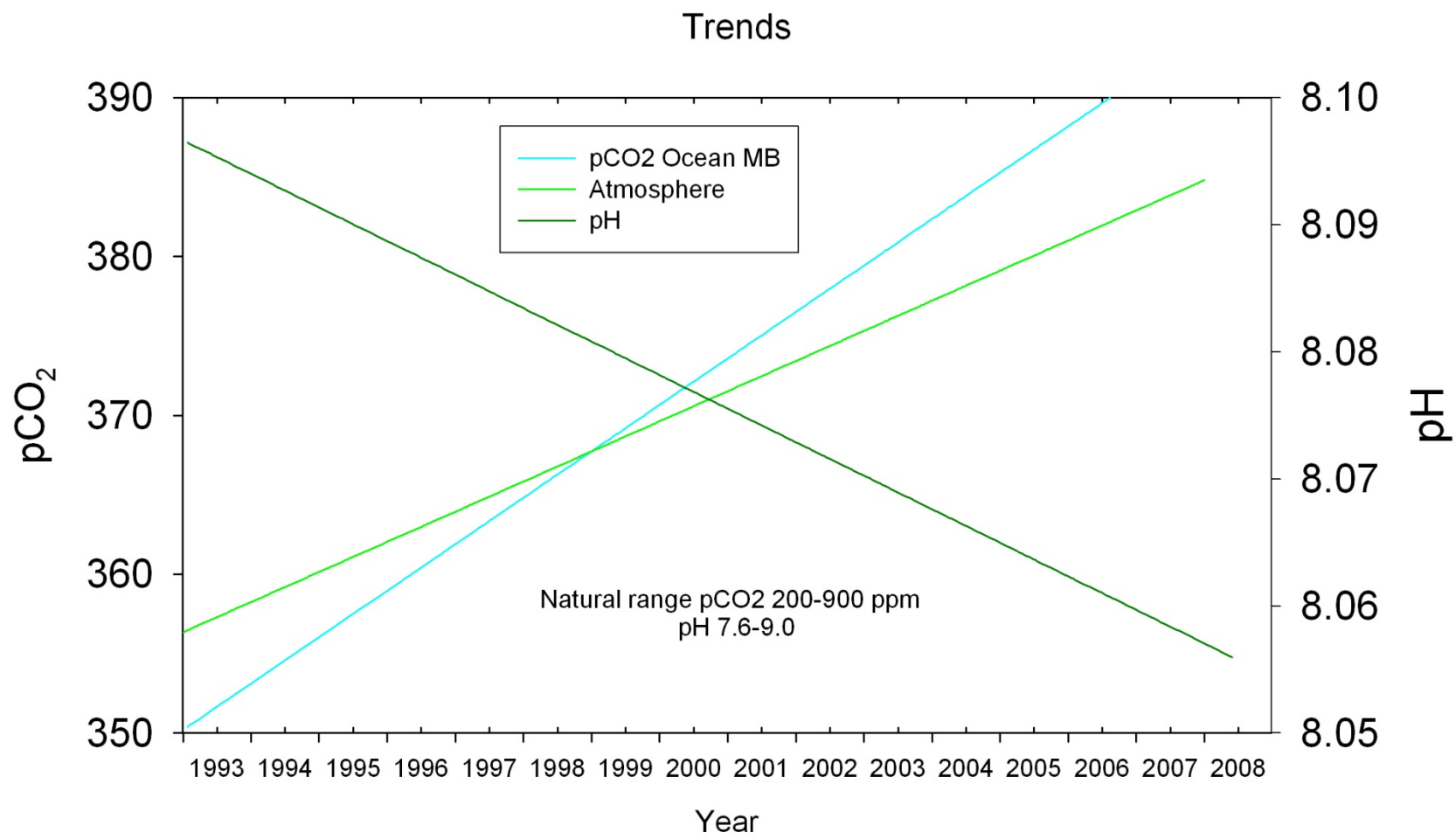






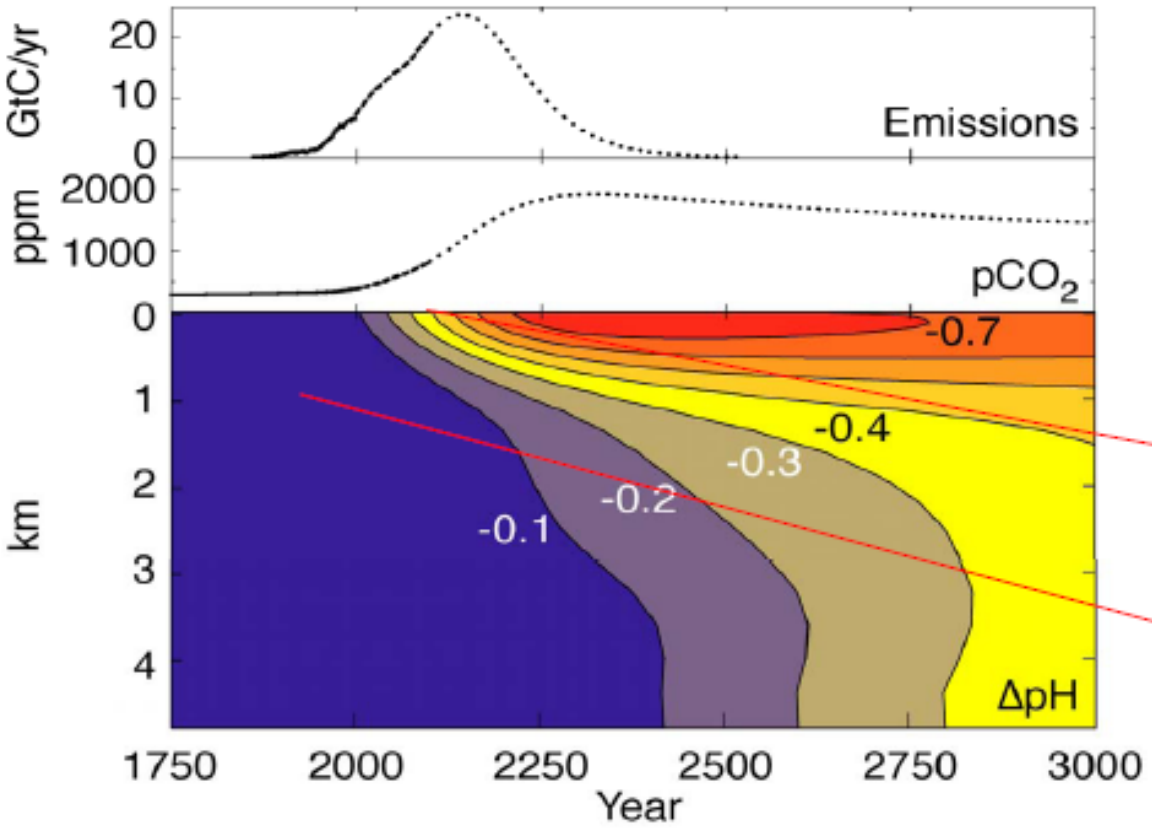





Trends
pCO2 Ocean MB
Atmosphere
pH
Natural range pCO2 200-900 ppm
pH 7.6-9.0
pCO2
pH
Year
390
380
370
360
350
8.10
8.09
8.08
8.07
8.06
8.05
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008

The Ocean Acidification Timeline …….

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



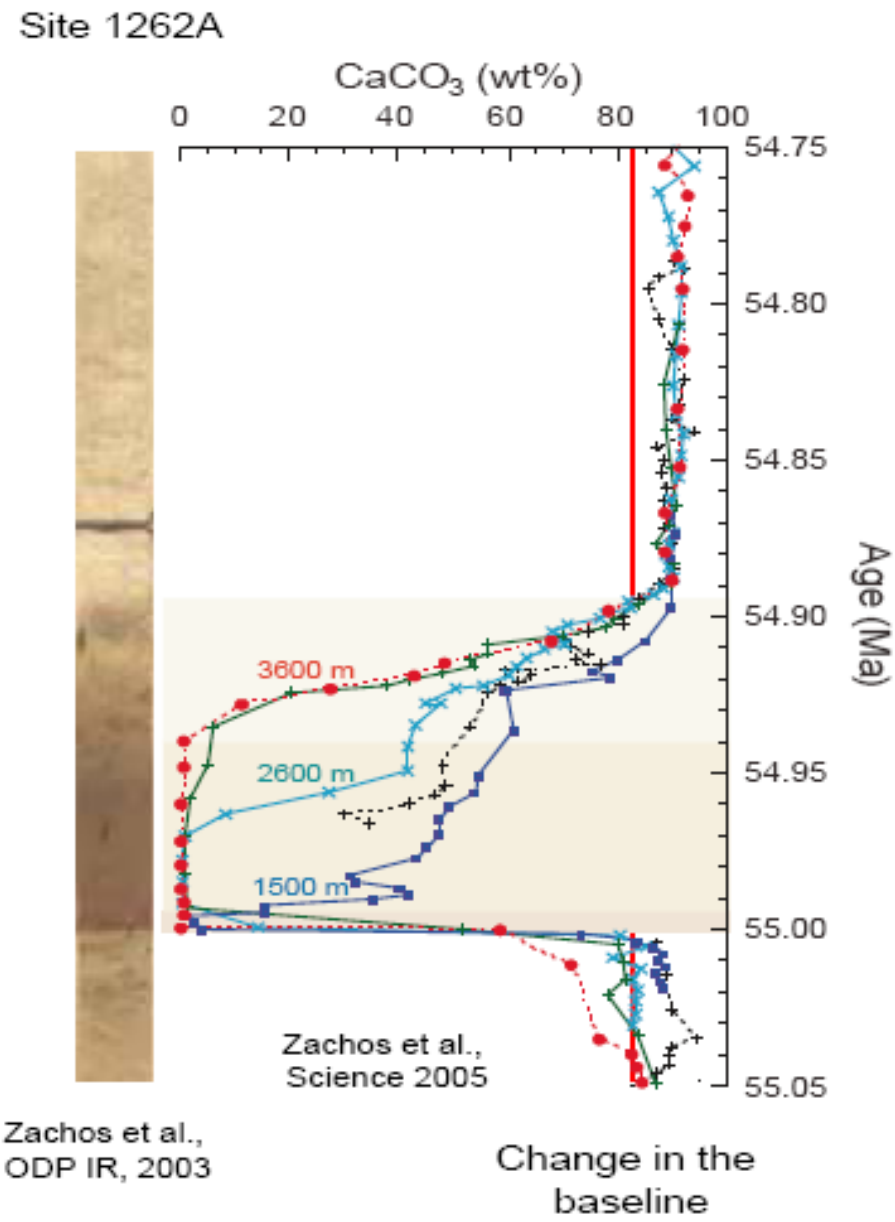
Caldeira & Wickett 2003, Nature: A simulation of changes in ocean pH assuming continued usage of known fossil fuel reserves

Oceans are an important reservoir for CO_2 with c. 30% of CO_2 produced from fossil fuel burning & land-use change taken up by oceans (Sabine et al. 2004 *Science*) – effectively buffering climate change

CO_2 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 CO_2 - 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

end of acidification

Benthic foraminiferal mass extinction

onset of acidification

"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?

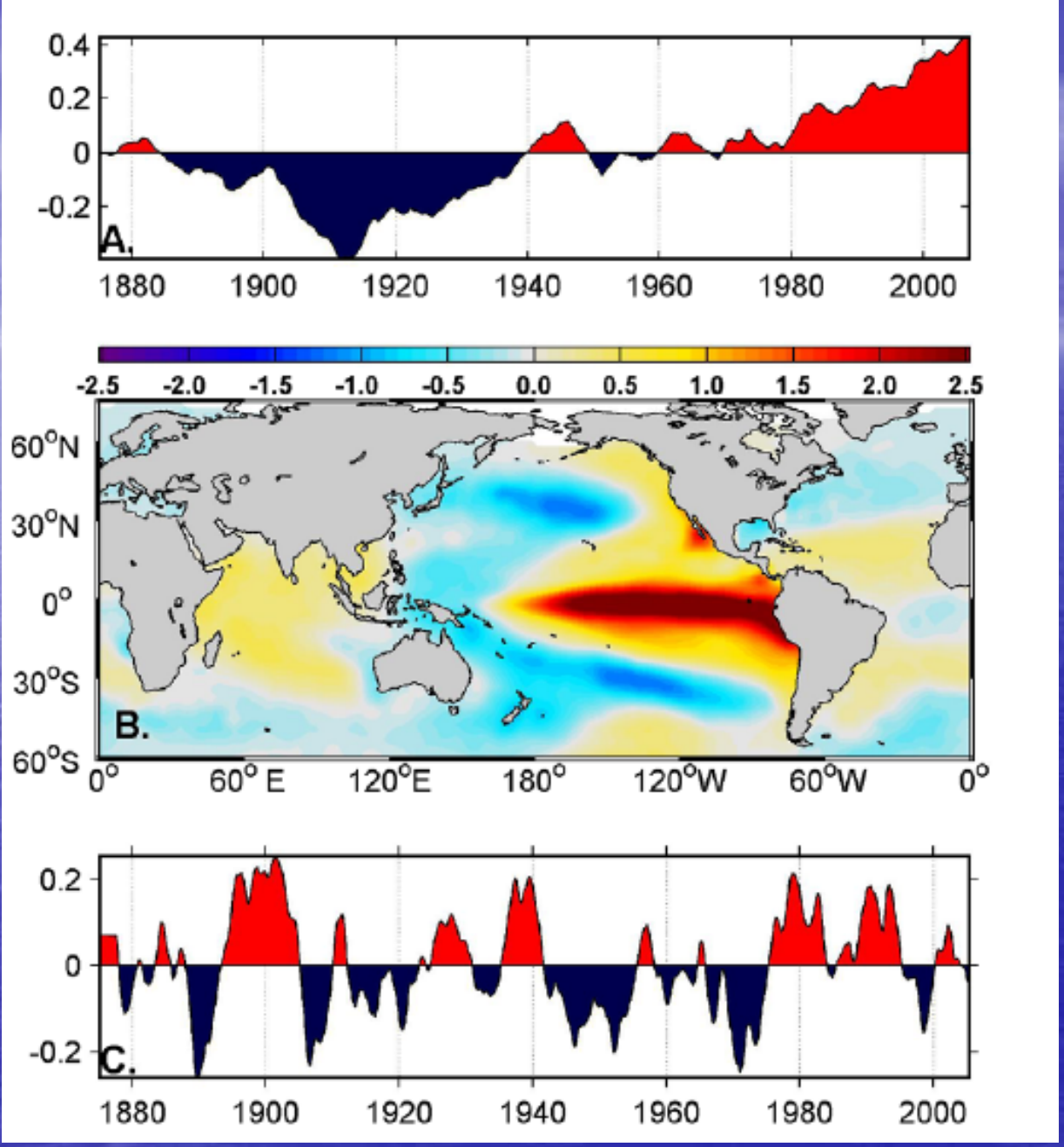
- Where are we on long term changes in the ocean?
- What are the sources of natural variability?
- What will the future bring? Uncertainty!

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)

Change

Varia-
bility



Two
Primary
States

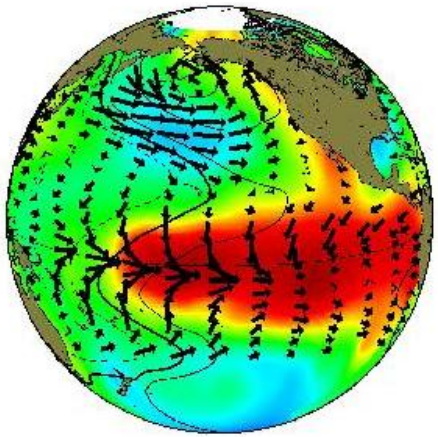
Chavez et al. 2008

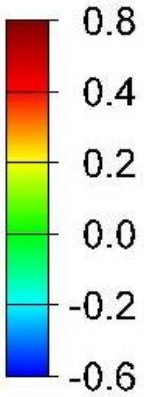
It is a familiar story

Once ever 3-8 years

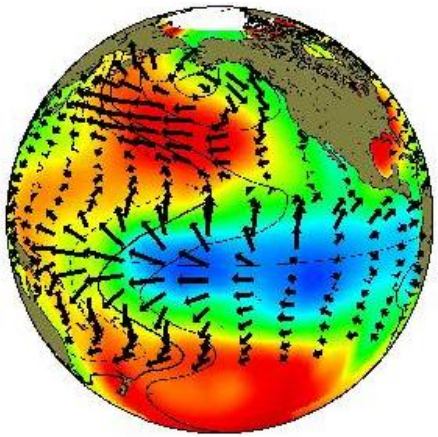
El Niño

Child

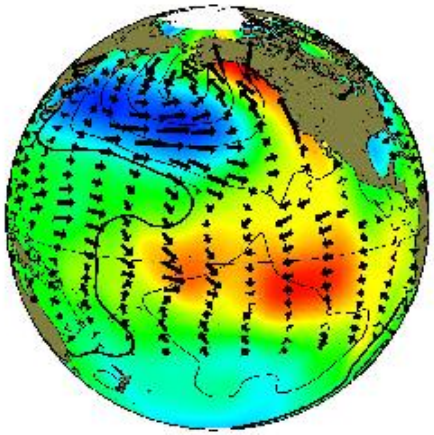




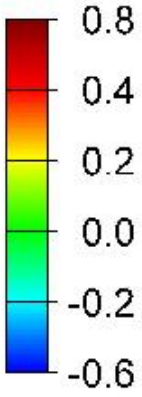
La Niña



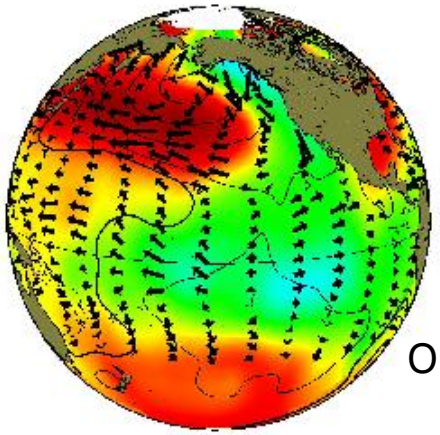
El Viejo



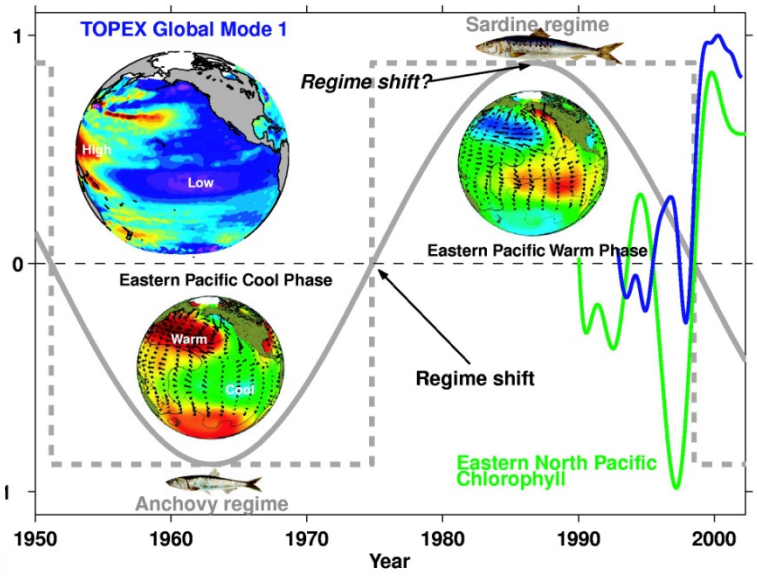
Parent



La Vieja

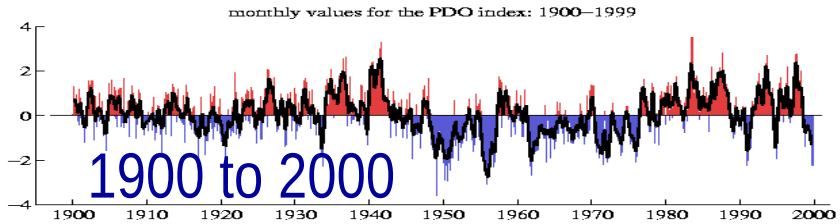


El Viejo



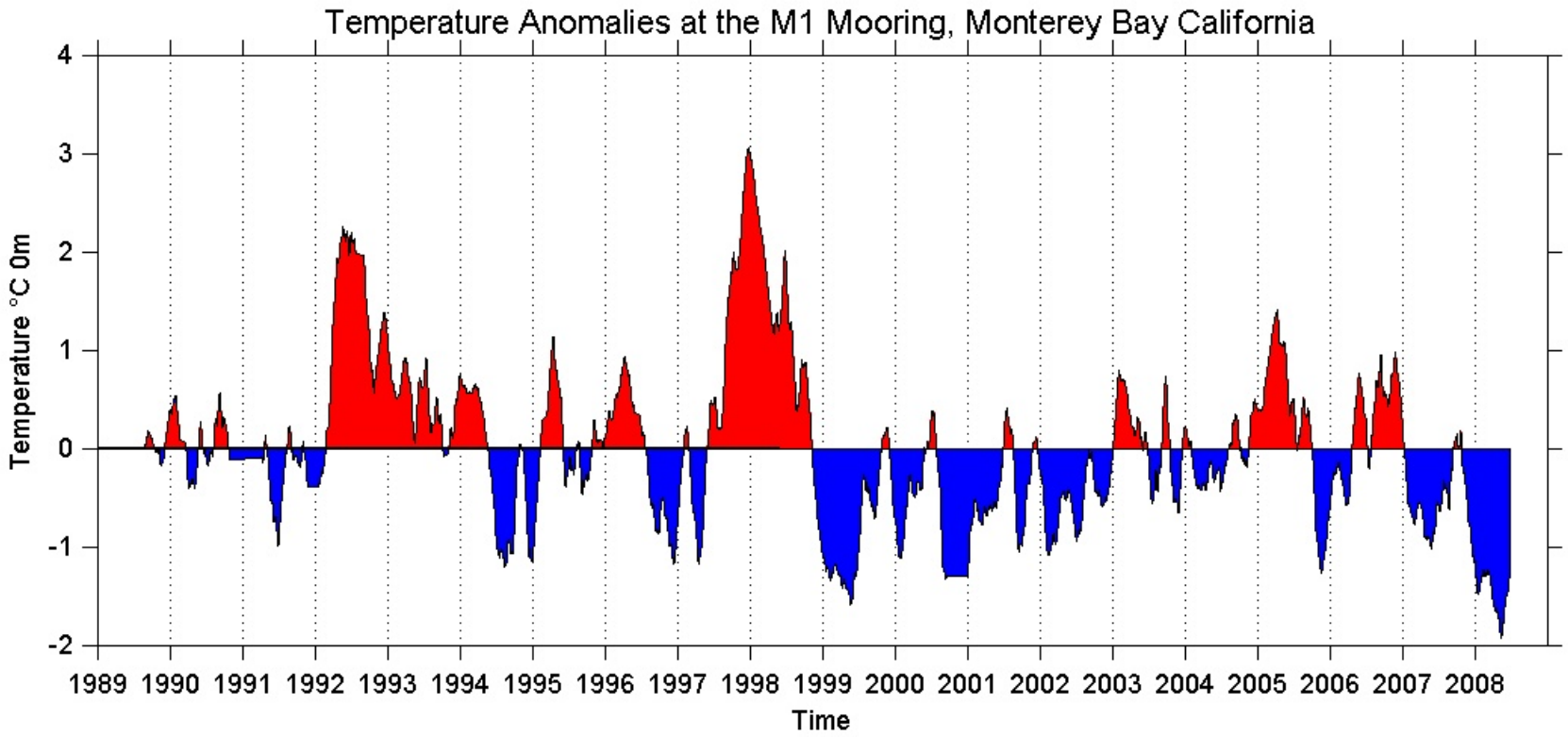
La Vieja

Once ever 25-40 years



1900 to 2000

Record cold temperatures during 2008

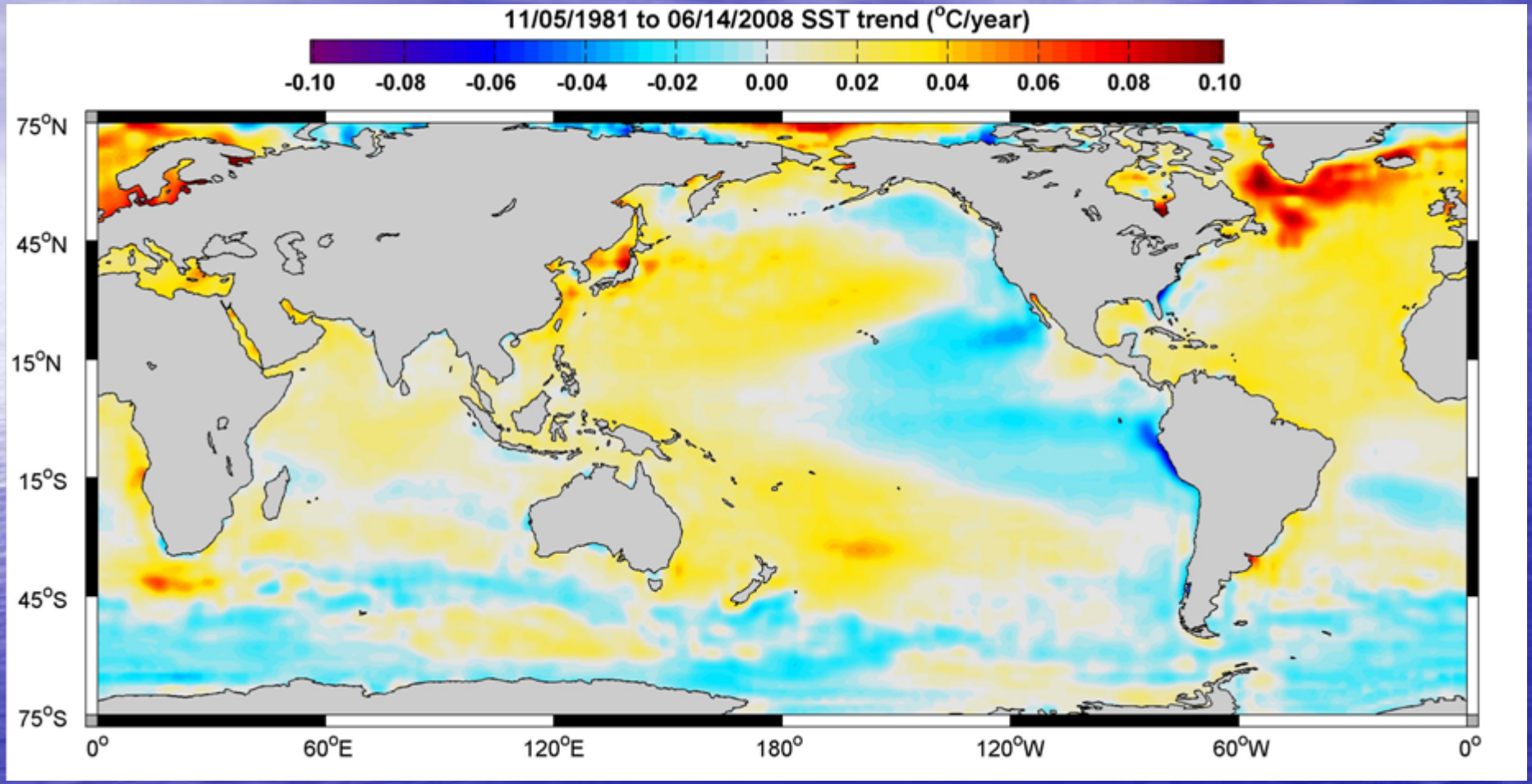


Note: 60 point moving average applied to daily averaged values.

Monterey Bay Aquarium Research Institute
Contact: reiko[at]mbari.org

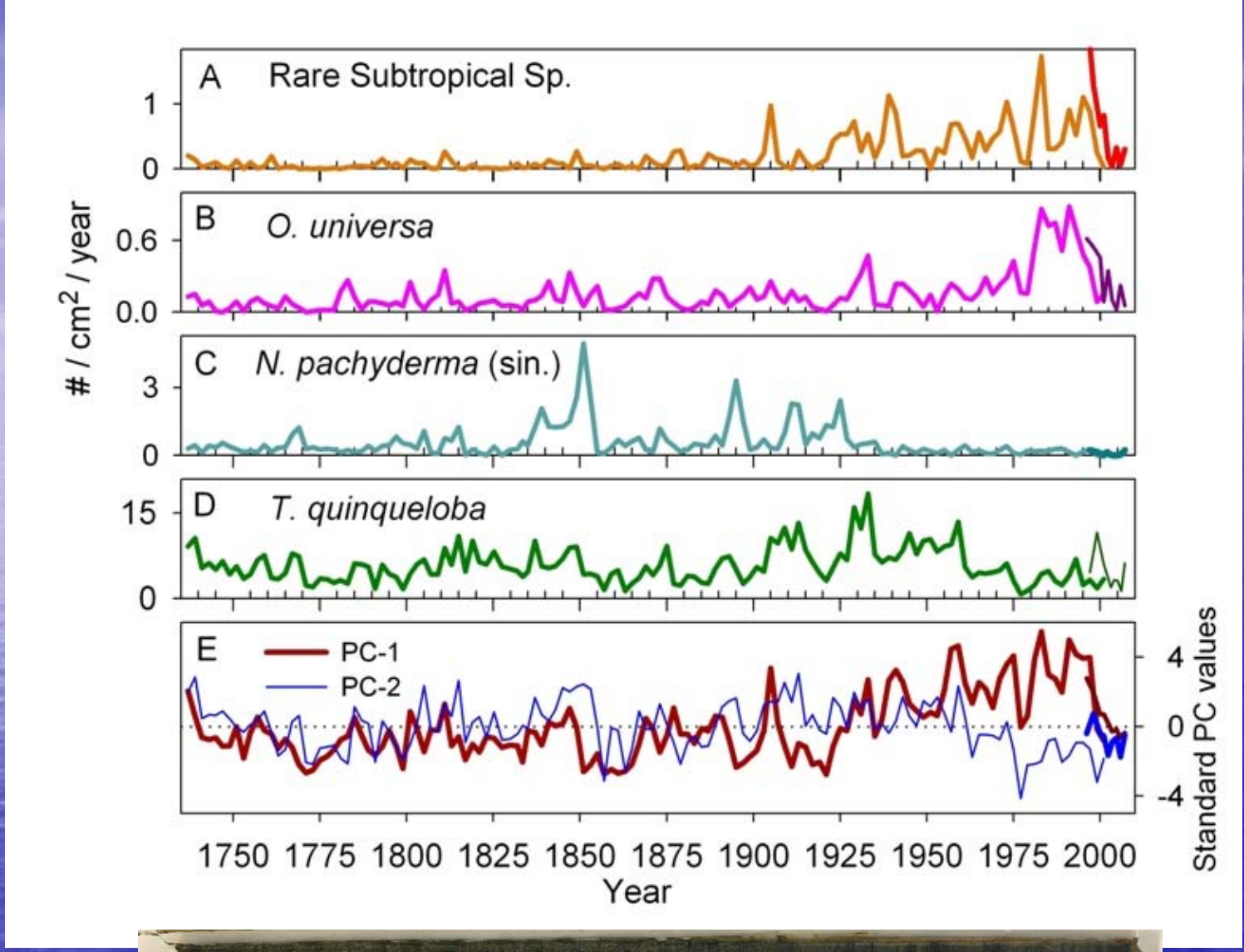
Updated:23-Jun-2008

Part of a larger spatial scale trend



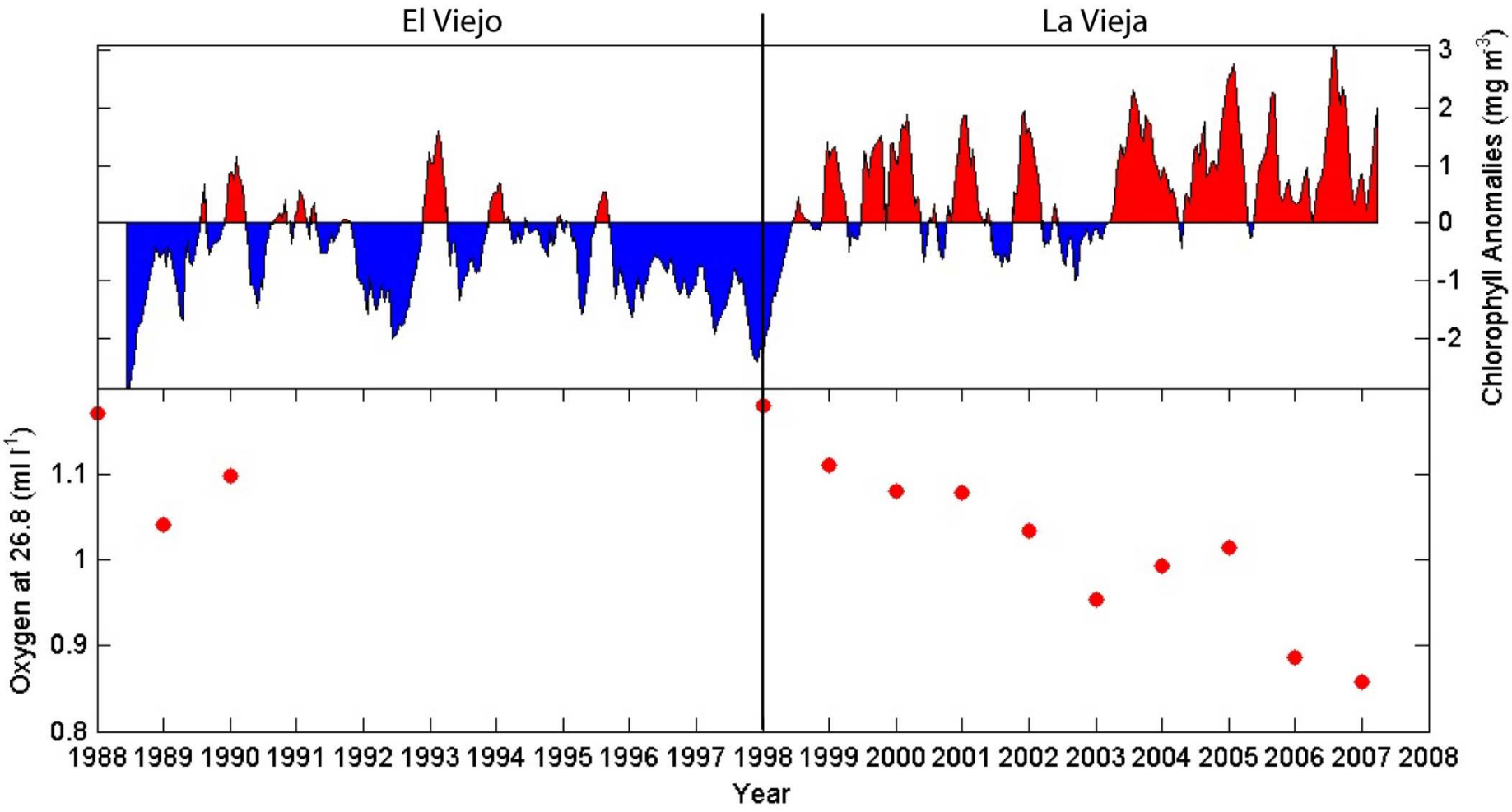
Effects will not be uniformly distributed

Chavez et al. 2008

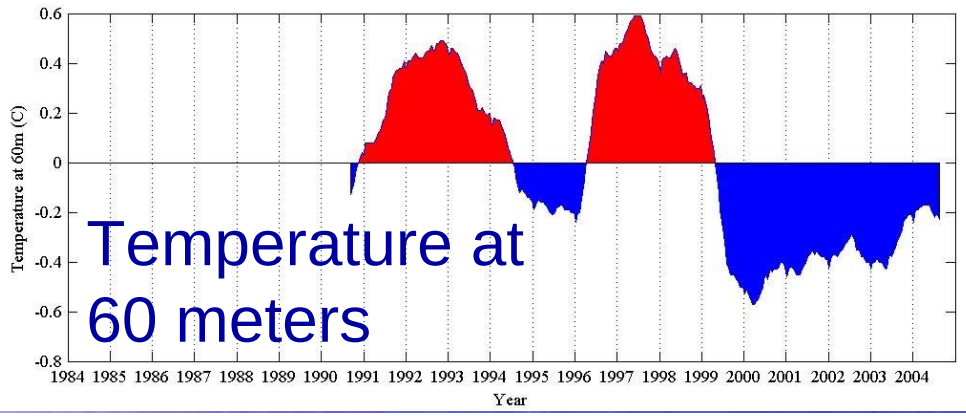

A Rare Subtropical Sp.
1
0
B O. universa
0.6
0.0
C N. pachyderma (sin.)
3
0
D T. quinqueloba
15
0
E
PC-1
PC-2
4
0
-4
/ cm2 / year
Standard PC values
1750 1775 1800 1825 1850 1875 1900 1925 1950 1975 2000
Year


Global warming reversed?

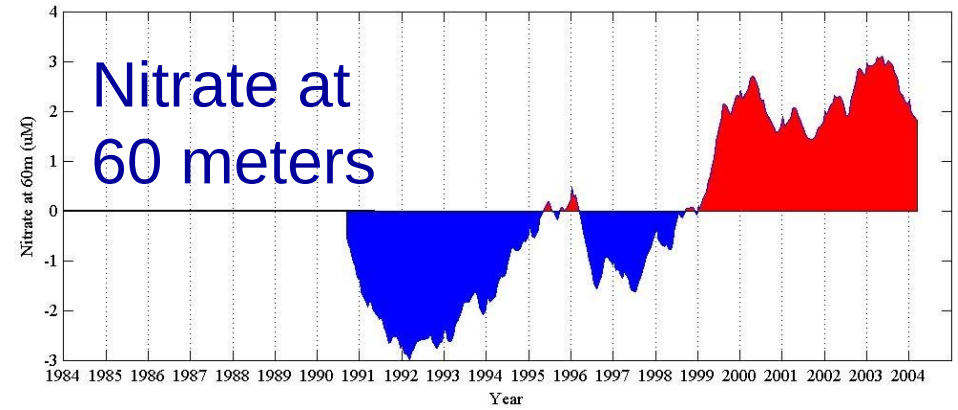
Are oxygen levels in Monterey Bay responding to increased productivity during La Vieja or are there other processes at play?



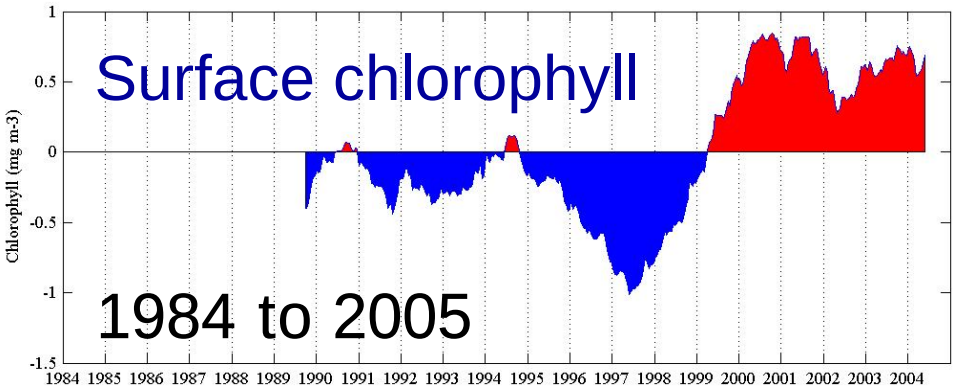
Greening correlated with cooling and increase of nutrients at depth



Monterey Bay
Temperature
at Depth



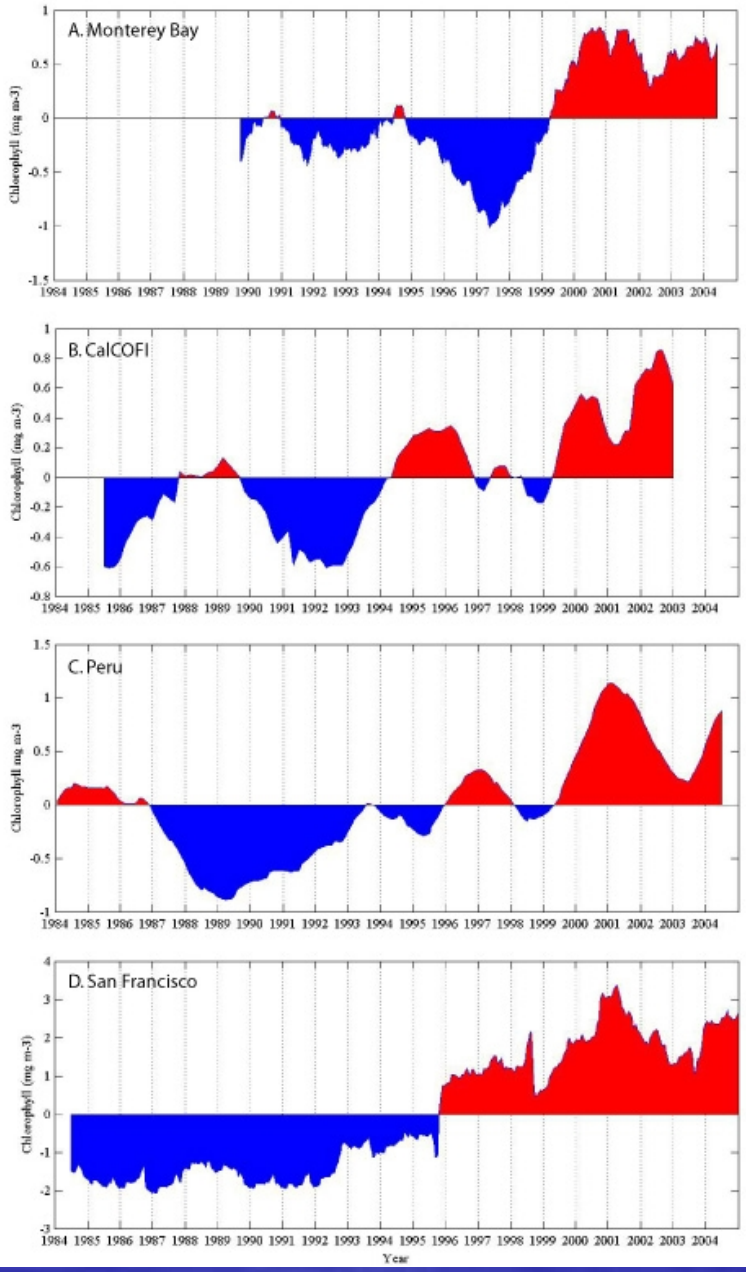
Monterey Bay
Nitrate at Depth



Monterey Bay
Surface
Chlorophyll

1985 1990 1995 2000 2005

Patterns consistent in many time series



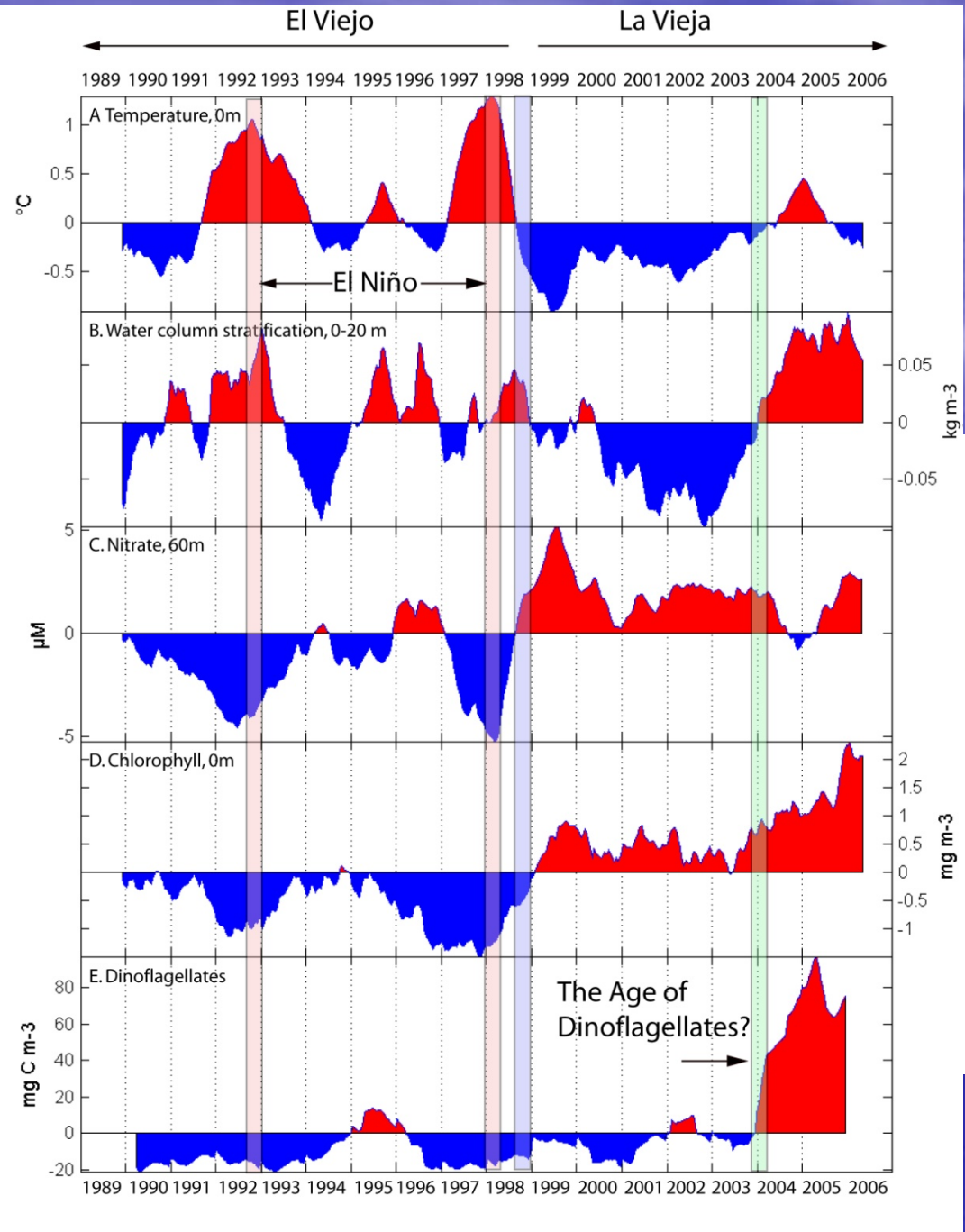
1985 1990 1995 2000 2005

Monterey Bay chlorophyll

Southern California chlorophyll

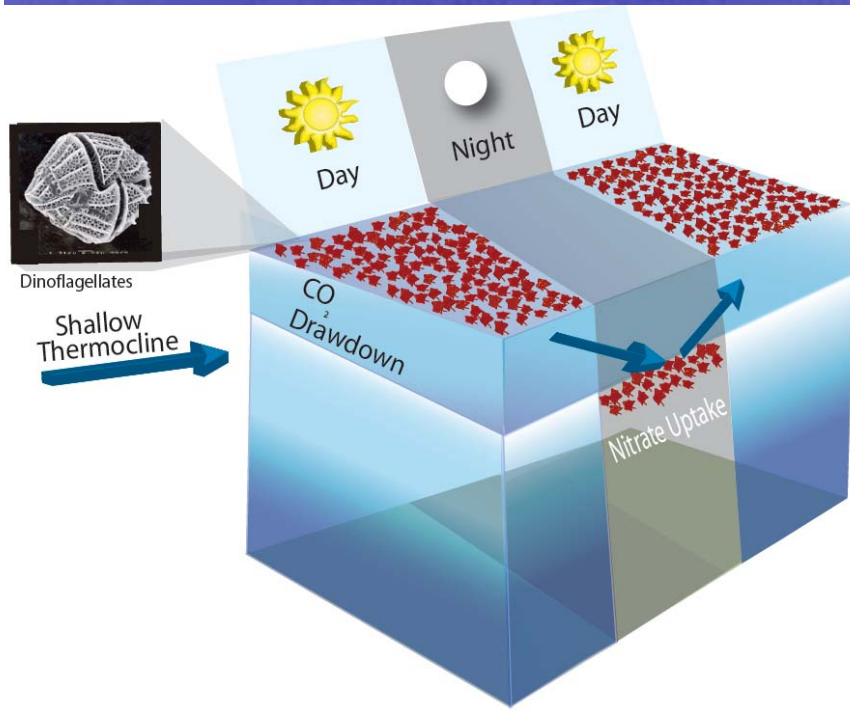
Peru chlorophyll

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?

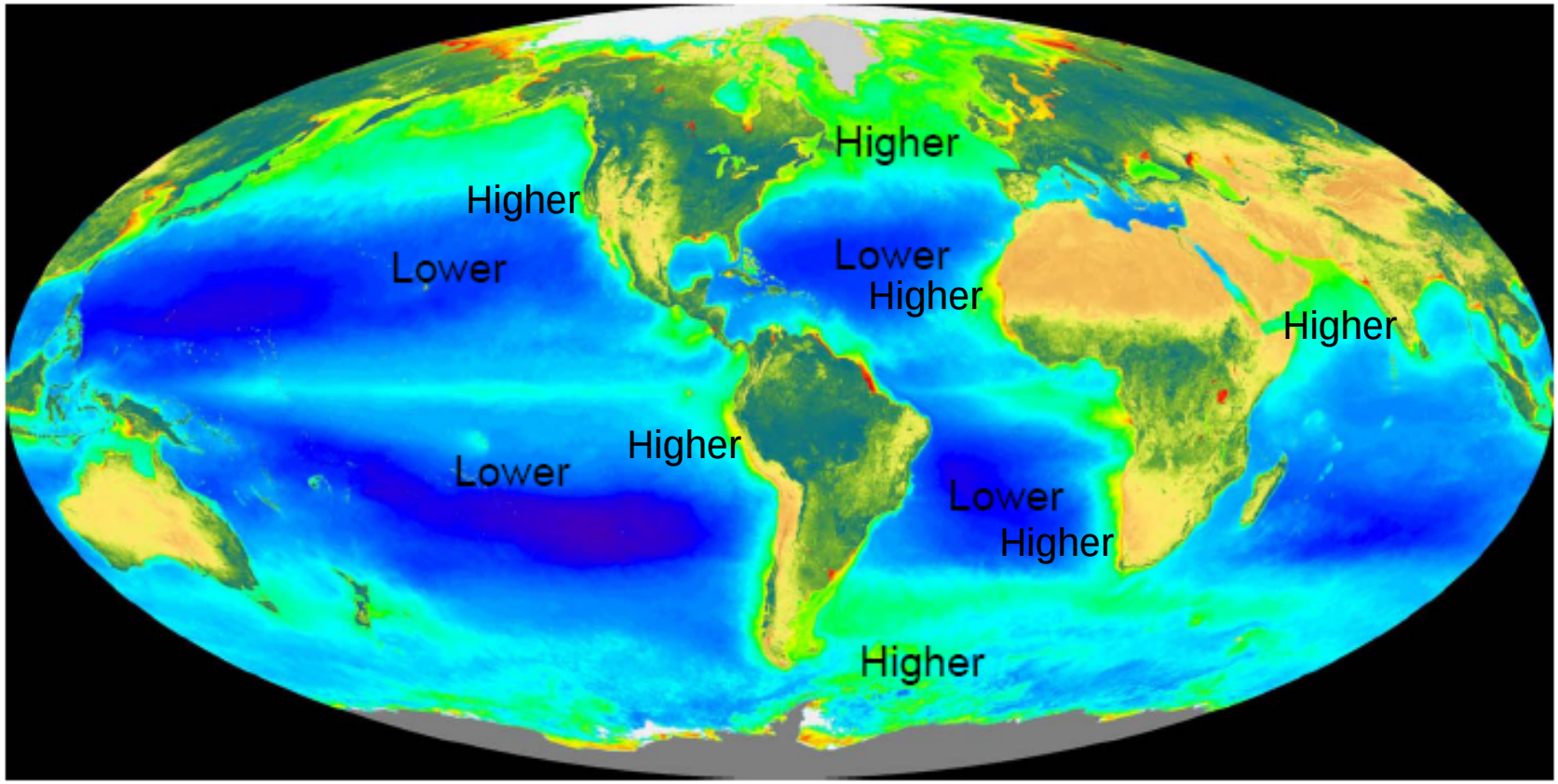


1990 1995 2000 2005

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 ….

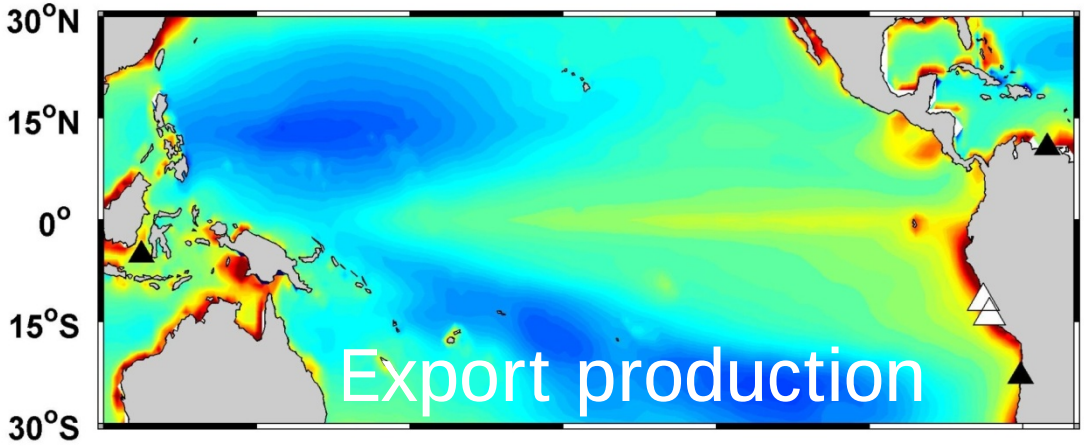


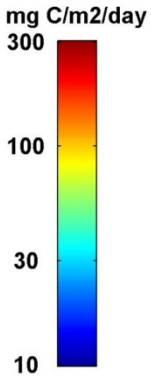
Will this be passed on to higher trophic levels?

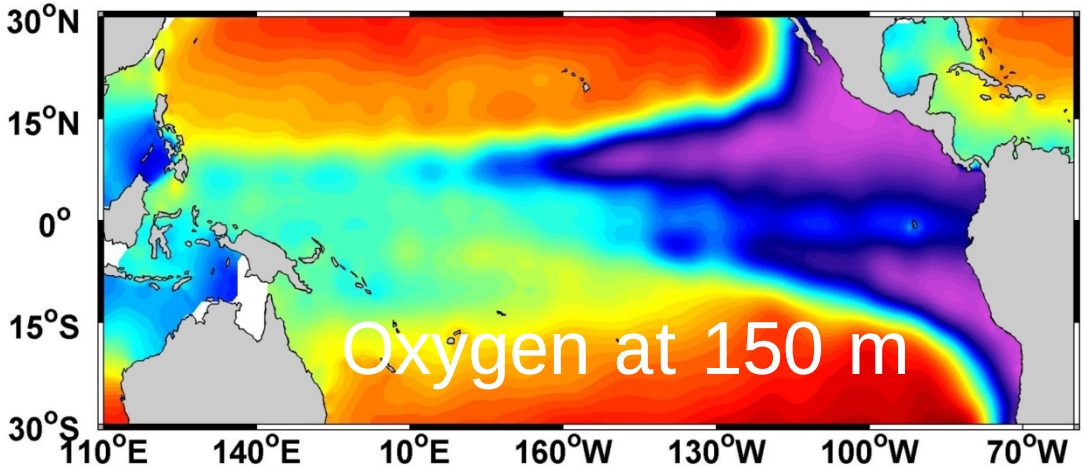
Will this draw down more CO_2 or less?

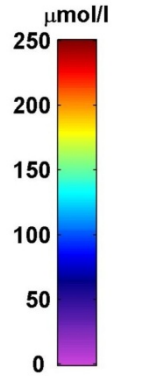
Longer Centennial changes

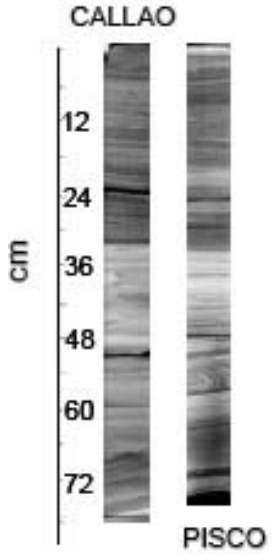
We can learn from the sediments







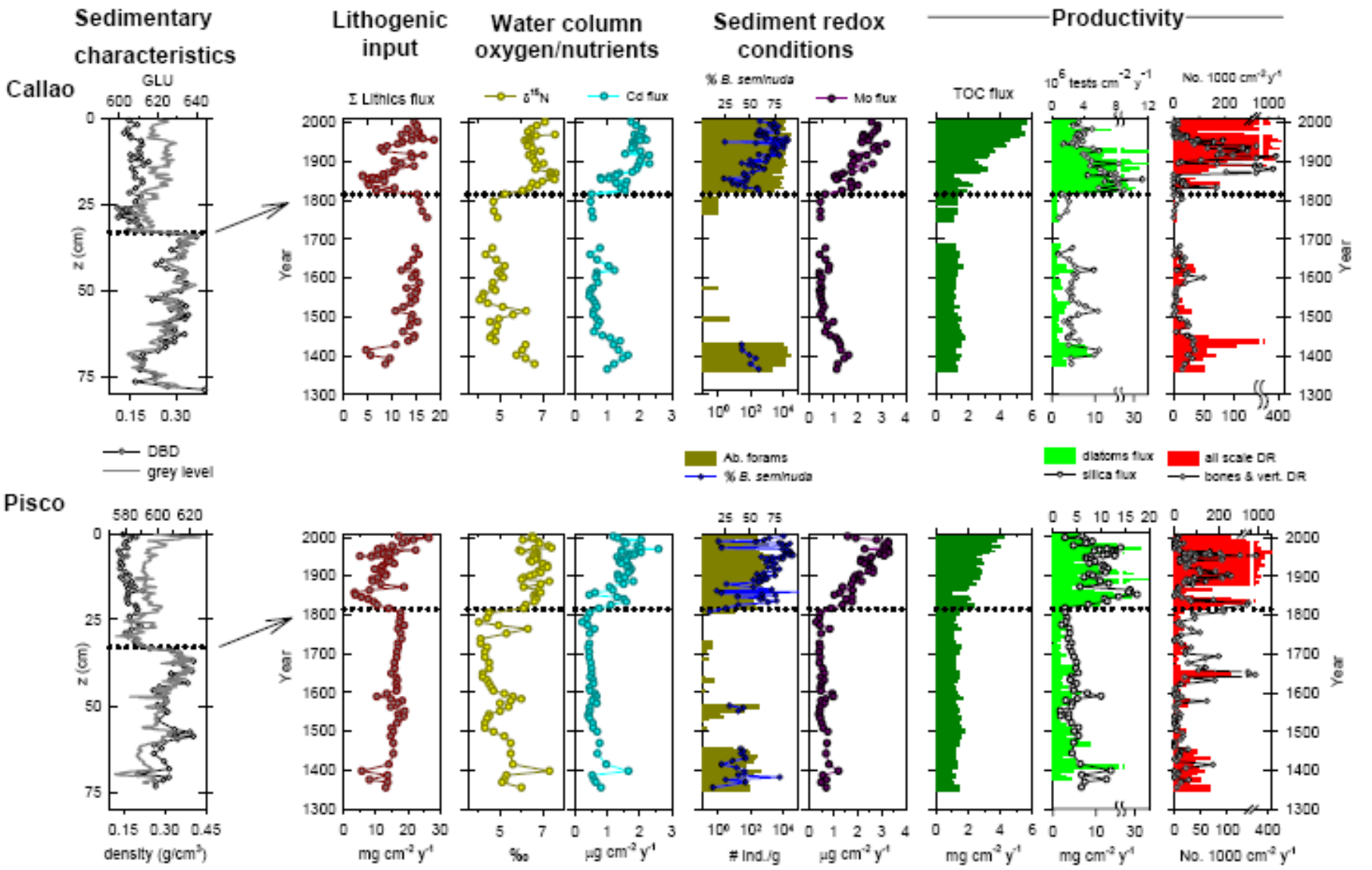




And the oxygen story

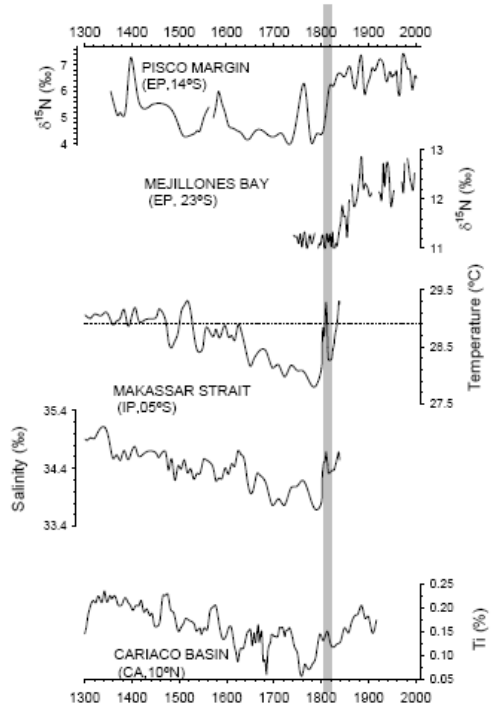
Gutierrez et al. - Paleopeces

Summary, during Little Ice Age ocean off Peru high oxygen (low fish), low oxygen (high fish) after



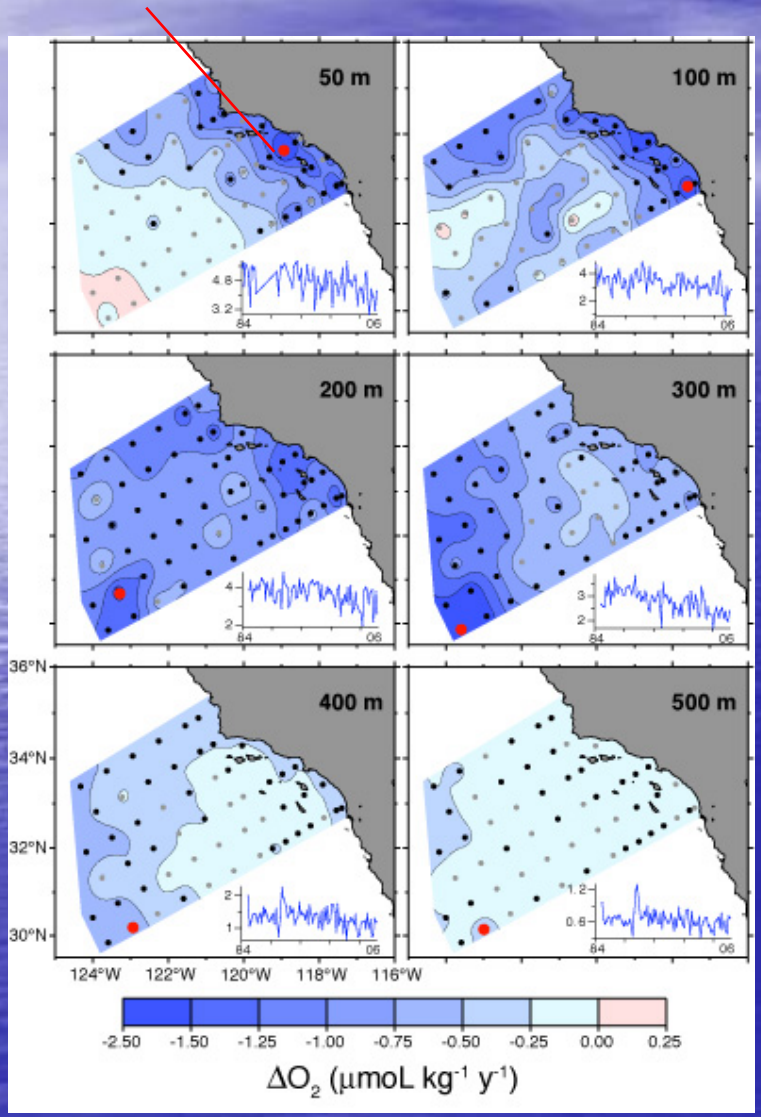
The low oxygen expanded southward in to Chile, what about the recent record (~50 years)

- California
- Peru



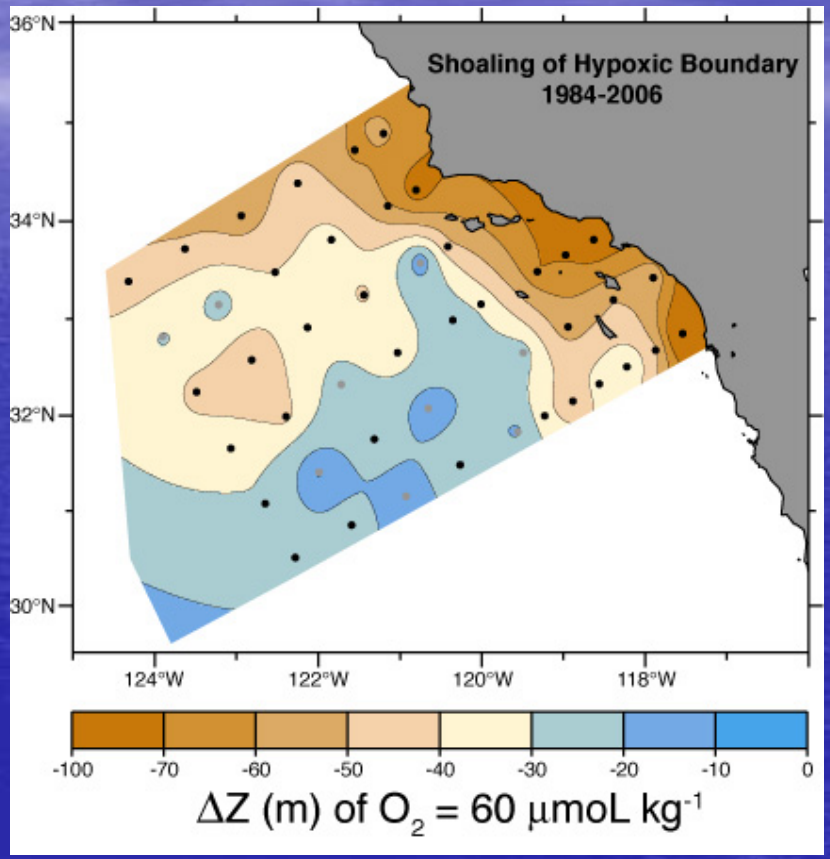
Long-Term Trends in Dissolved Oxygen off California

-2.1 μmol/kg/y



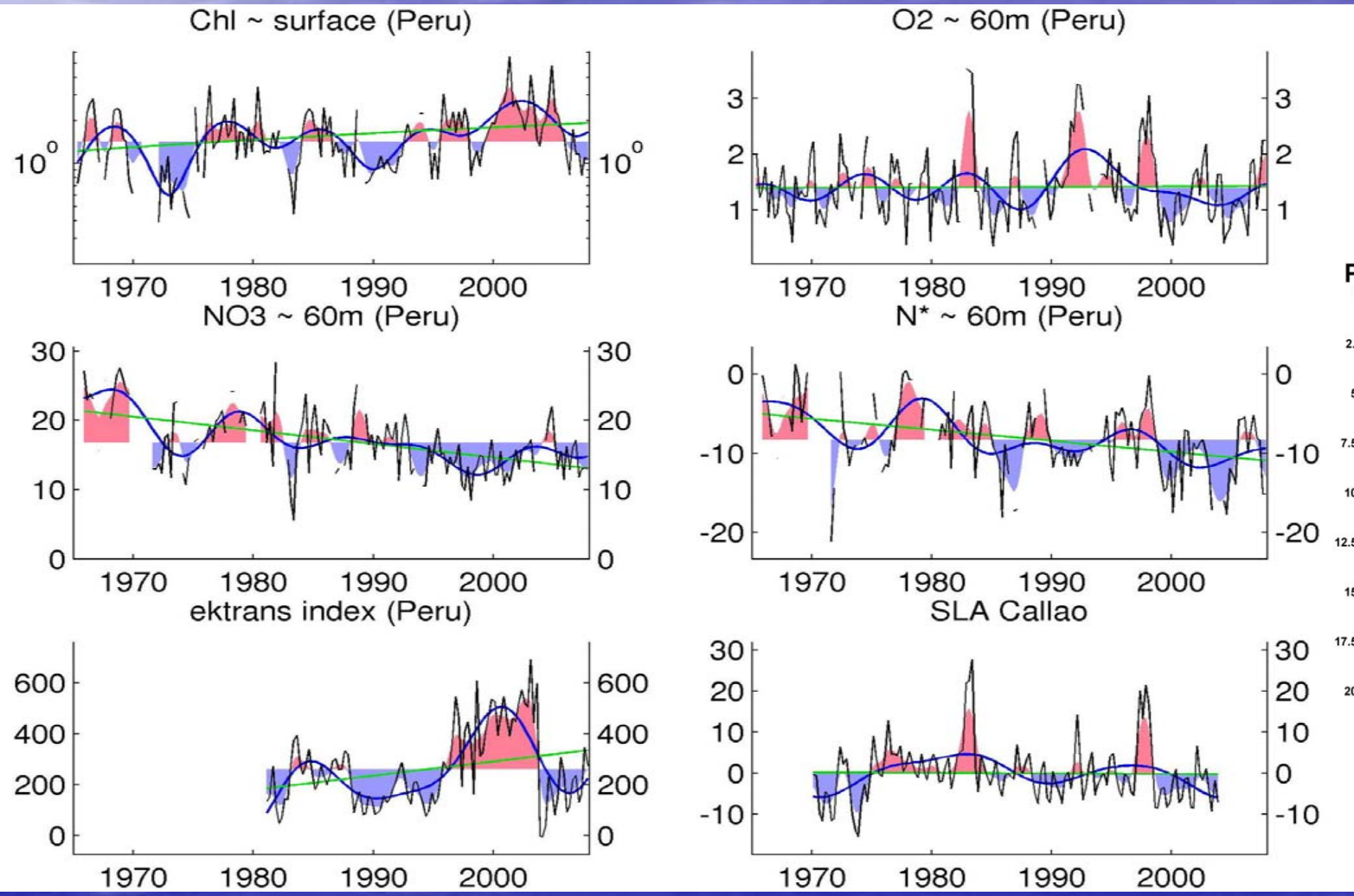
ΔZ_{mean} = -41 m

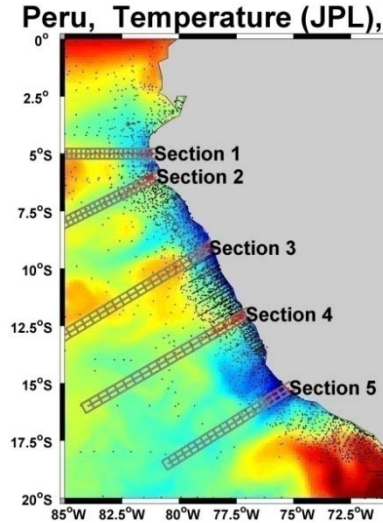
ΔZ_{max} = -92 m



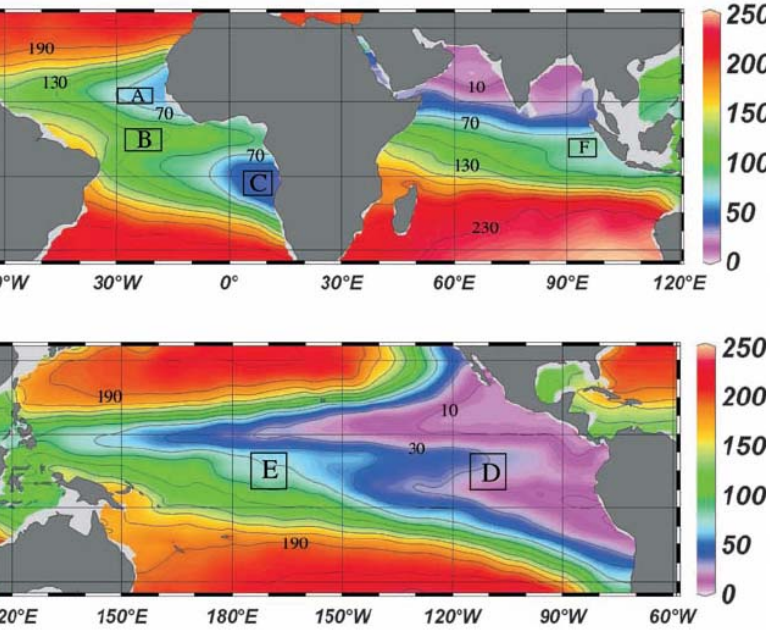
Expansion of Low-Oxygen Habitat

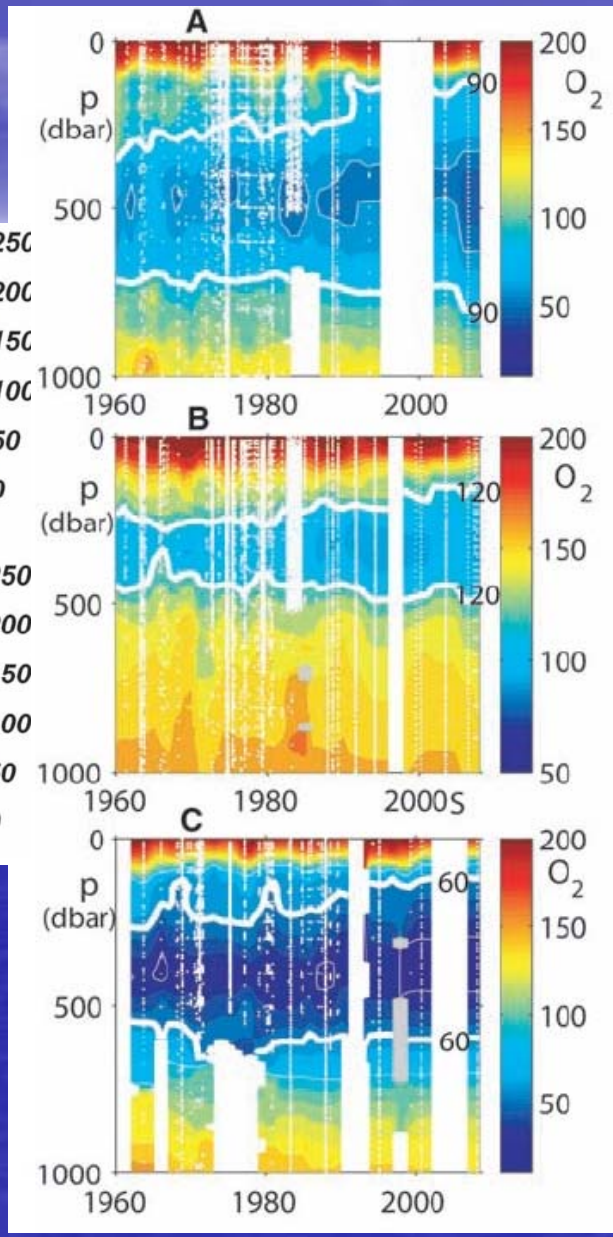
In situ oceanographic data off Peru shows that ocean losing nitrate (oxygen is zero so nitrate electron donor) and increasing productivity

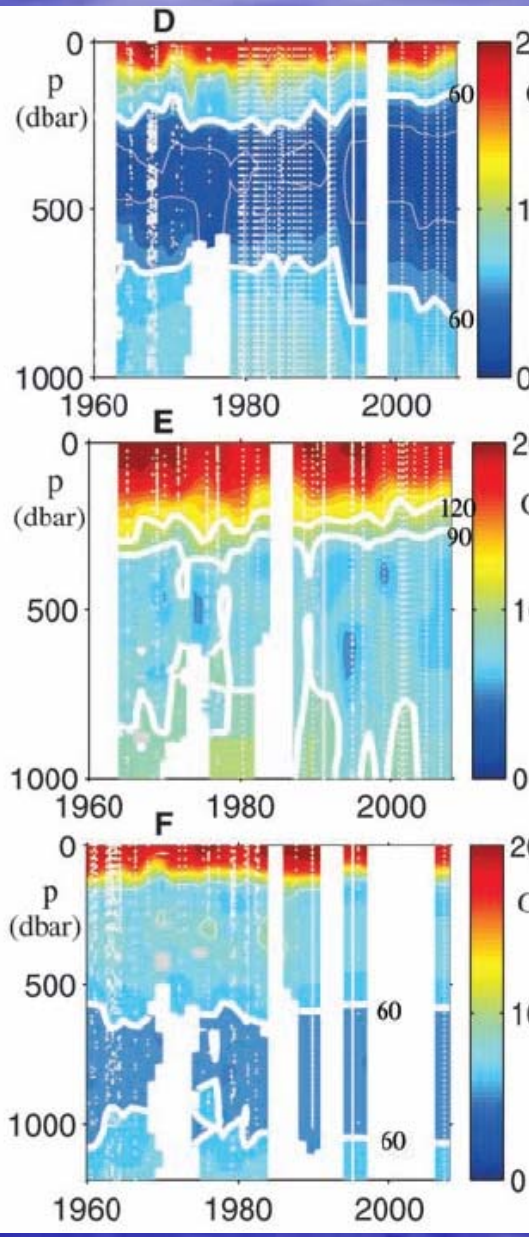




Stramma et al in Science on expanding low oxygen



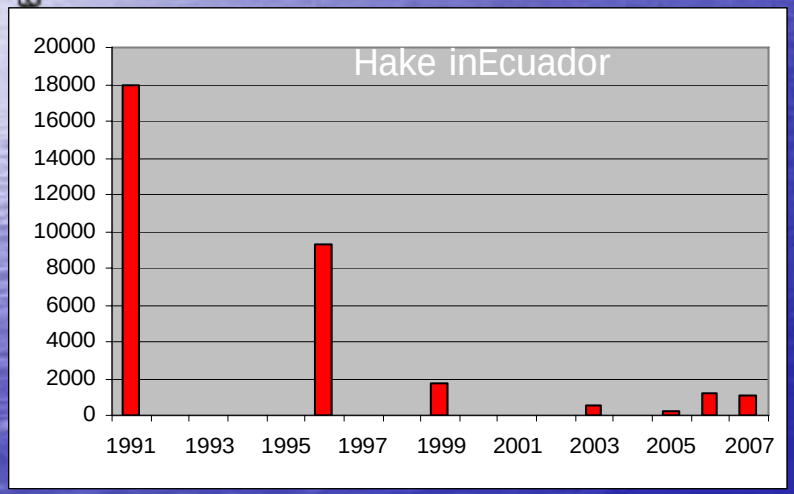


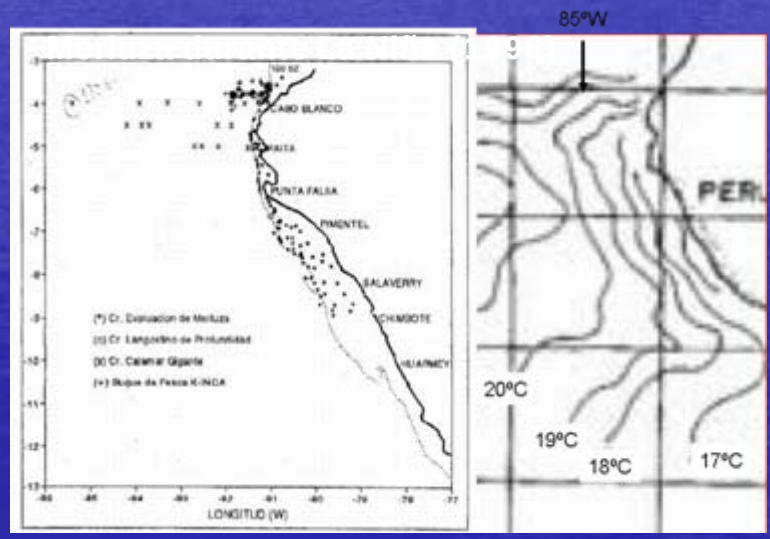


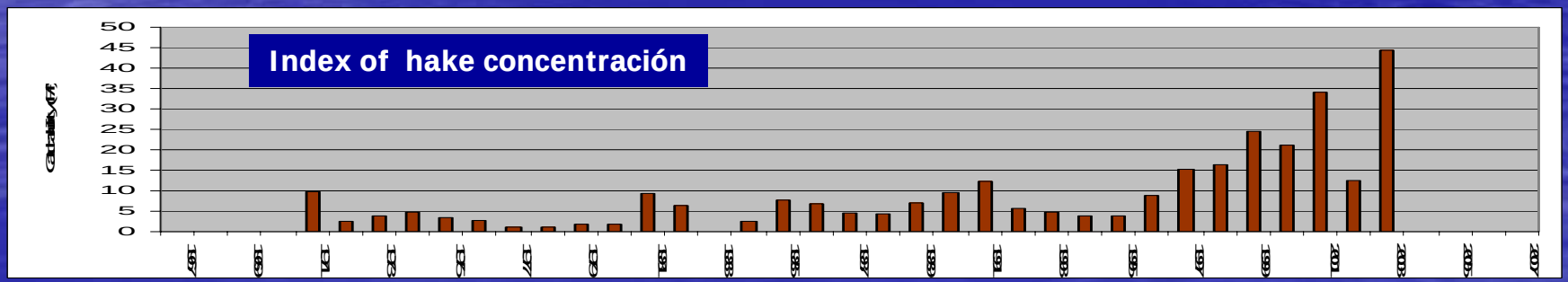
It appears as if the tropical (eastern Pacific) low oxygen regions reformed after the Little Ice Age and continue to expand (and increase in productivity?) today

Are there biological indicators of this expansion?

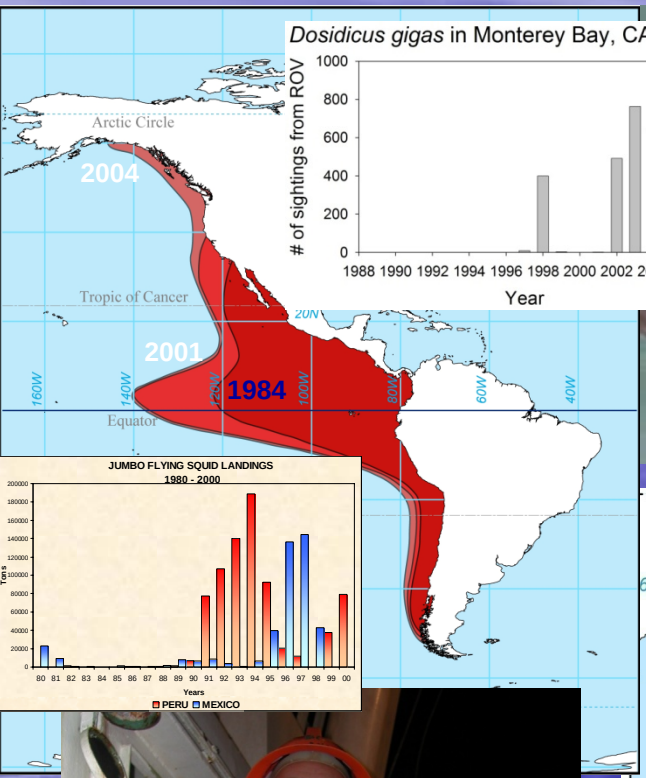
The Hake off Peru has retreated and gotten more concentrated







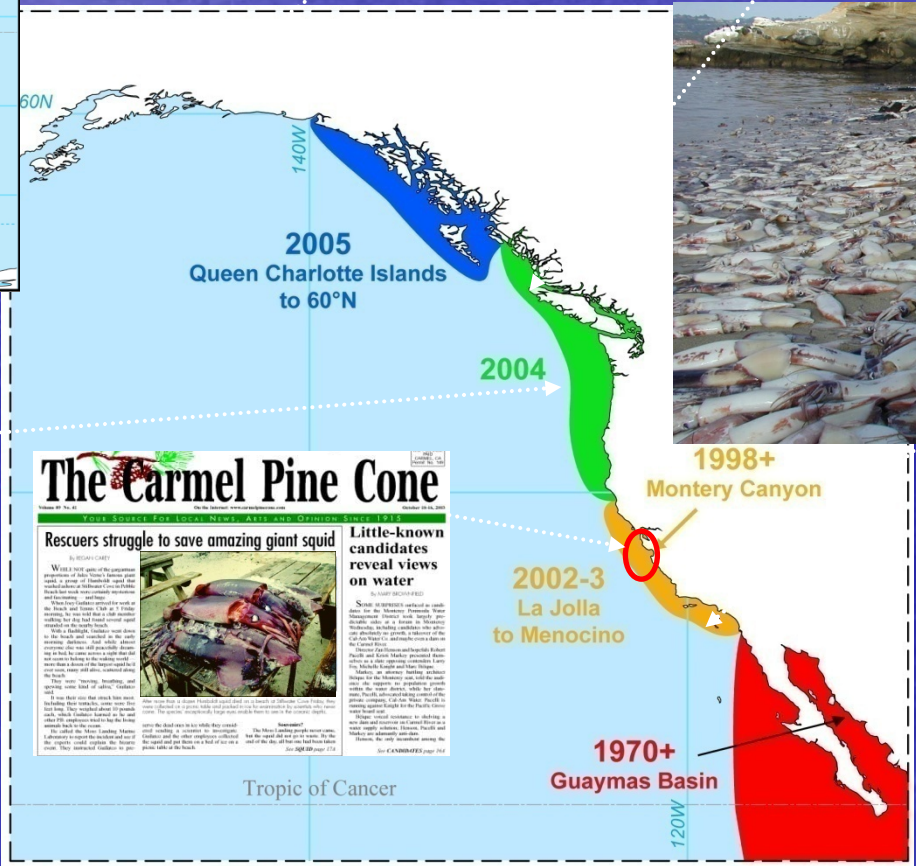
Post 1997/98 expansion of *Dosidicus gigas* range



July 2005
Tracy Arm (Sitka), AK

2004
Outer Coast, BC

La Jolla Cove, CA.
July, 2002



The Carmel Pine Cone

Rescuers struggle to save amazing giant squid

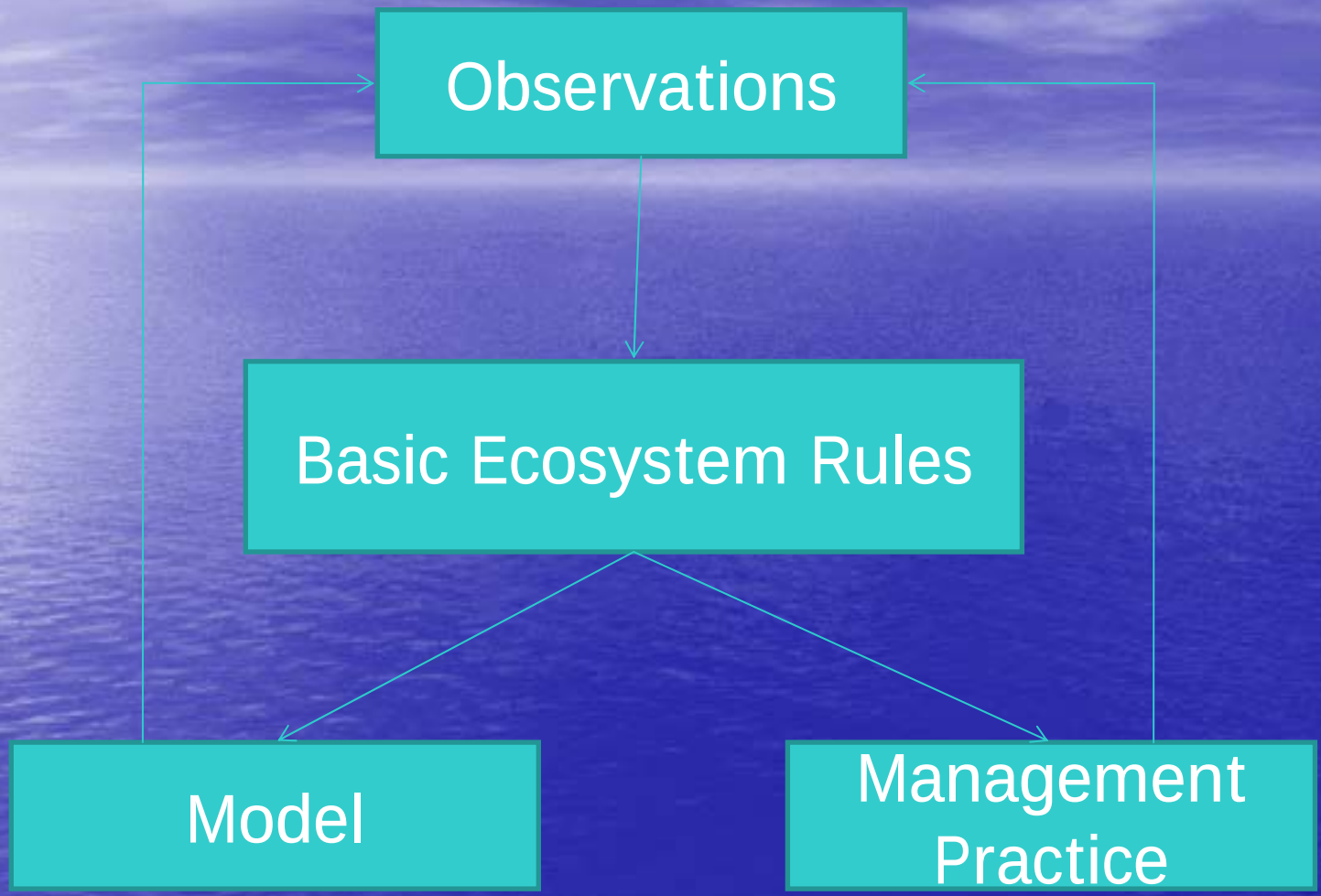
Little-known candidates reveal views on water

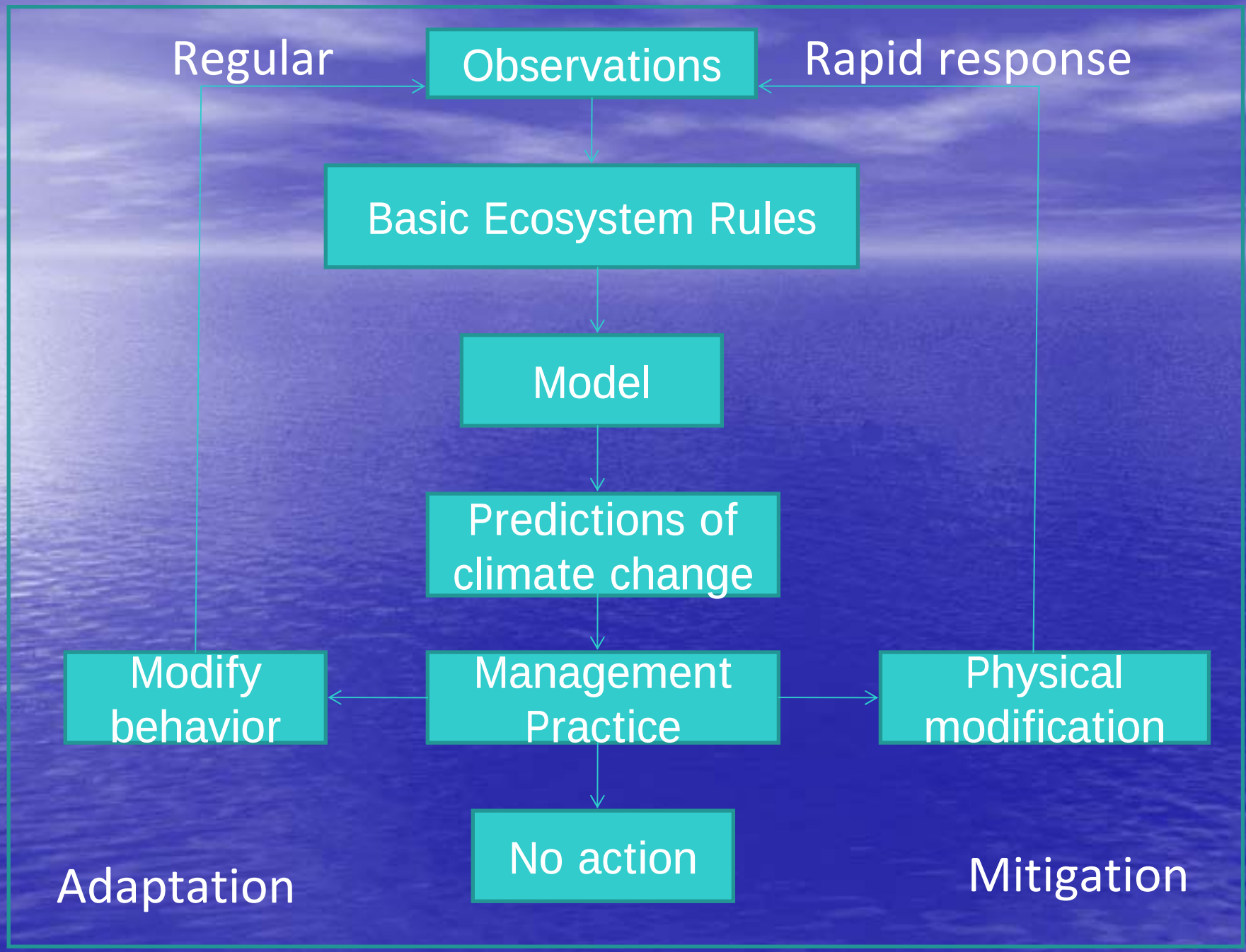
Summary

- 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, CO_2 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


Regular
Observations
Rapid response
Basic Ecosystem Rules
Model
Predictions of climate change
Modify behavior
Management Practice
Physical modification
No action
Adaptation
Mitigation

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