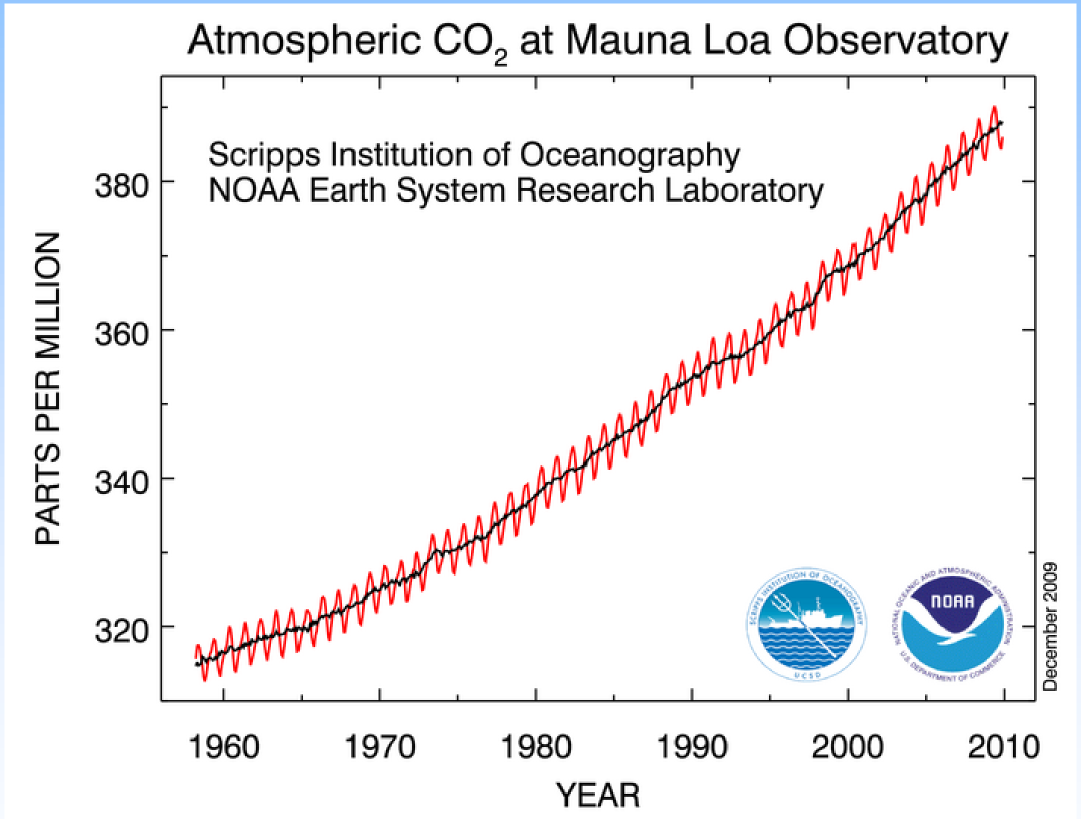
Please note that this presentation was given during the United Nations Climate Change Conference (COP-15) in Copenhagen, December 7-18, 2009 for more information please visit http://www.cop15.state.gov/ .

Ocean Carbon Uptake & Ocean Acidification

Scott Doney, Woods Hole Oceanographic Institution



"Thus human beings are now carrying out a large scale geophysical experiment…"

Revelle and Suess, Tellus, 1957

Fate of Anthropogenic CO_2 Emissions

1.5 Pg C y^{-1}

+

7.5 Pg C y^{-1}

4.2 Pg y^{-1}

Atmosphere
46%

2.6 Pg y^{-1}

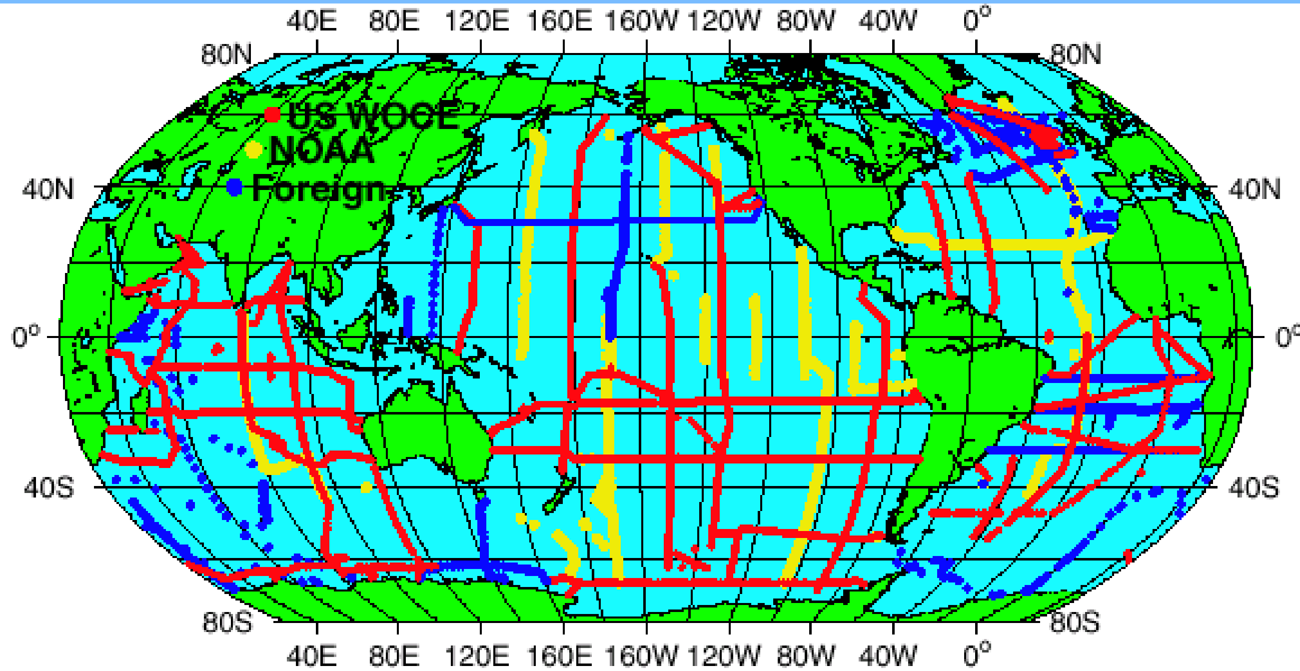
Land
29%

2.3 Pg y^{-1}

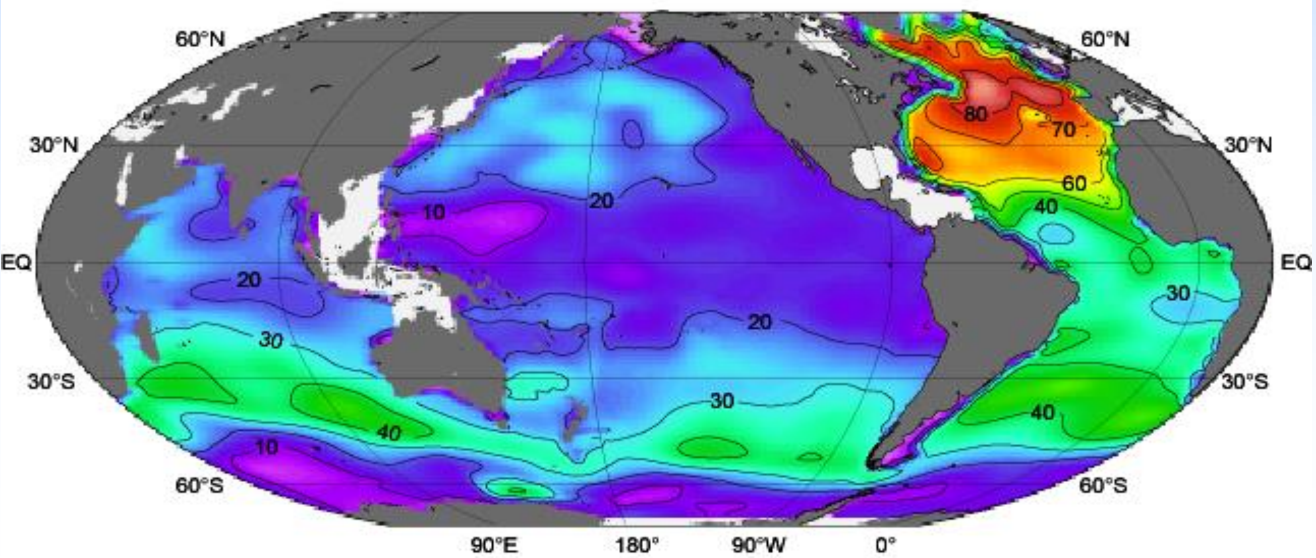
Oceans
26%

Canadell et al. PNAS 2007; LeQuere et al. Nature Geosciences 2009

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930



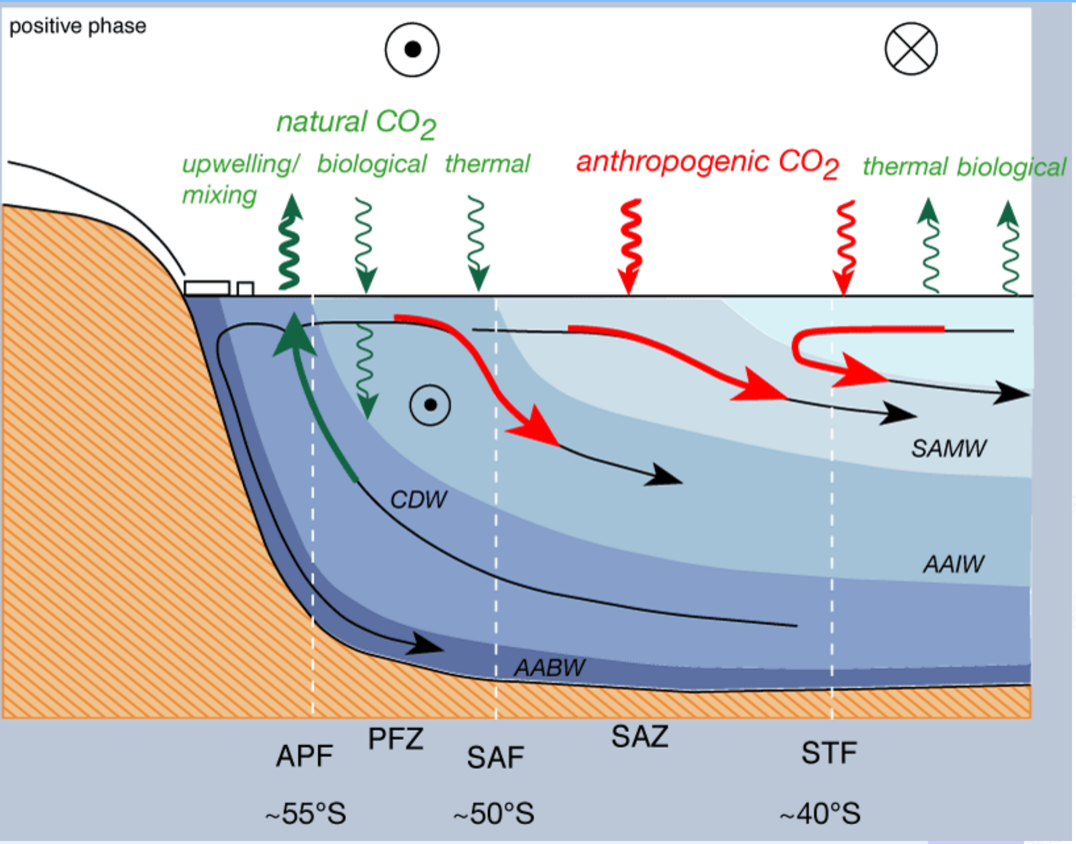
Anthropogenic CO_2 Column Inventories (mol m^{-2})

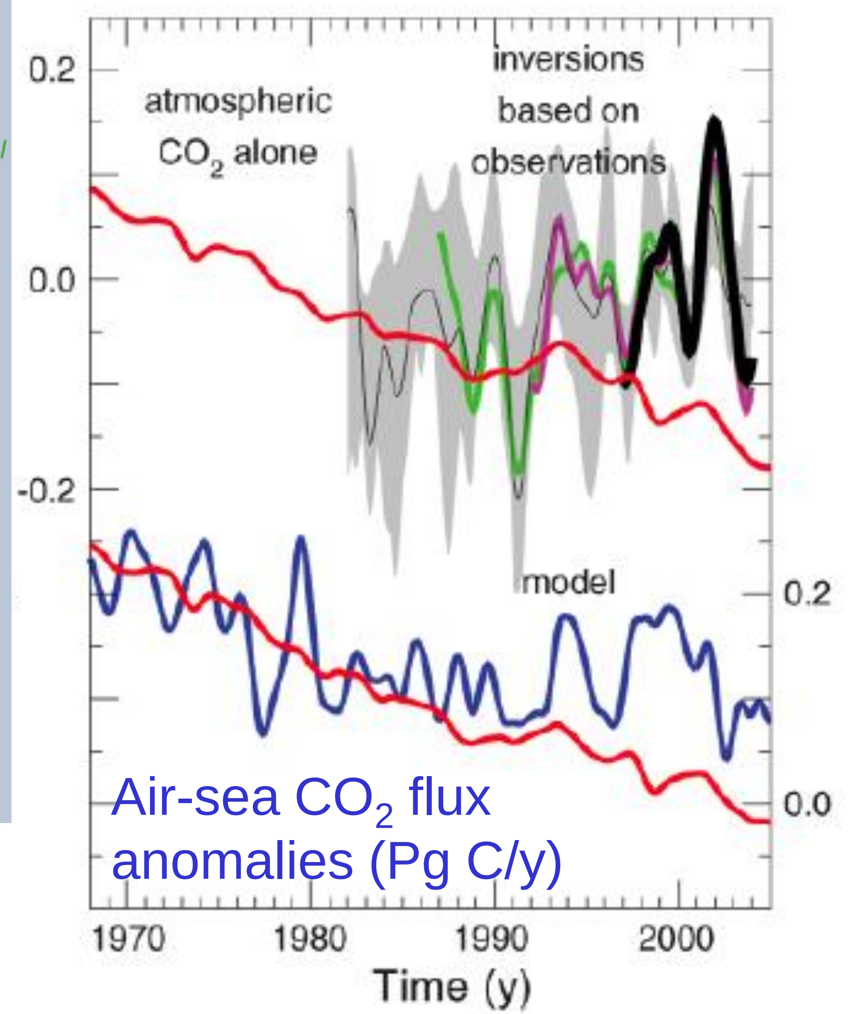


Carbon Inventory

-Global ocean CO_2 survey (mid-1990s)
-Decadal repeat of key transects
-Challenges
•under-sampled ocean
•large natural background
•climate variability

Stengthening of Southern Annular Mode (SAM)





-positive SAM from atm. ozone and CO_2 trends

-natural CO_2 efflux > anthro. CO_2 uptake

-net decrease in effectiveness of ocean CO_2 sink

Le Quere et al., Science (2007)
Lovenduski et al., Global Biogeochem. Cycles (2007; submitted)

Sea-Air pCO_2 Trends

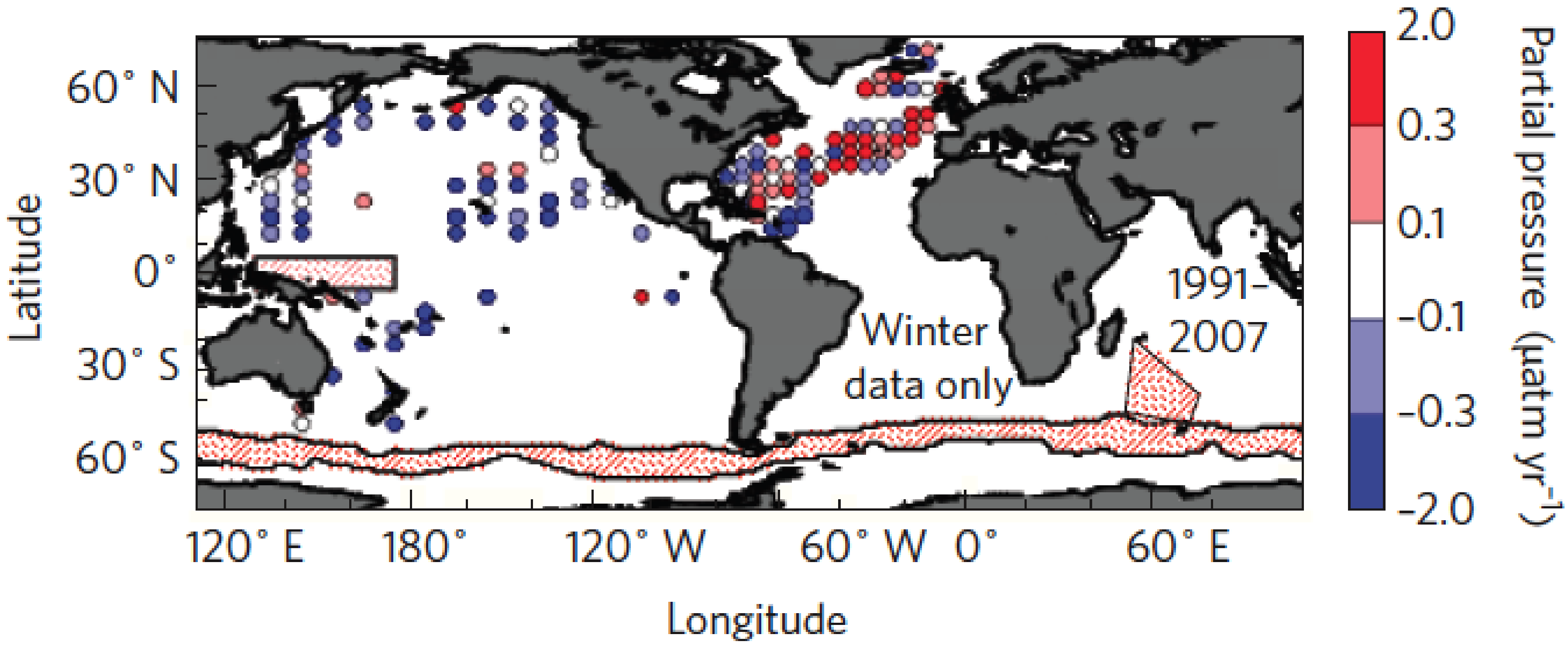
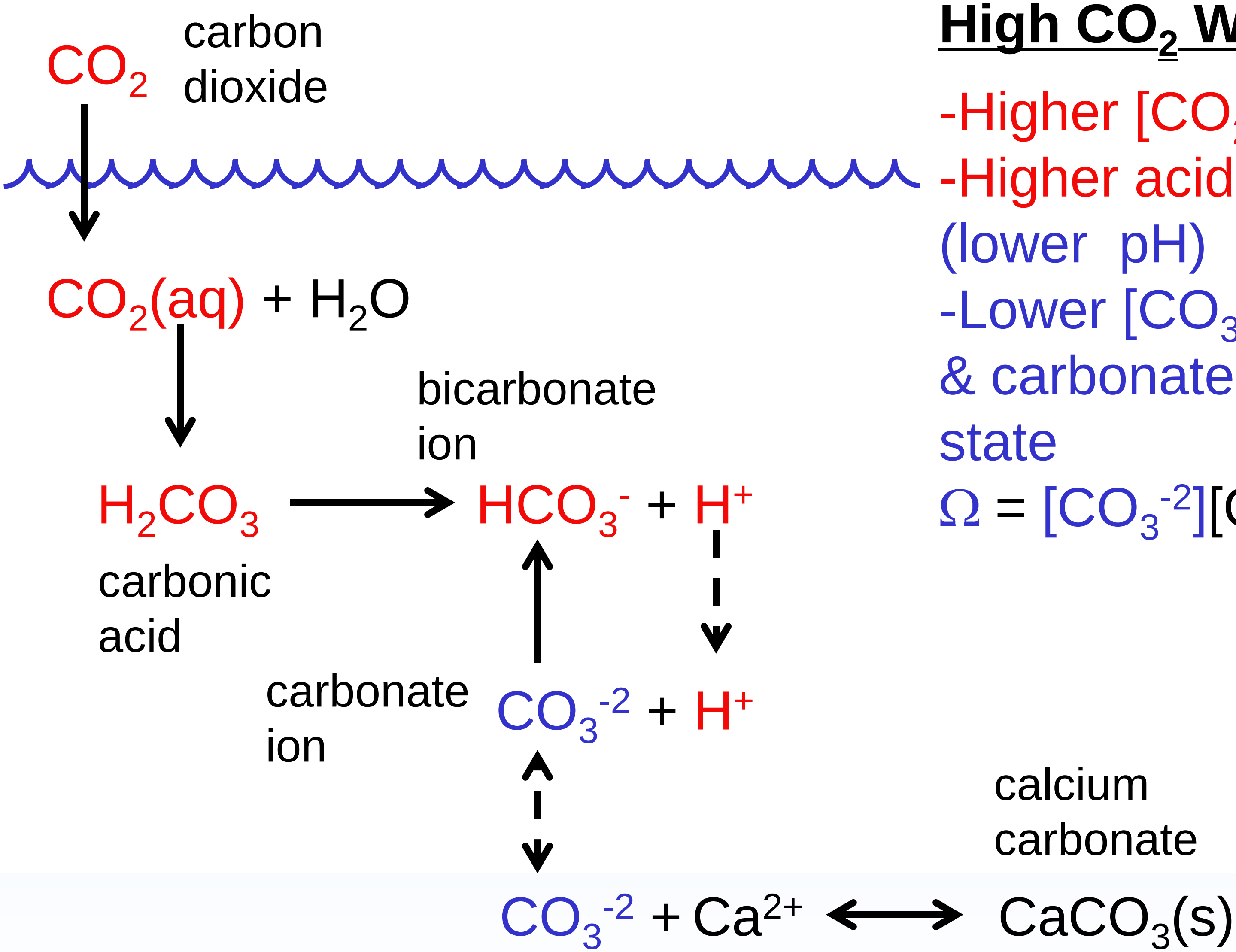


Figure 3 | Trends in the observed partial pressure of CO_2 for ocean minus air, for 1981–2007. The observed trends are calculated by fitting a

Le Quere et al., Nature Geosciences, 2009 (in press)

Ocean Acidification Primer



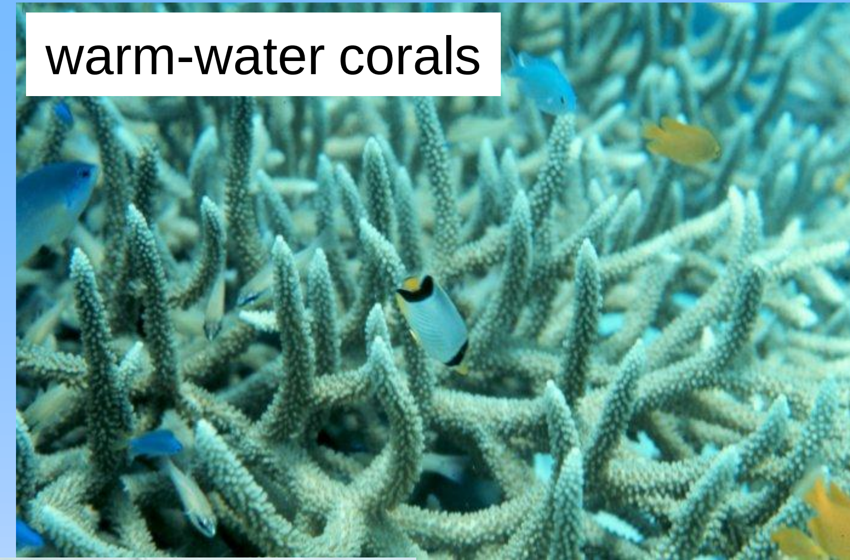
High CO_2 World

- Higher $[CO_2](aq)$
- Higher acidity $[H^+]$ (lower pH)
- Lower $[CO_3^{-2}]$ & carbonate saturation state

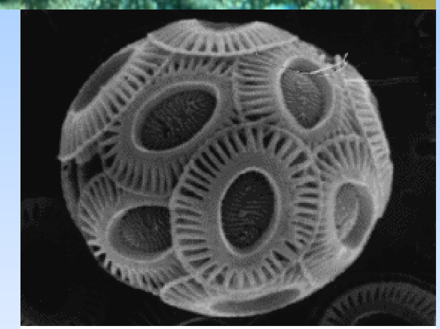
$\Omega = [CO_3^{-2}][Ca^{2+}]/K_{sp}$

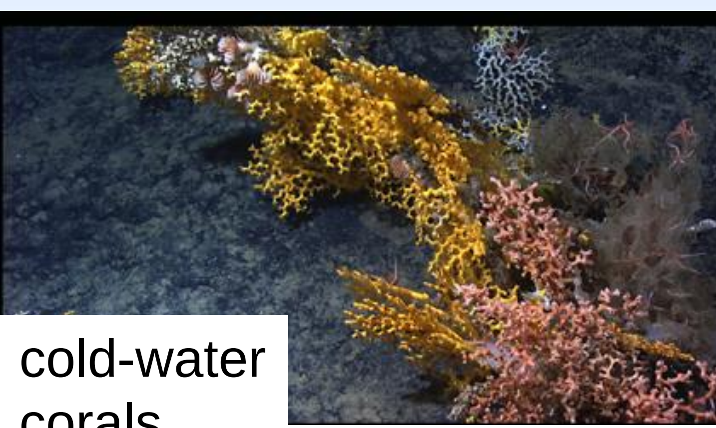
Biological Impacts

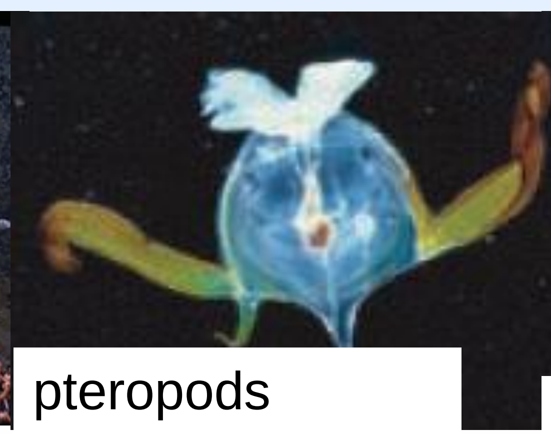
- Shell forming plants & animals
  - reduced shell formation (calcification)
  - lower reproduction & growth rates
- Habitat loss (reefs)
- Less food for predators
  - humans, fish, whales
- Possible negative effects on larvae


warm-water corals

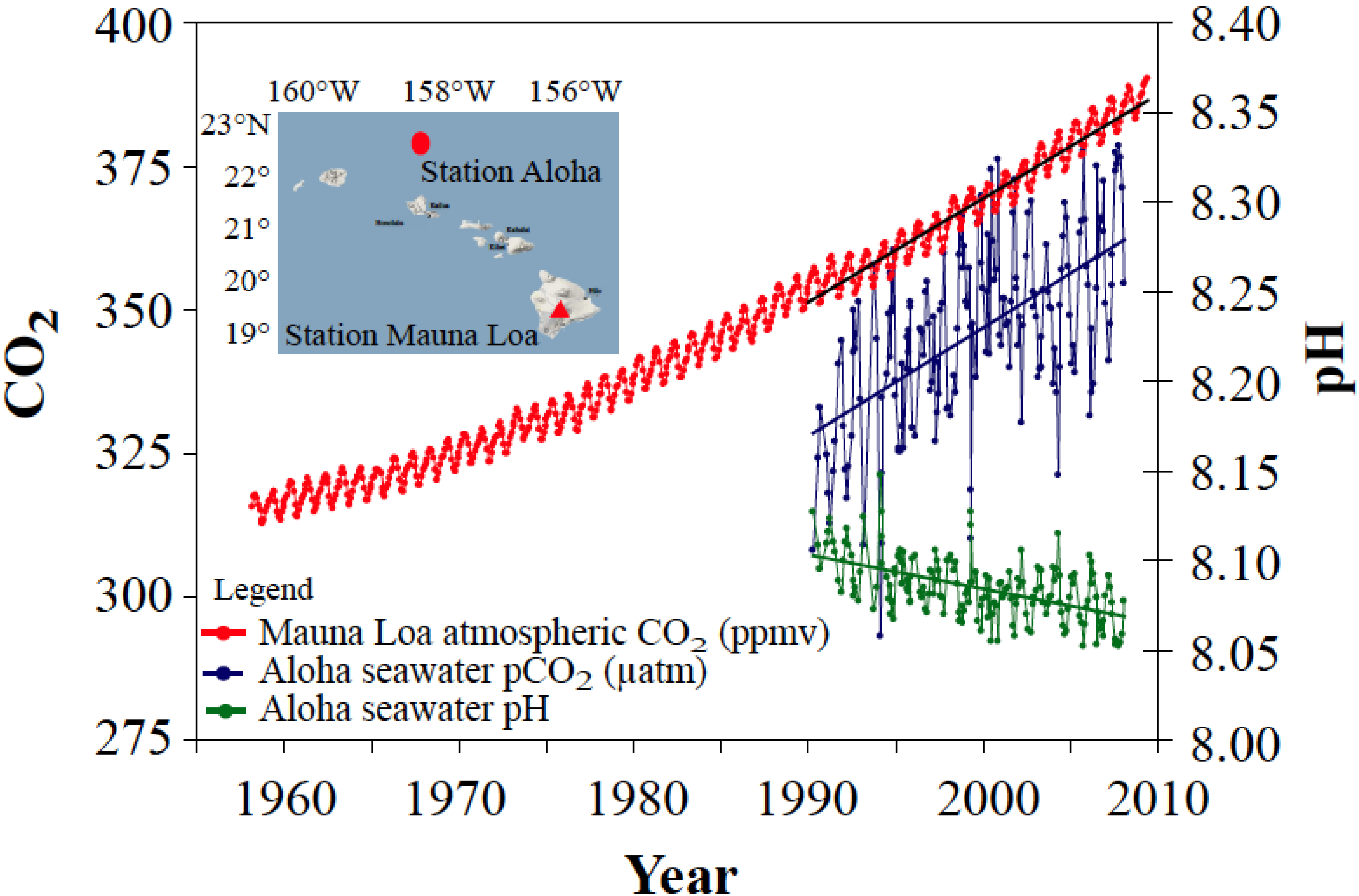

lobsters, crabs


some plankton


cold-water corals


pteropods planktonic snails

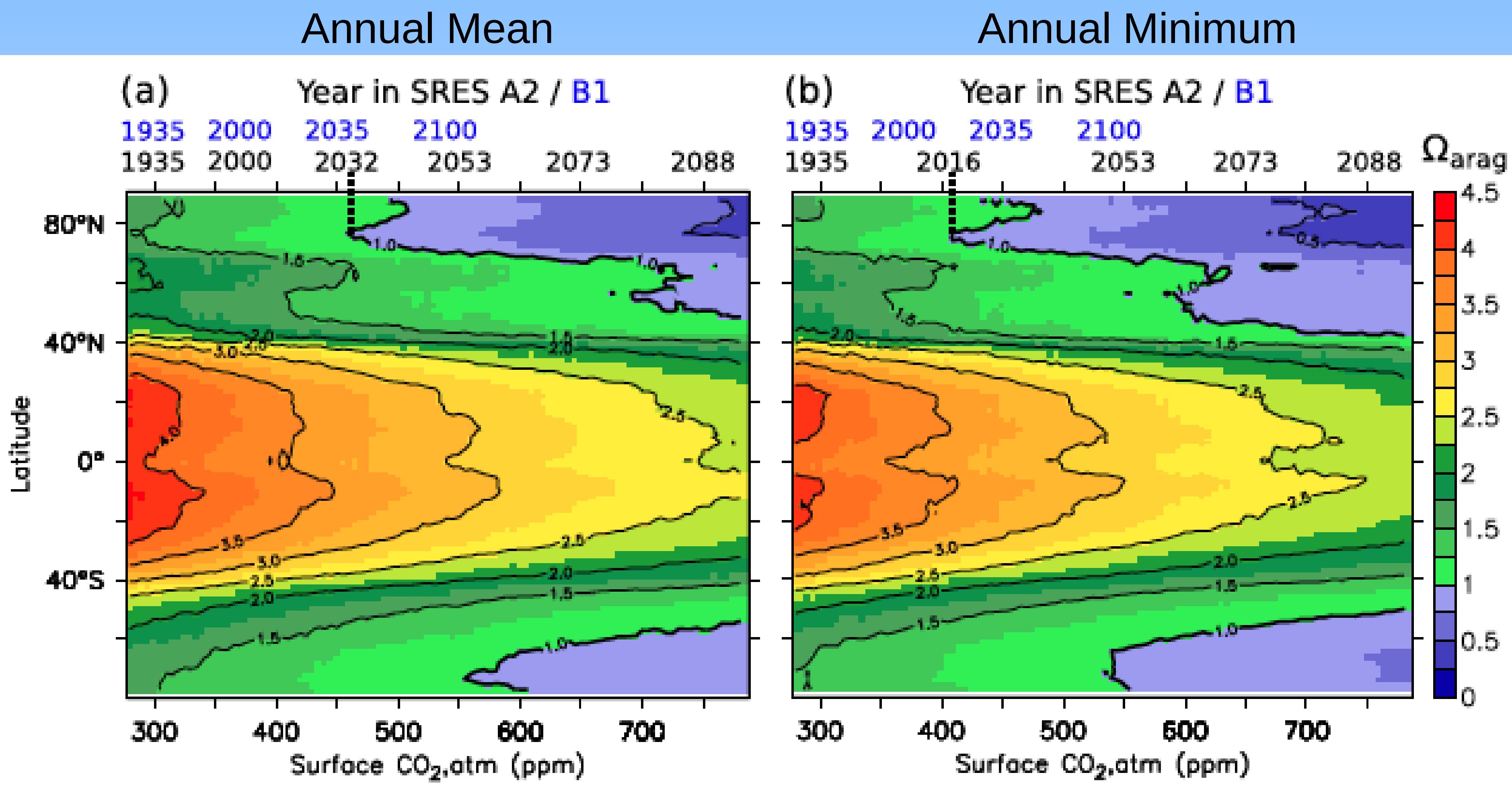

scallops, clams, oysters



Doney et al. Ann. Rev. Mar. Sci. 2009
Dore et al. PNAS 2009

Surface Aragonite Saturation

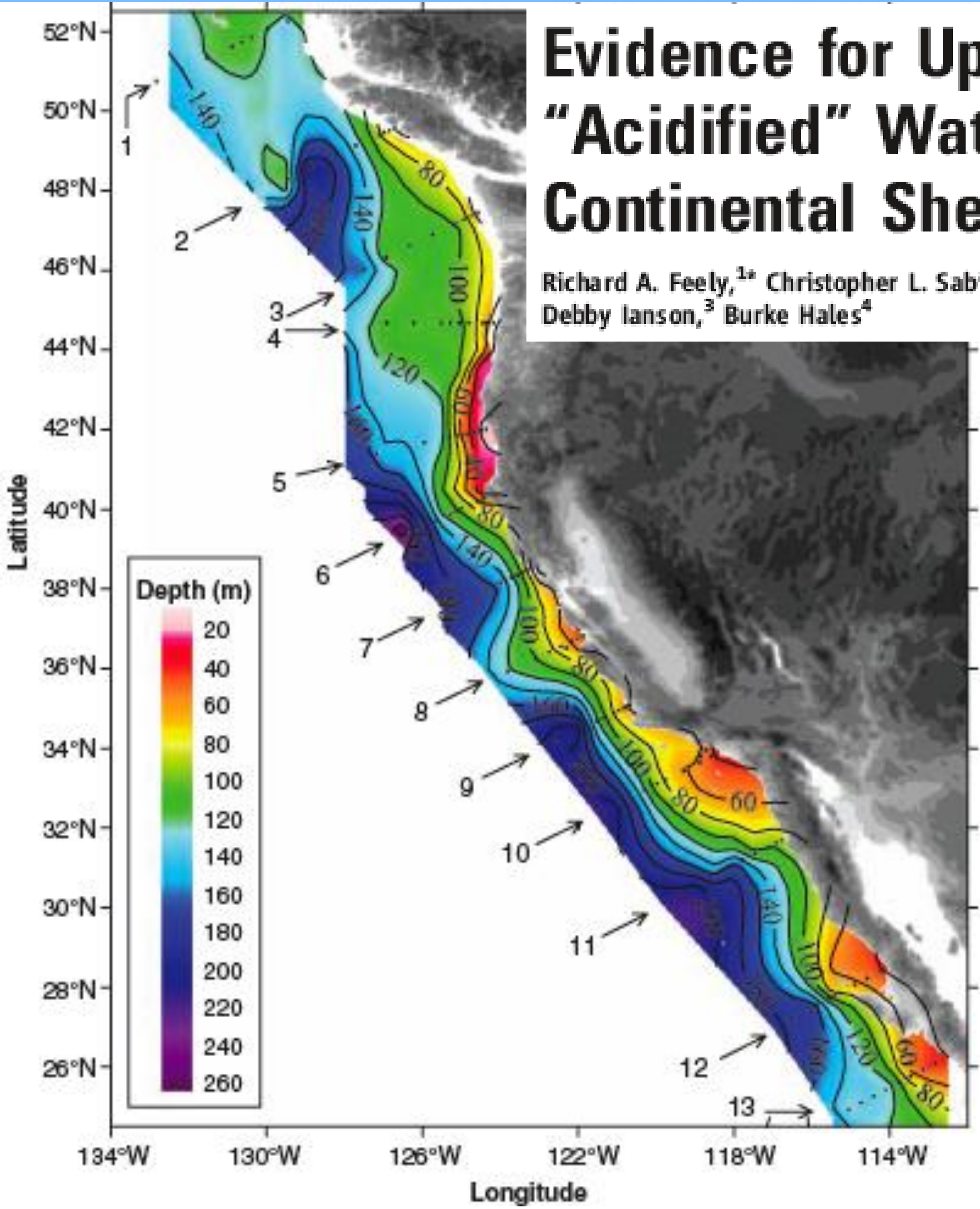
Zonal mean Ω vs. atmospheric CO_2



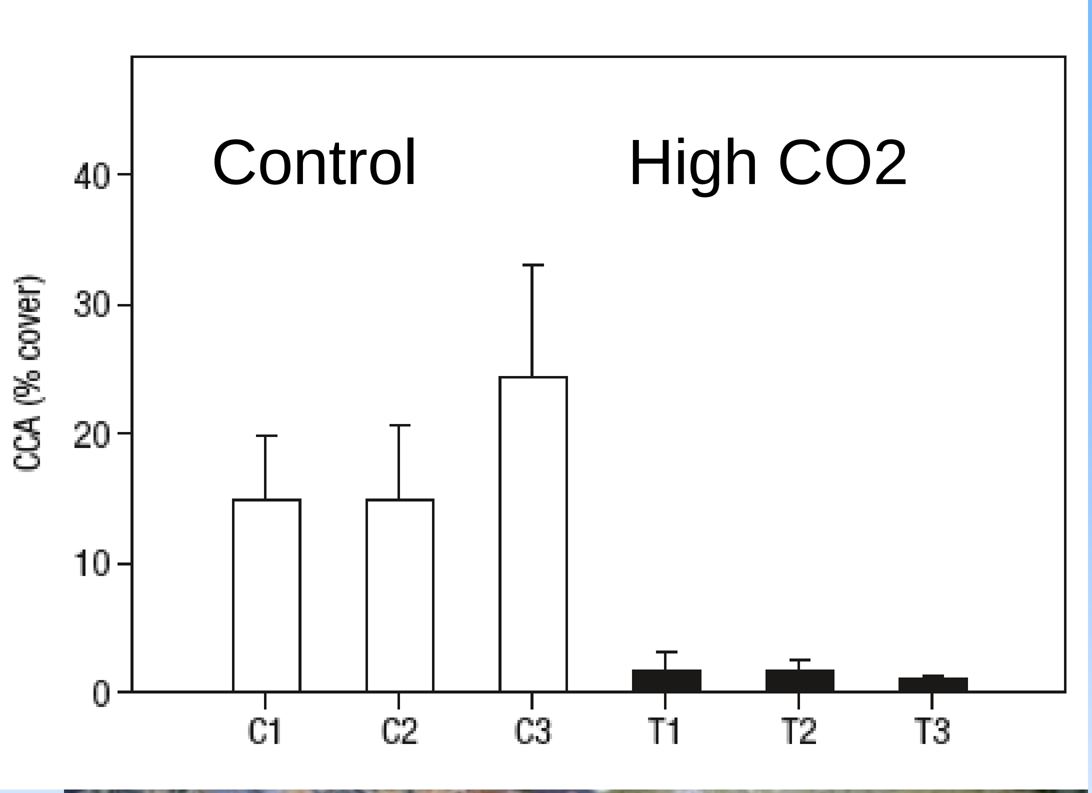
Steinacher et al. Biogeosci., 2009

Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf

Richard A. Feely,[1*] Christopher L. Sabine,[1] J. Martin Hernandez-Ayon,[2]
Debby Ianson,[3] Burke Hales[4]



Laboratory Tanks & Mesocosms

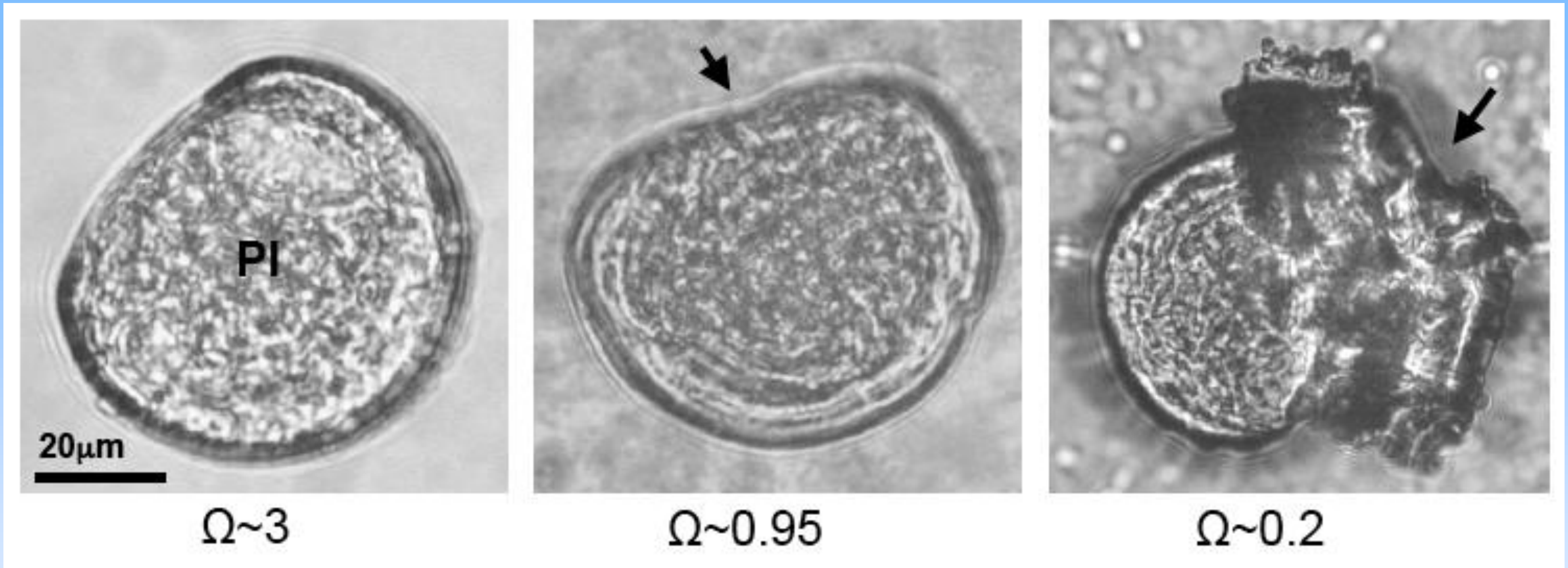


Crustal Coralline Algae

Coralline algae is replaced by non-calcifying algae

Kuffner et al. Nat. Geosci. 2007

Larval Eastern Oyster (*Crassostrea virginica*)



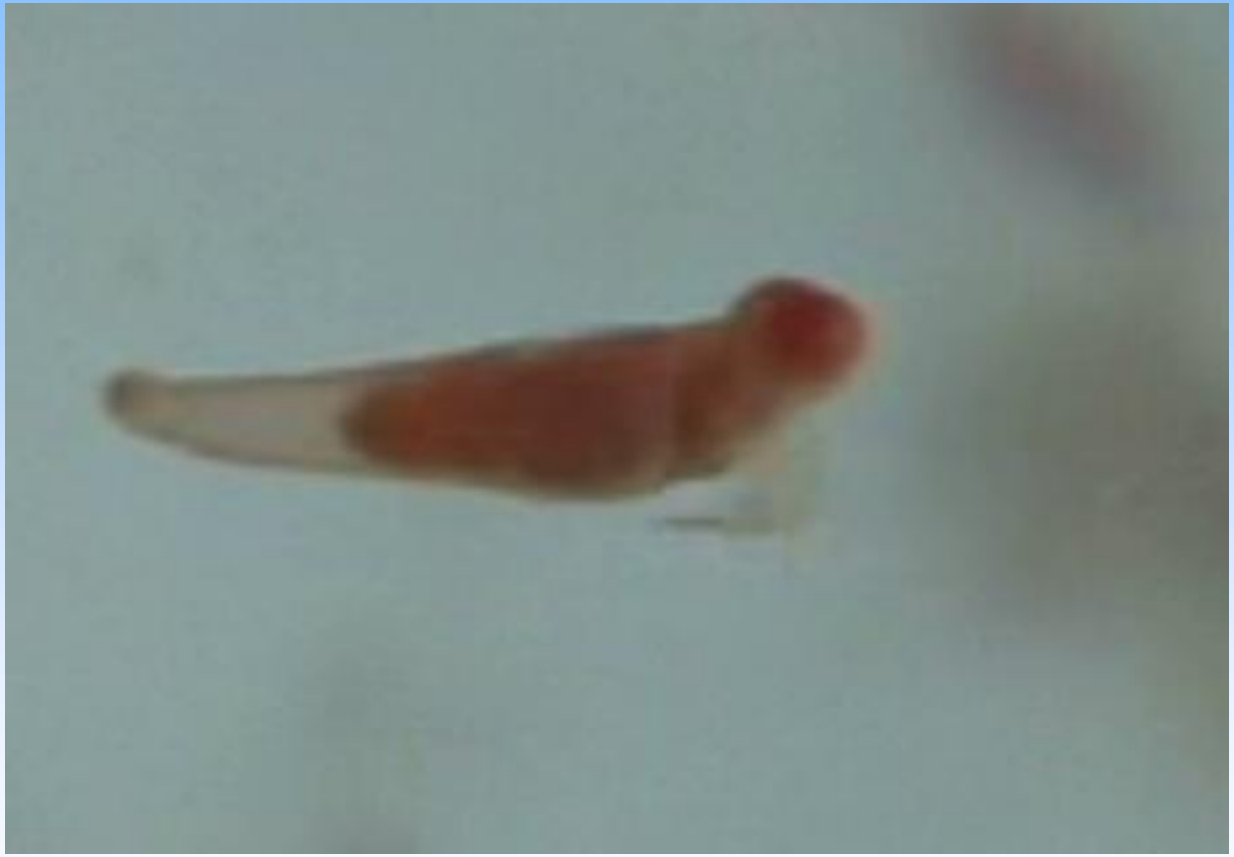
Increasing Acidity

→

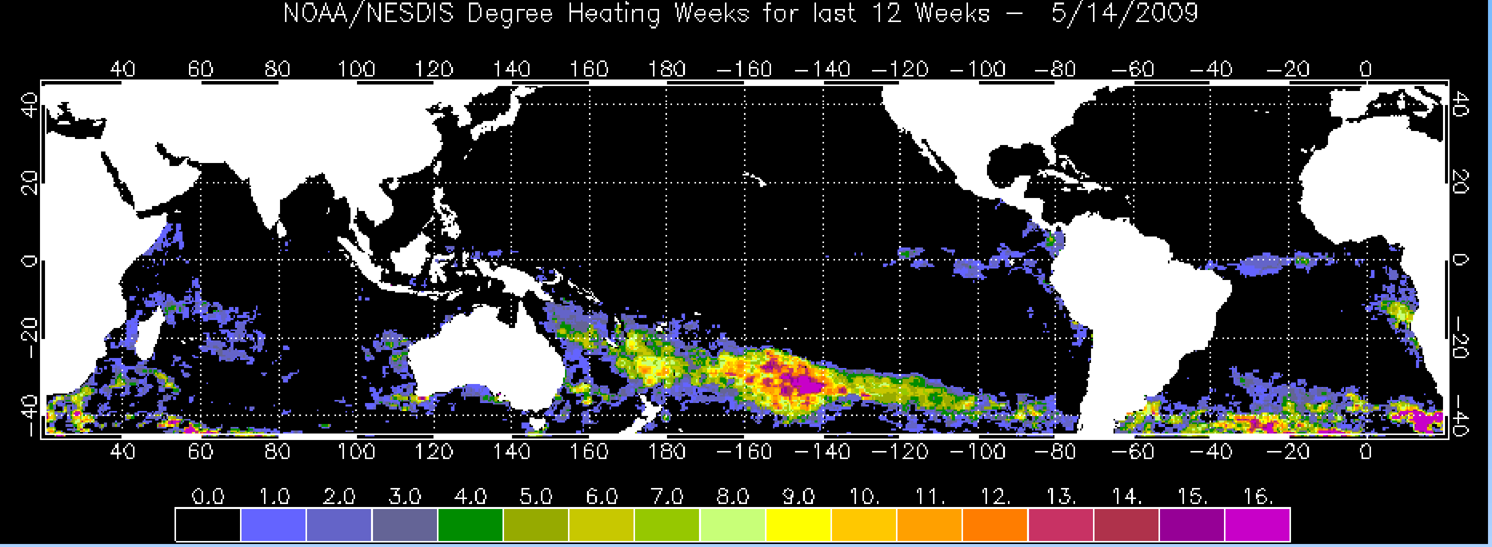
Larval shellfish grow with more soluble shells and more be more sensitive to acidification

Anne Cohen and Dan McCorkle, WHOI

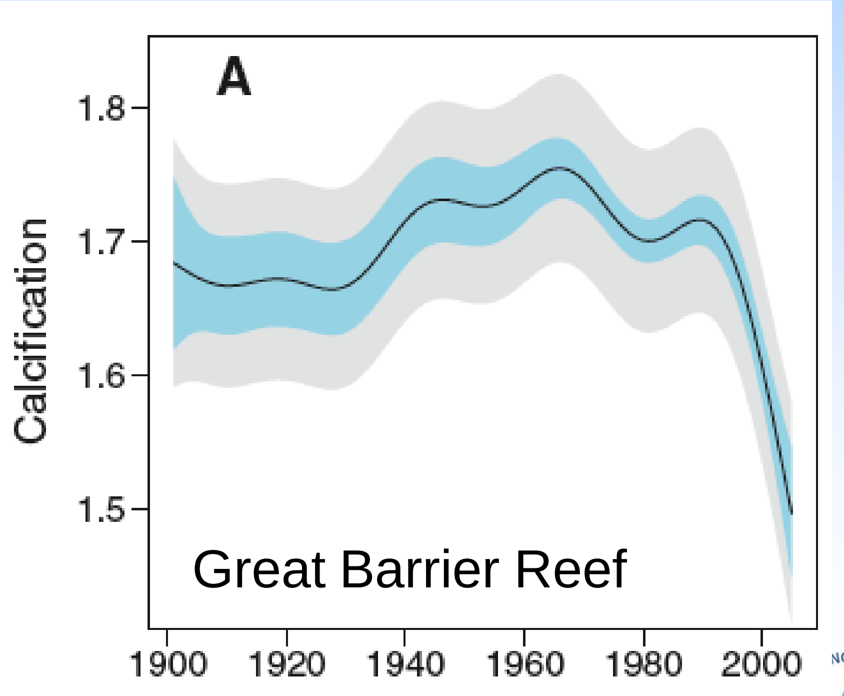
Pteropod Movie



Coral Bleaching



http://www.osdpd.noaa.gov/PSB/EPS/SST/dhw_retro.html



De'ath et al., Science, 2009

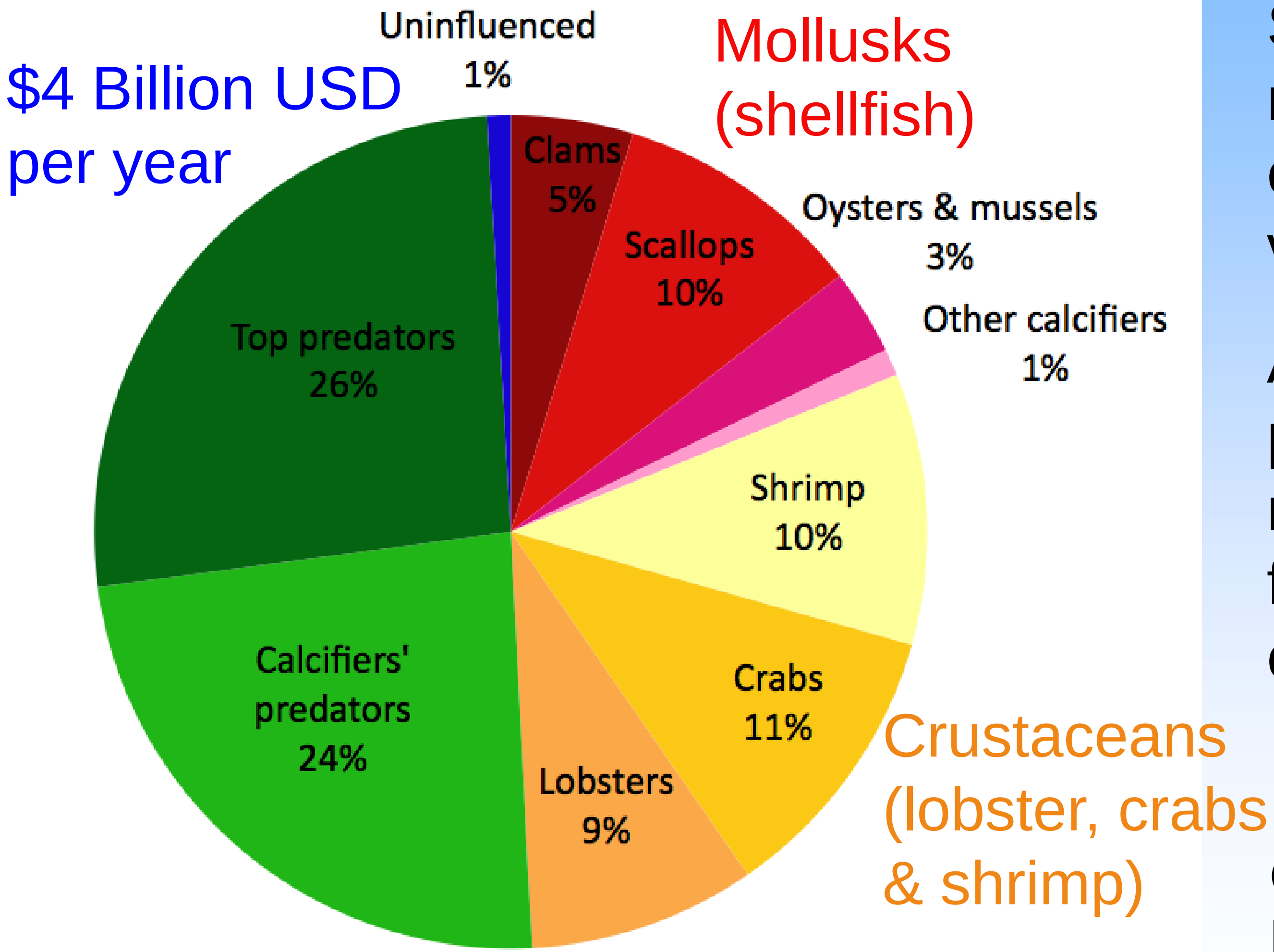
Economic and Social Impacts of Ocean Acidification

-Ocean acidification threatens:
- •fisheries & aquaculture
- •coral reefs (tourism, coastal protection)
- •ecosystem services

-Coastal and island populations at particular risk

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Valuable commercial fisheries depend on species sensitive to ocean acidification



2007 U.S. domestic ex-vessel revenue

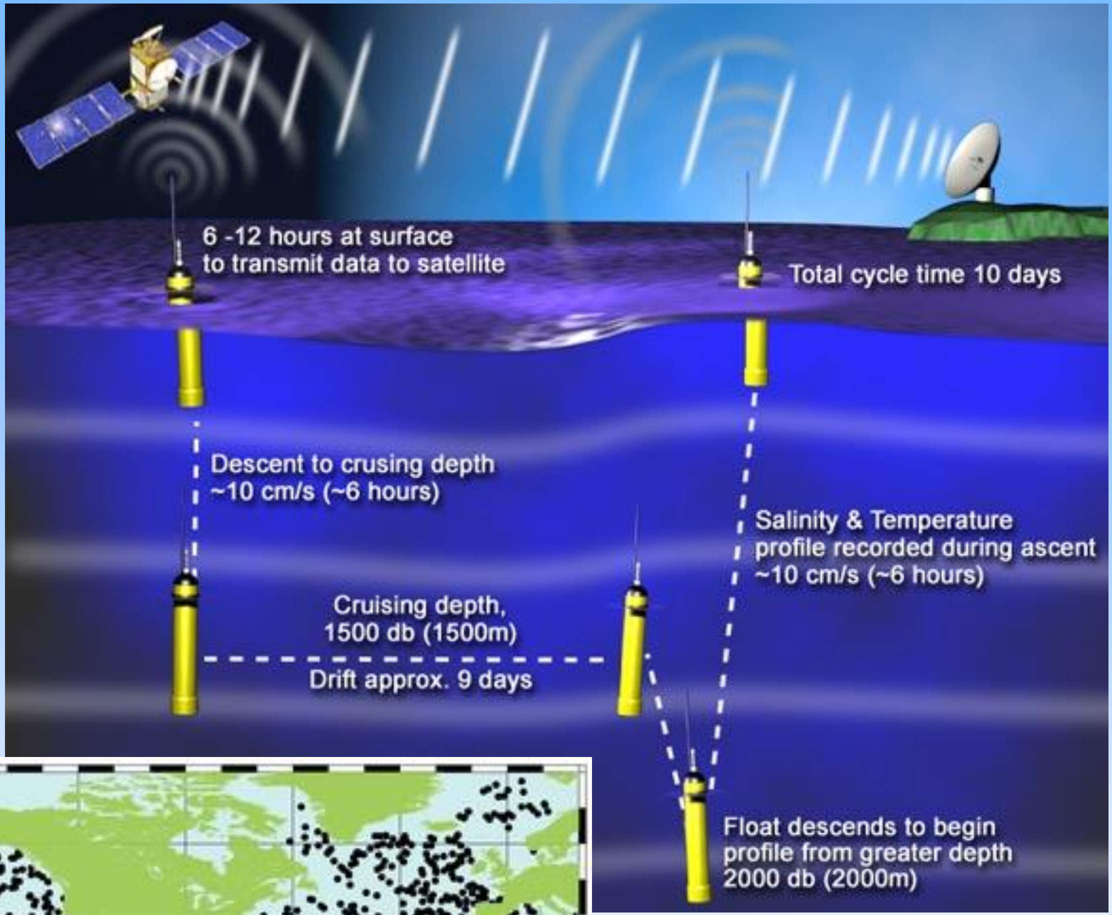
Shell-forming mollusks & crustaceans form valuable fisheries

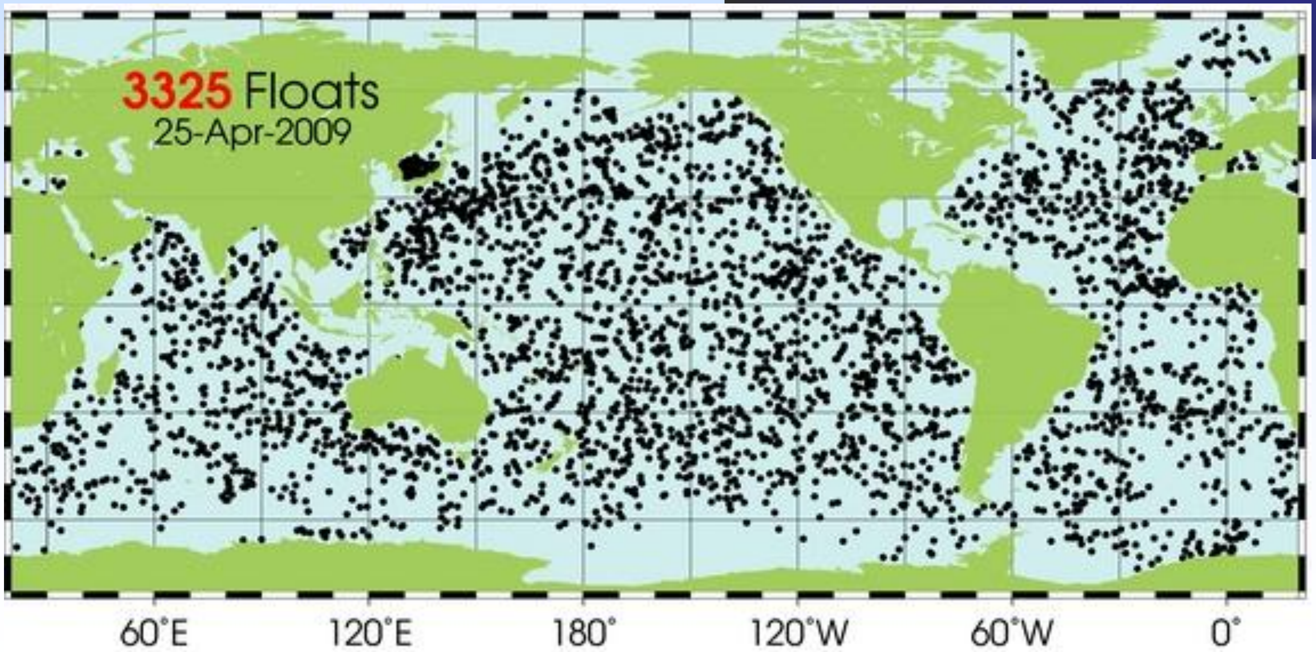
About 50% of U.S. primary fishery revenue comes from mollusks & crustaceans

Cooley & Doney Environment Research Letters, 2009

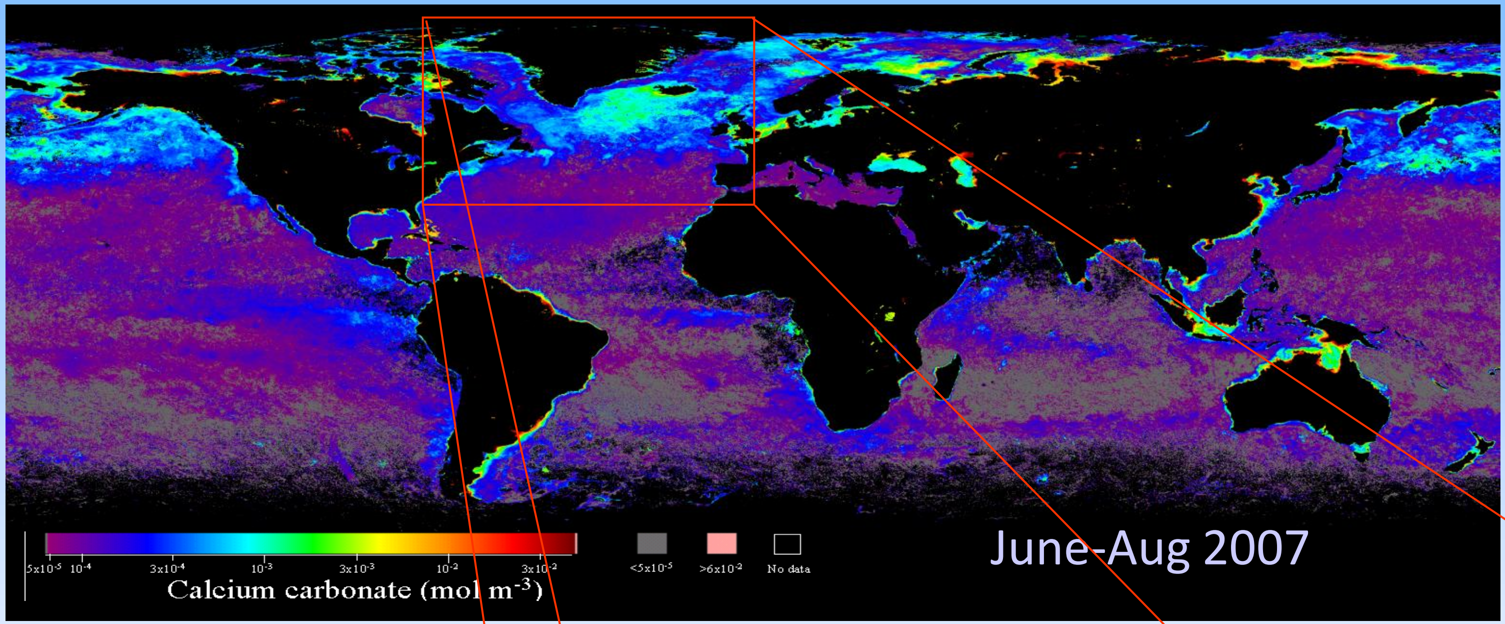
Profiling Floats (Argo Network)

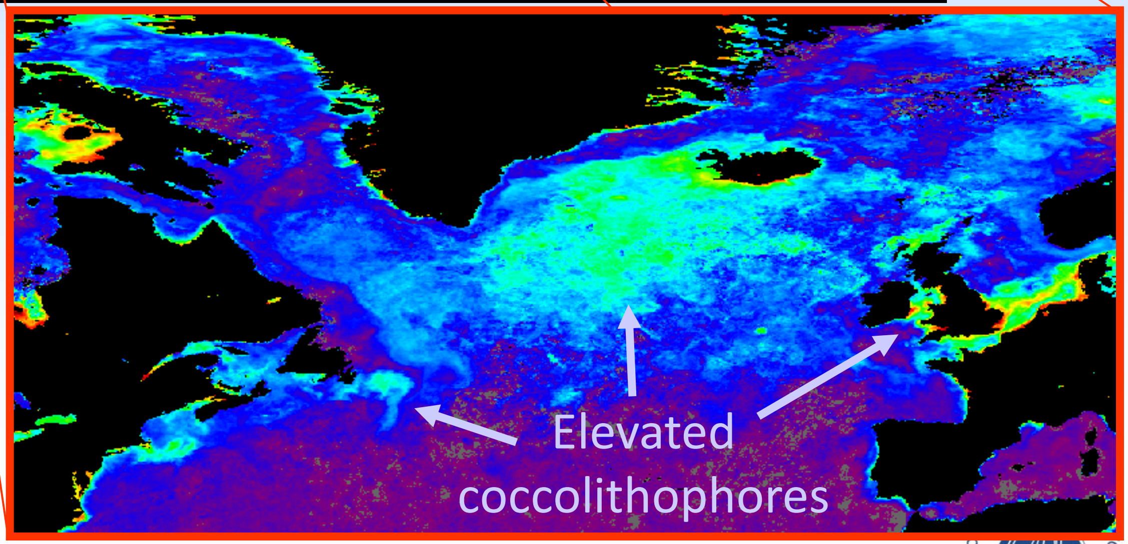
-each float profiles once every 10 days
-temperature & salinity
-handful of oxygen sensors
-no carbon sensors yet





Global distribution of Coccolithophores from NASA's MODIS sensor

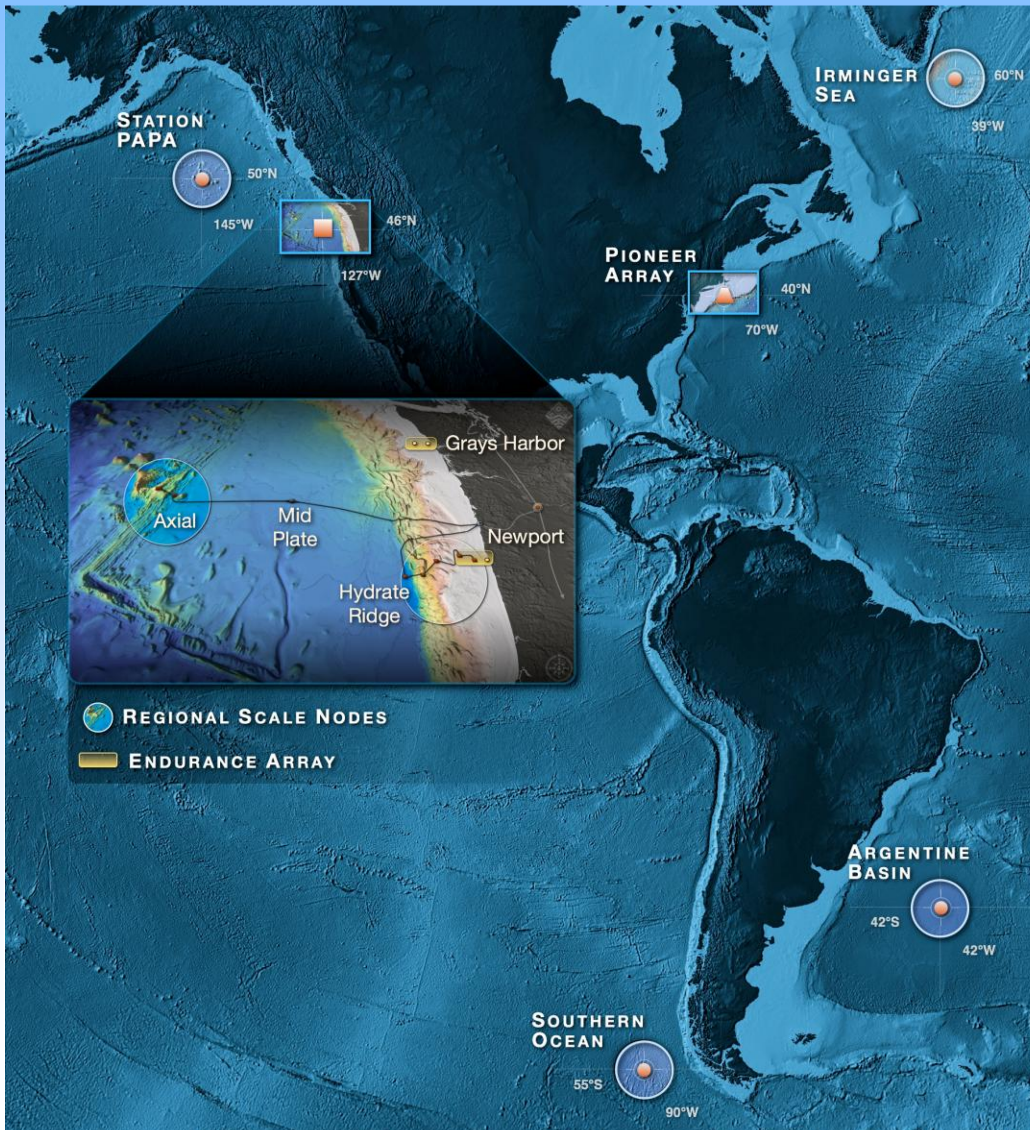




Coccolithophores
> produce the largest known algal blooms on earth
> are critical to burial and long term sequestration of carbon in ocean sediments
> will be dramatically affected by ocean acidification

W. Balch, Bigelow Laboratory for Ocean Sciences

National Science Foundation: Ocean Observatory Initiative

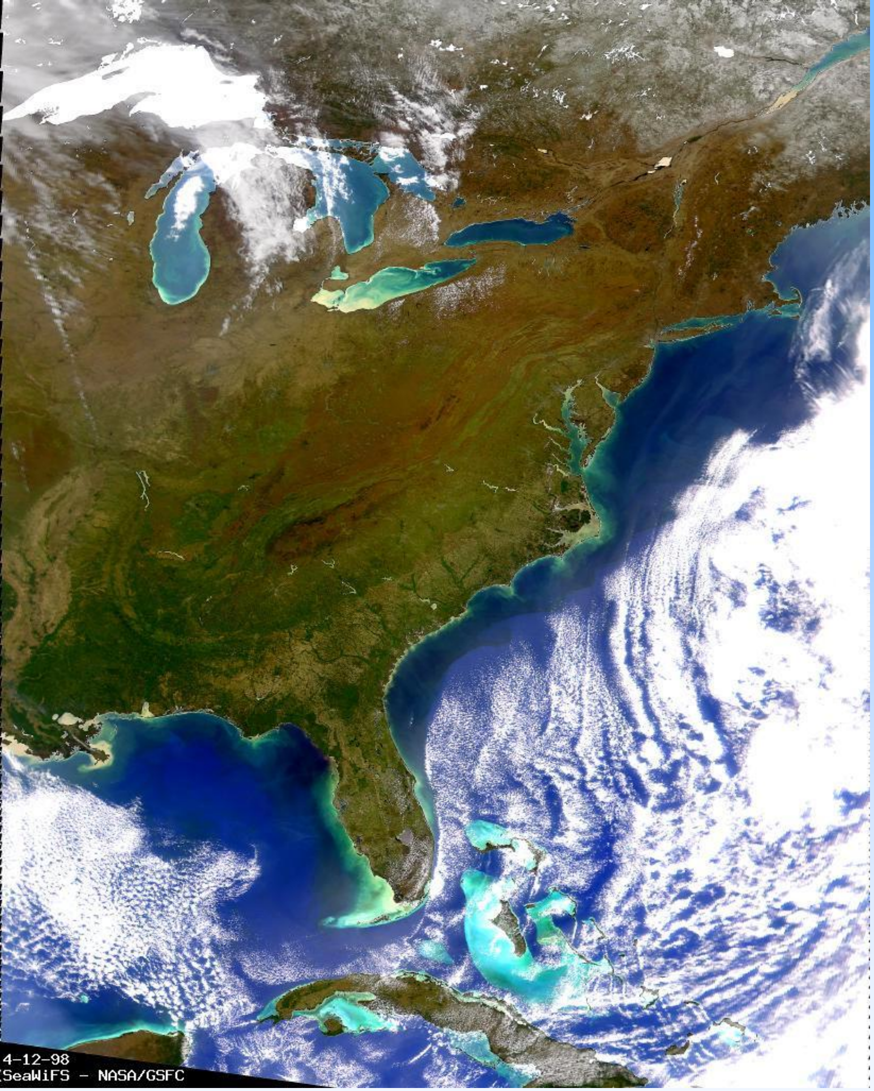


-Sustained sites for open-ocean & coastal observations

-Focal points for process studies

Woods Hole Oceanographic Institution 1930

Scott Doney
Woods Hole Oceanographic Institution
sdoney@whoi.edu



Special Thanks To:
Sarah Cooley
Victoria Fabry
Richard Feely
Jason Hall-Spenser
Joan Kleypas
Nancy Knowlton

OCB
Ocean Carbon & Biogeochemistry

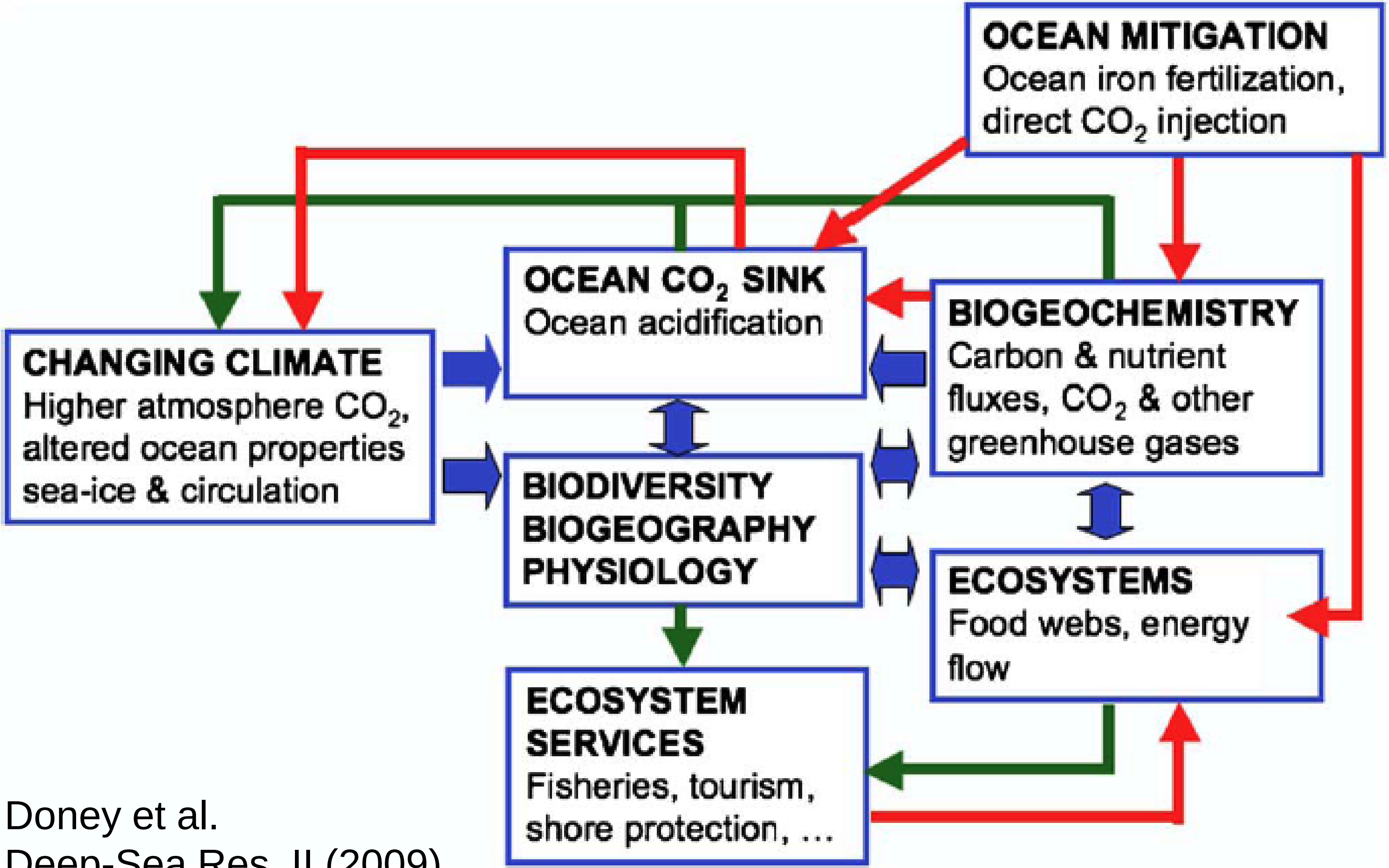
NASA

NSF

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

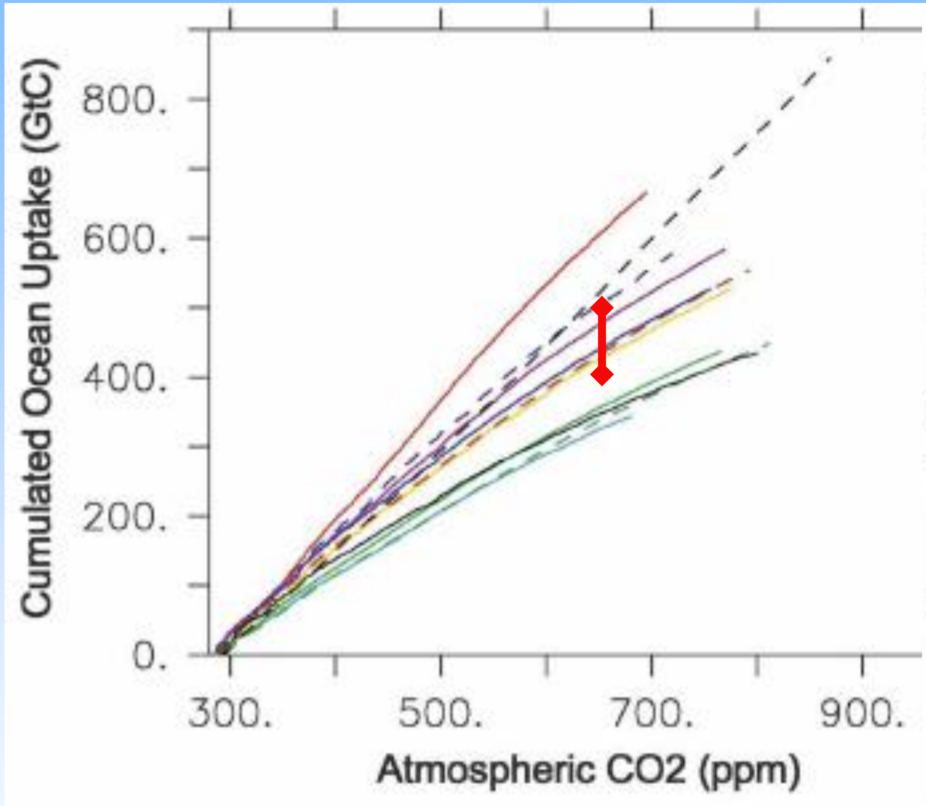
Ocean Climate Impacts & Feedbacks



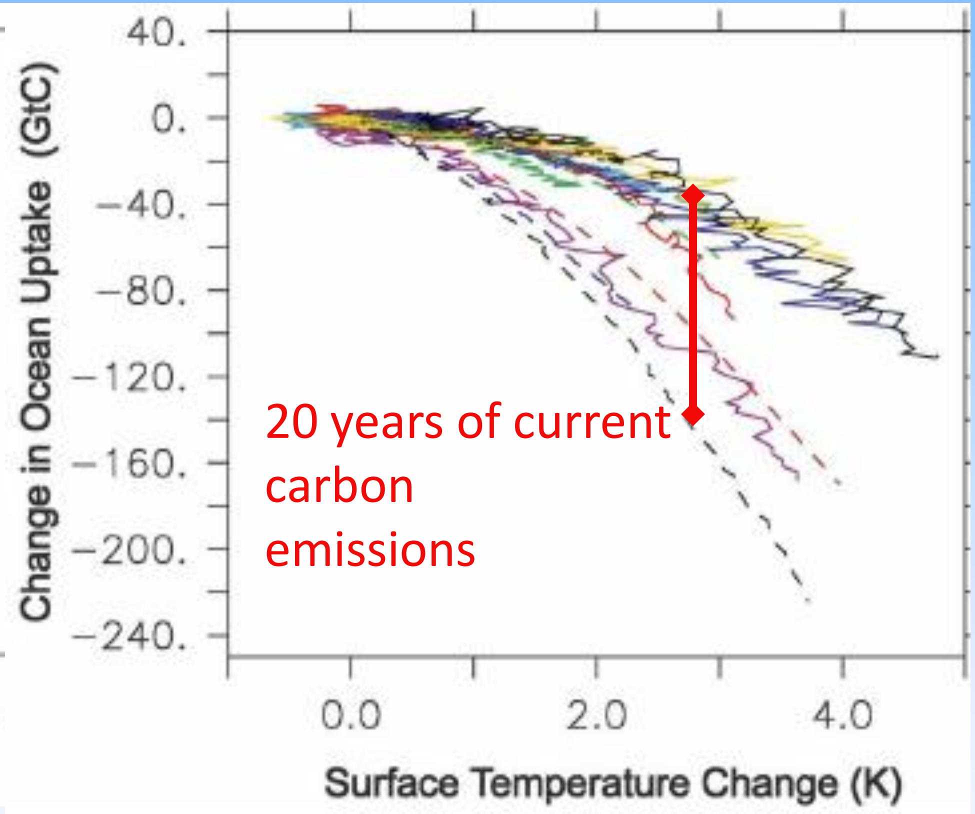
Doney et al.
Deep-Sea Res. II (2009)

Uncertainties about the Future

Strength of Ocean CO_2 Sink



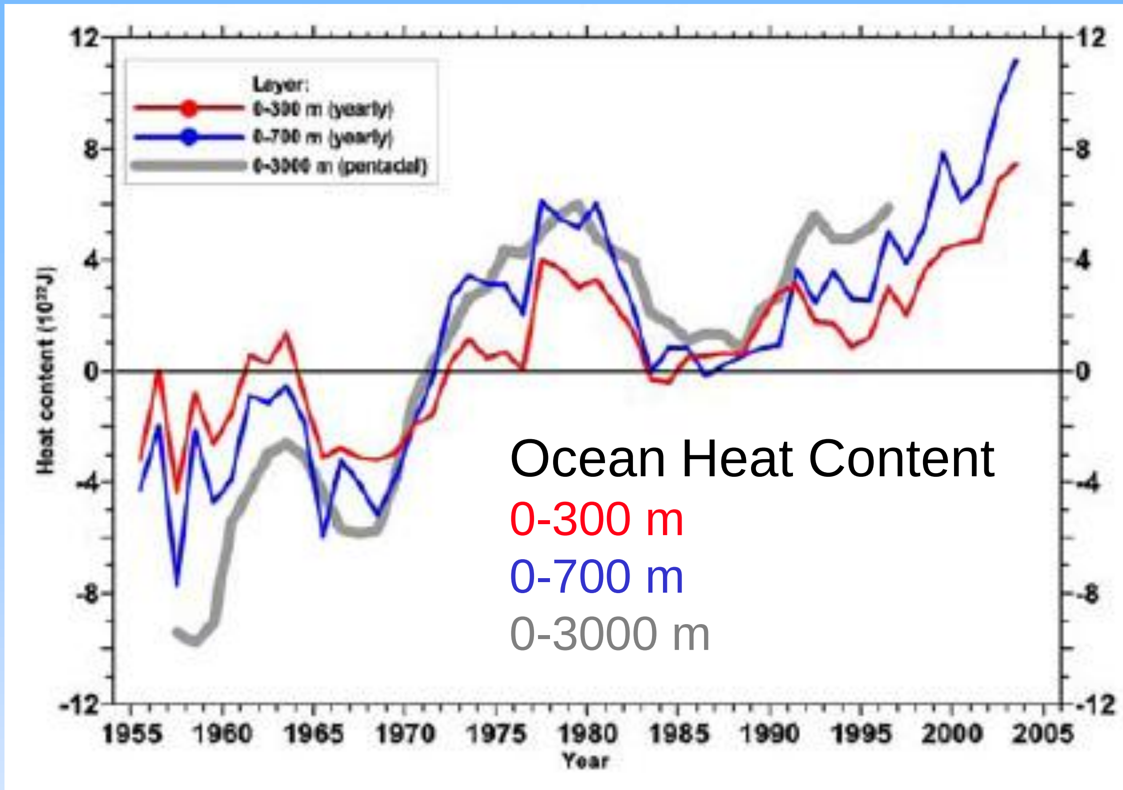
Sensitivity to Climate Warming



-The ocean is slowing the rate of global warming by removing CO_2 from the atmosphere

-With time & warming the ocean will become less effective in removing CO_2

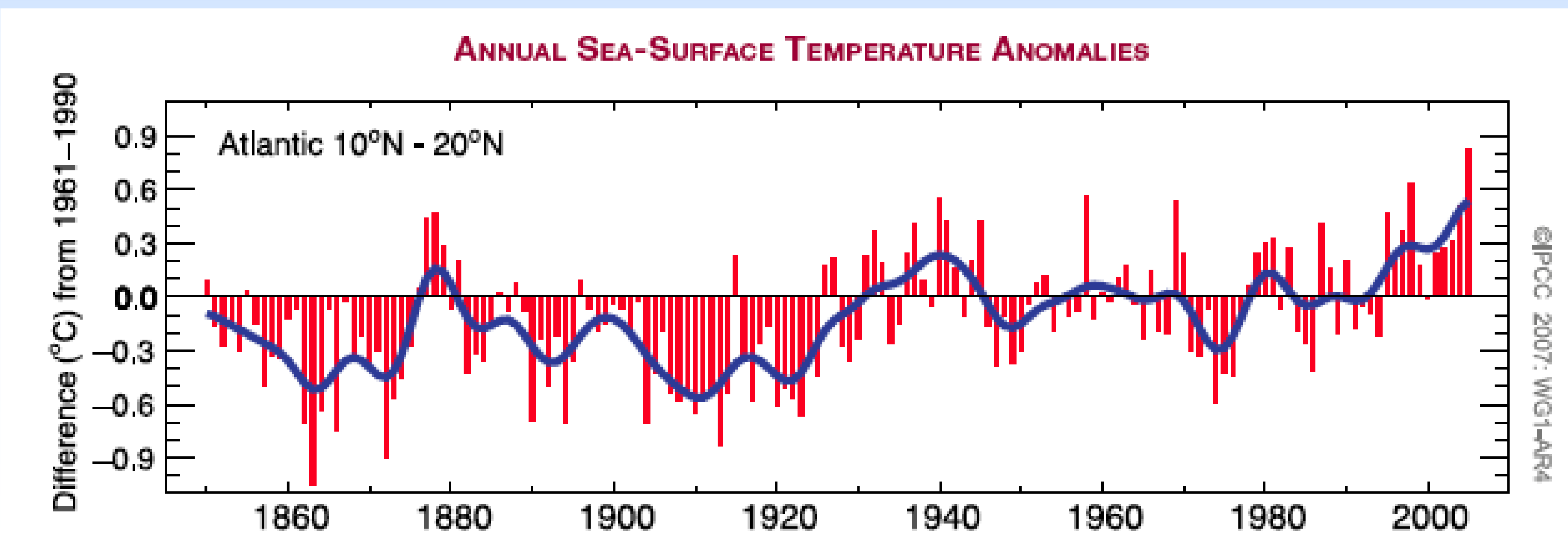
Friedlingstein et al., J. Climate, (2006)



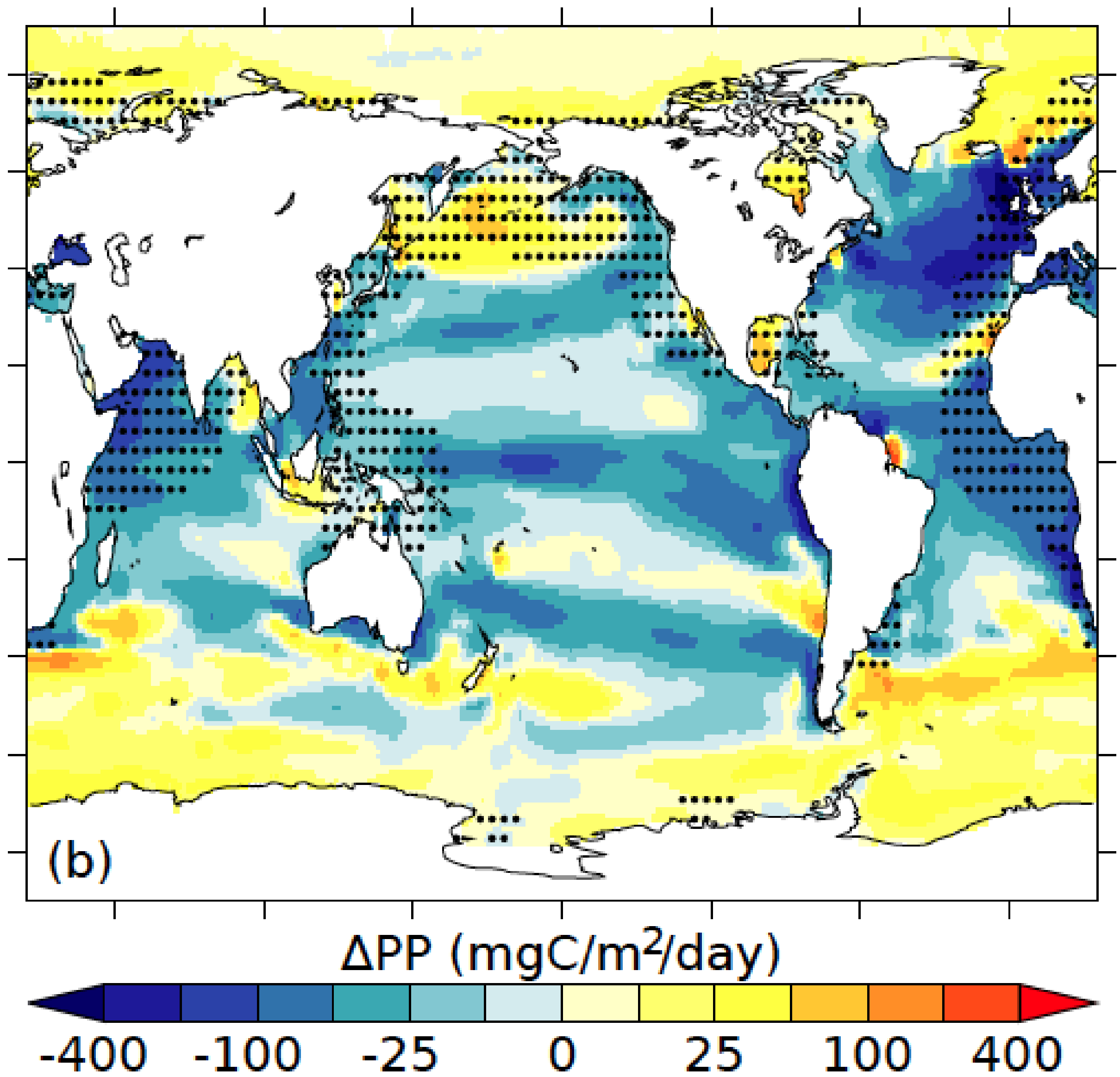
Ocean Warming

-anthropogenic warming & decadal variability signatures
-80% of excess heat in climate system is in the oceans

Levitus et al. Geophys. Res. Lett.(2005)



IPCC (2007)



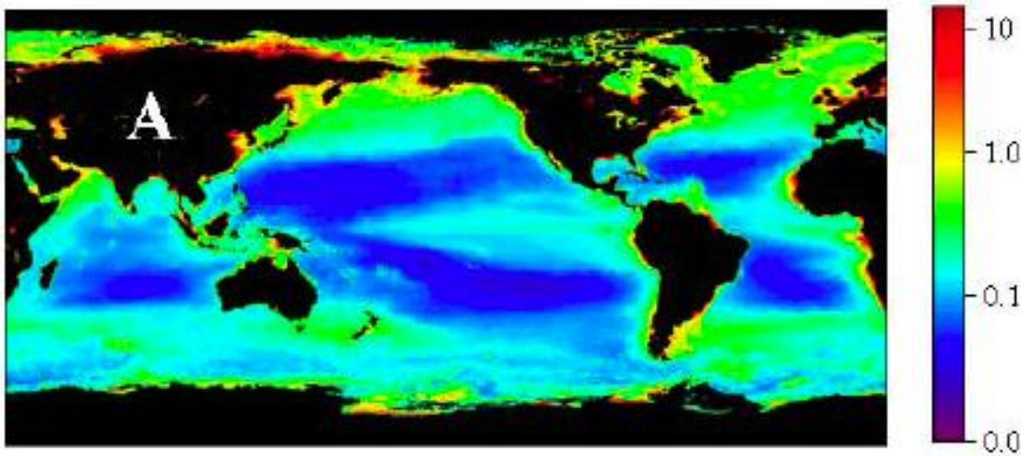
Climate Impacts on Primary Productivity

Tropics & subtropics:
- Reduced production
- Increased stratification
- Lower nutrient supply

Mid- to high latitudes
- Increased production
- Weaker mixing
- Less sea-ice

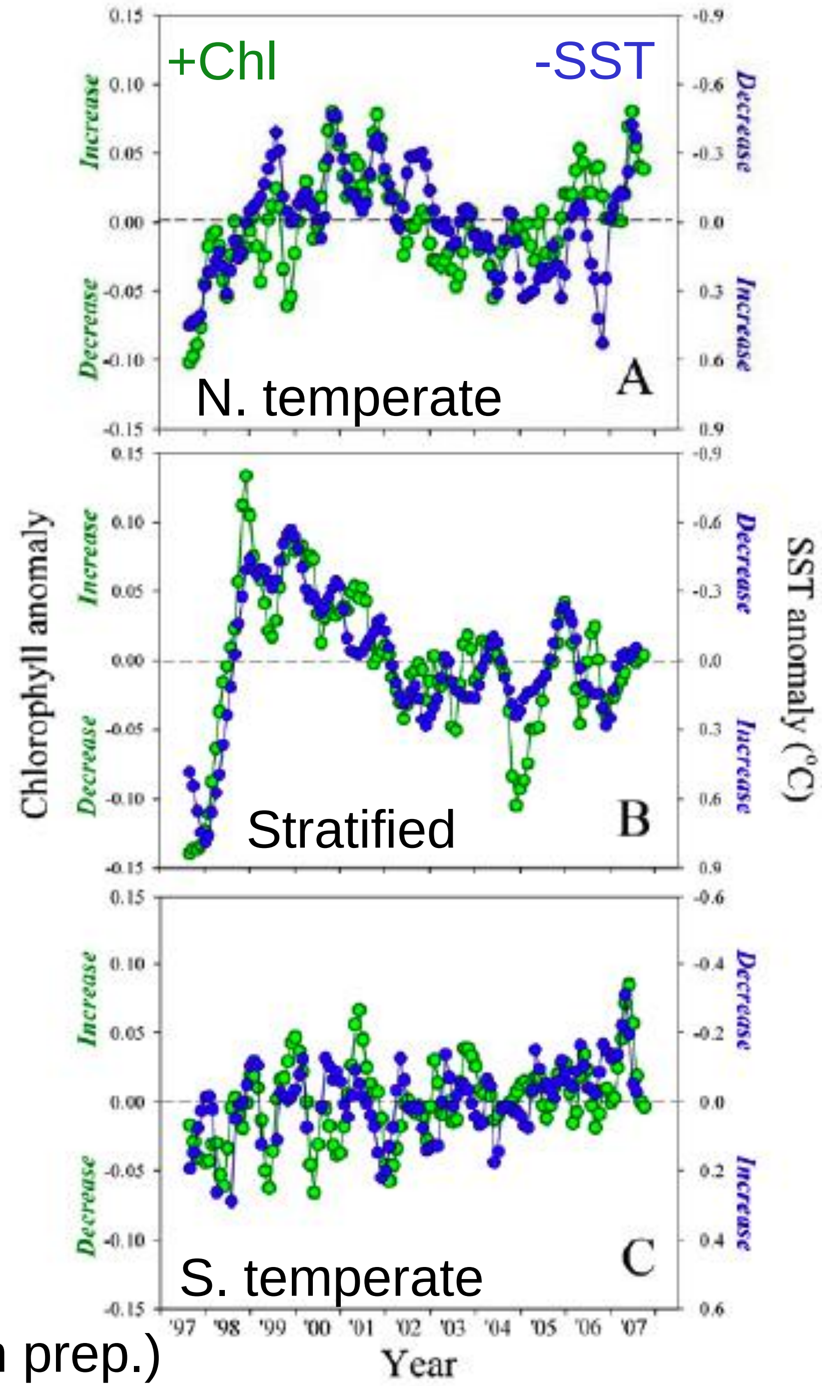
Steinacher et al. Biogeosci. Disc. 2009

Satellite Observations of Ocean Biology



-Global observations essential
-Phytoplankton chlorophyll (biomass proxy) decreases when temperature increases:

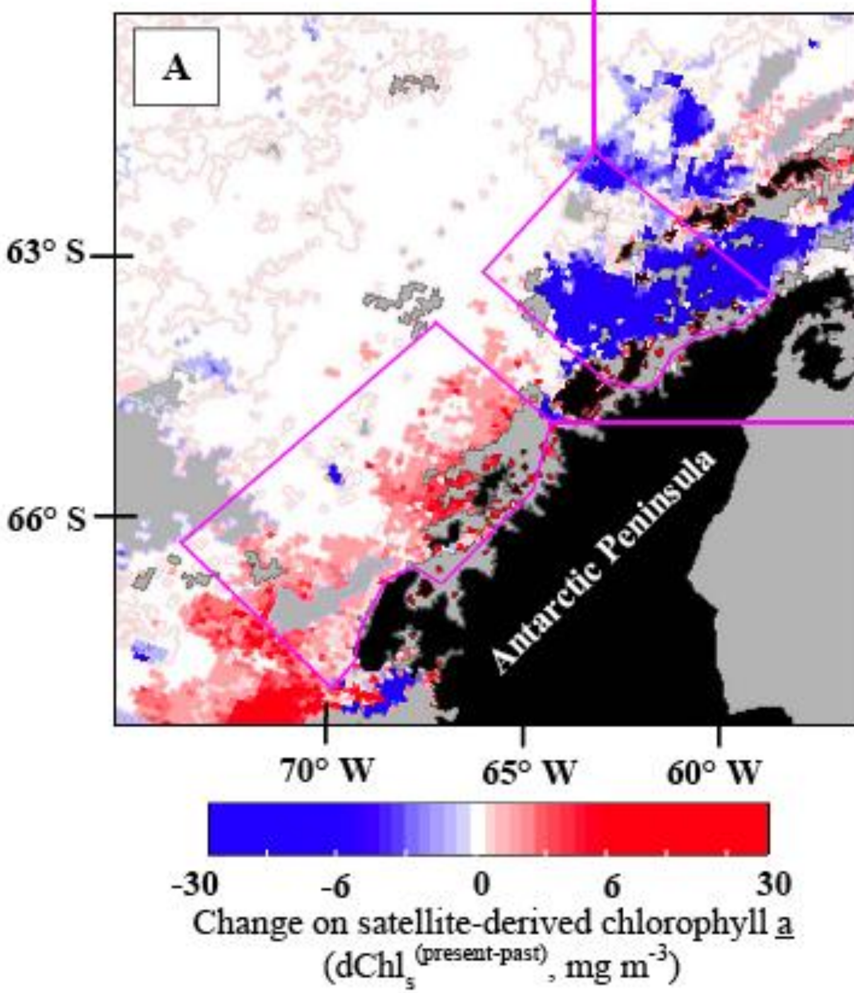
- •tropics/subtropics (agree with models)
- •temperate/polar (contradict models)



Behrenfeld et al. (2006; in prep.)

Ecological Changes to Retreating Sea-Ice

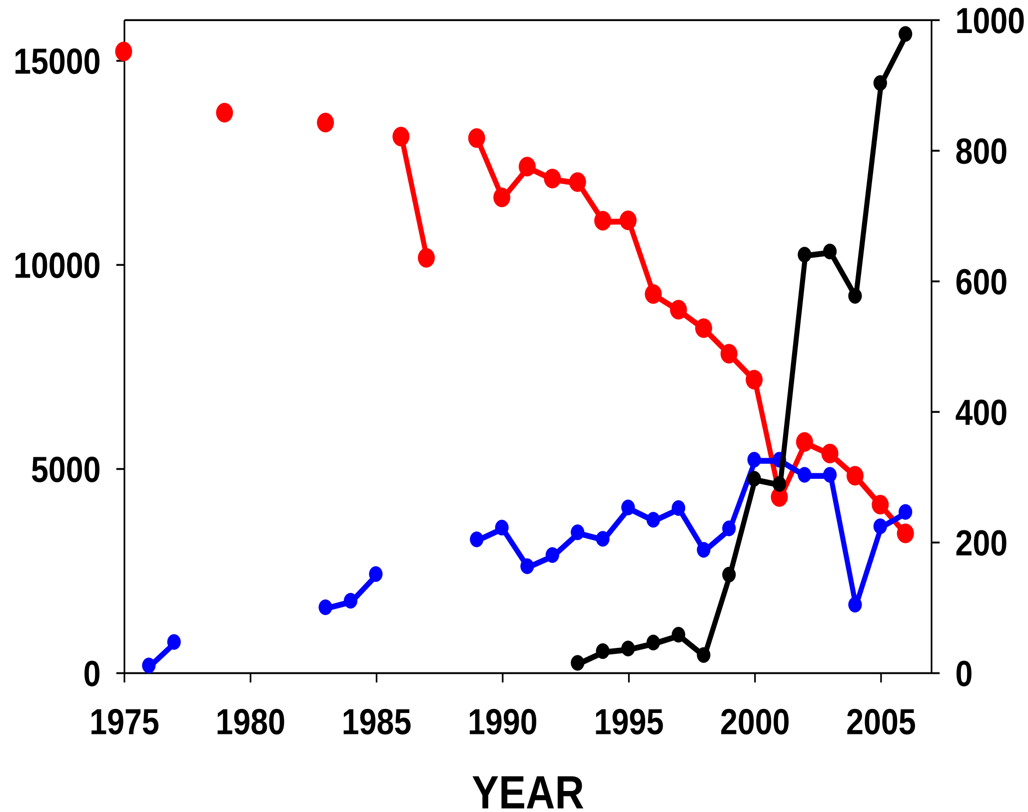
Decadal Change in Surface Chlorophyll



Montes et al. Science (2009)

Penguin Populations near Palmer Station

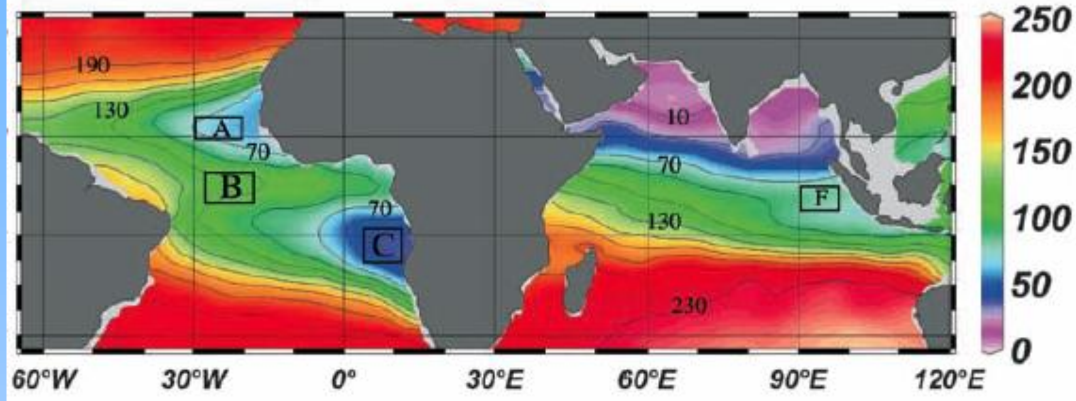
Adélies declining, Gentoos and Chinstraps invading and increasing

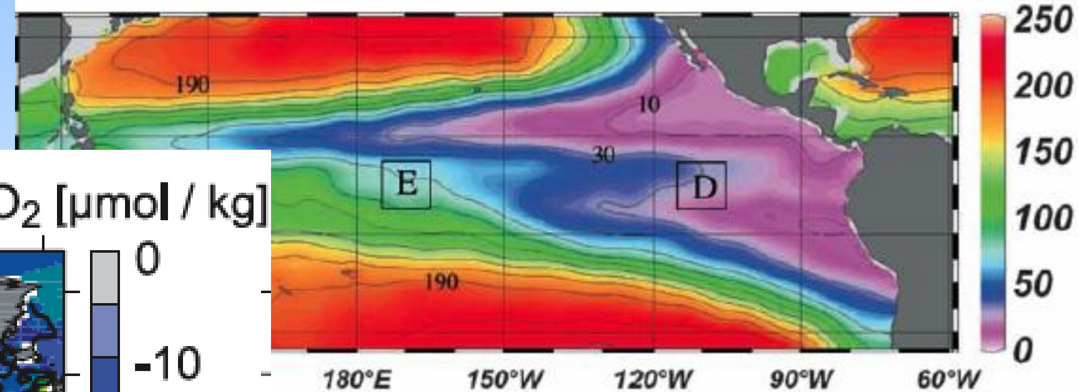


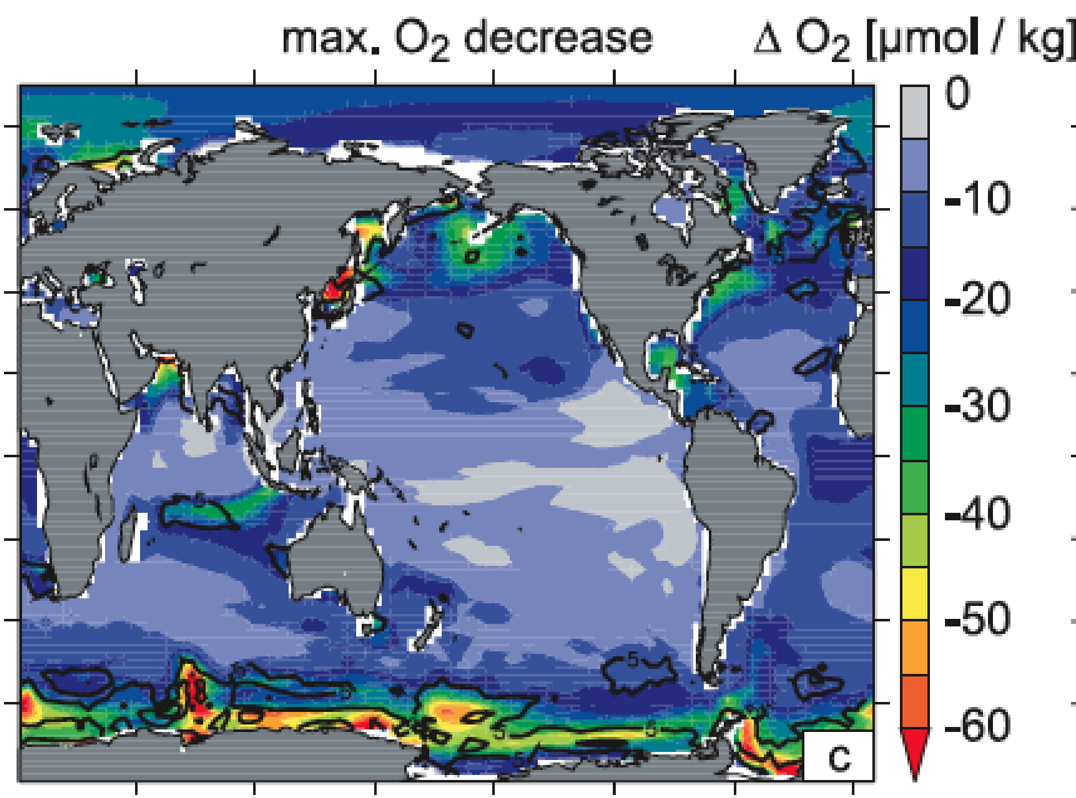
Bill Fraser

Expanding Ocean Oxygen Minimum Zones

Ocean will loss oxygen because of warming, altered circulation & changes in biology

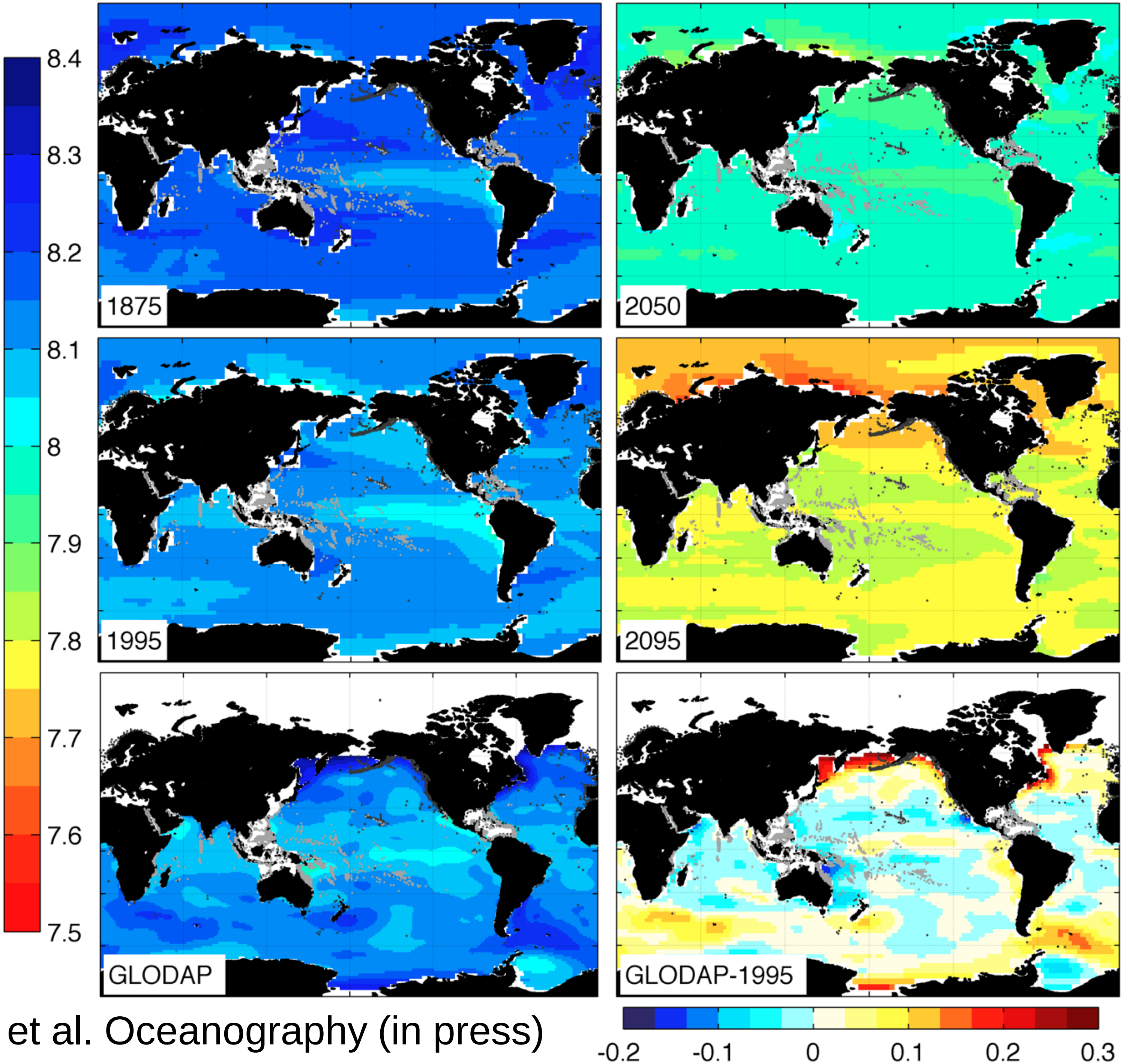






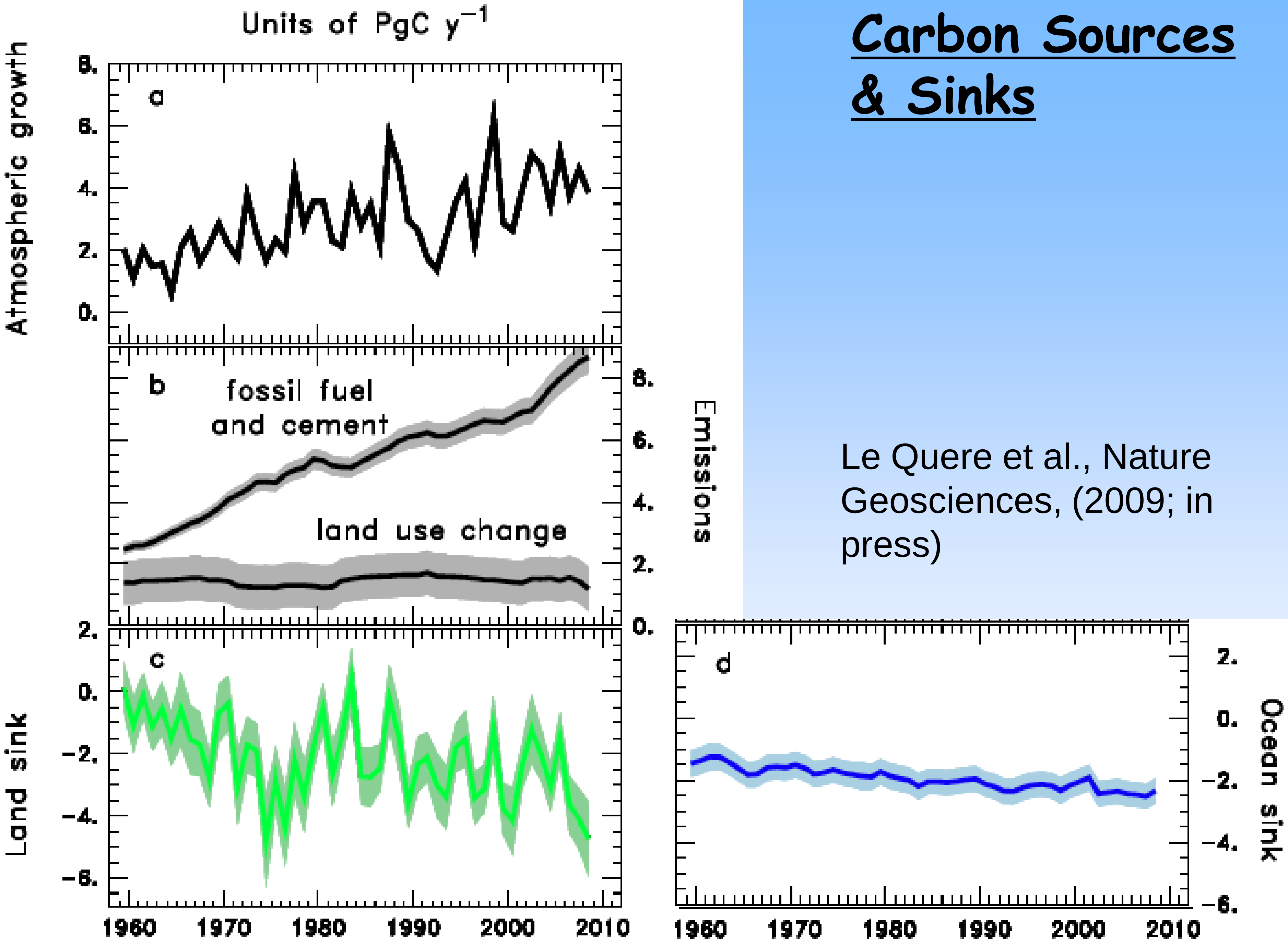
Stramma et al. *Science* (2008)

Froelicher et al. *Global Biogeochemical Cycles* (2009) pH

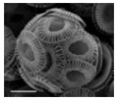


Feely et al. Oceanography (in press)

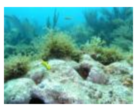
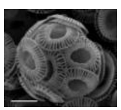
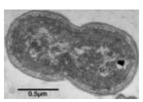
Carbon Sources & Sinks

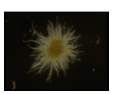


Le Quere et al., Nature Geosciences, (2009; in press)







Physiological Response	Major group	# species studied	Response to increasing CO_2 a	b	c	d
Calcification						
	Coccolithophores	4	2	1	1	1
	Planktonic Foraminifera	2	2	-	-	-
	Molluscs	6	5	-	1	-
	Echinoderms	3	2	1	-	-
	Tropical corals	11	11	-	-	-
	Coralline red algae	1	1	1	-	-
Photosynthesis[1]						
	Coccolithophores[2]	2	-	2	2	-
	Prokaryotes	2	-	1	1	-
	Seagrasses	5	-	5	-	-
Nitrogen Fixation						
	Cyanobacteria	4	-	3	1	-
Reproduction						
	Molluscs	4	4	-	-	-
	Echinoderms	1	1	-	-	-

Adapted from Doney et al. Annual Review of Marine Sciences (2009)