Marine Biogeochemical Modeling: Ocean Acidification

Scott Doney (WHOI)

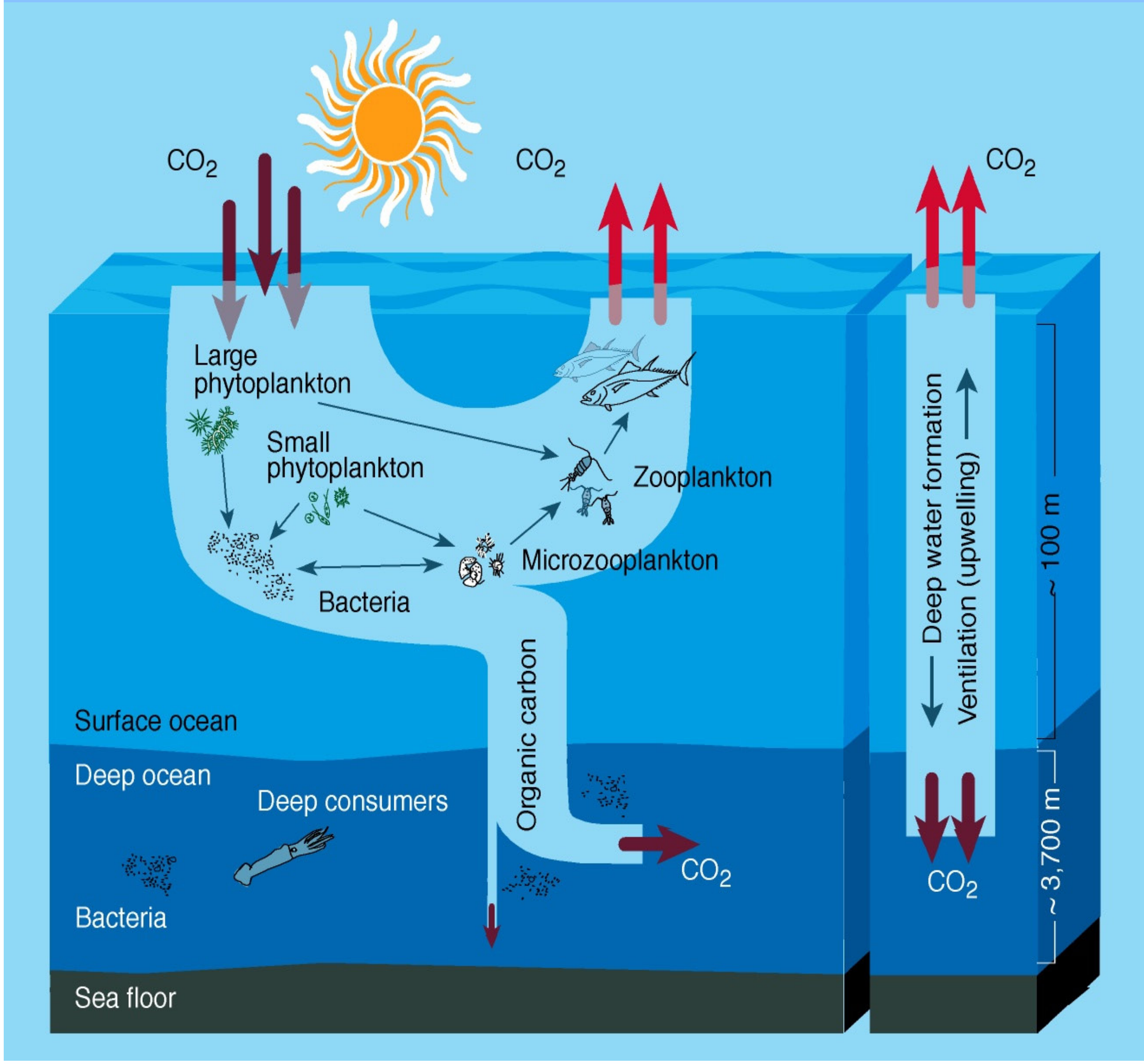
OCB Ocean Acidification Short Course 2009

Talk Outline

- Fossil Fuels & Global Carbon Cycle
- Past & Future Seawater Chemistry
- Climate-Carbon Cycle Feedbacks
- Calcification & Biogeochemistry
- Biological & Ecological Effects
- Policy, Economic & Social Dimensions

Supported by:

Ocean Carbon Cycle & Ocean Acidification



Anthropogenic CO_2 uptake currently controlled by ocean circulation; but in future, what will be role of climate & biology?

For ocean acidification may want models to address many different aspects:

-patterns & trends in seawater chemistry

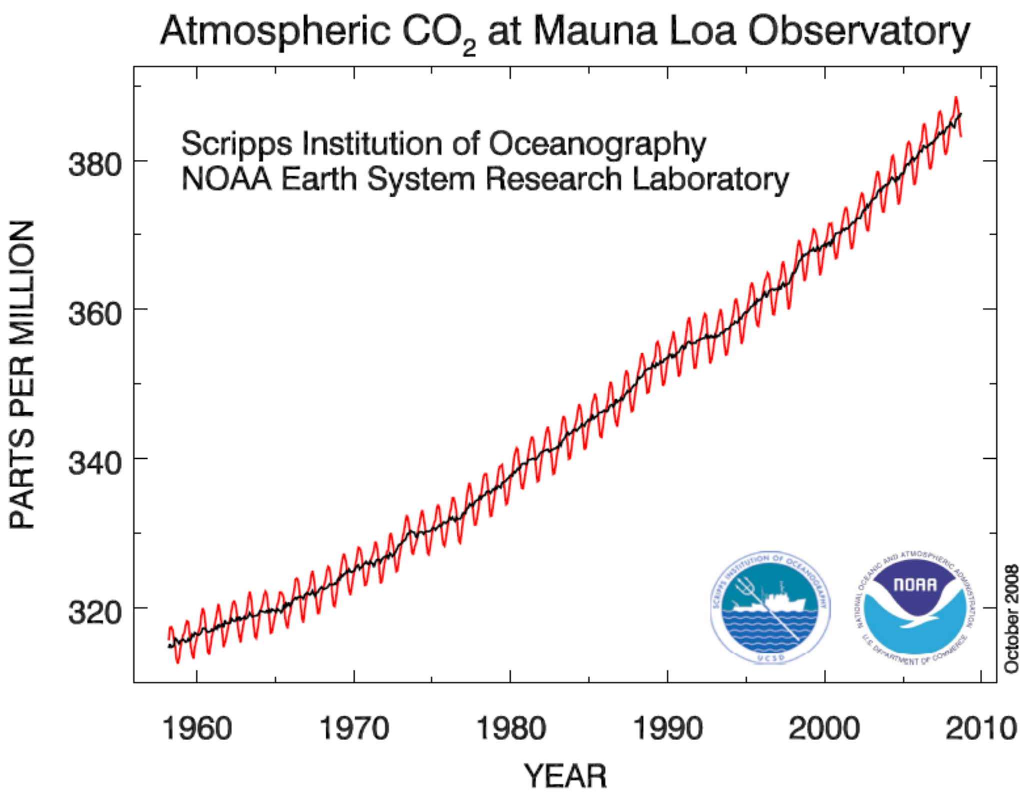
-population biology of individual species

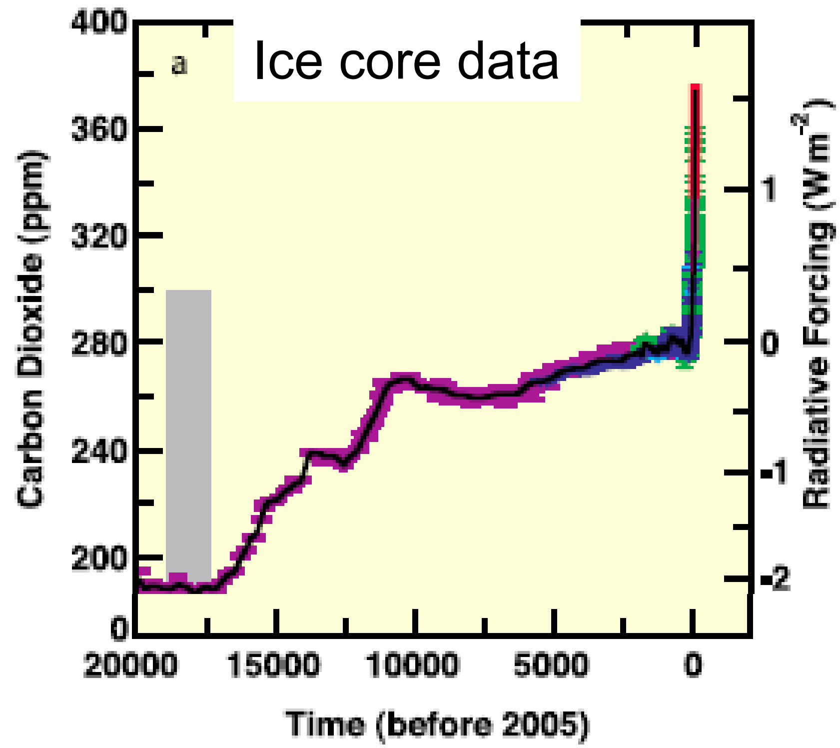
-food-web & ecological interactions

-biogeochemical feedbacks

-socio-economic effects on fisheries & ecosystem services

Rising Atmospheric CO_2

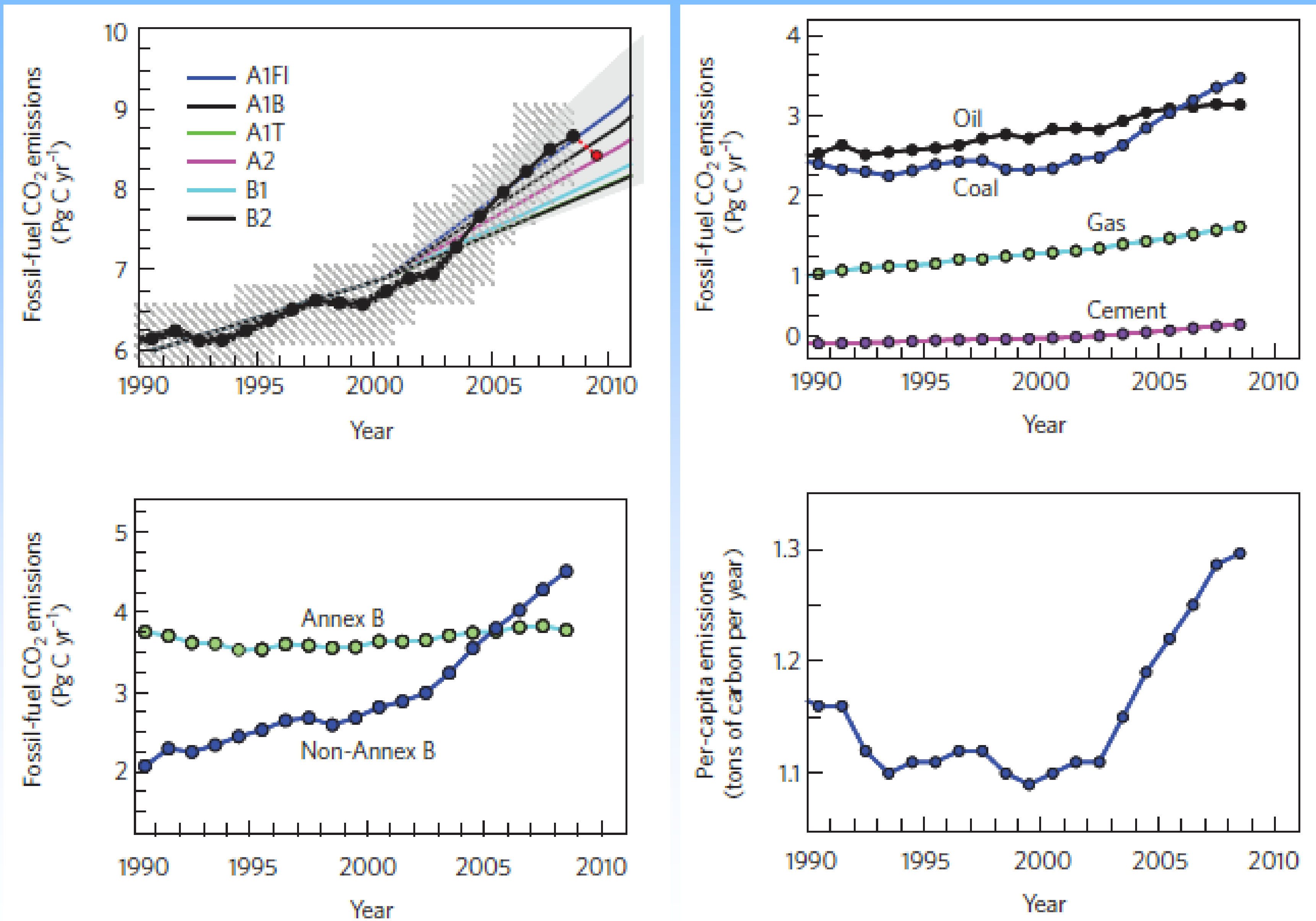




-strong evidence for human causation
-highest level in at least last million years

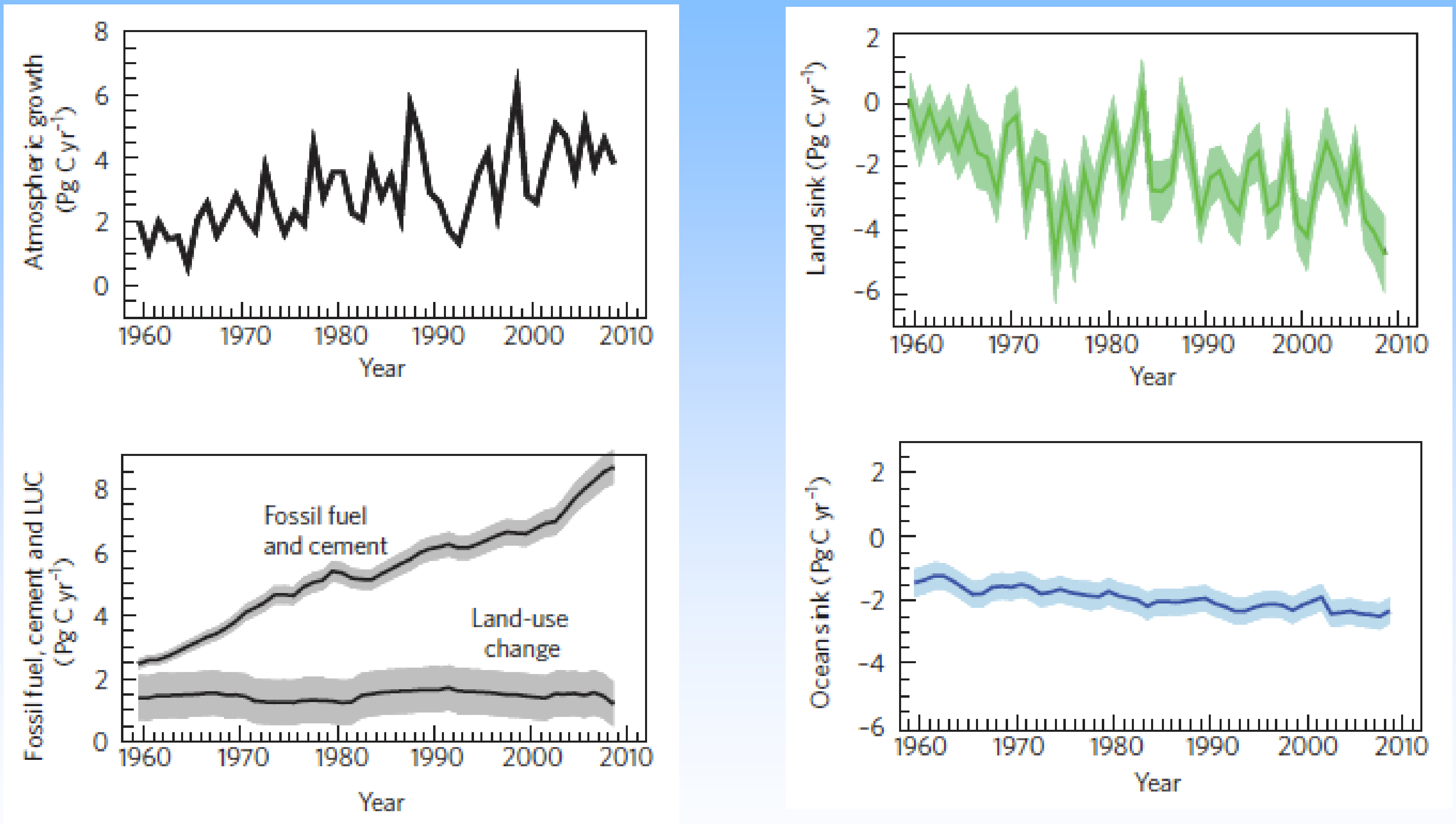
"Thus human beings are now carrying out a large scale geophysical experiment…"
Revelle and Suess, Tellus, 1957

Fossil Fuel Emissions



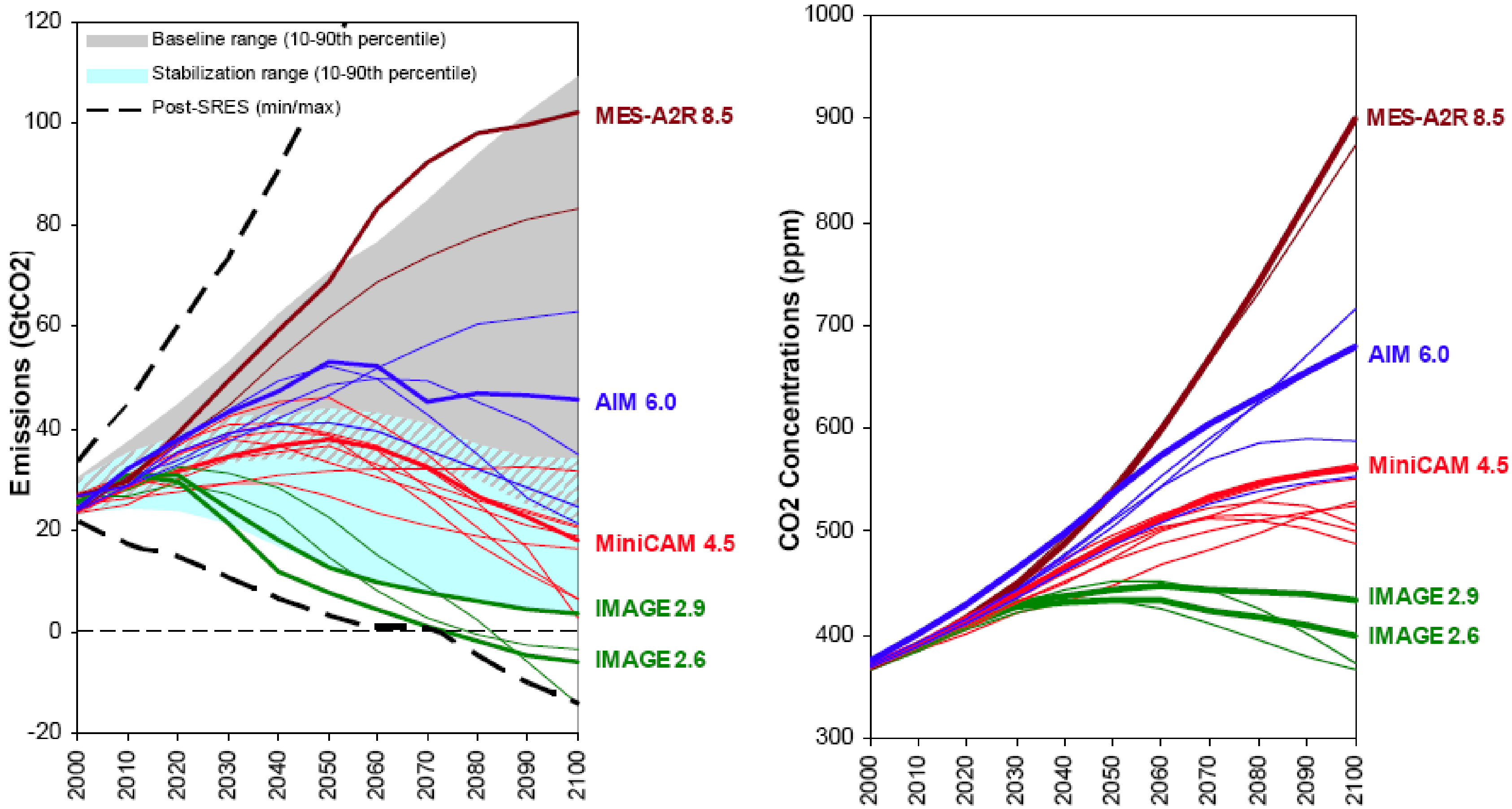
Le Quere et al., Nature Geosciences, 2009 (in press)

Ocean & Land CO_2 Sinks



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

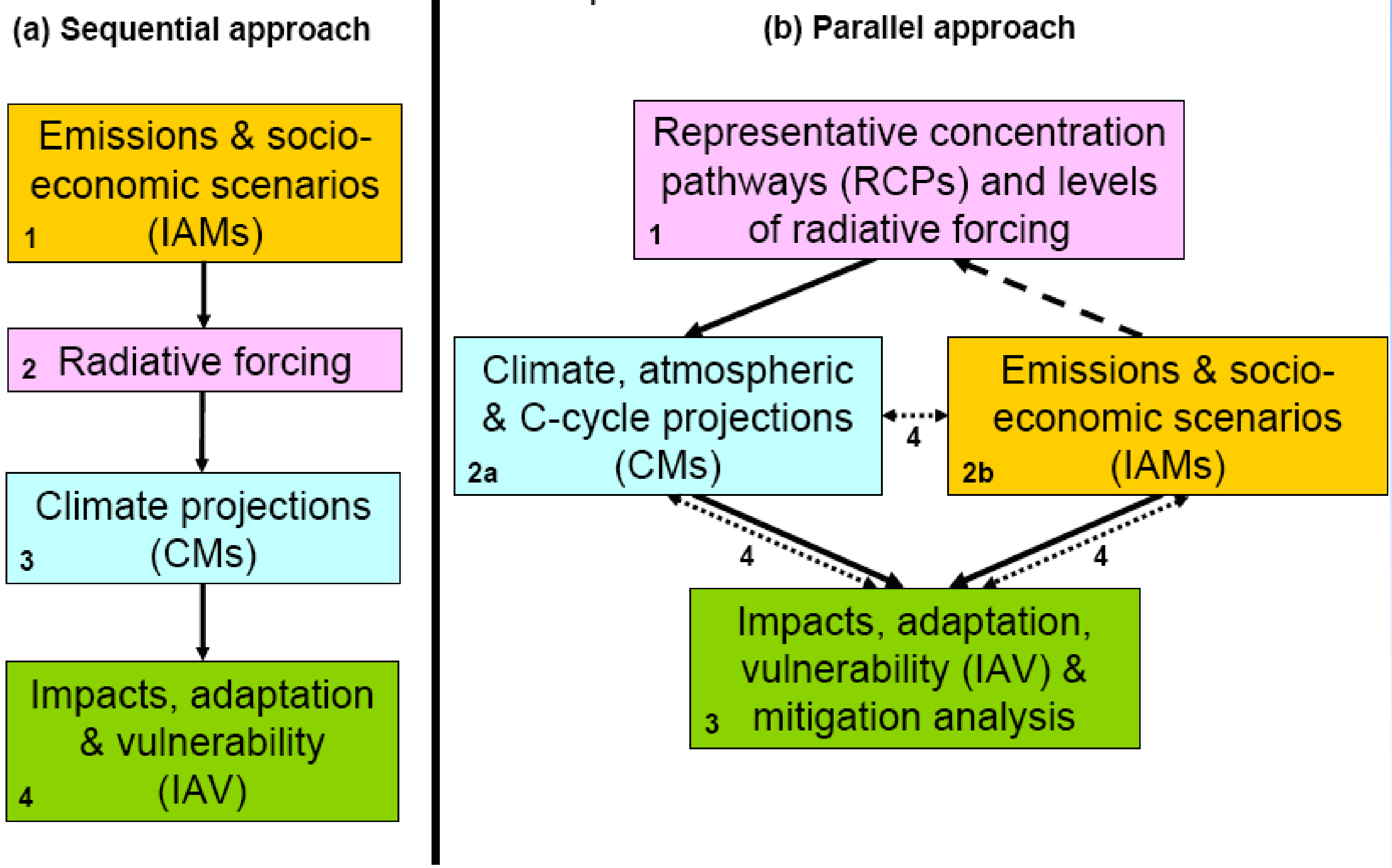
New mitigation scenarios: representative concentration pathways (RCPs)



(Taylor, K.E., R.J. Stouffer, and G.A. Meehl, 2009: A summary of the CMIP5 Experimental Design. http://www-pcmdi.llnl.gov/)

New way of producing/using scenarios devised by WG1, WG2 and WG3 communities (not IPCC)

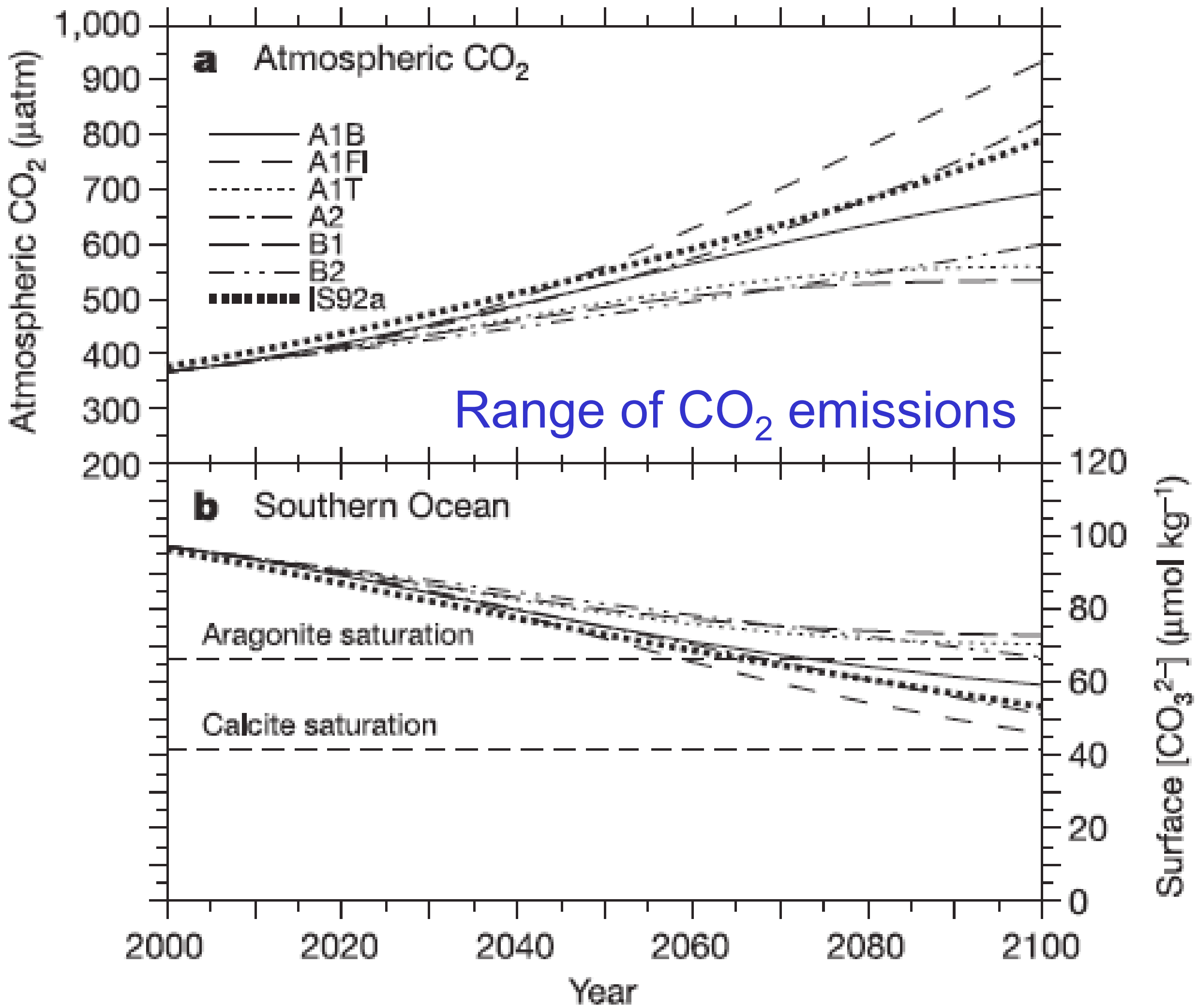
pre-AR4: post-AR4:



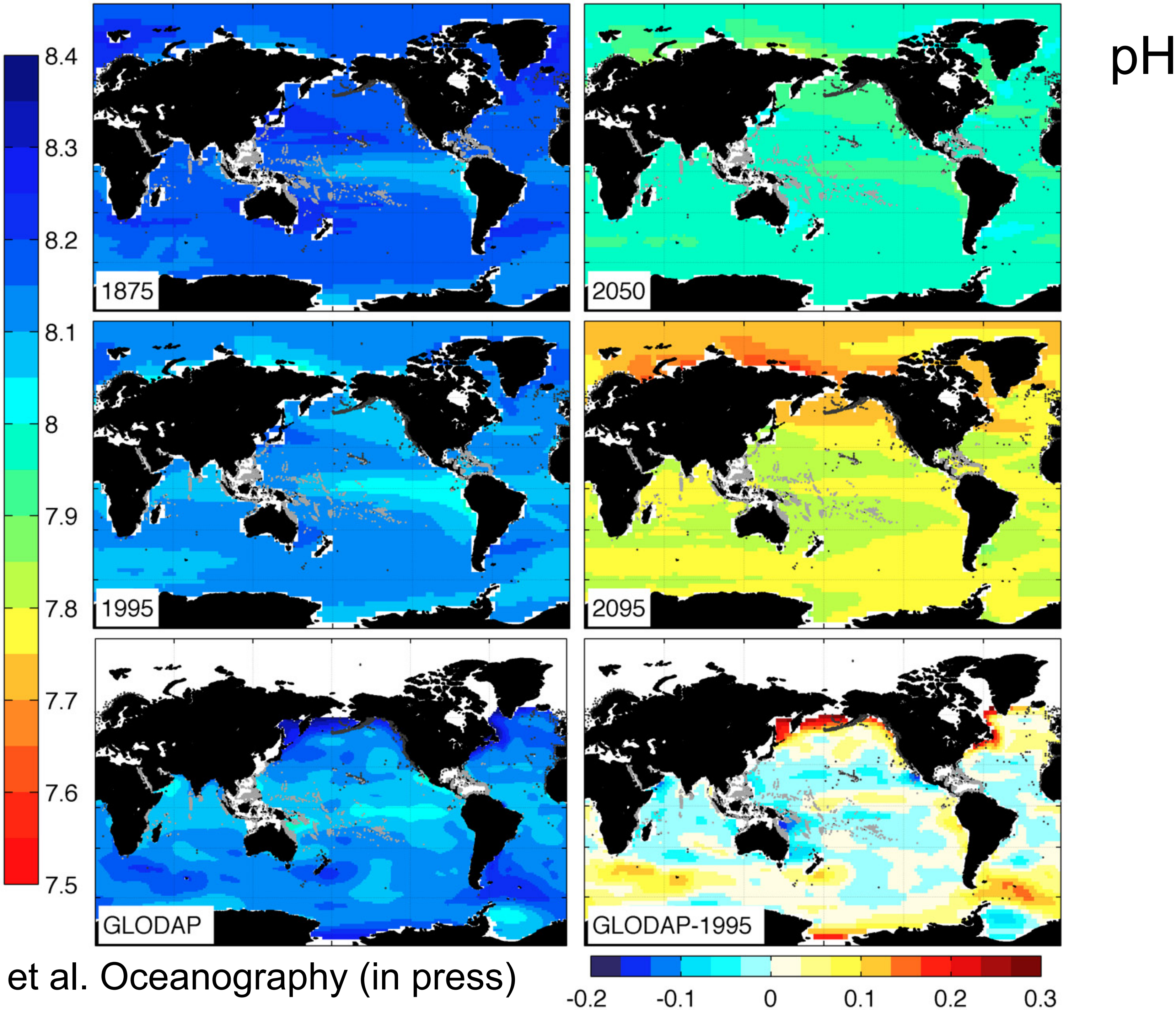
(Moss, R., et al., 2009: Representative Concentration Pathways: A New Approach to Scenario Development for the IPCC Fifth Assessment Report. *Nature*, in press.)

Anthropogenic CO_2 & Ocean pH

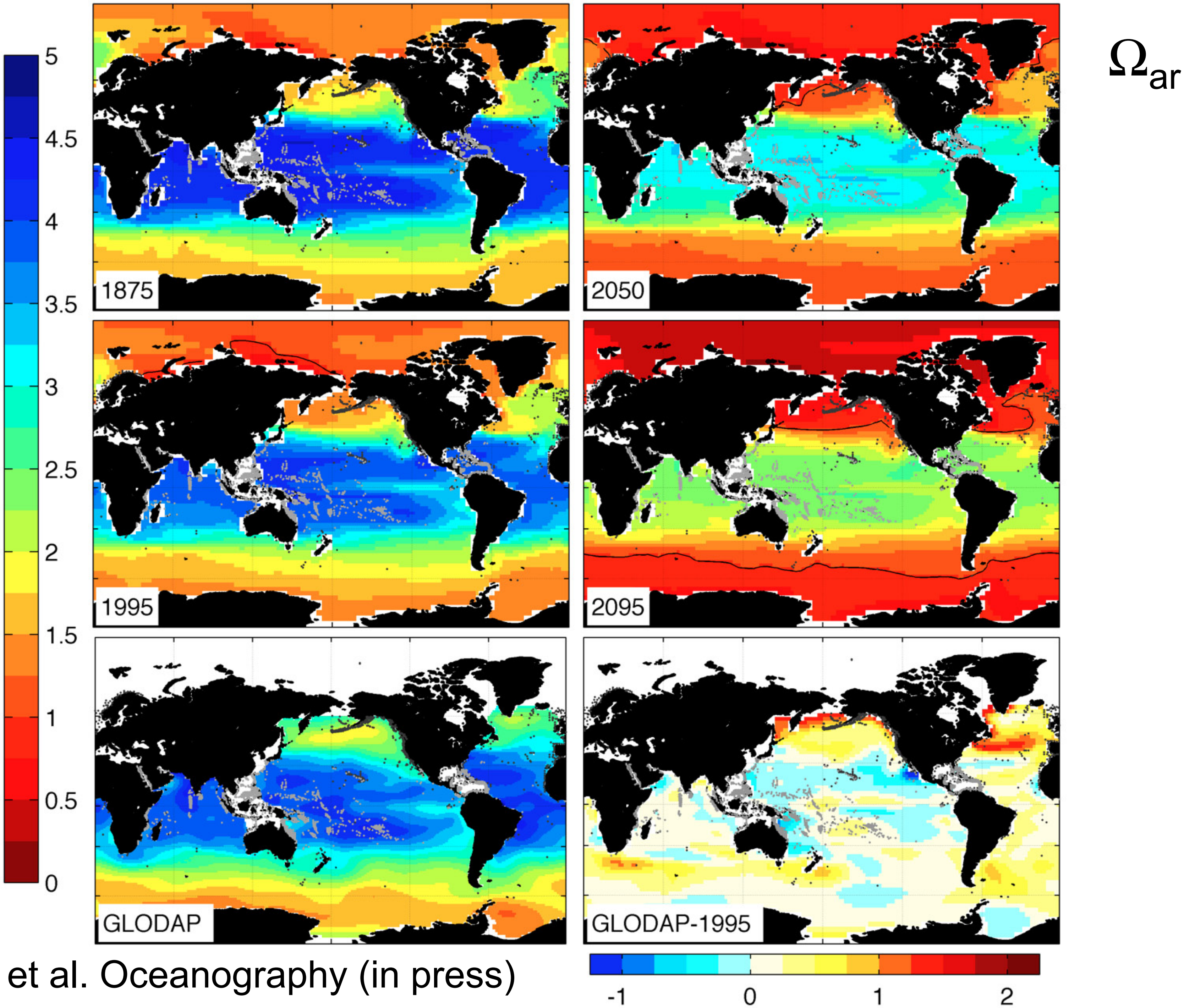
-CO_2 emissions (social, political, economic)
-atmospheric CO_2 (land & ocean uptake; climate-carbon feedbacks)
-ocean chemistry & circulation



Orr et al., Nature (2005)



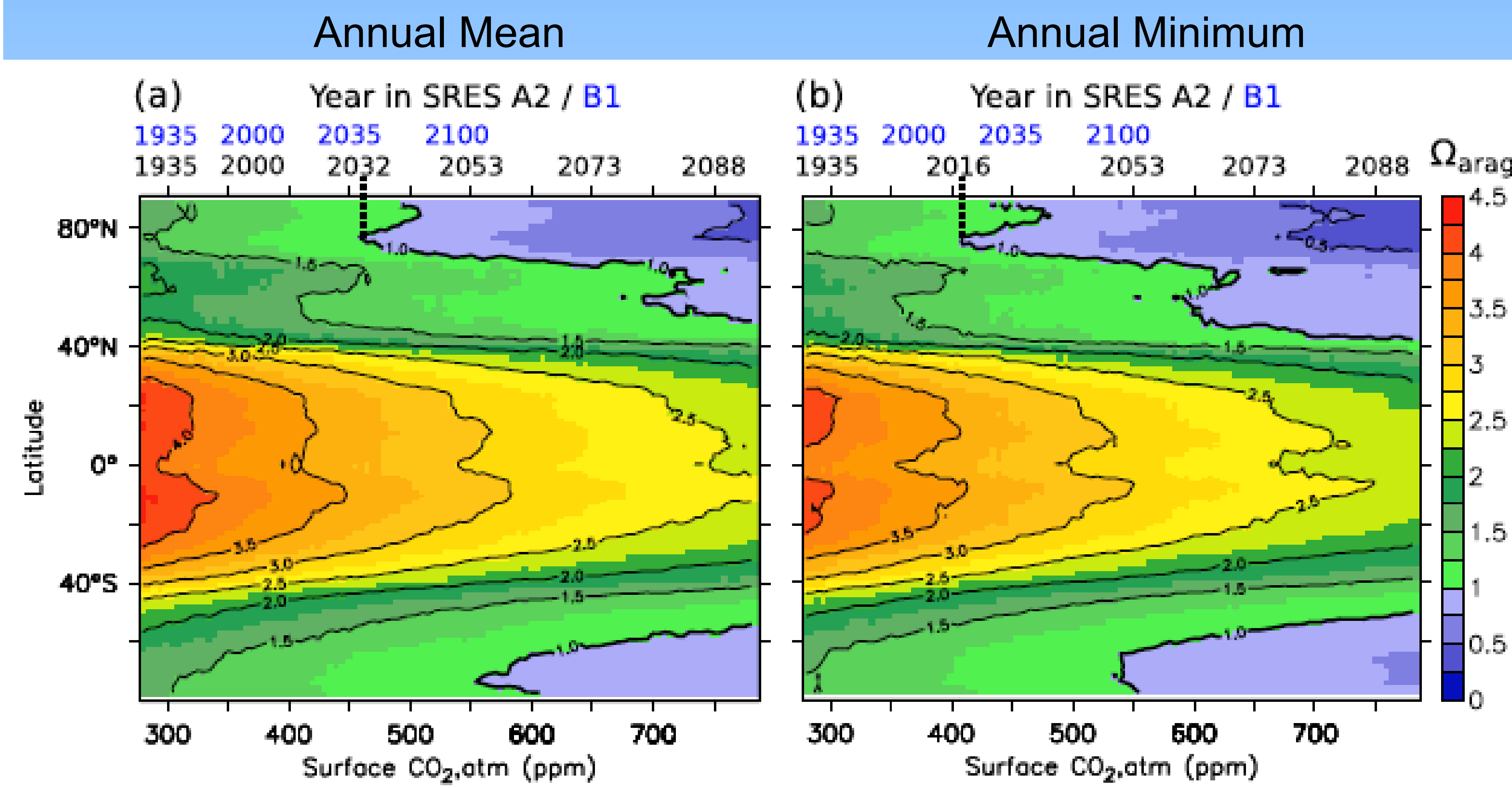
Feely et al. Oceanography (in press)



Feely et al. Oceanography (in press)

Surface Aragonite Saturation

Zonal mean Ω vs. atmospheric CO_2

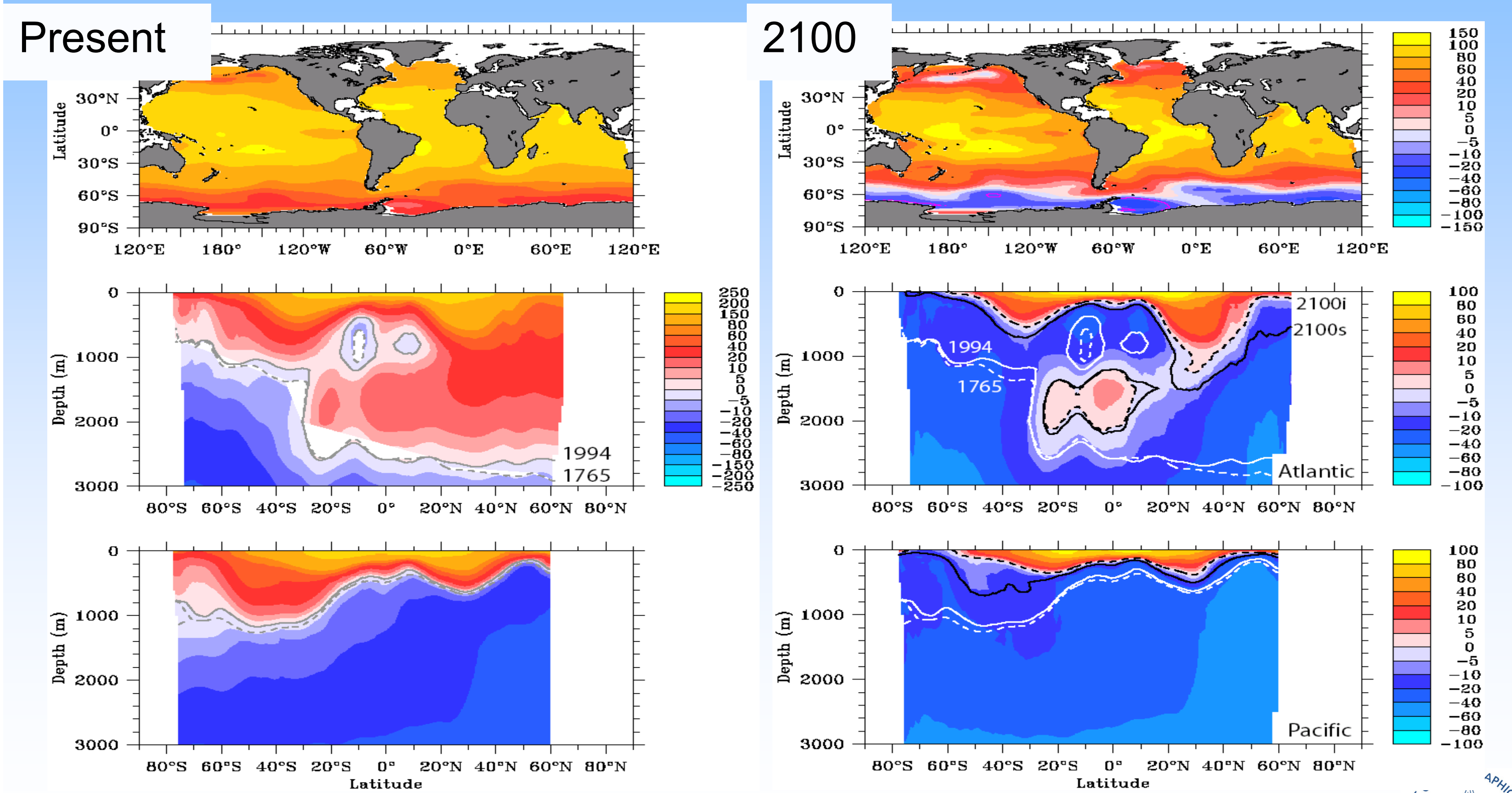


Steinacher et al. Biogeosci., 2009

Shoaling of Aragonite Saturation Horizons

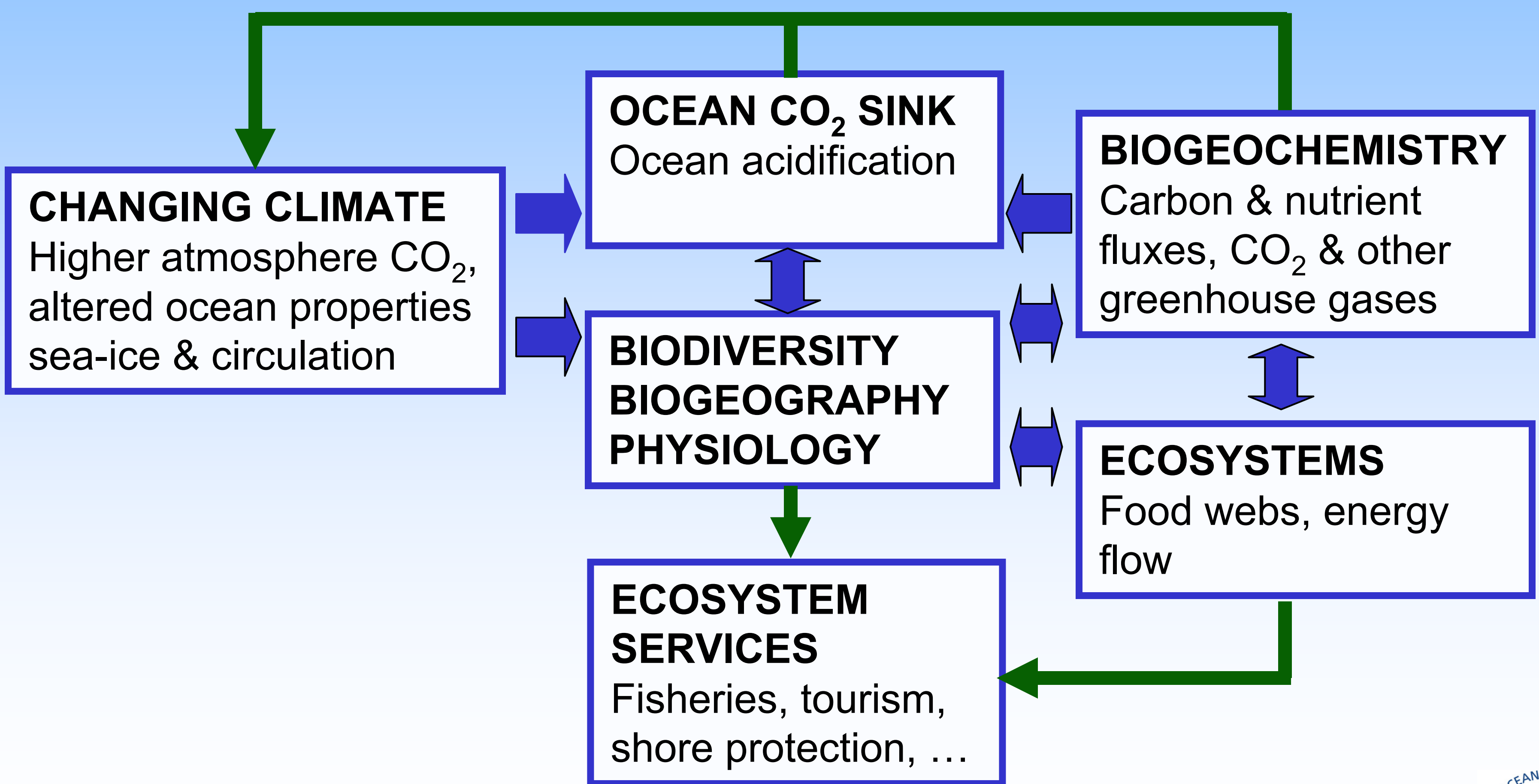
$\Omega = [Ca^{2+}][CO_3^{2-}] / K_{sp}$

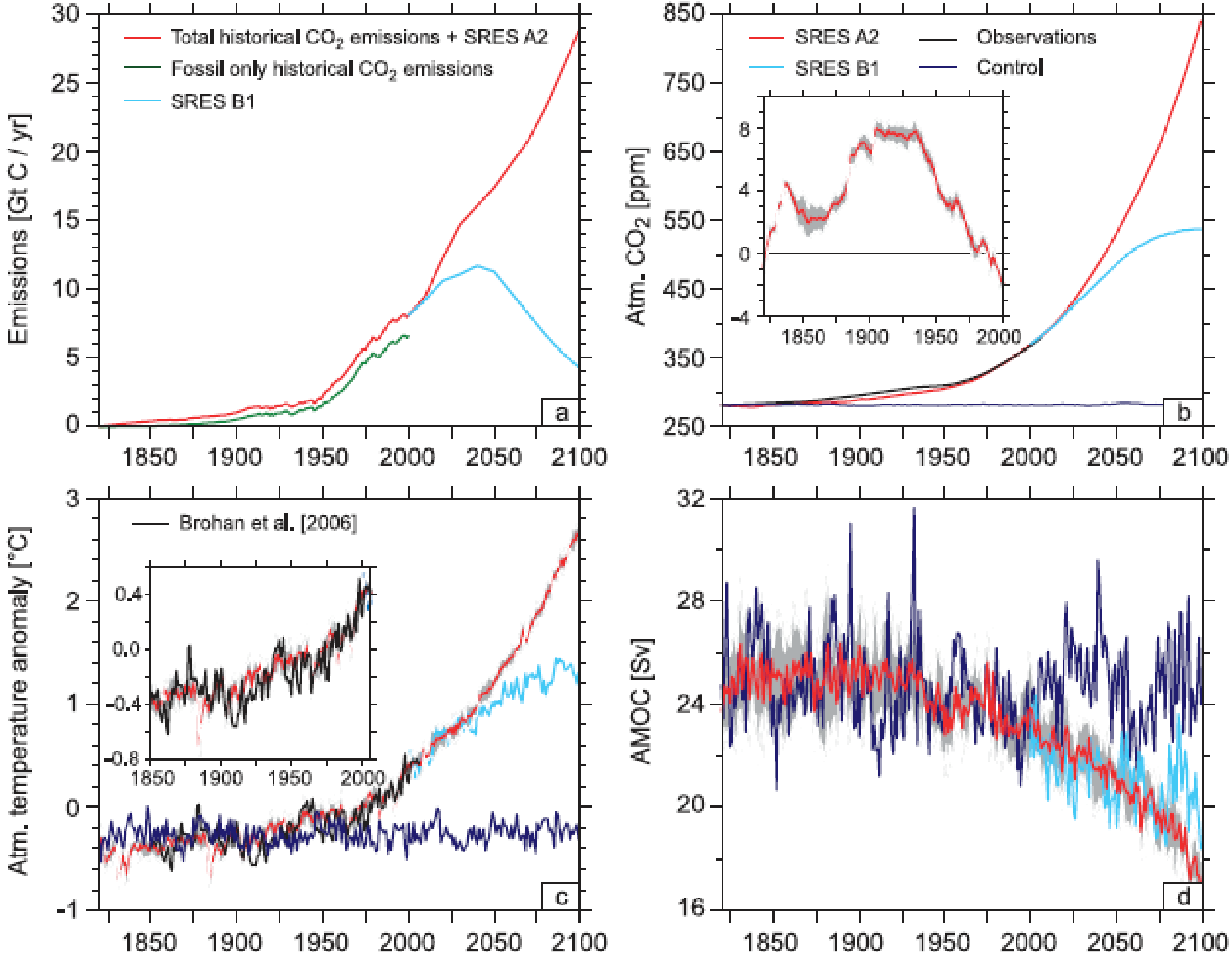
$\Delta[CO_3^{2-}] = [CO_3^{2-}]_{obs} - [CO_3^{2-}]_{sat}$



Orr et al. Nature (2005)

Ocean Climate Responses & Feedbacks

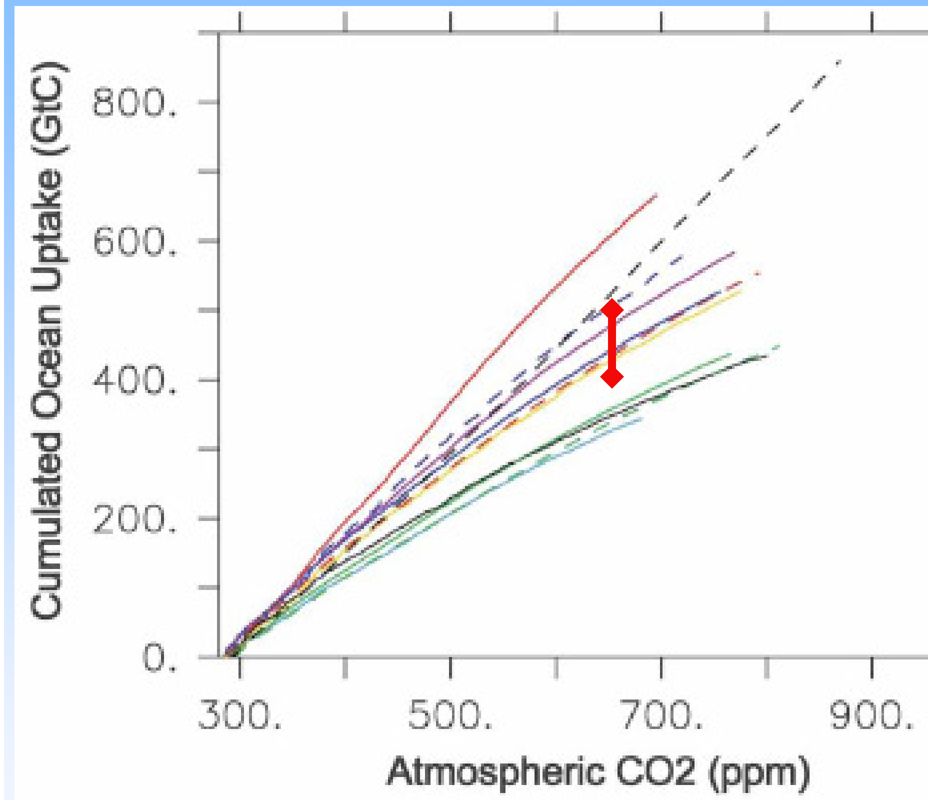




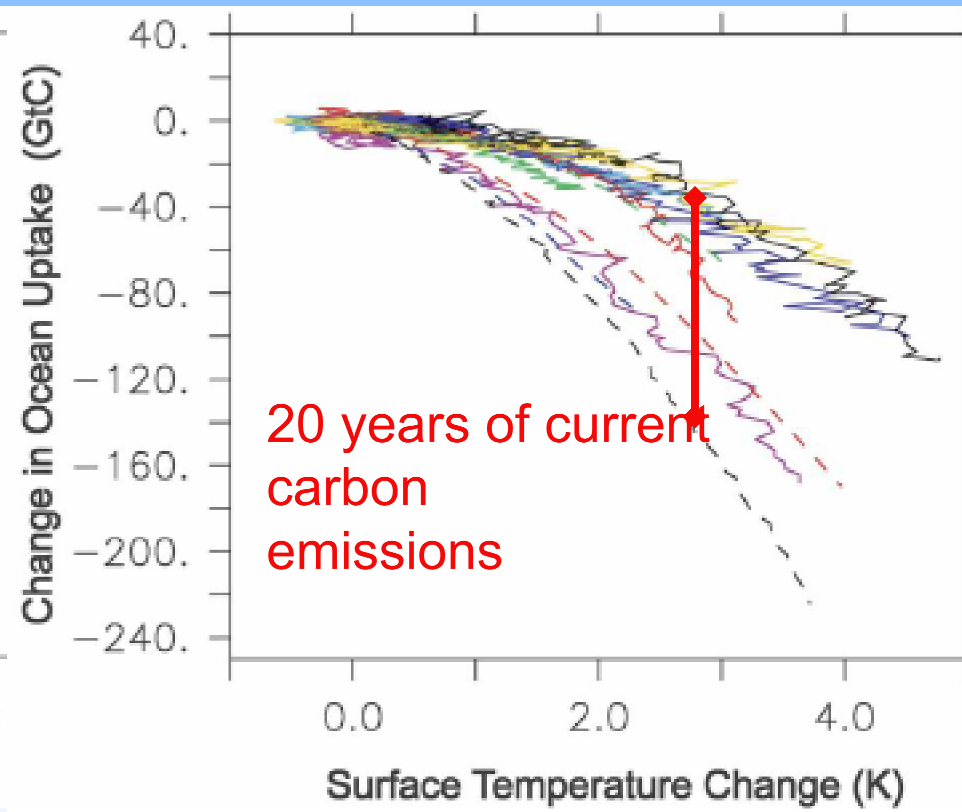
Frolicher et al. Global Biogeochem. Cycles 2009

Coupled Model Uncertainties

Strength of Ocean CO_2 Sink

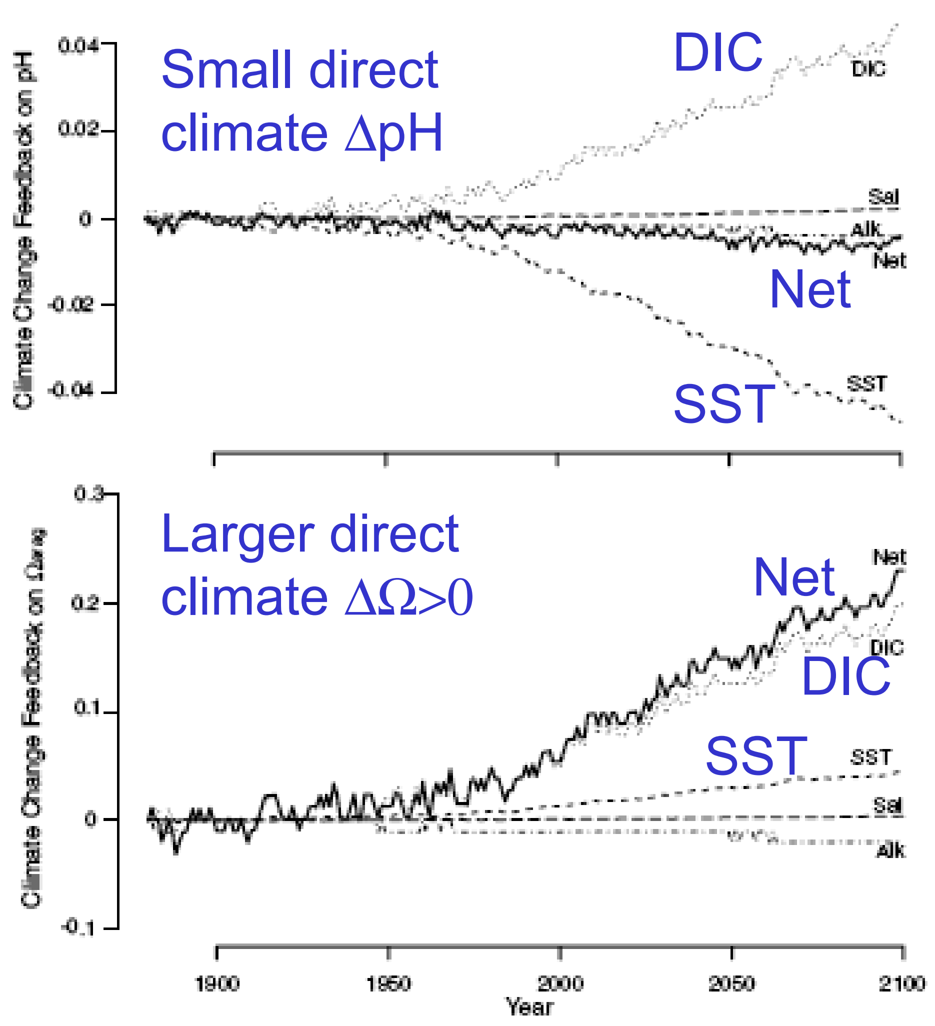


Sensitivity to Climate Warming

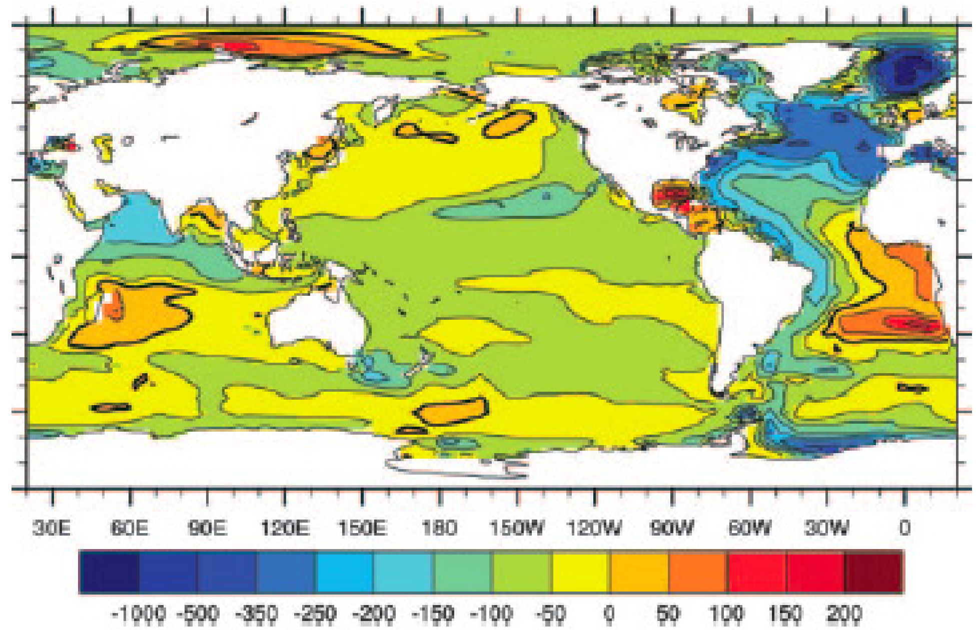


Friedlingstein et al. *J Climate* 2006

Climate Feedbacks



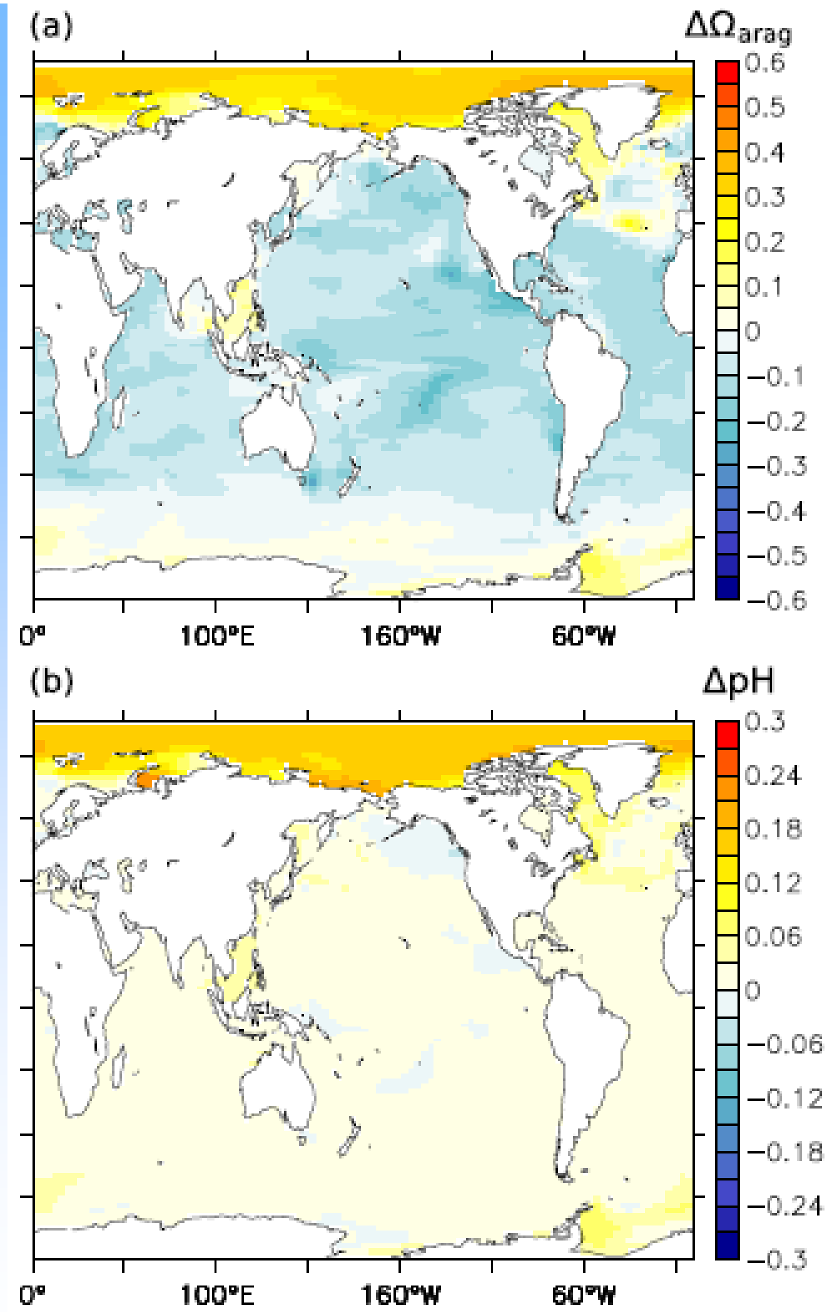
indirect ocean circulation changes

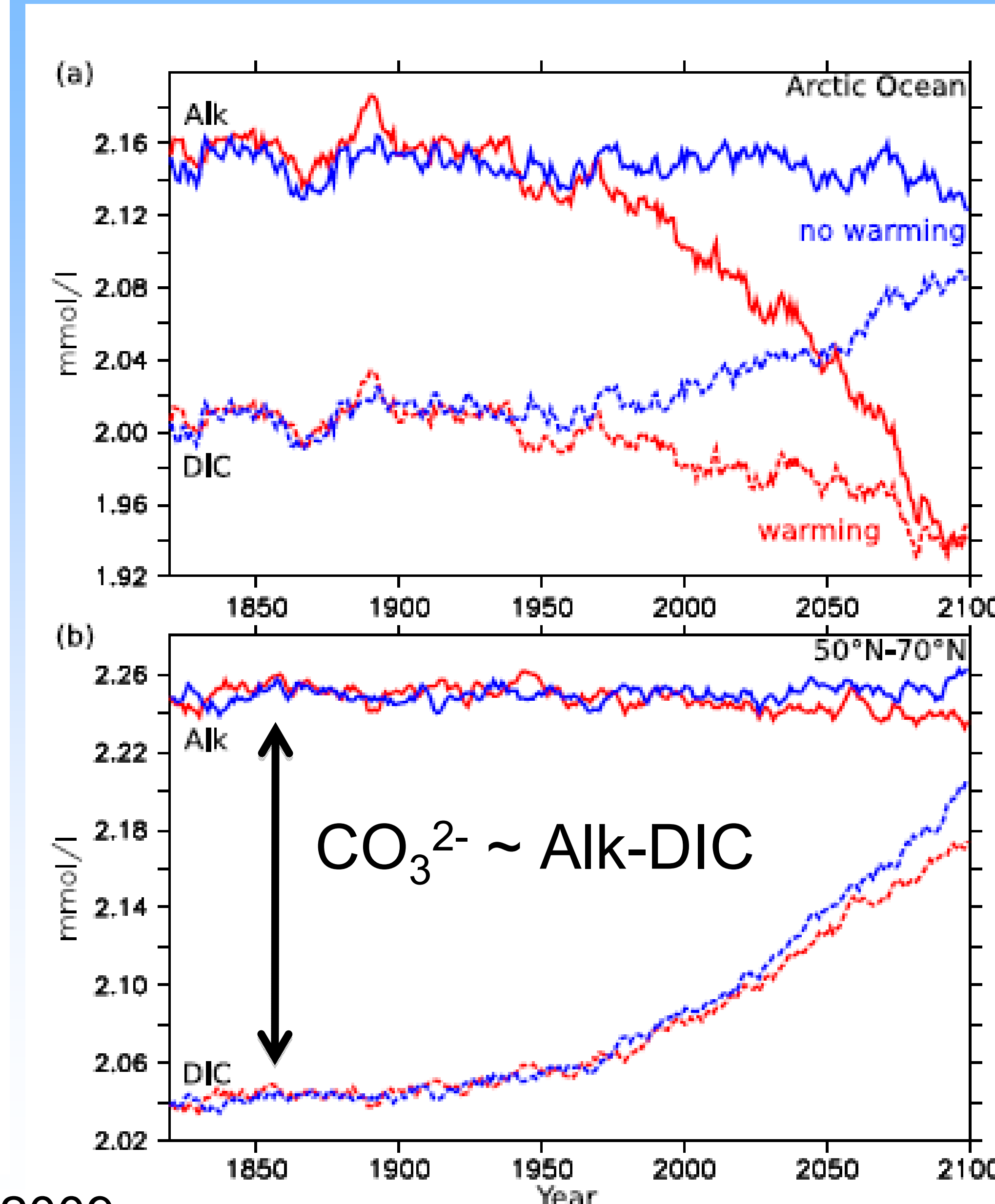


Fung et al. PNAS (2005)

McNeil and Matear, Tellus (2007)
Cao et al., GRL (2007)

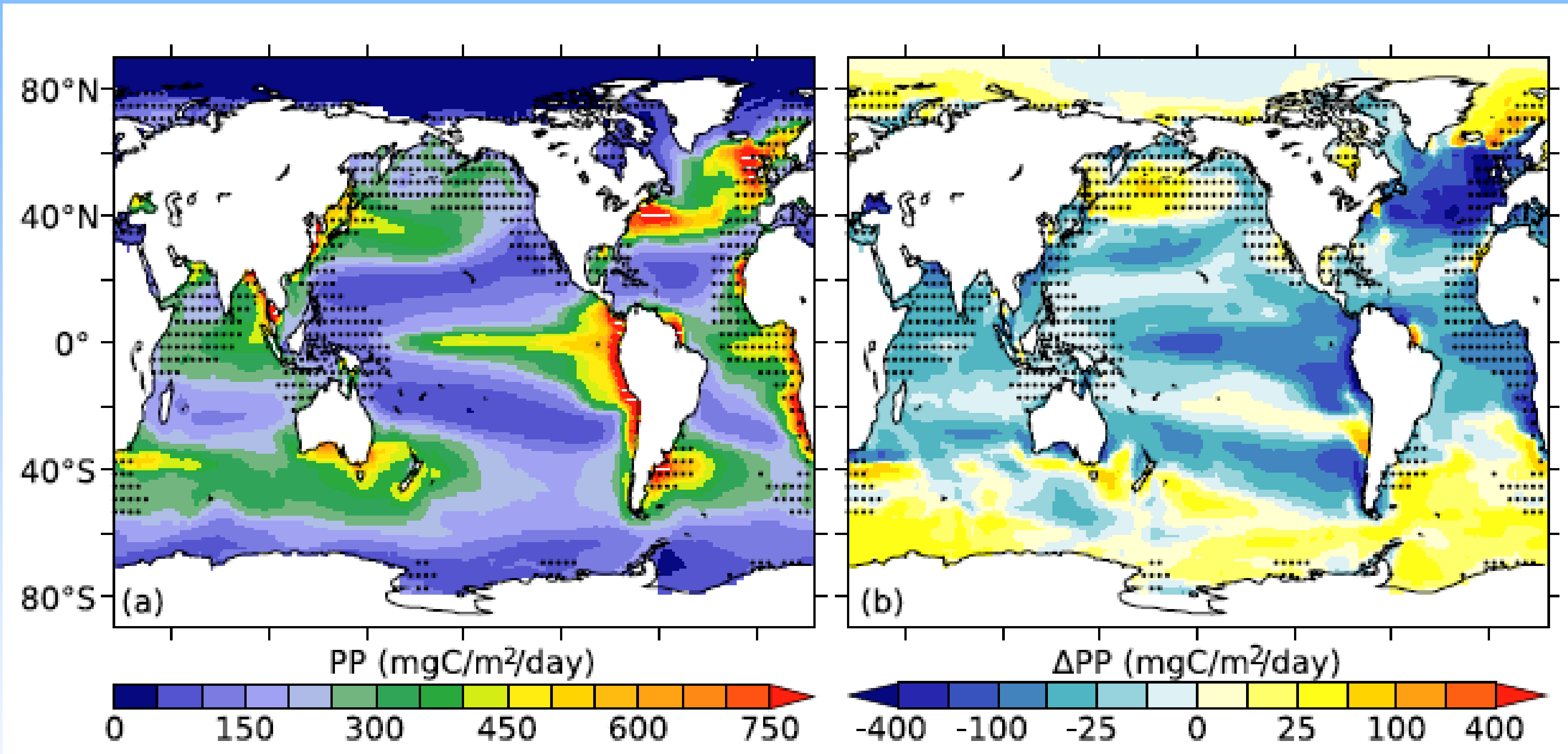
Climate Change Feedbacks





Steinacher et al., *Biogeosciences,* 2009

Climate Change Impacts on Primary Productivity



Steinacher et al. Biogeosciences Disc. 2009

Sea-Air pCO_2 Trends

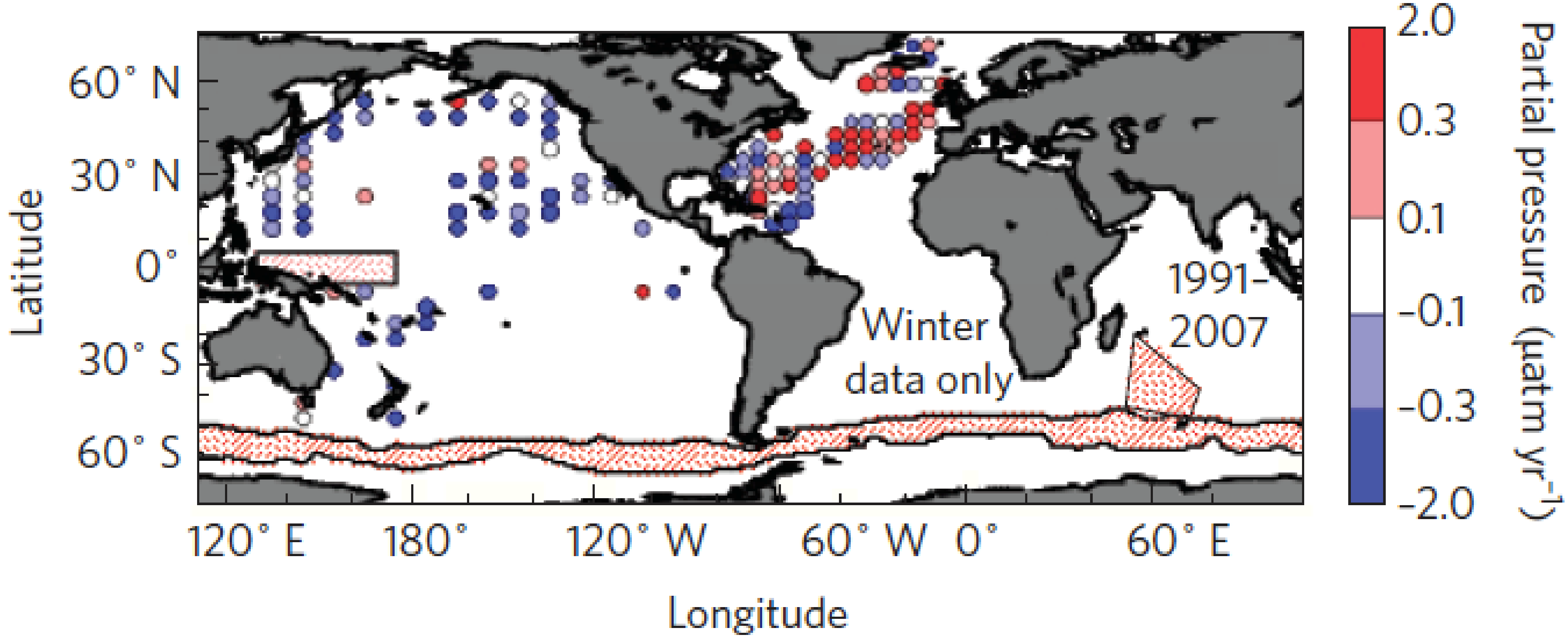
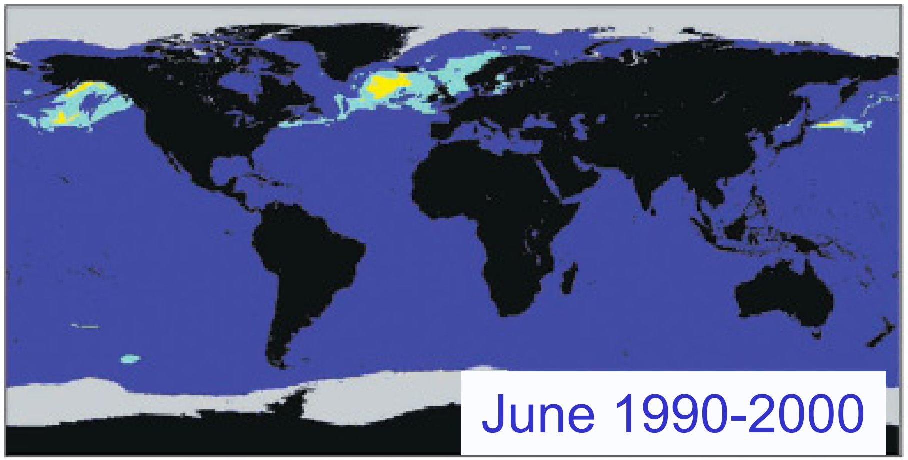


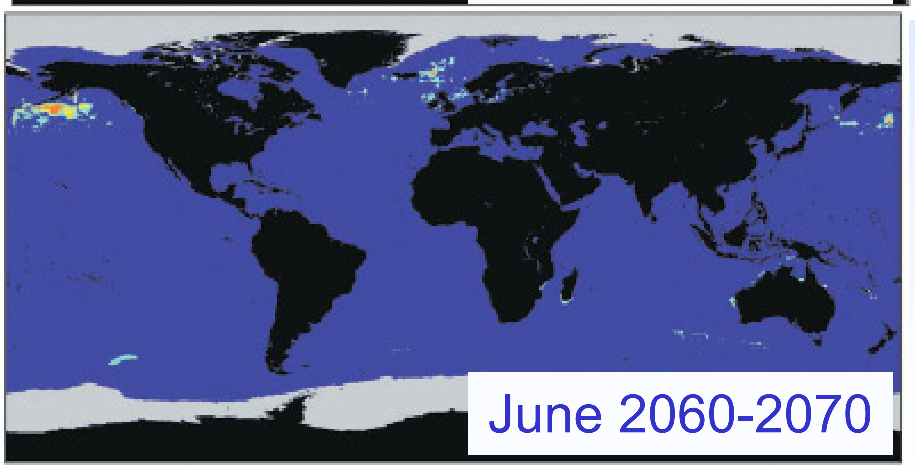
Figure 3 | Trends in the observed partial pressure of CO_2 for ocean minus air, for 1981–2007. The observed trends are calculated by fitting a

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

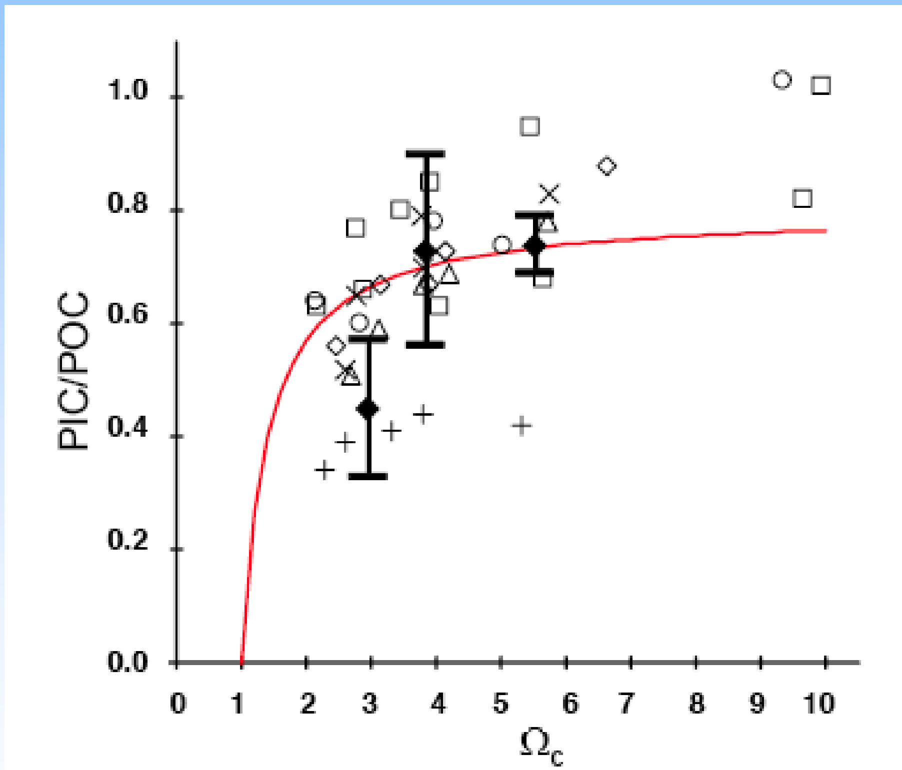
Climate Forcing: Synergistic effects of changes in temperature, nutrients, trace metals, sea-ice, mixed-layer depth, CO_2(aq), pH and Ω

Biotic Interactions: Competition, predatory-prey, viruses, …





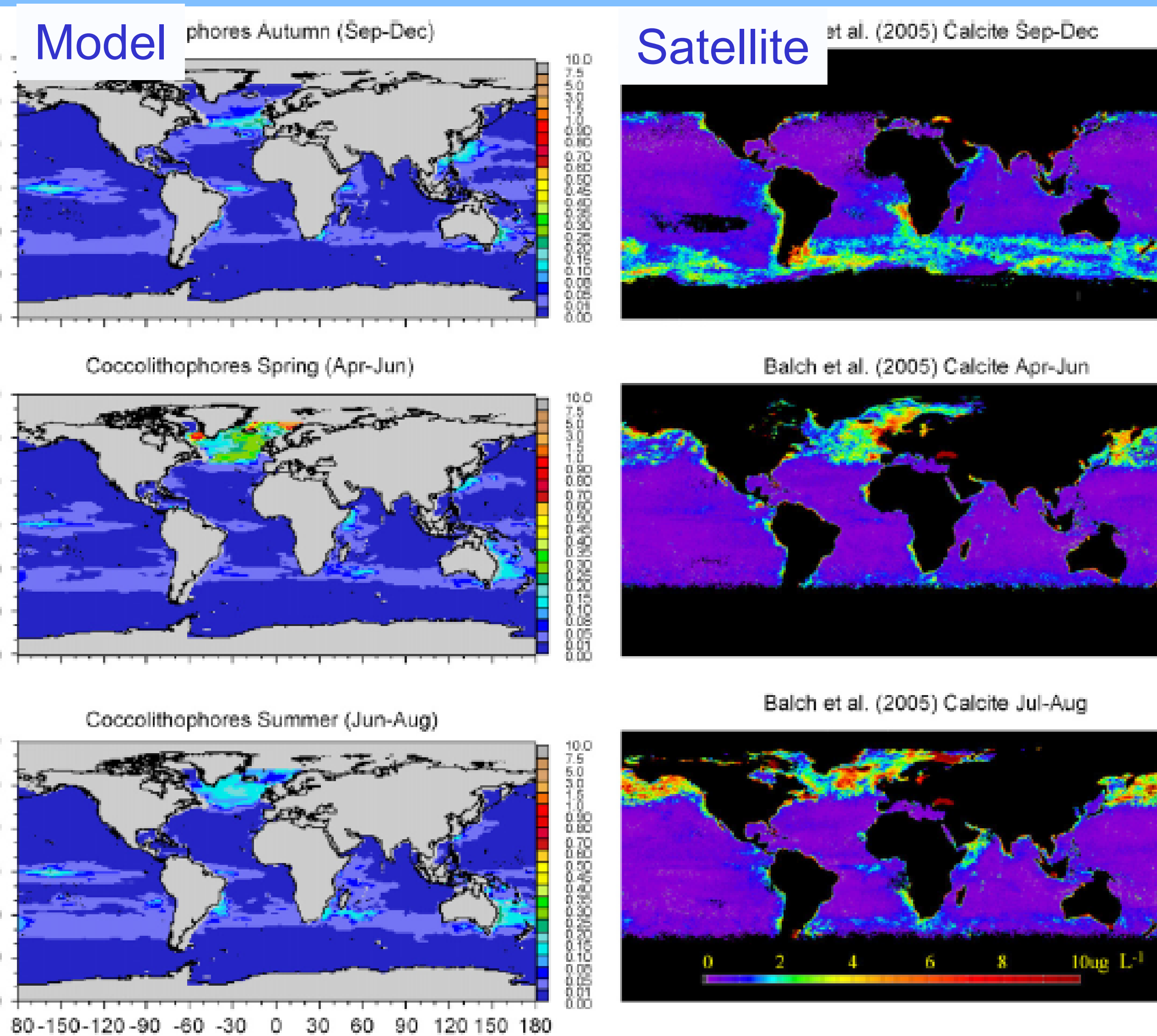
Iglesias-Rodriguez et al. Global Biogeochem. Cycles (2002)



Gehlen et al. Biogeosciences (2007)

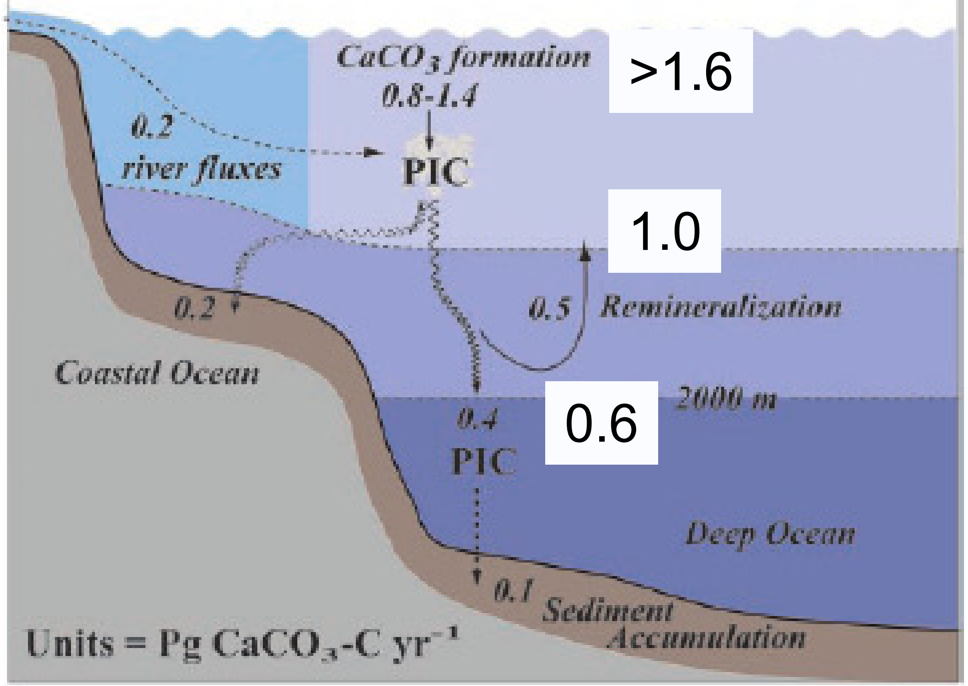
Calcification in Ecosystem Models

- Model approach
  fixed PIC/POC, statistical, dynamic
- Prognostic models
  (light, MLD, SST, nutrients, grazing)
- Functional groups
  coccolithophorids, forams, pteropods
- Data limitations for verification and parameterization (satellites, field, laboratory)



Gregg & Casey Deep-Sea Res. II (2007)
Moore et al. (2004); Le Quere et al. (2005)

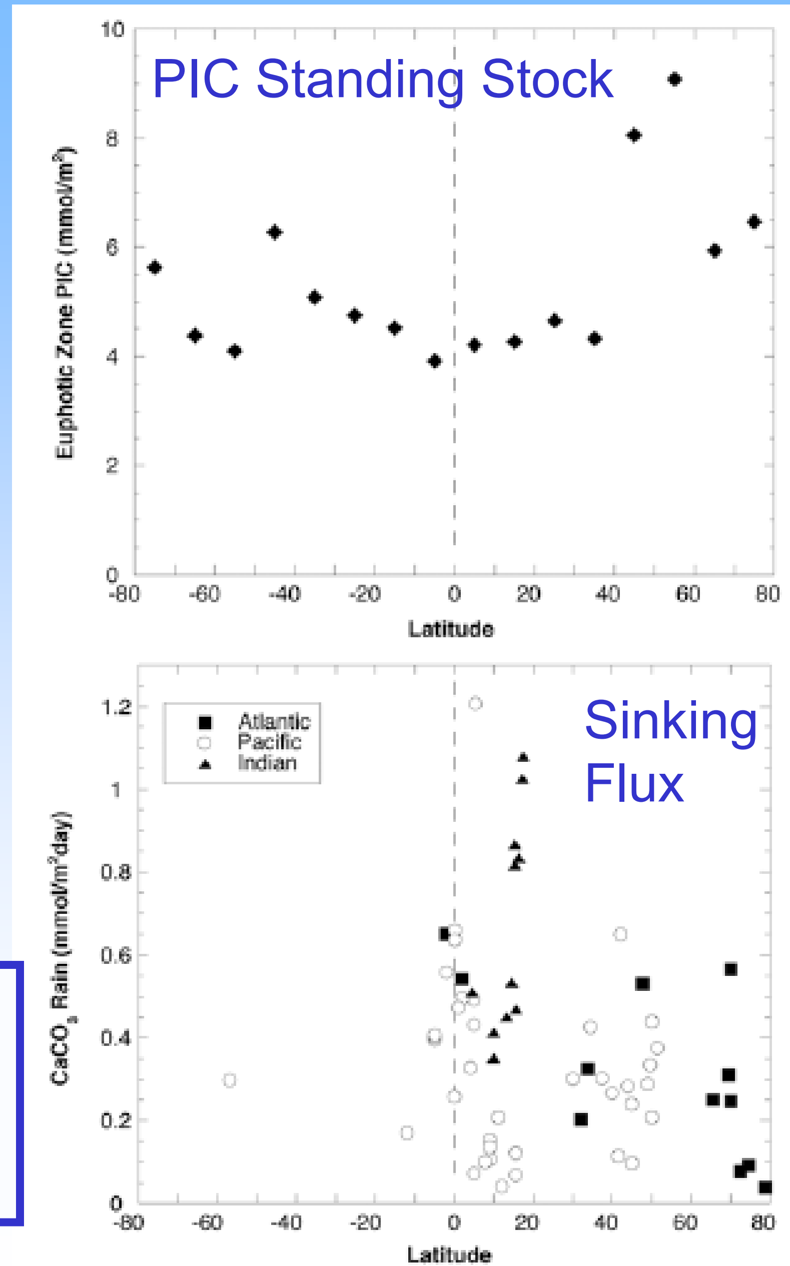
Global Budget Pg $CaCO_3$-C/yr



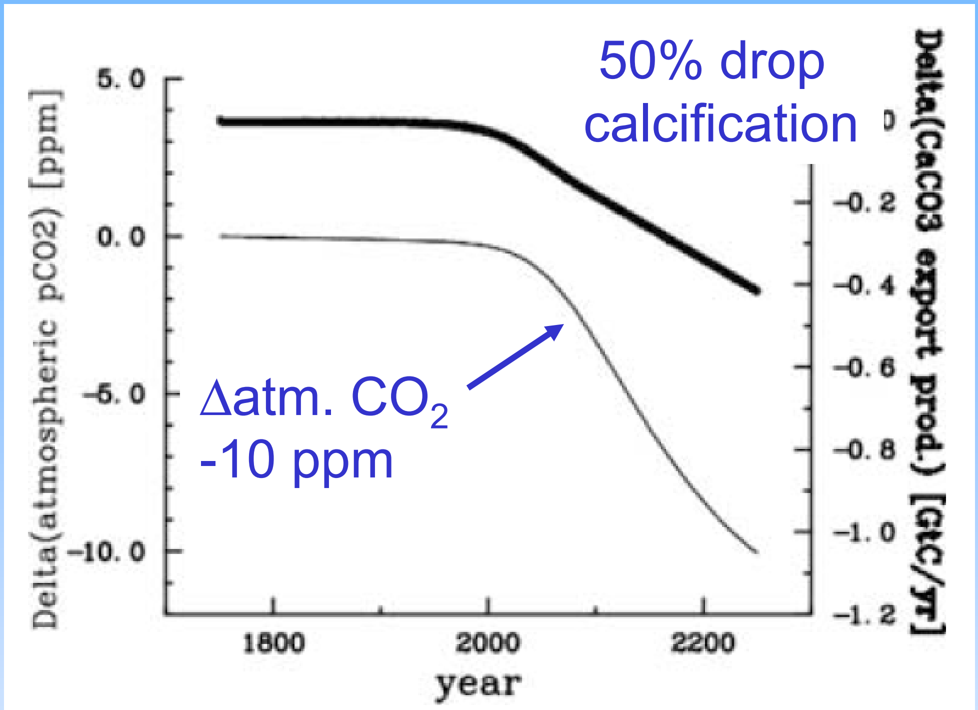
Feely et al. Science (2004);
Berelson et al. GBC (2007);
Sarmiento et al. GBC (2002)

Global rates & regional patterns of water column dissolution, flux from deep traps

Geochemical Constraints



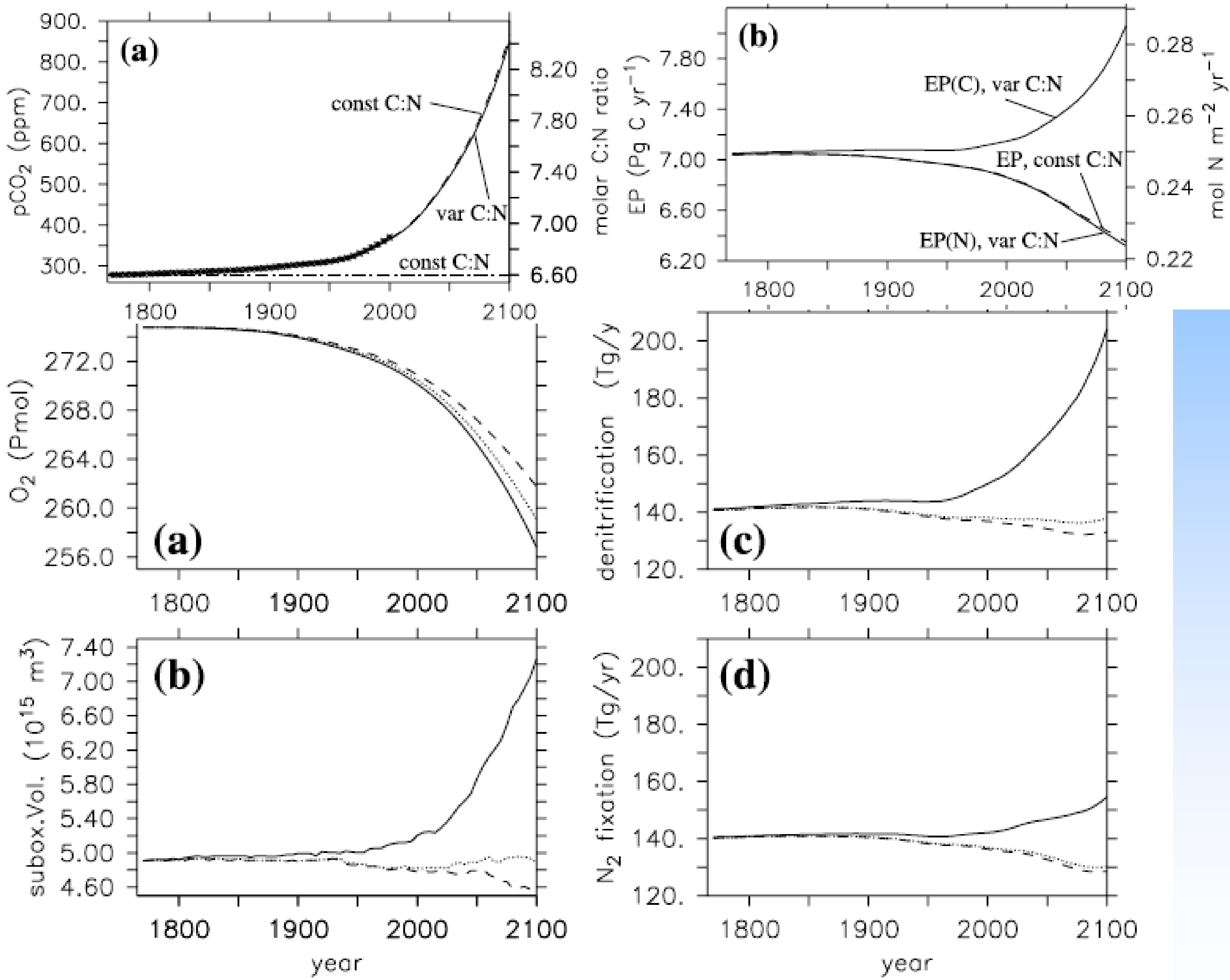
Acidification, Calcification & Climate Feedbacks



Negative (damping) climate feedbacks
Δ atm. $CO_2 < 0$
$\Delta DIC_{surf} < 0$
$\Delta Alk_{surf} > 0$

Heinze, Geophys. Res. Lett. (2004)
Zondervan et al. Global Biogeochem. Cycles (2001); Gehlen et al. Biogeoscience (2007); Ridgwell et al. Biogeoscience (2007)

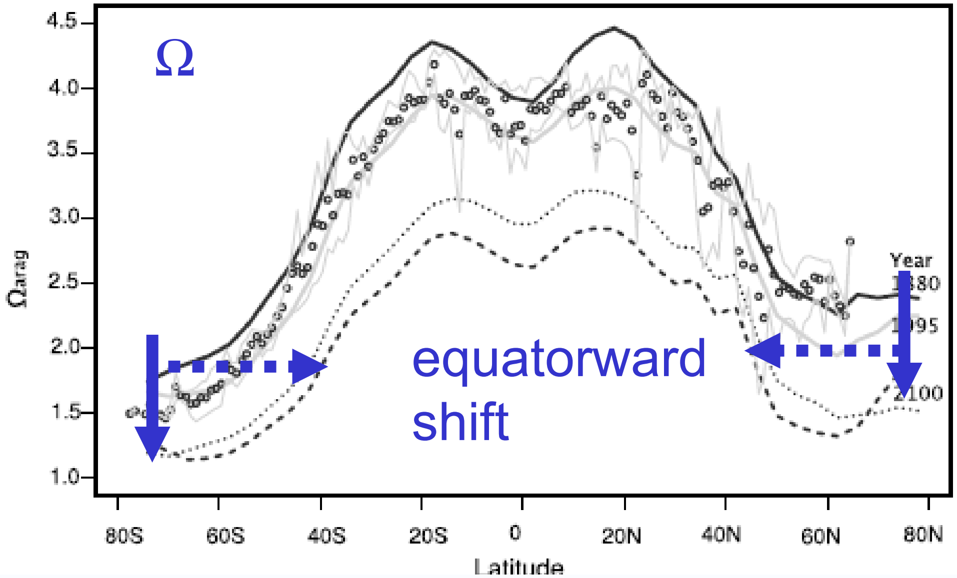
- Reduced formation of biogenic $CaCO_3$
- Decrease organic matter remineralization lengthscale (ballasting)
- Increase subsurface $CaCO_3$ dissolution

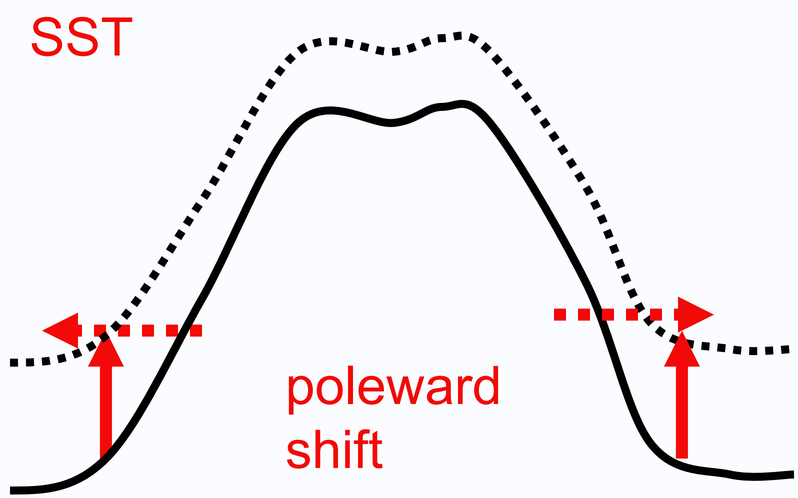


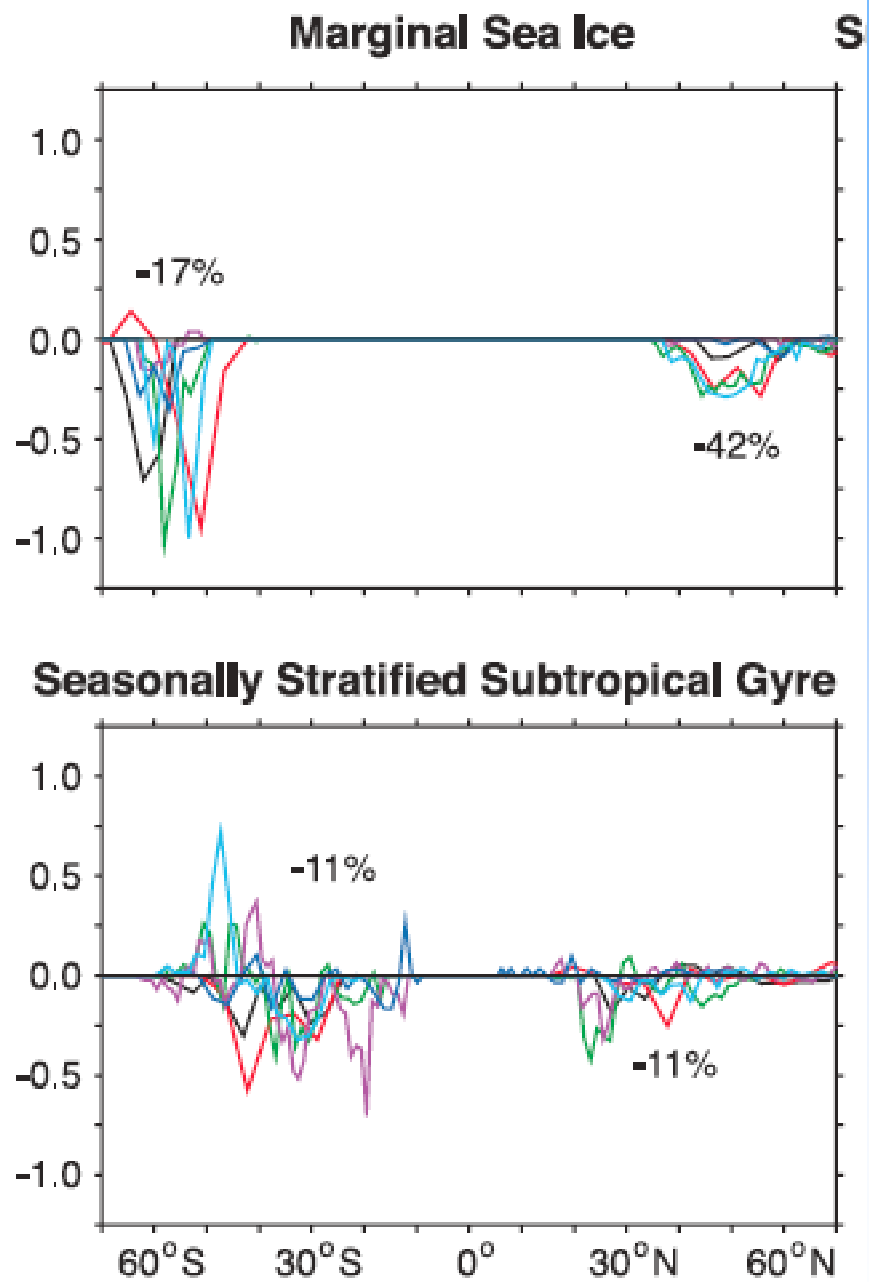
Oshlies et al. Global Biogeochem. Cycles (2008)

Niches & Plasticity

No current analogues to some future climate conditions??

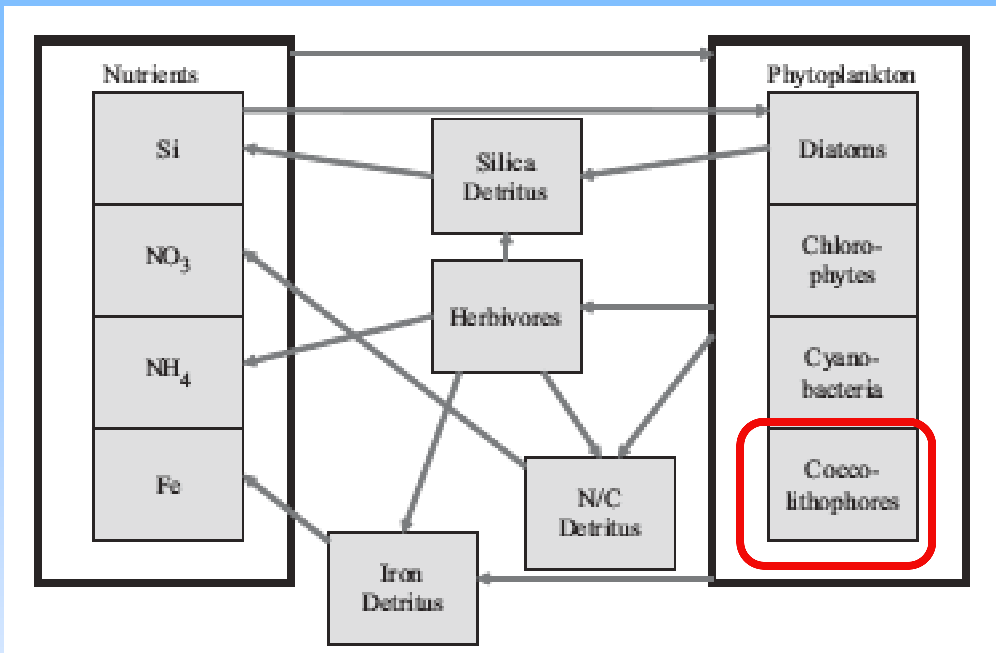




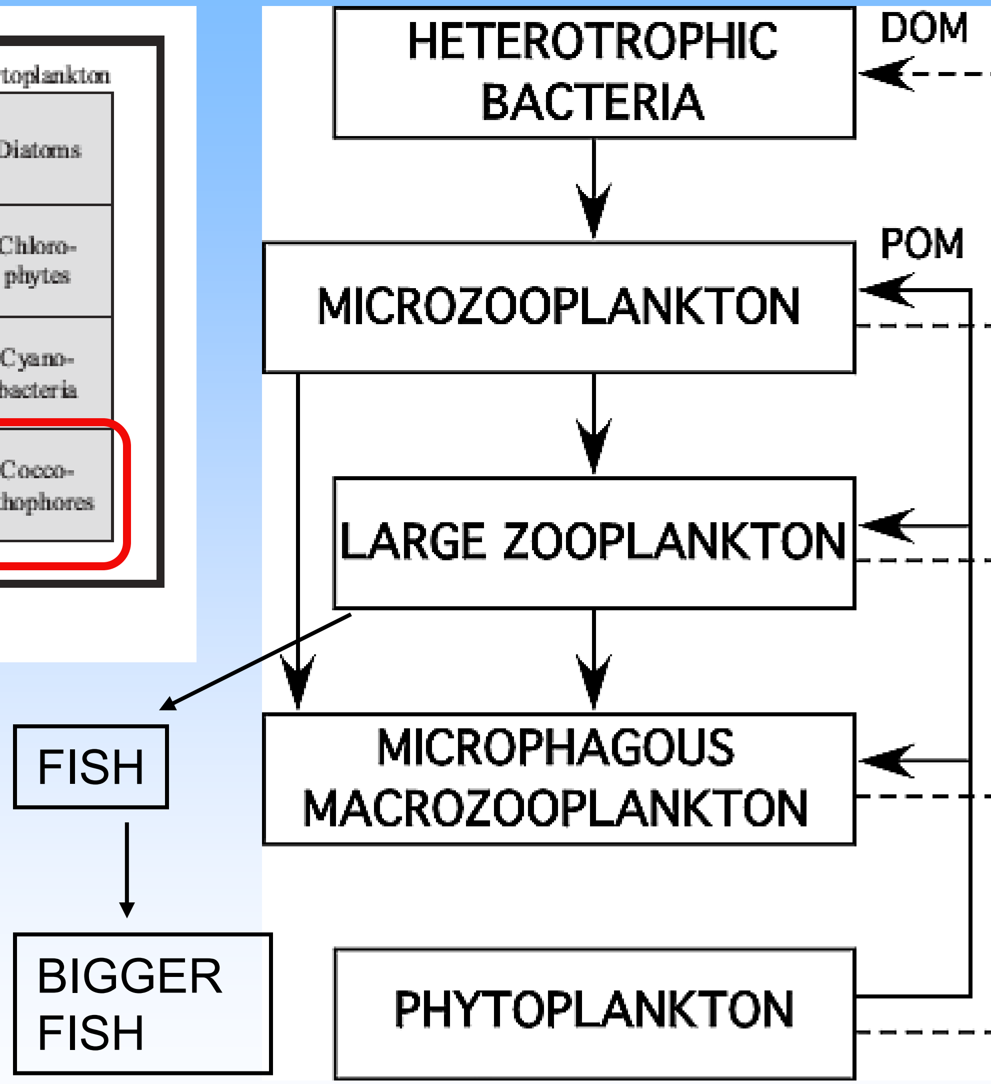


Sarmiento et al. Global Biogeochem. Cycles (2004)

Food-web Interactions



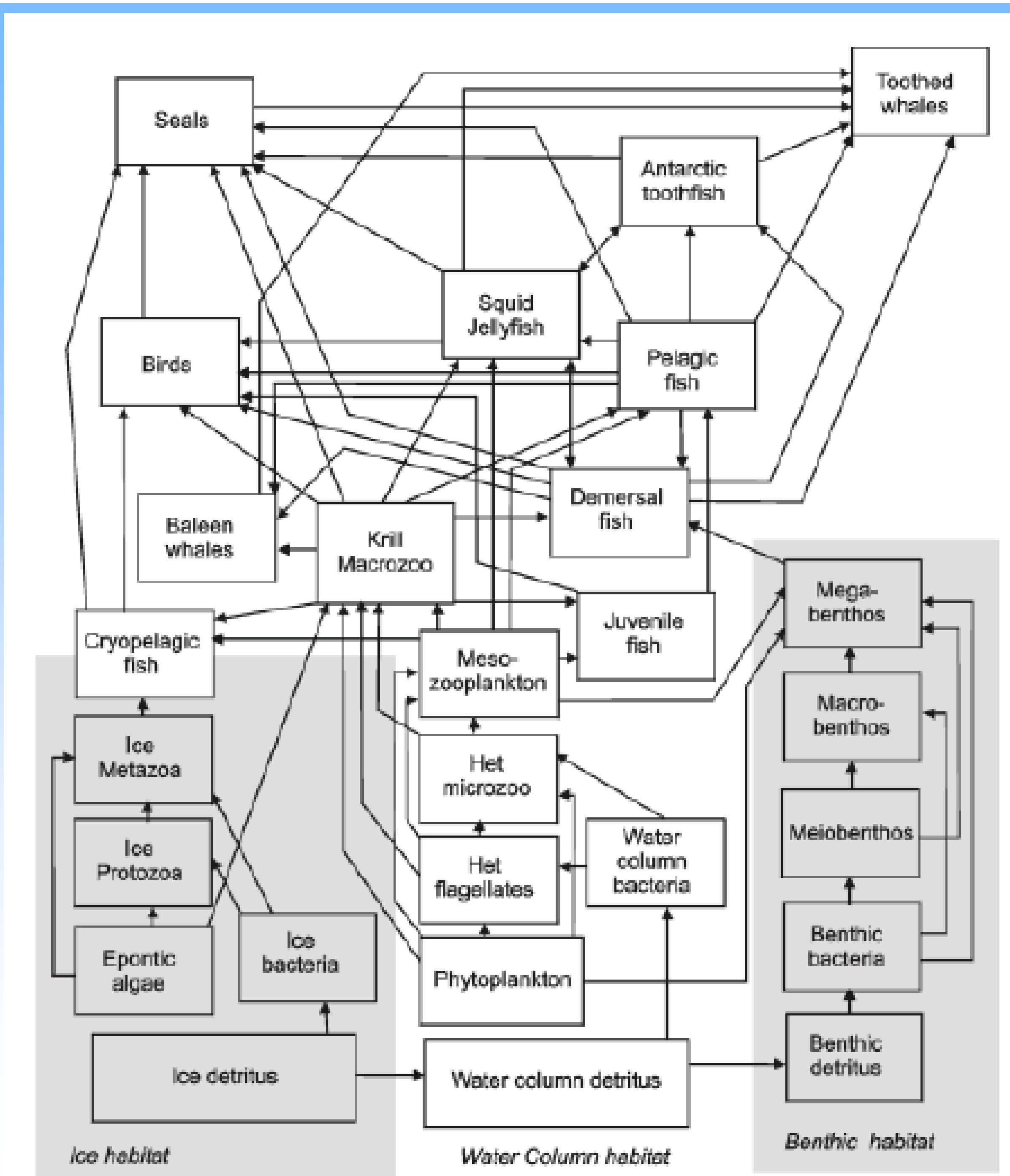
Gregg & Casey Deep-Sea Res. II (2007)

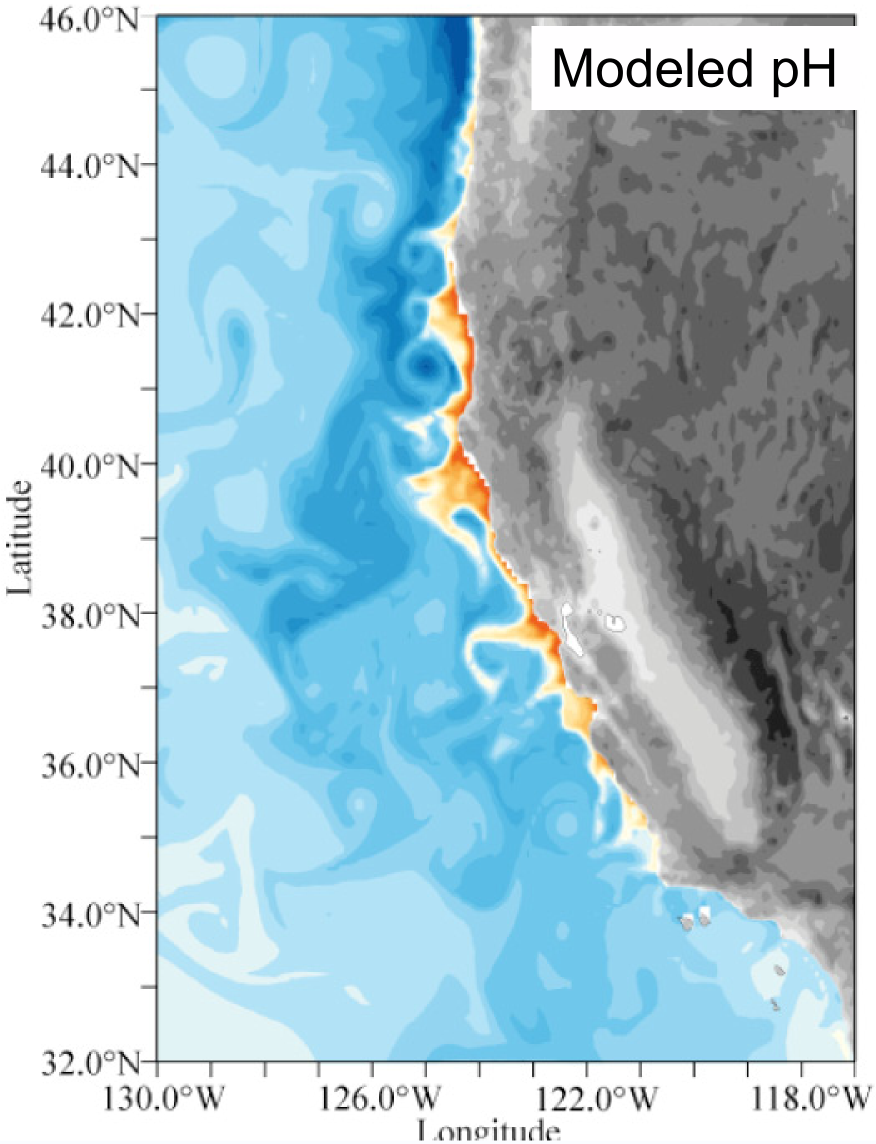


- Complicated (complex?) food-web interactions
- How do we test model forecasts? (spatial & interannual variability

From Legendre and Rivkin (2005)

Food Web Models





Gruber et al. Deep-Sea Res. 2006
Hauri et al. Oceanography (in press)

Regional Models

-Upwelling & mesoscale eddies
-Coastal models
-Basin-scale models

Blackford & Gilbert J. Mar. Systems 2007
Seasonal variation of pH

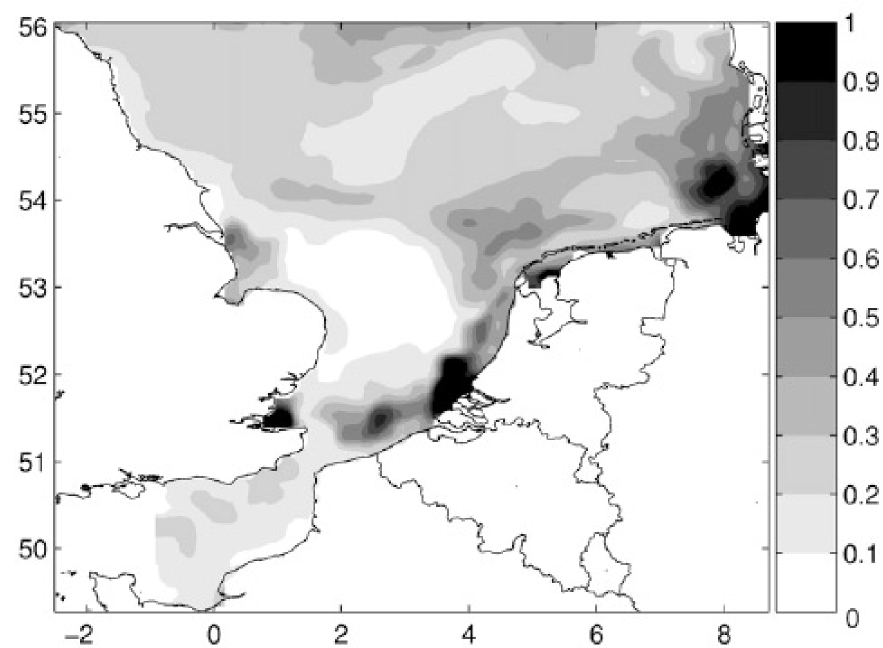
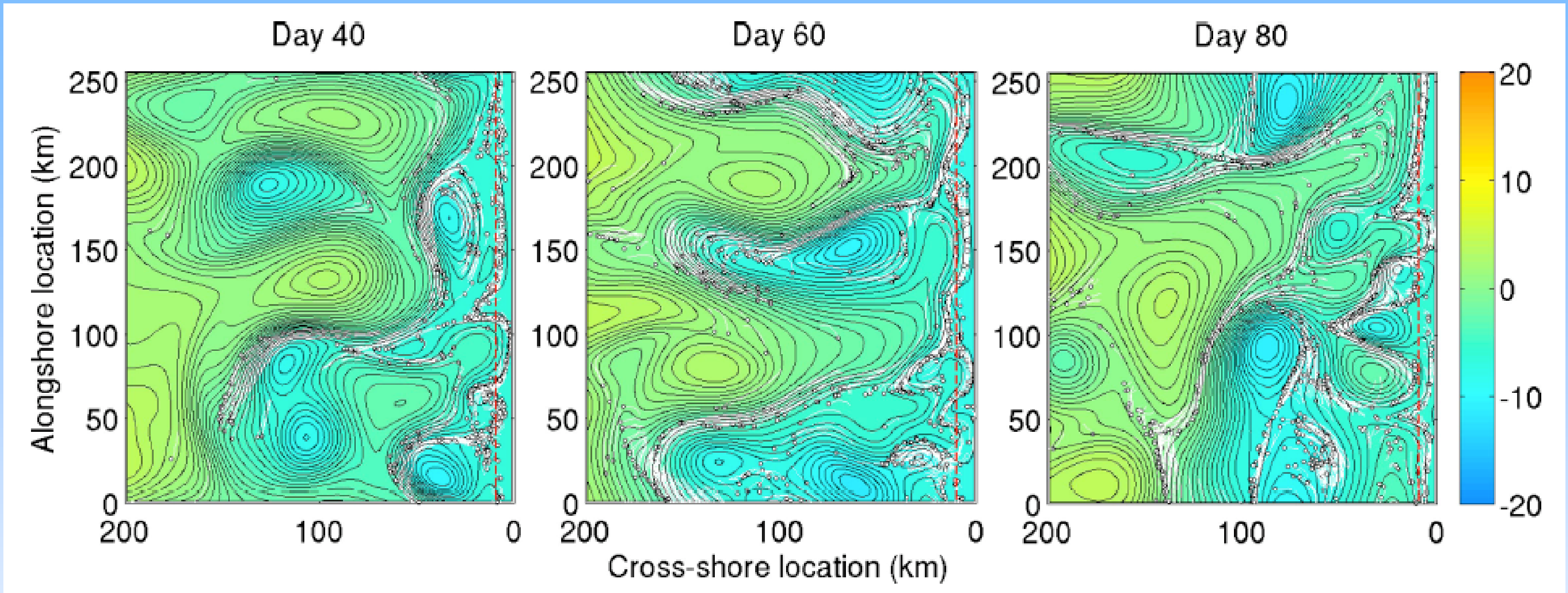


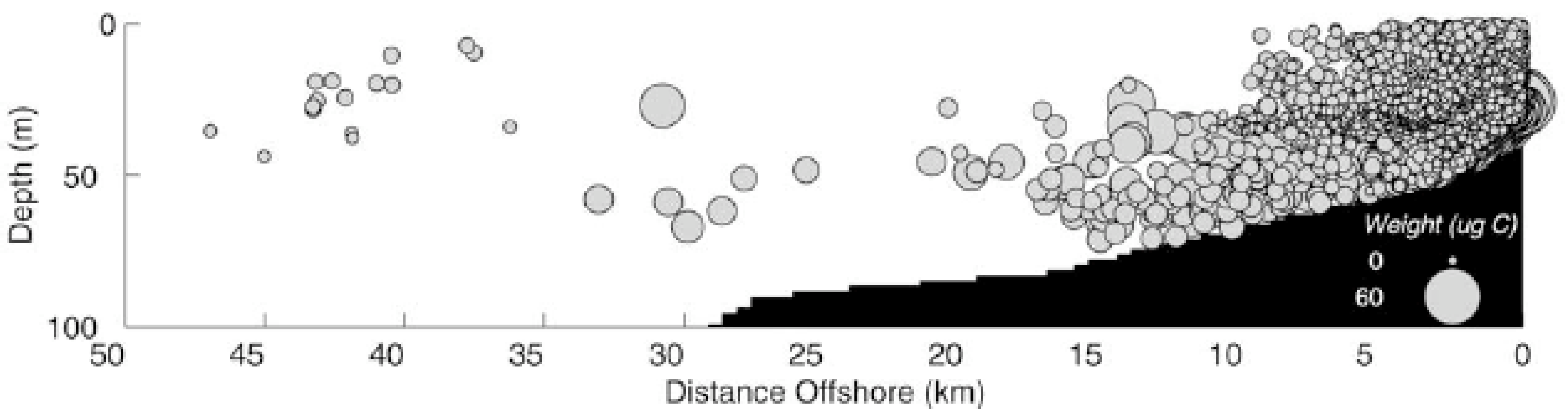
Fig. 6. Map of the modelled annual pH range simulated across the southern North Sea domain.

Particle Tracking-Individual Based Models



Mitarai et al. J. Mar. Systems 2008

Batchelder et al. Prog. Ocean. 2002



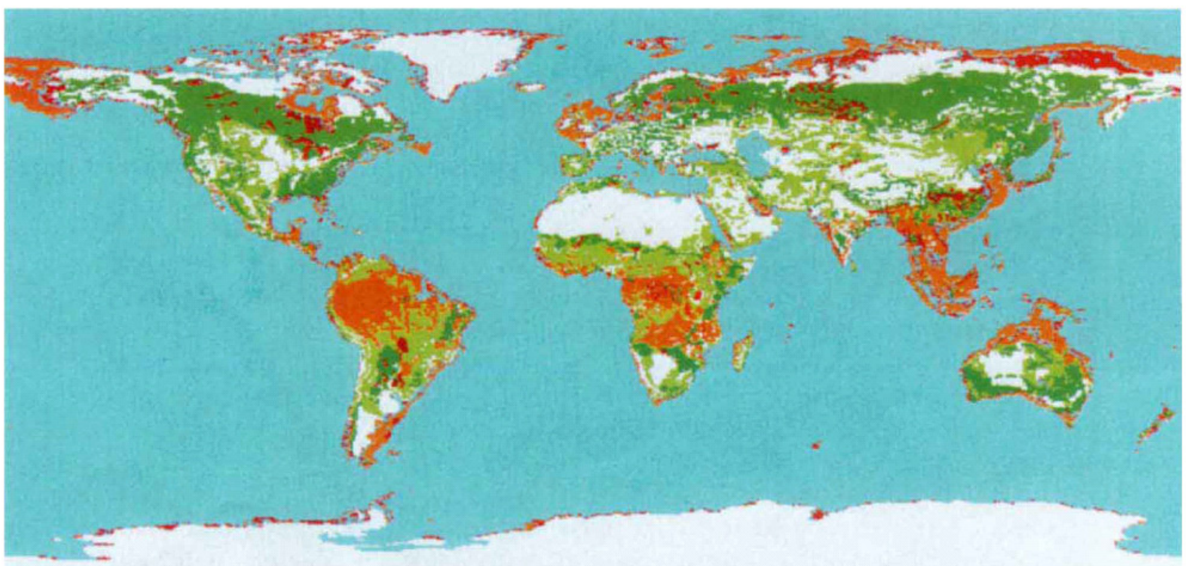
Resource	Impacted by Acidification
Fisheries	Plankton – food chain dynamics Mollusks and Crustaceans Reefs – critical habitat
Coastal Protection	Reefs – Protect shore lines Erosion of $CaCO_3$ deposits
Ocean CO_2 Uptake	Surf. alkalinity; biological pump

Ecosystem Services

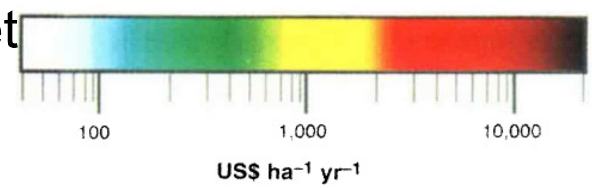
-Provide direct benefits to society

-Valuation estimates:

- difficult to replace by technology
- cost of total loss dramatic
- moral choices involved in valuation
- both market and non-market value

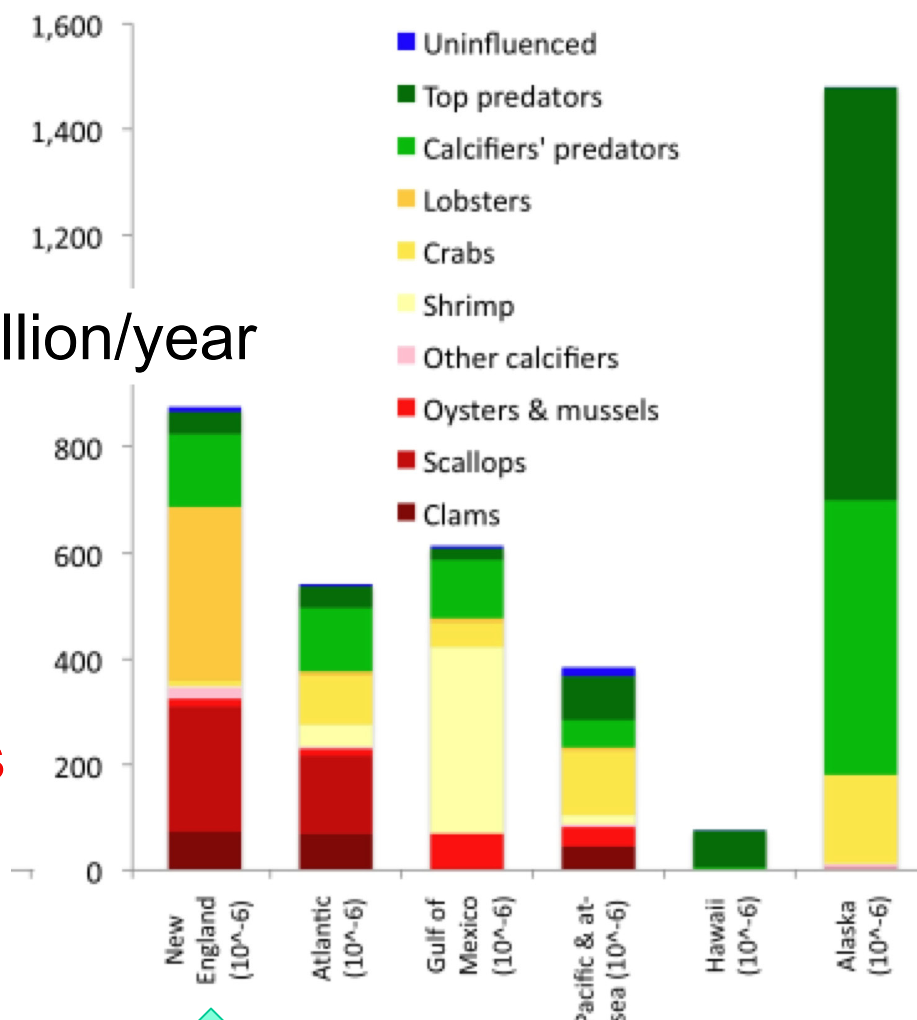


Costanza et al. (1997)



1994 Values

Commercial fisheries depend on species at risk



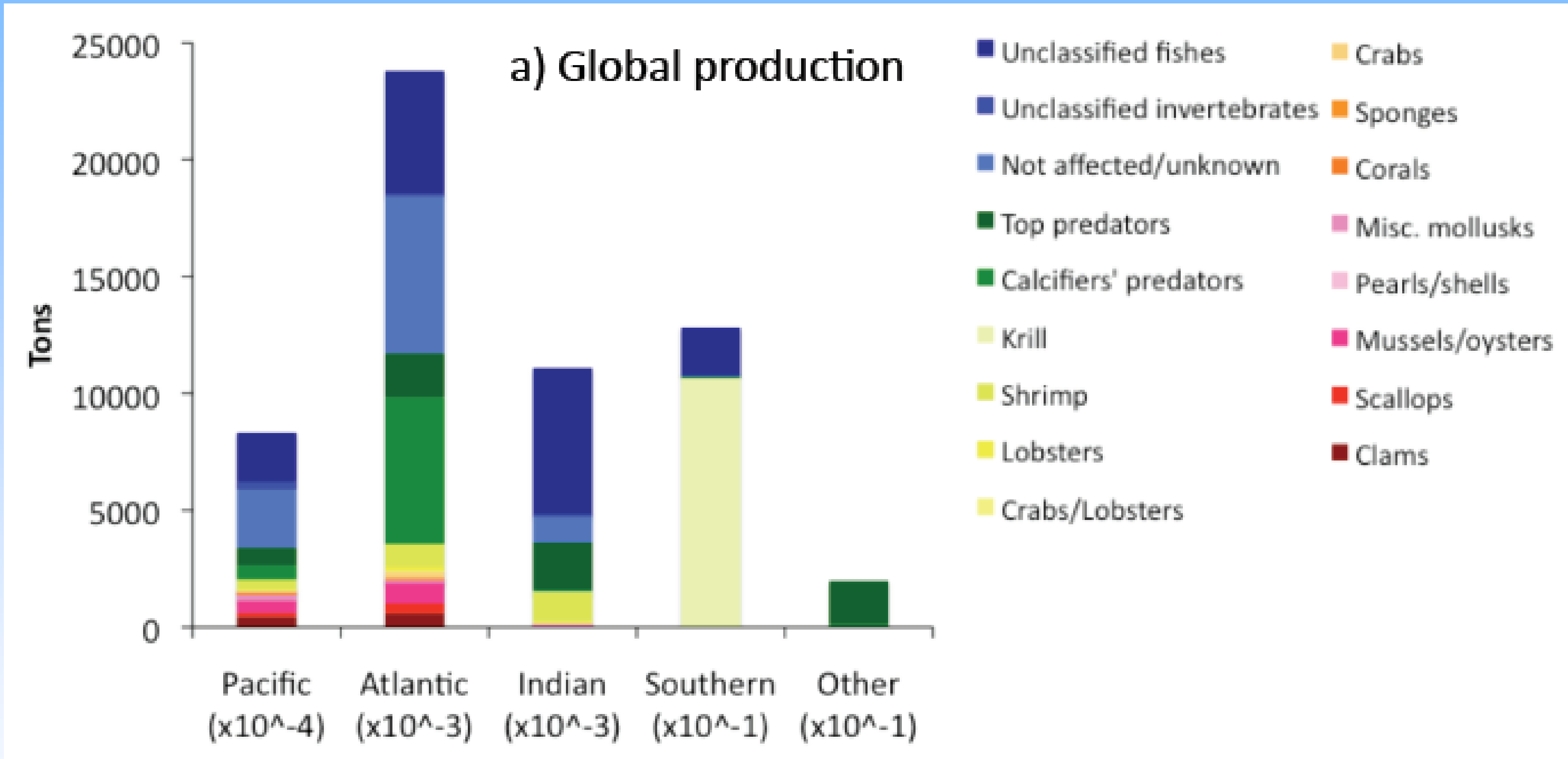
$1 Billion/year

lobsters & crabs

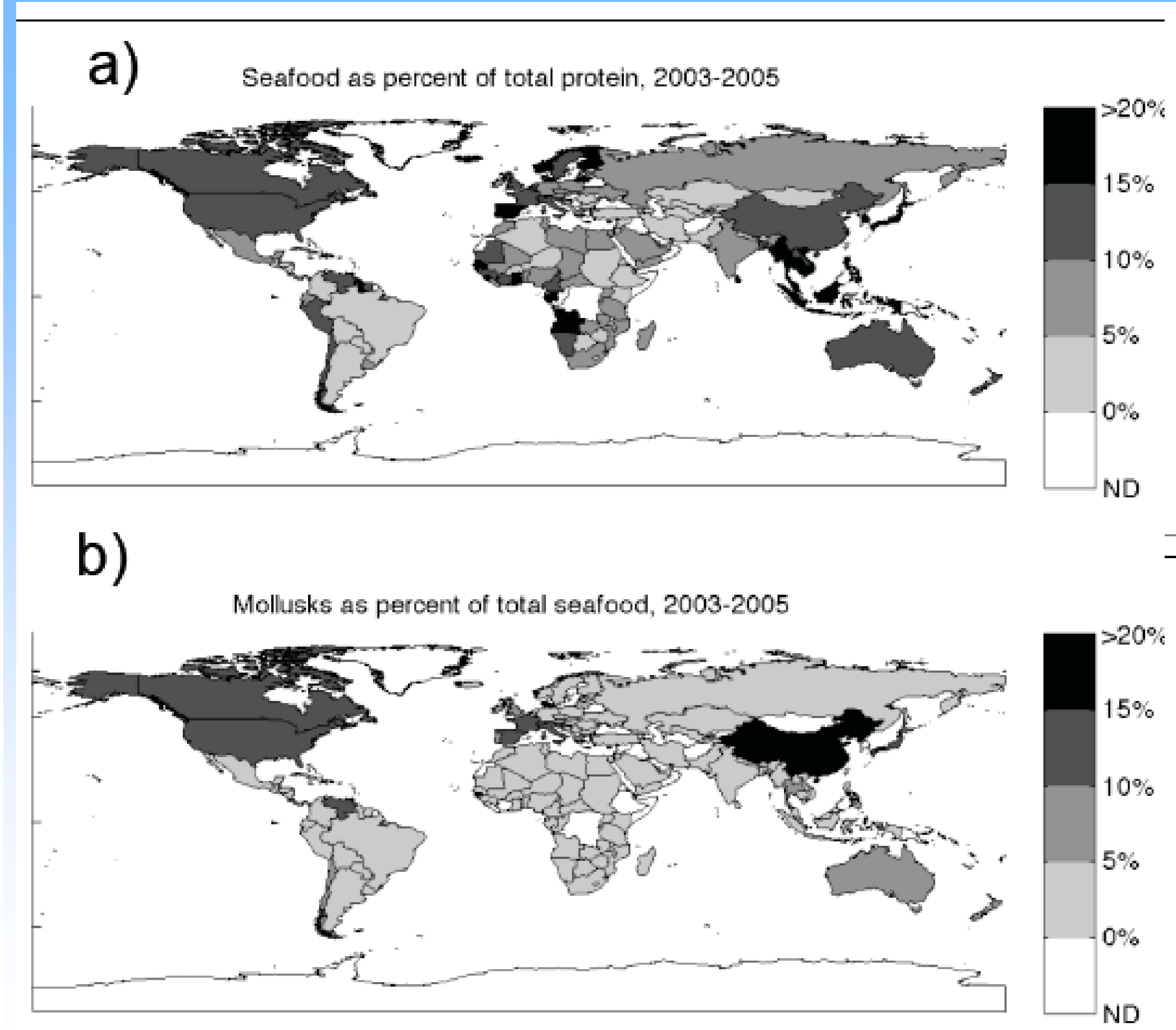
scallops & clams

New England primary fishery revenue
~$850 million/year
~80% are from shellfish

Cooley & Doney
Environ. Res. Lett.
2009



Cooley, Powell & Doney
Oceanography (in press)



Cooley, Powell & Doney
Oceanography
(in press)

Uncertainties in Future Projections (confidence)

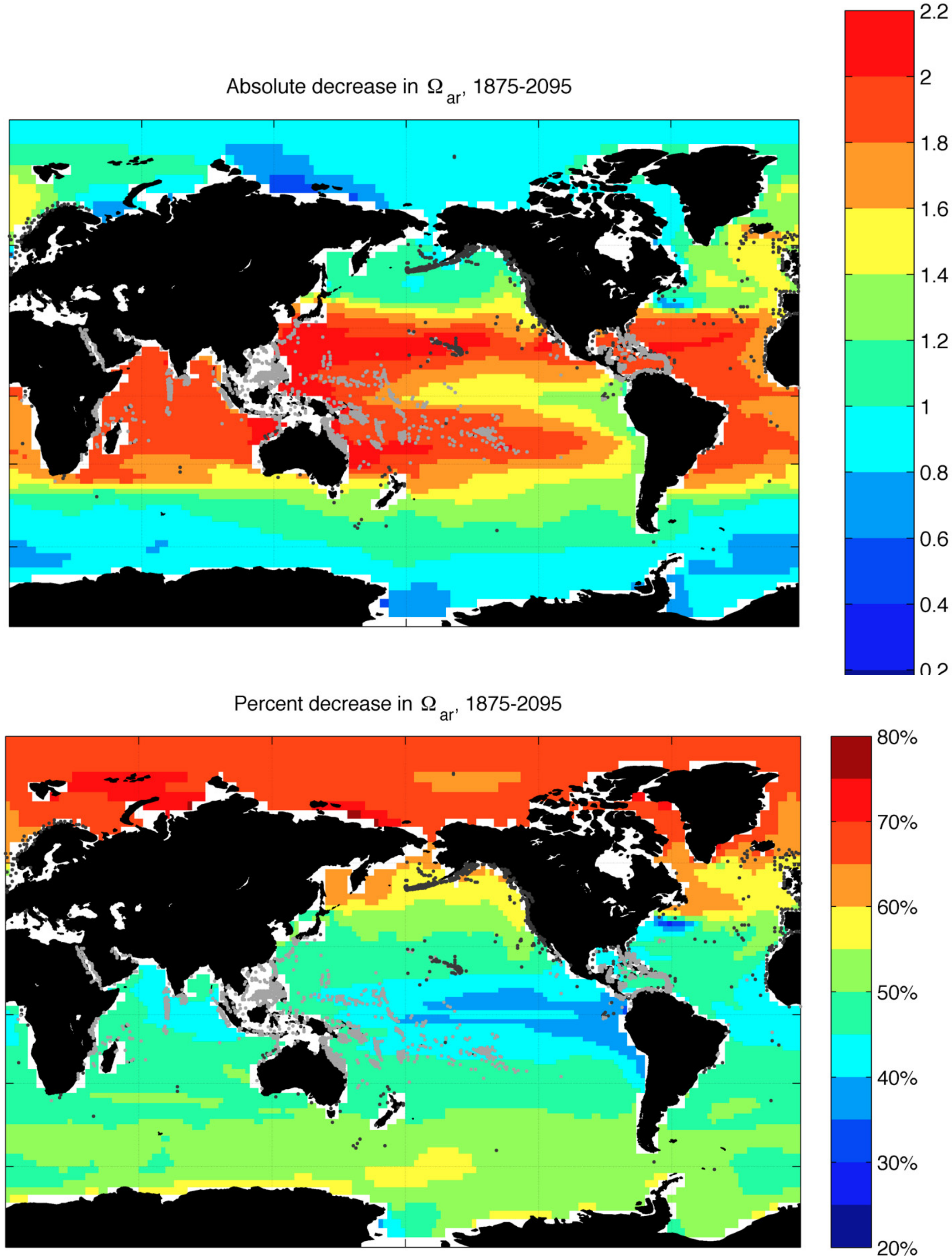
-anthropogenic CO_2, pH & $CaCO_3$ saturation Ω
- fossil fuel emissions & atmosphere CO_2 (med.)
- ocean pH & Ω; surface (high) & subsurface (med.)
- small climate/carbon feedbacks (med.)

-other acidity/alkalinity inputs
- atmosphere N & S => reduce coastal Alk & outgas CO_2 (med.)
- sediments, rivers, & goundwater (low/med.)

-calcification & biogeochemical impacts
- higher surface alkalinity & atm. CO_2 drawdown (med.)
- particle ballast, elemental stochiometry, trace gases

-biological & ecological effects
- individual organisms: transient (high), adaptation (low)
- effects on foodwebs & higher trophic levels (low)

-policy, economic & social dimensions
- atm. CO_2 guard rail (0.2 pH drop?) (low/med.)
- economic value fisheries, coral reefs, biodiversity (low)



Feely et al.
Oceanography
(in press)