Modeling Challenges for Ocean Acidification

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<u>Processes, Magnitudes & Uncertainties</u>

(with a bottom-up, pelagic bias)

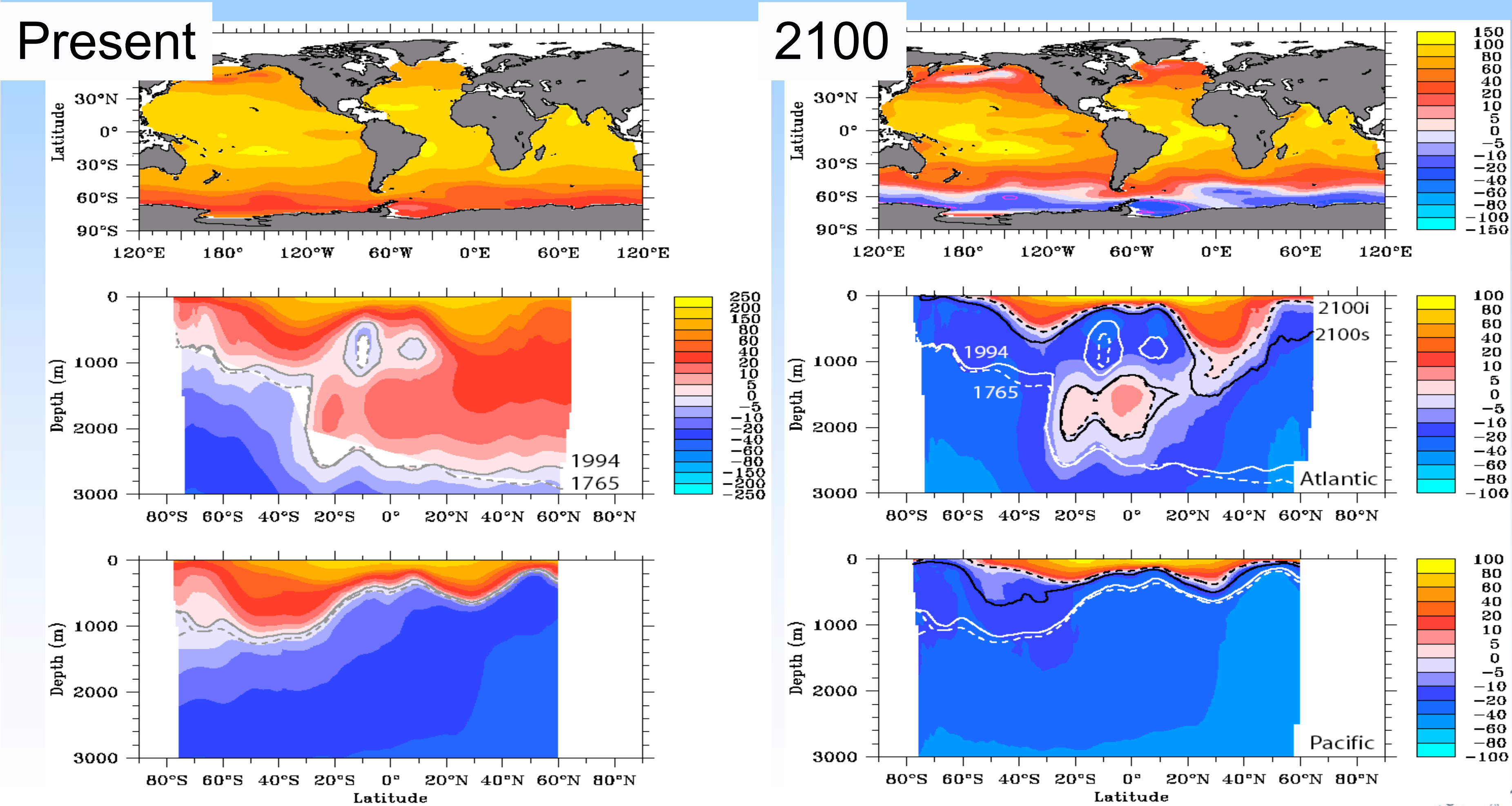
- anthropogenic CO_2, pH & $CaCO_3$ saturation Ω
- other acidity/alkalinity inputs
- biogeochemical and ecological impacts
- policy, economic & social dimensions

Ocean Carbon & Biogeochemistry

CO_2 Effects on $CaCO_3$ Saturation Ω (aragonite)

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

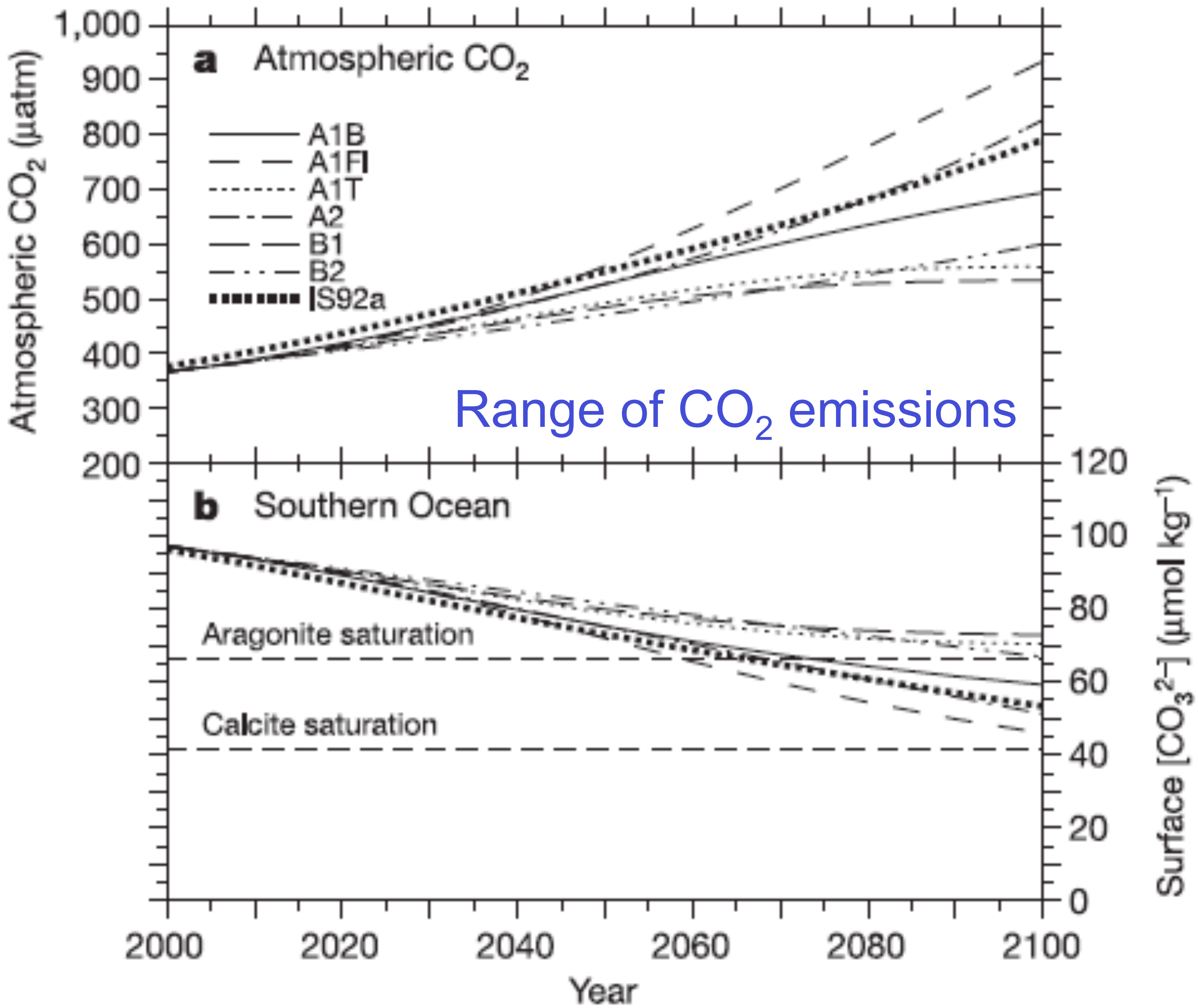
$$\Delta[CO_3^{2-}] = [CO_3^{2-}]_{obs} - [CO_3^{2-}]_{sat}$$



Orr et al. Nature (2005)

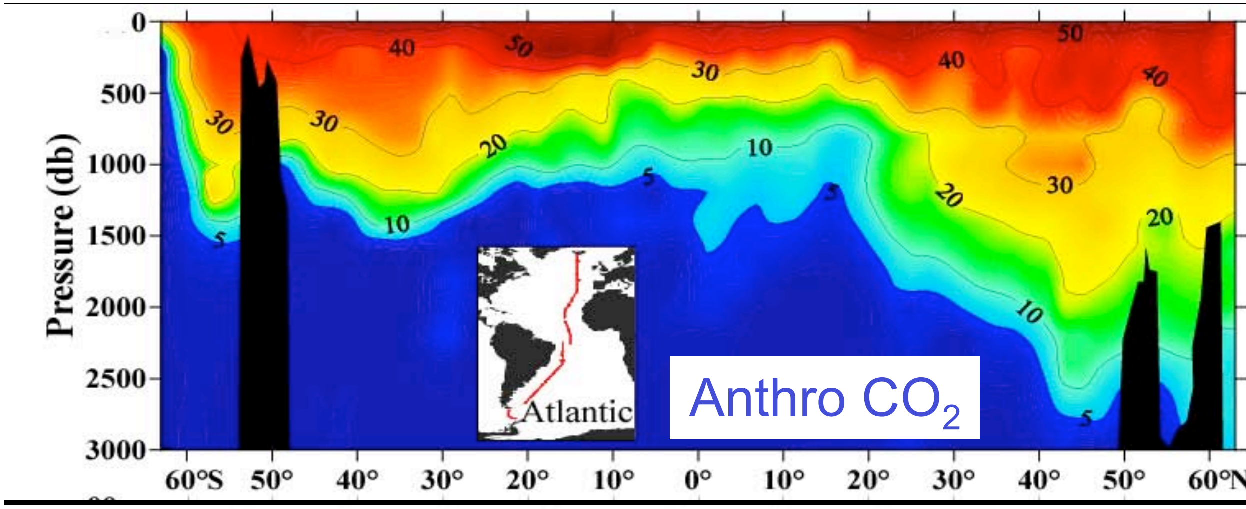
Anthropogenic CO_2 & Ocean pH

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

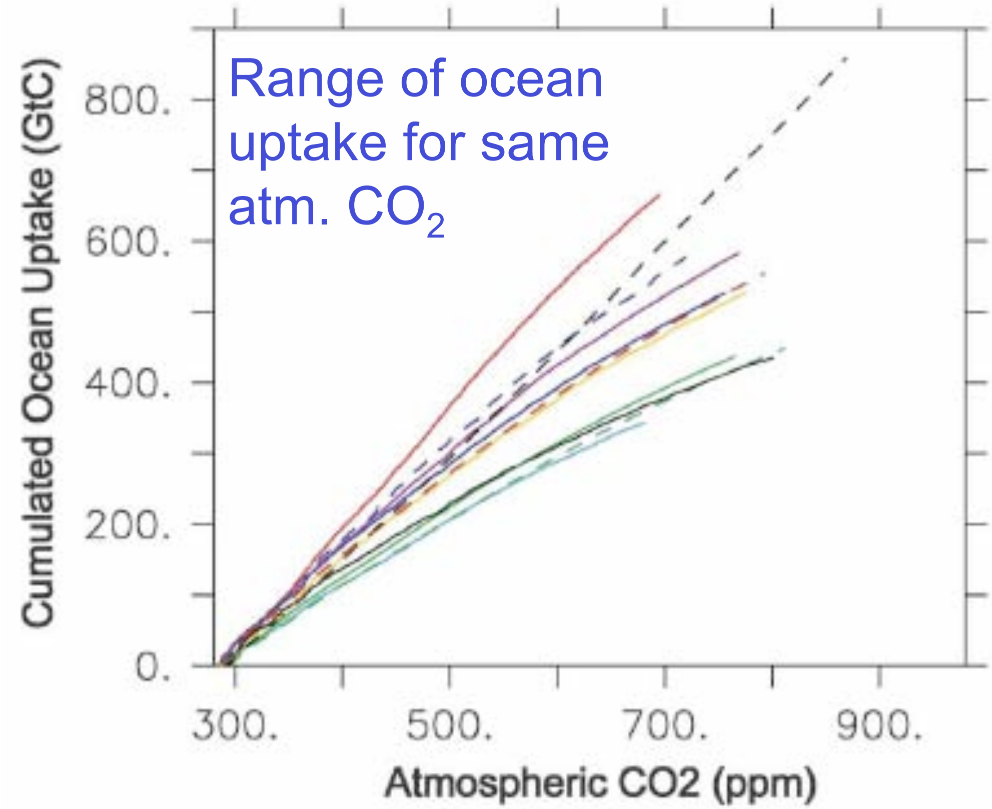


Orr et al., Nature (2005)

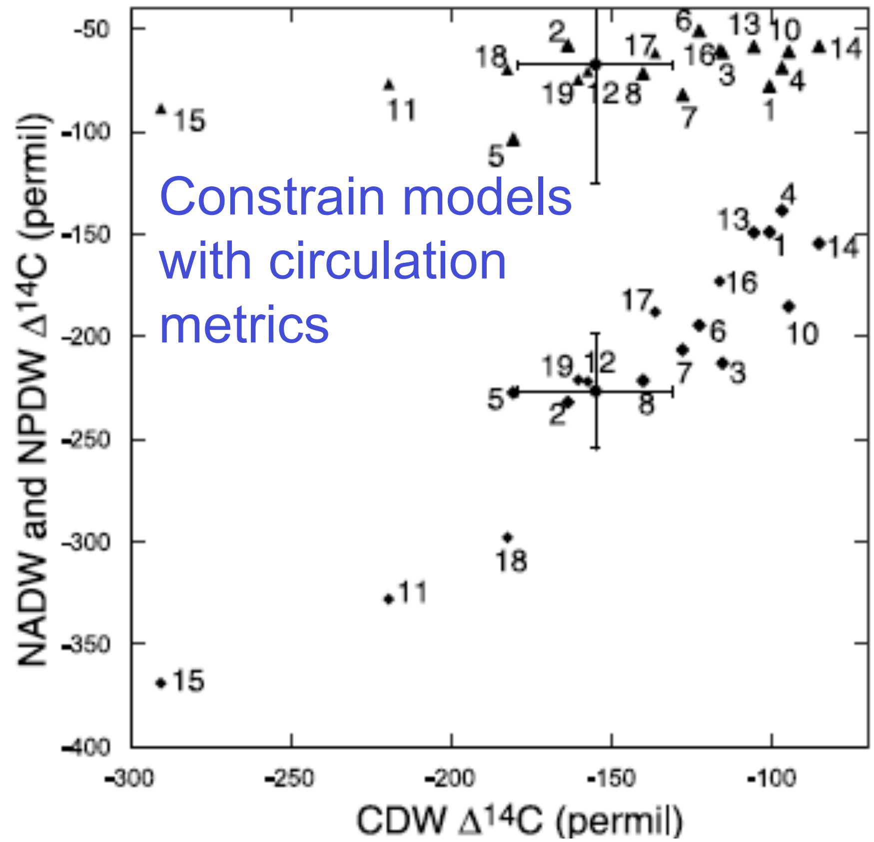
CO_2 Uptake & Ocean Circulation



Sabine et al., Science (2004)



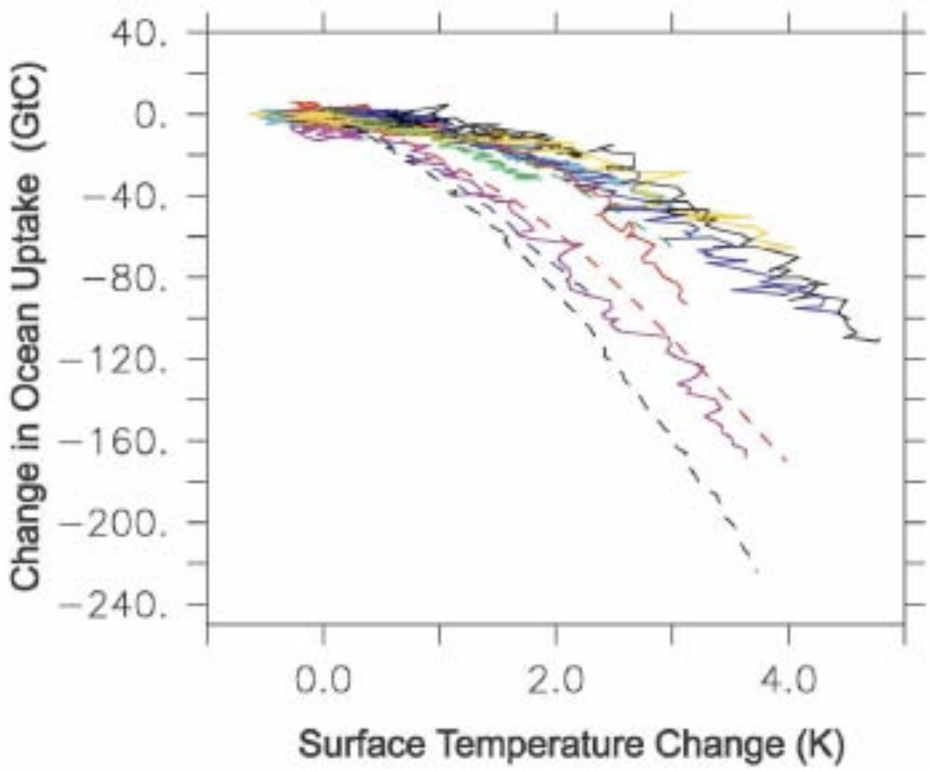
Friedlingstein et al., J. Climate (2006)



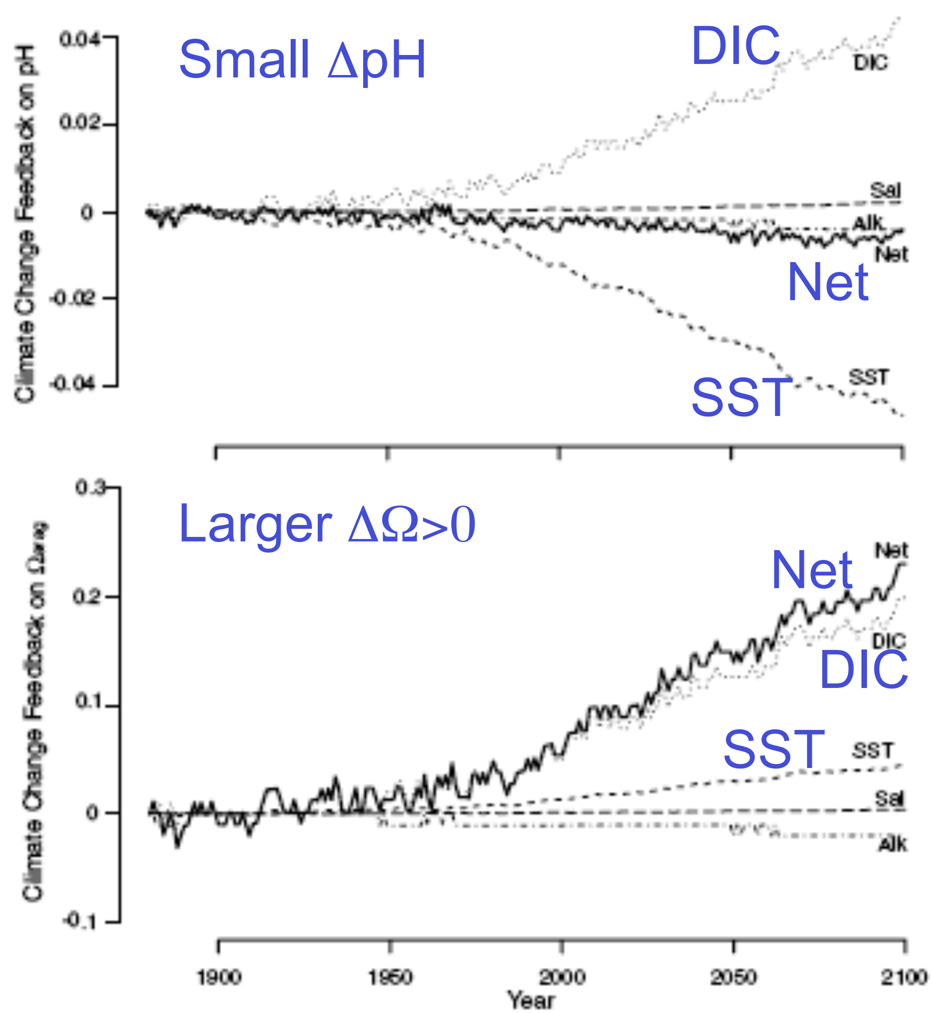
Matsumoto et al., GRL (2004)

Effect of Climate Change Feedbacks

Reduced CO_2 uptake due to warming & altered circulation

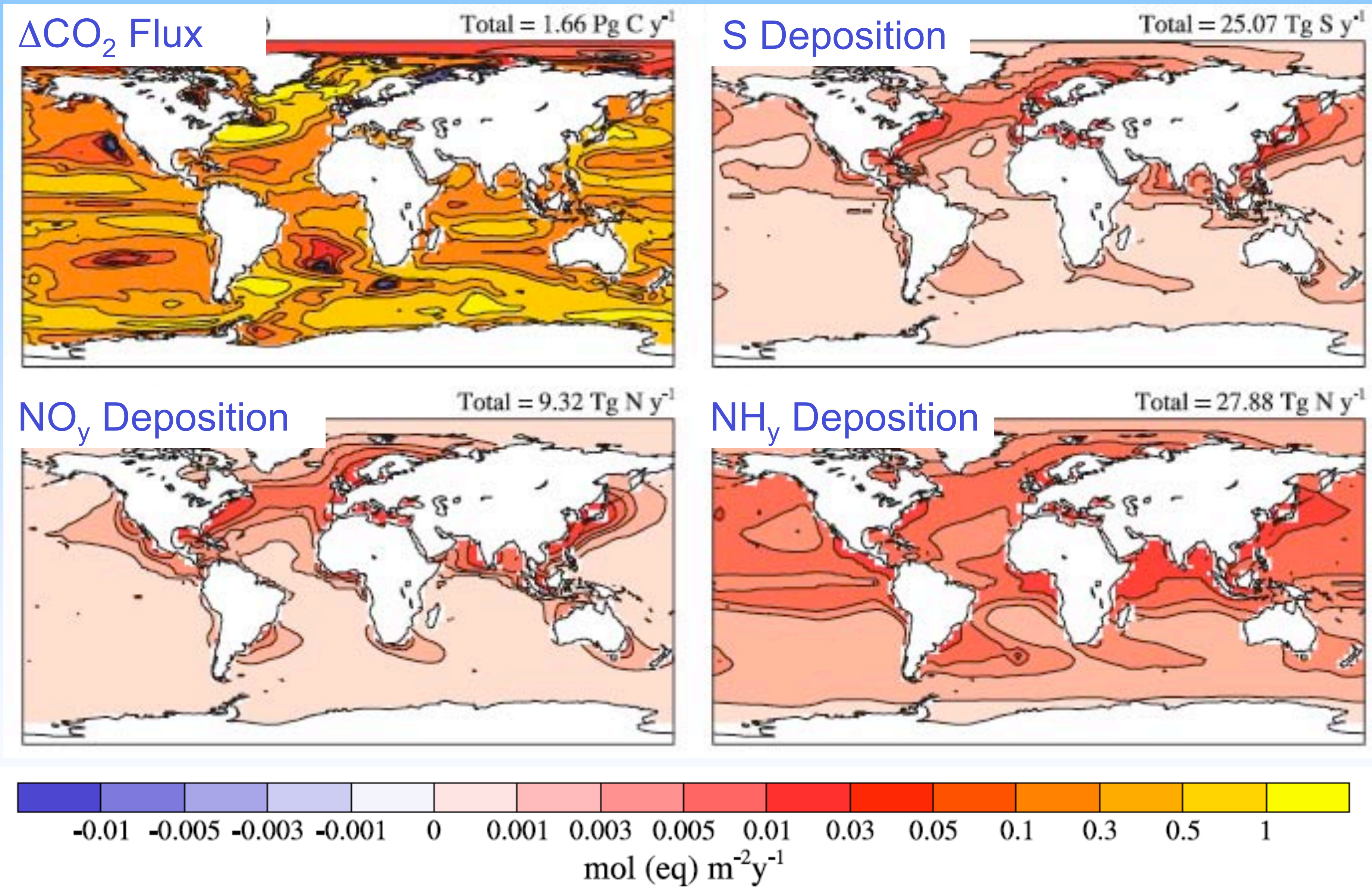


Friedlingstein et al. J. Climate (2006); Fung et al. PNAS (2005)



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

Anthropogenic Fluxes of CO_2, N and S



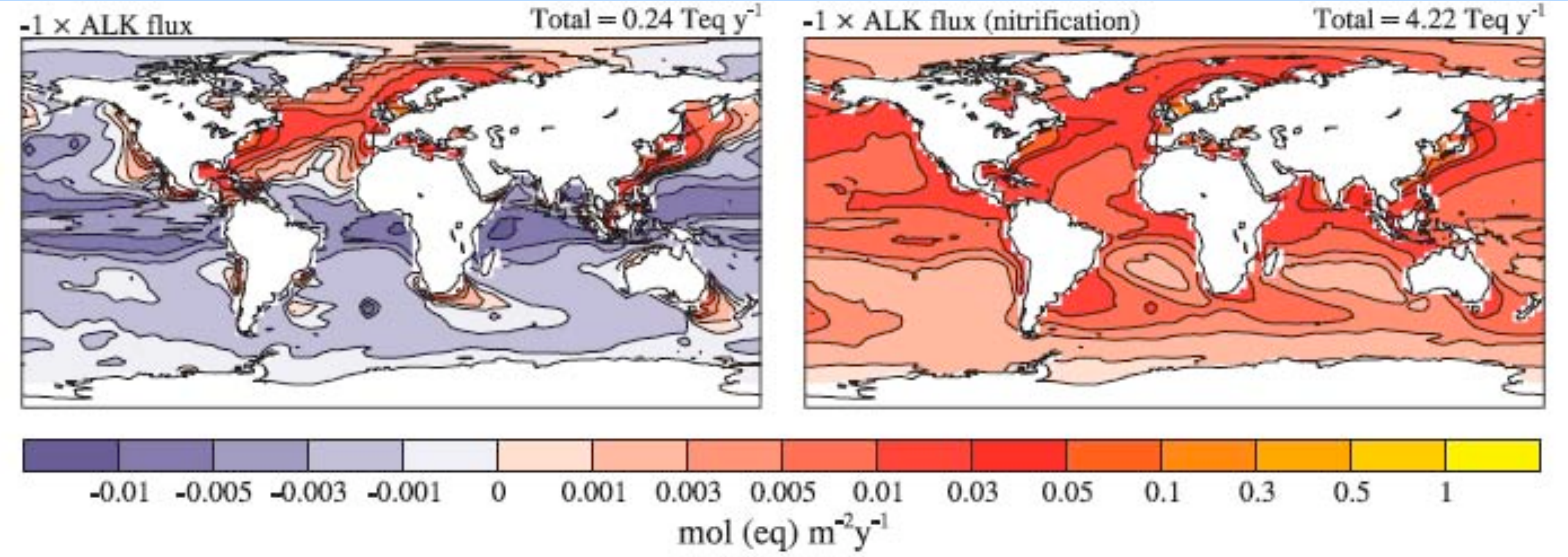
Doney et al., PNAS, 2007

Atmospheric Alkalinity Deposition

$$fAlk = 2fCa^{2+} - 2fSO_2 - 2fSO_4^{2-} - fNO_3^- + fNH_3 + fNH_4^+$$

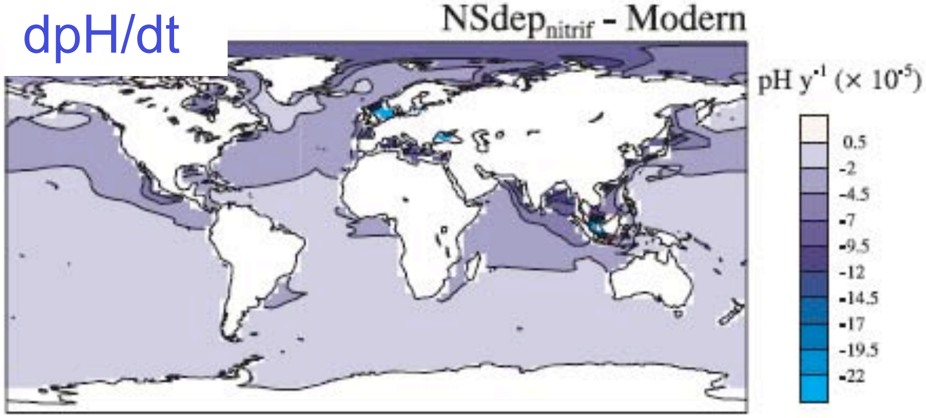
With full nitrification of NH_3/NH_4

$$fAlk_{nitrif} = 2fCa^{2+} - 2fSO_2 - 2fSO_4^{2-} - fNO_3^- - fNH_3 - fNH_4^+$$

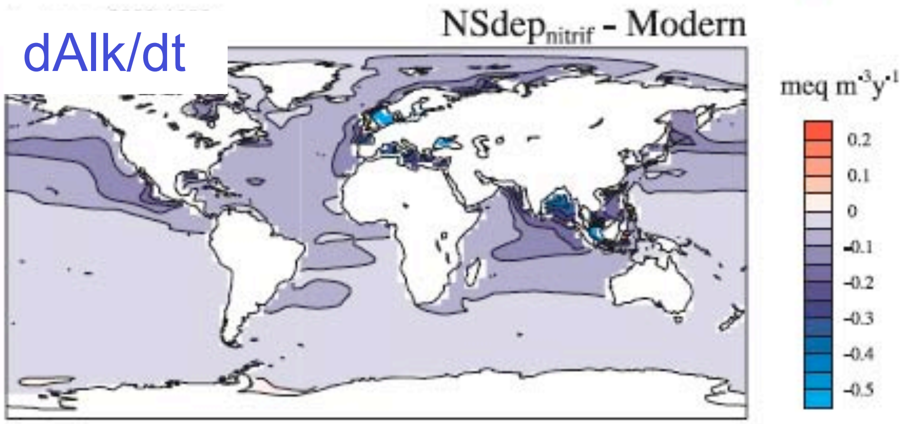


Geochemical Responses

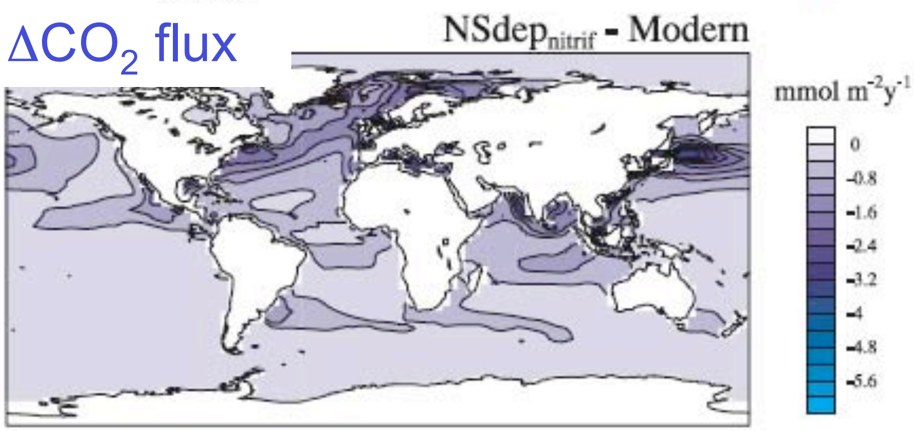
dpH/dt



dAlk/dt

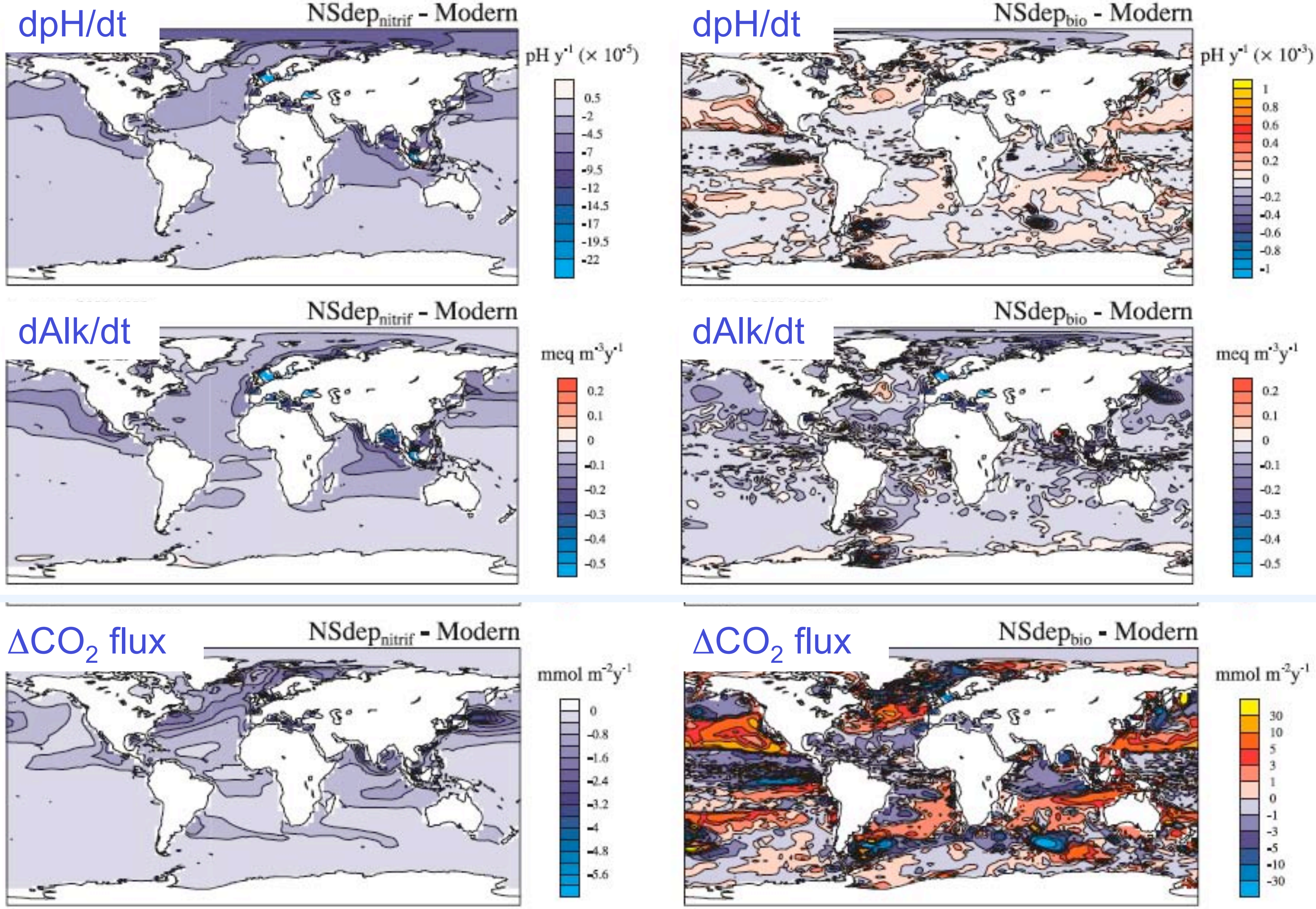


ΔCO_2 flux



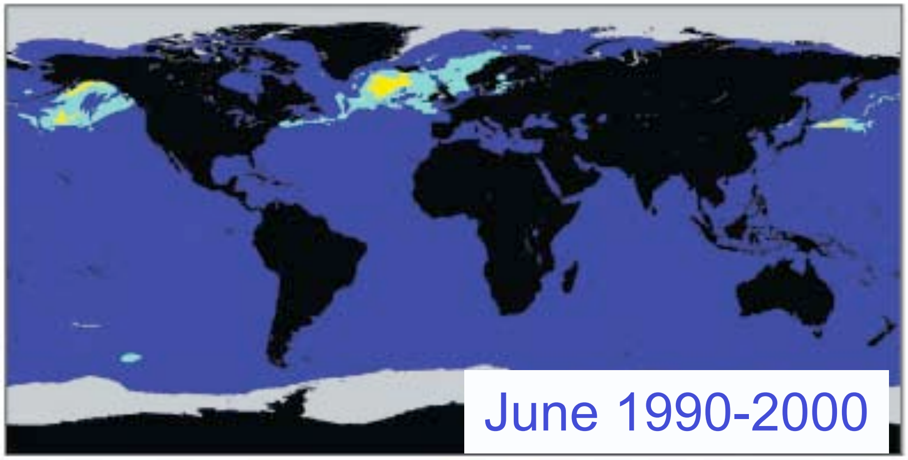
Geochemical Responses

w/ Nutrient Eutrophication

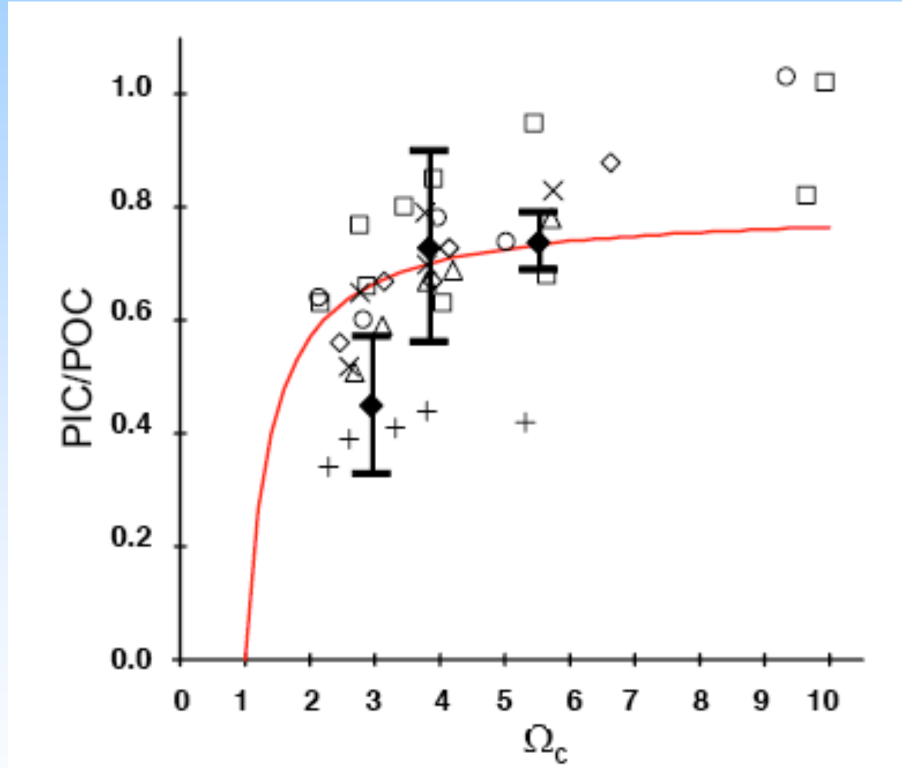


Climate Forcing: Synergistic effects of changes in temperature, nutrients, trace metals, sea-ice, mixed-layer depth, CO_2(aq), pH and Ω

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



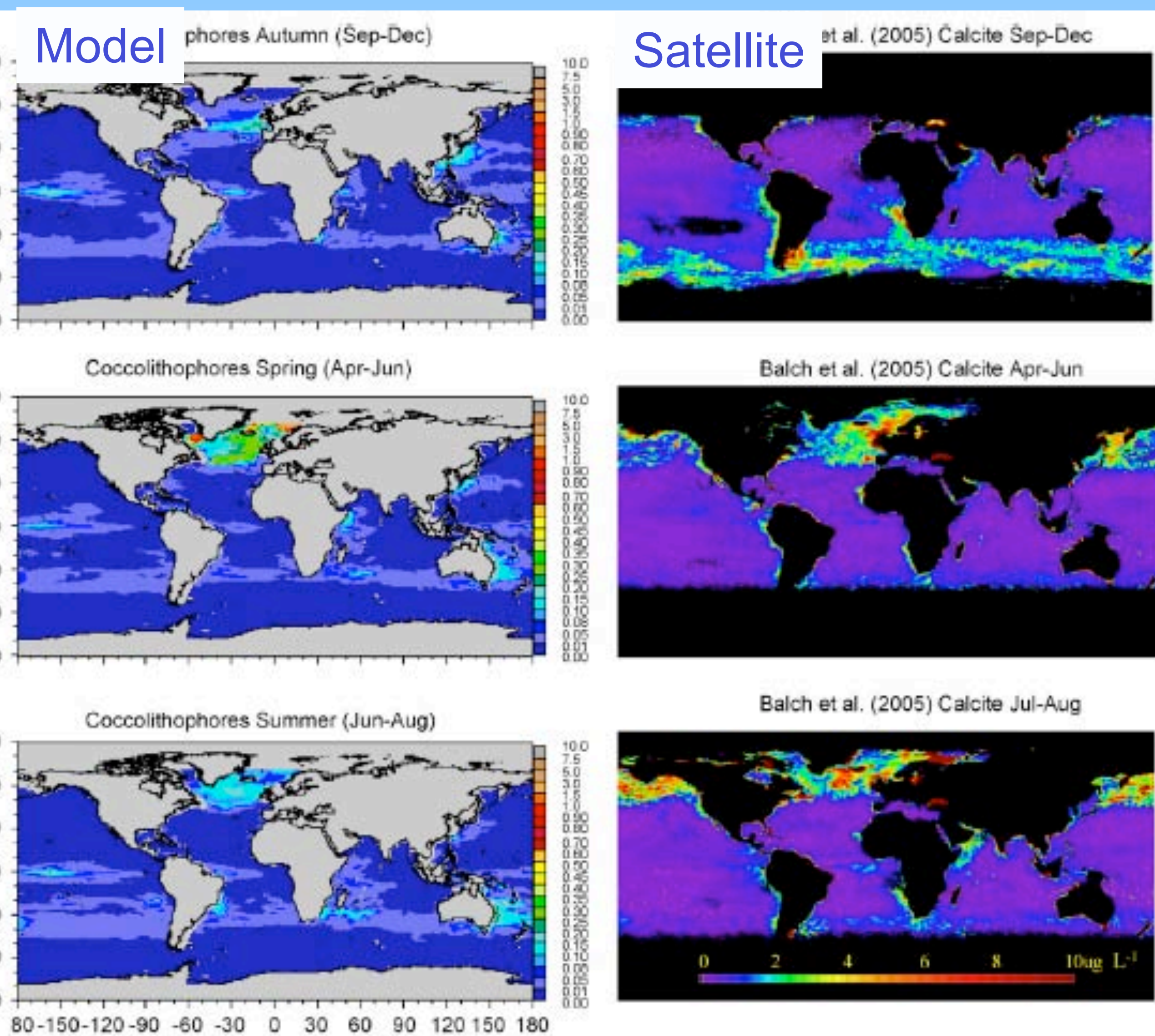
Iglesias-Rodriguez et al. Global Biogeochem. Cycles (2002)



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)

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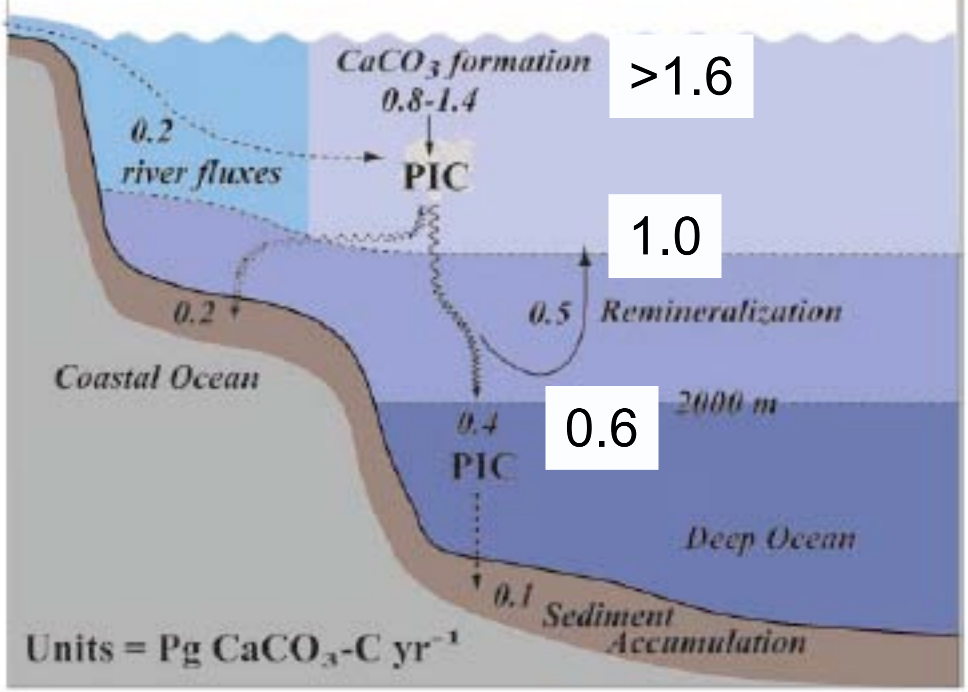
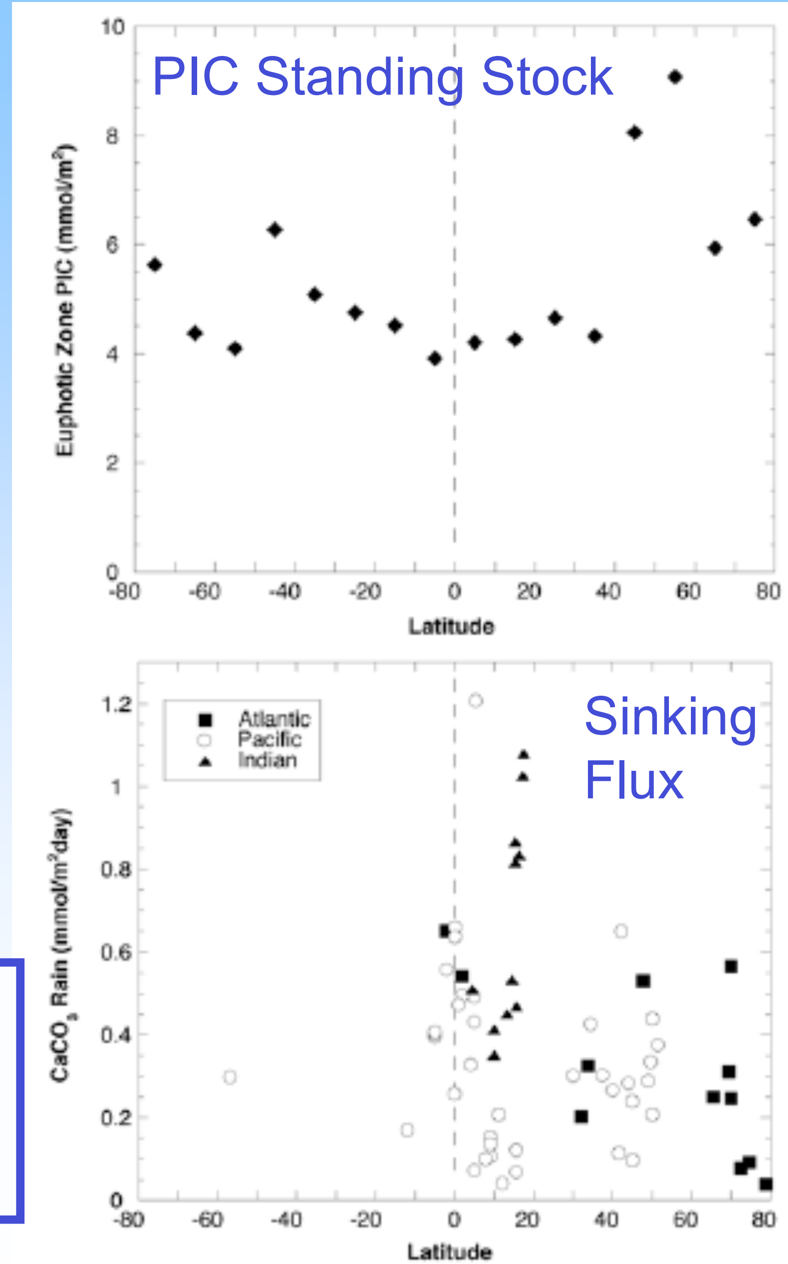
Geochemical constraints

Global Budget Pg $CaCO_3$-C/yr



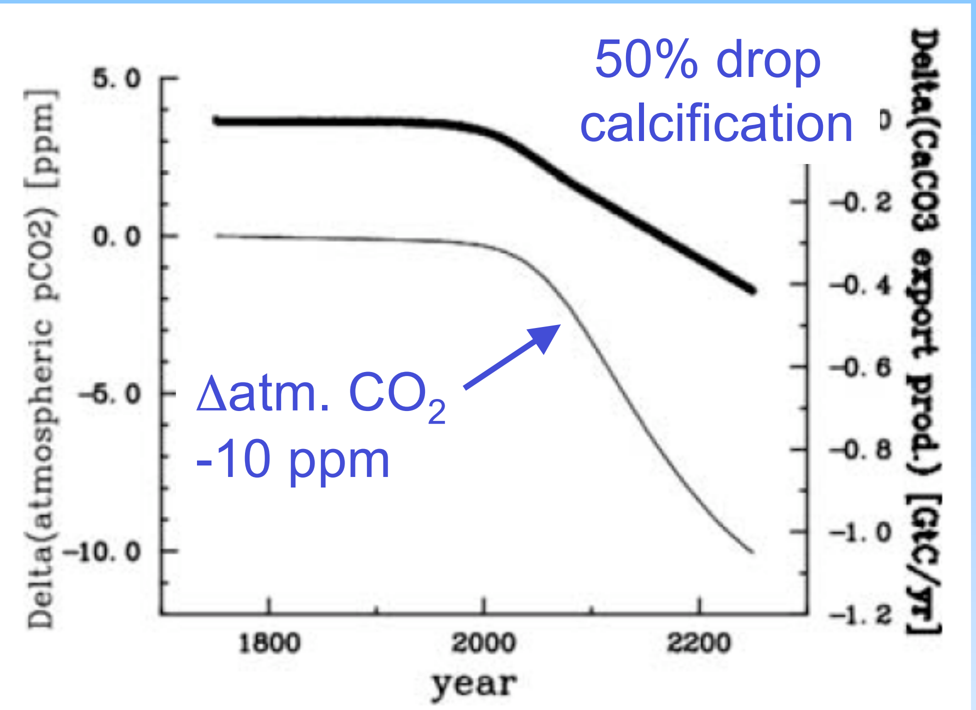


Feely et al. Science (2004);
Berelson et al. GBC (2007);
Sarmiento et al. GBC (2002)

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

Acidification, Calcification & Climate Feedbacks

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

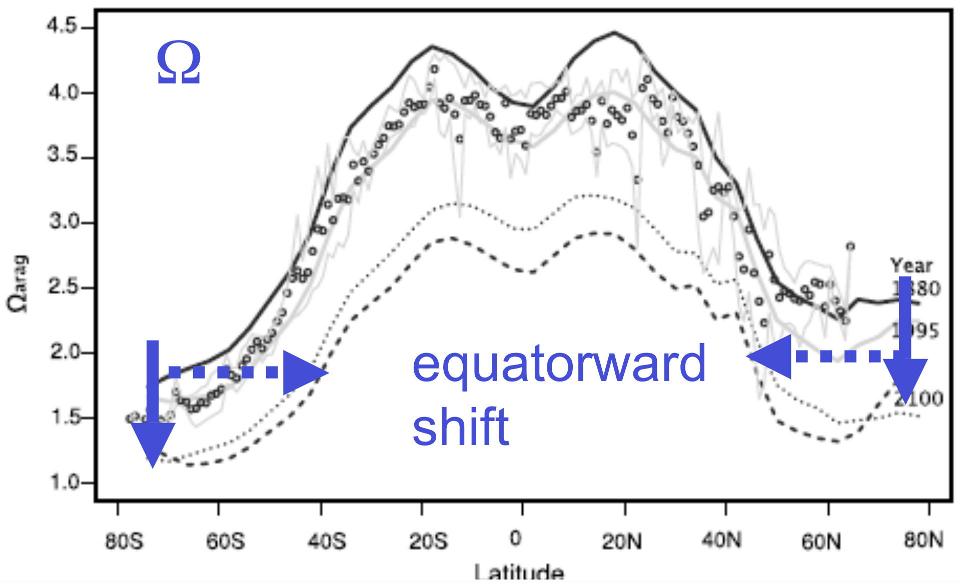


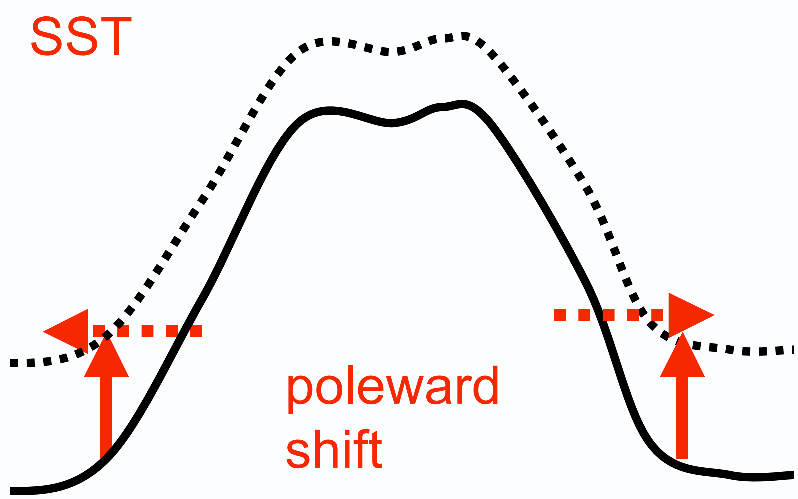
Heinze, Geophys. Res. Lett. (2004)
Zondervan et al. Global Biogeochem. Cycles (2001); Gehlen et al. Biogeoscience (2007); Ridgwell et al. Biogeoscience (2007)

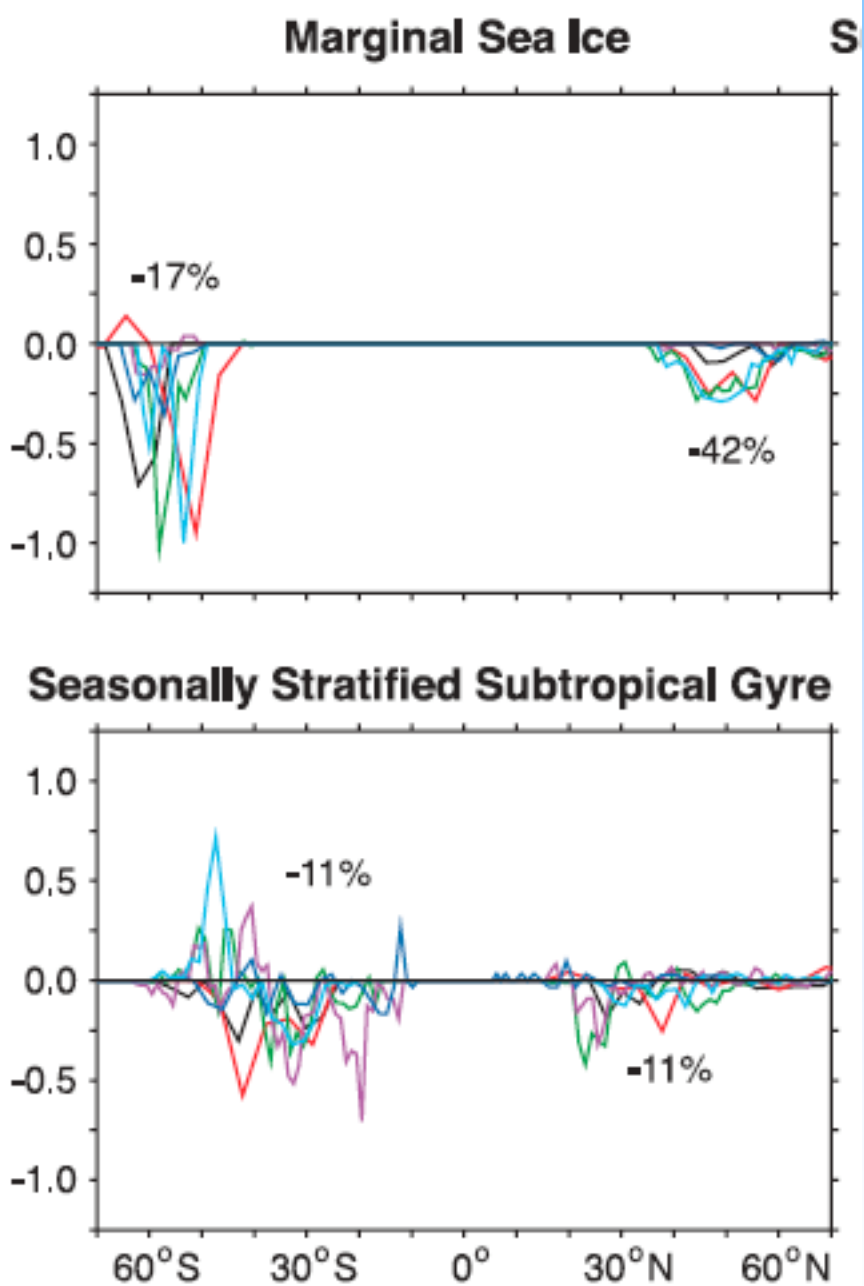
- Reduced formation of biogenic $CaCO_3$
- Decrease organic matter remineralization lengthscale (ballasting)
- Increase subsurface $CaCO_3$ dissolution

Niches & Plasticity

No current analogues to some future climate conditions??

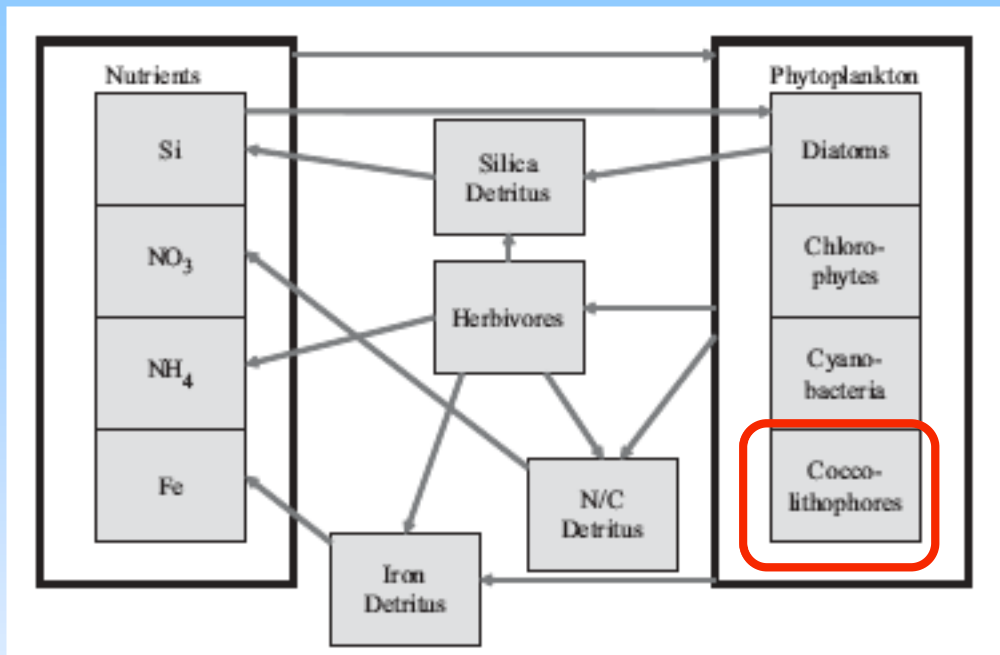




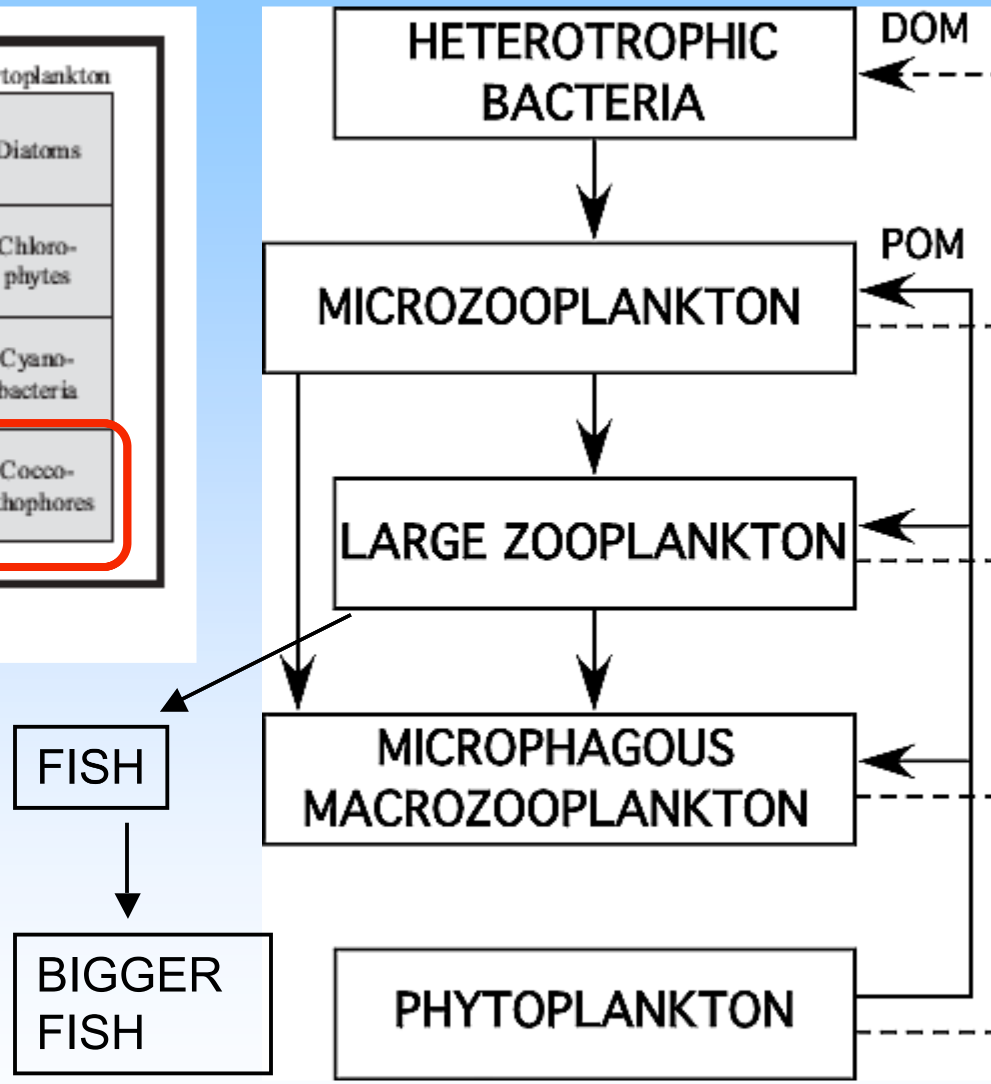


Sarmiento et al. GBC (2004)

Food-web Interactions



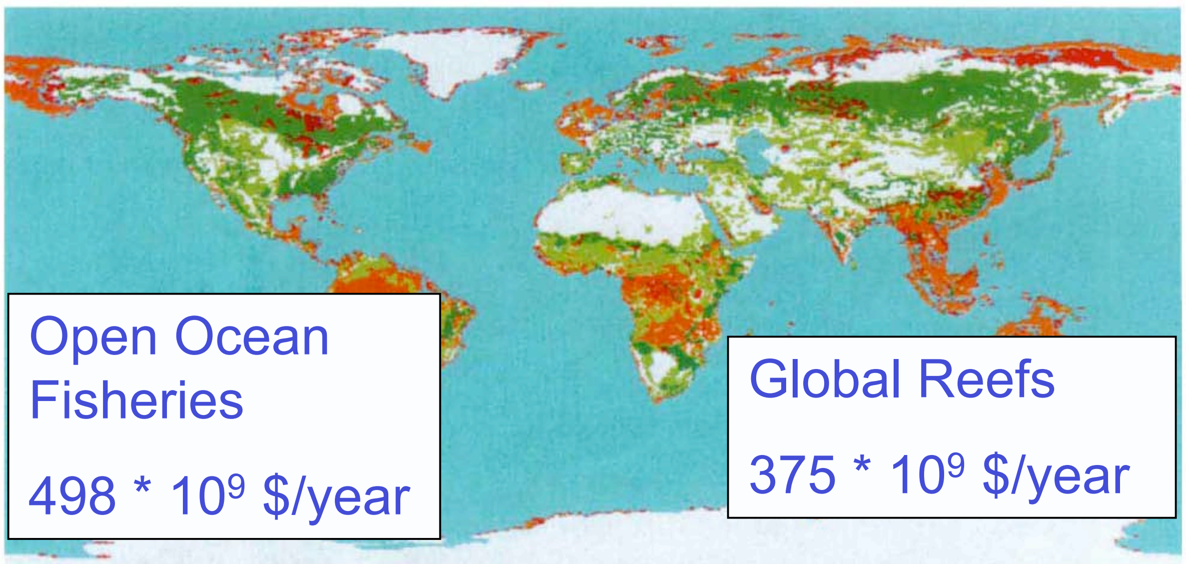
Gregg & Casey Deep-Sea Res. II (2007)



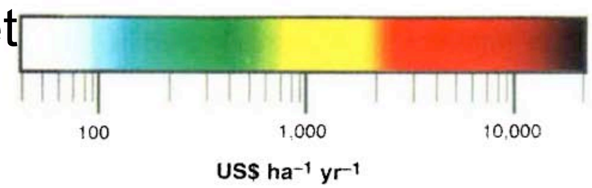
From Legendre and Rivkin (2005)

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

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



Costanza et al. (1997)



1994 Values

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

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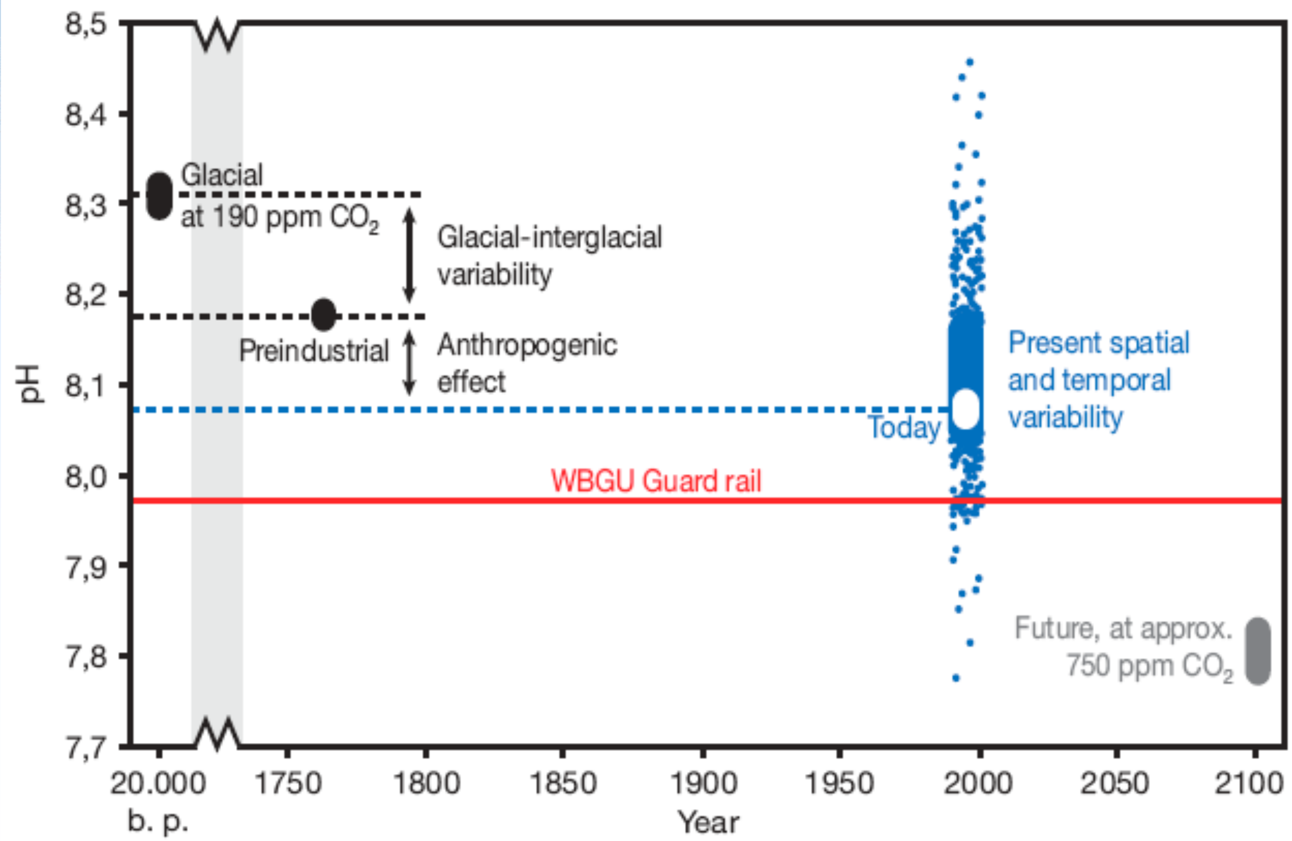
4.4.1
Proposed guard rail

To prevent undesirable or high-risk changes to the marine food web due to aragonite undersaturation (Section 4.3), the pH value of near surface waters should not drop more than 0.2 units below the pre-industrial average value of 8.18 in any larger ocean region (nor in the global mean). A pH drop of 0.2



CENTER for BIOLOGICAL DIVERSITY

The Center for Biological Diversity respectfully requests that the North Coast Water Quality Control Board recommend that:

All ocean waters under Region 1's jurisdiction be included in the state List of Impaired Waters ("303(d) List") under section 303(d) of the Clean Water Act as impaired for pH due to absorption of anthropogenic carbon dioxide pollution.

[5] The *U.S. Environmental Protection Agency* [1976] Quality Criteria for Water state: "For open ocean waters where the depth is substantially greater than the euphotic zone, the pH should not be changed more than 0.2 units outside the range of naturally occurring variation . . ." Atmospheric CO_2 concentrations would need to be stabilized at <500 ppm for the ocean pH decrease to remain within the 0.2 limit set forth by the *U.S. Environmental Protection Agency* [1976] (Table 1).

Caldeira et al. Geophys. Res. Lett. (2007).

-anthropogenic CO_2, pH & $CaCO_3$ saturation state 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, & groundwater (low/med.)

-biogeochemical and ecological impacts

- •lower calcification + reduced subsurface dissolution
  => modest atm. CO_2 drawdown (med.)
- •altered particle ballast, elemental stochiometry, trace gases (low)
- •population adaptation and plasticity
- •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)
- •adaptation strategies for resource managers