Intro to Biogeochemical Modeling Ocean & Coupled

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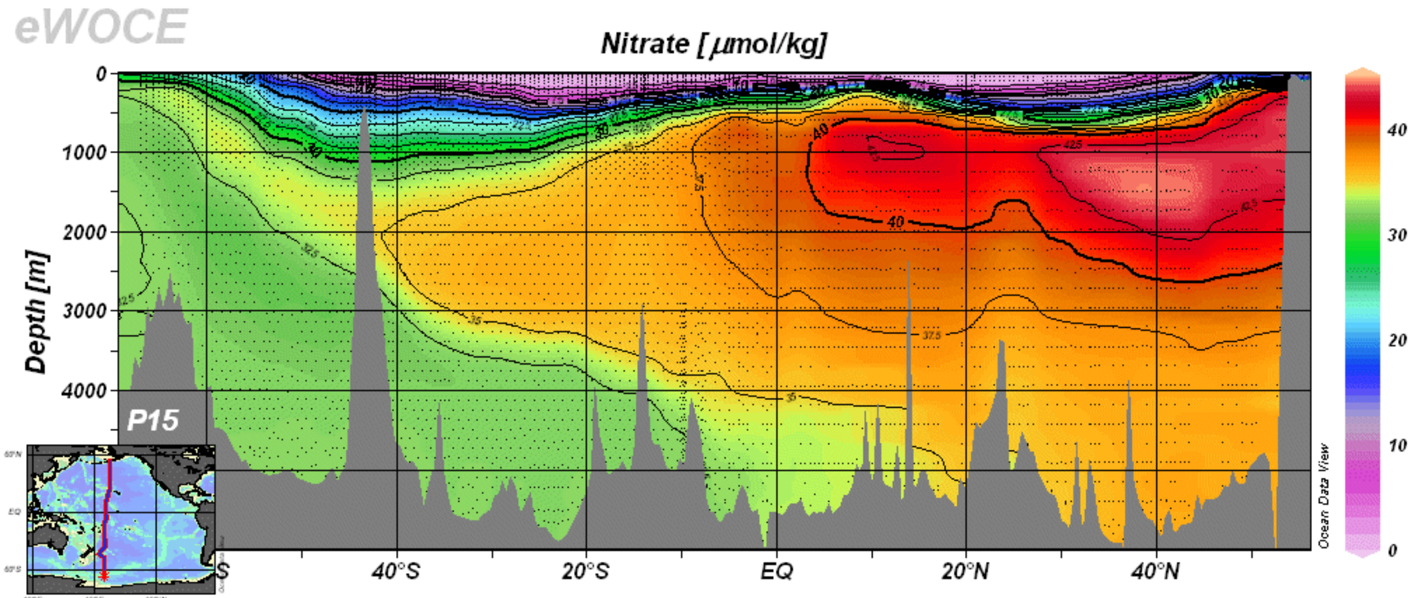
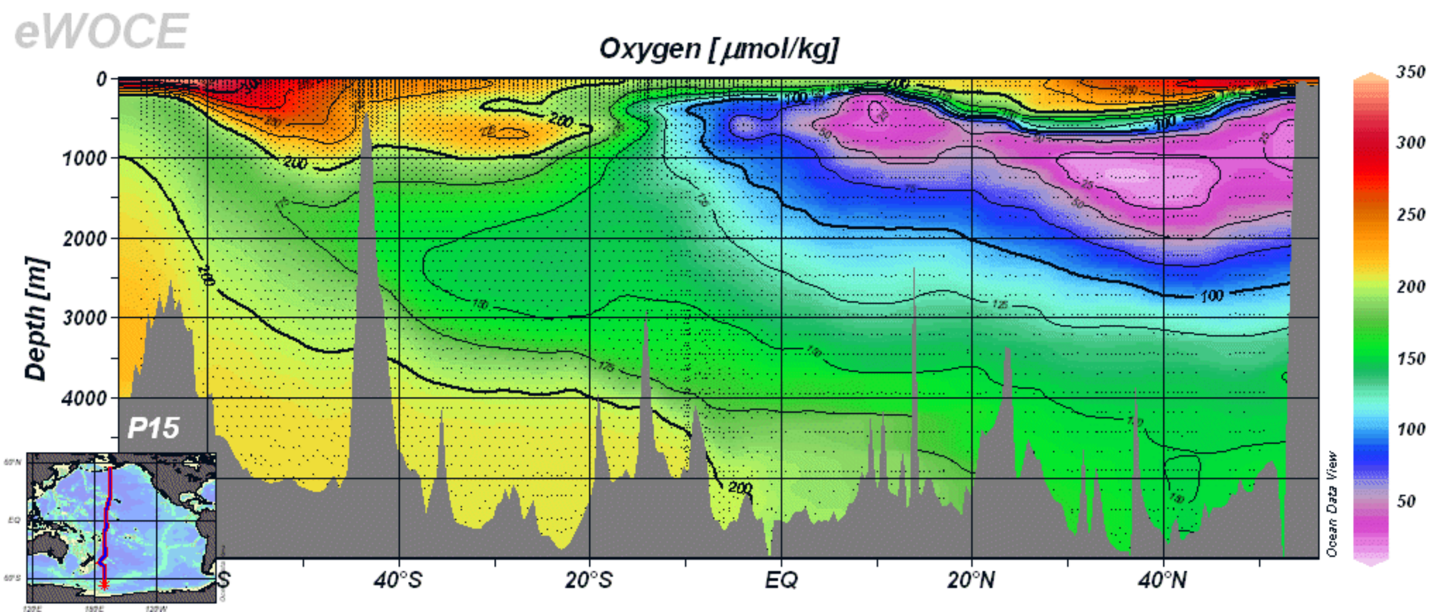
NCAR is sponsored by the National Science Foundation

Lecture Outline

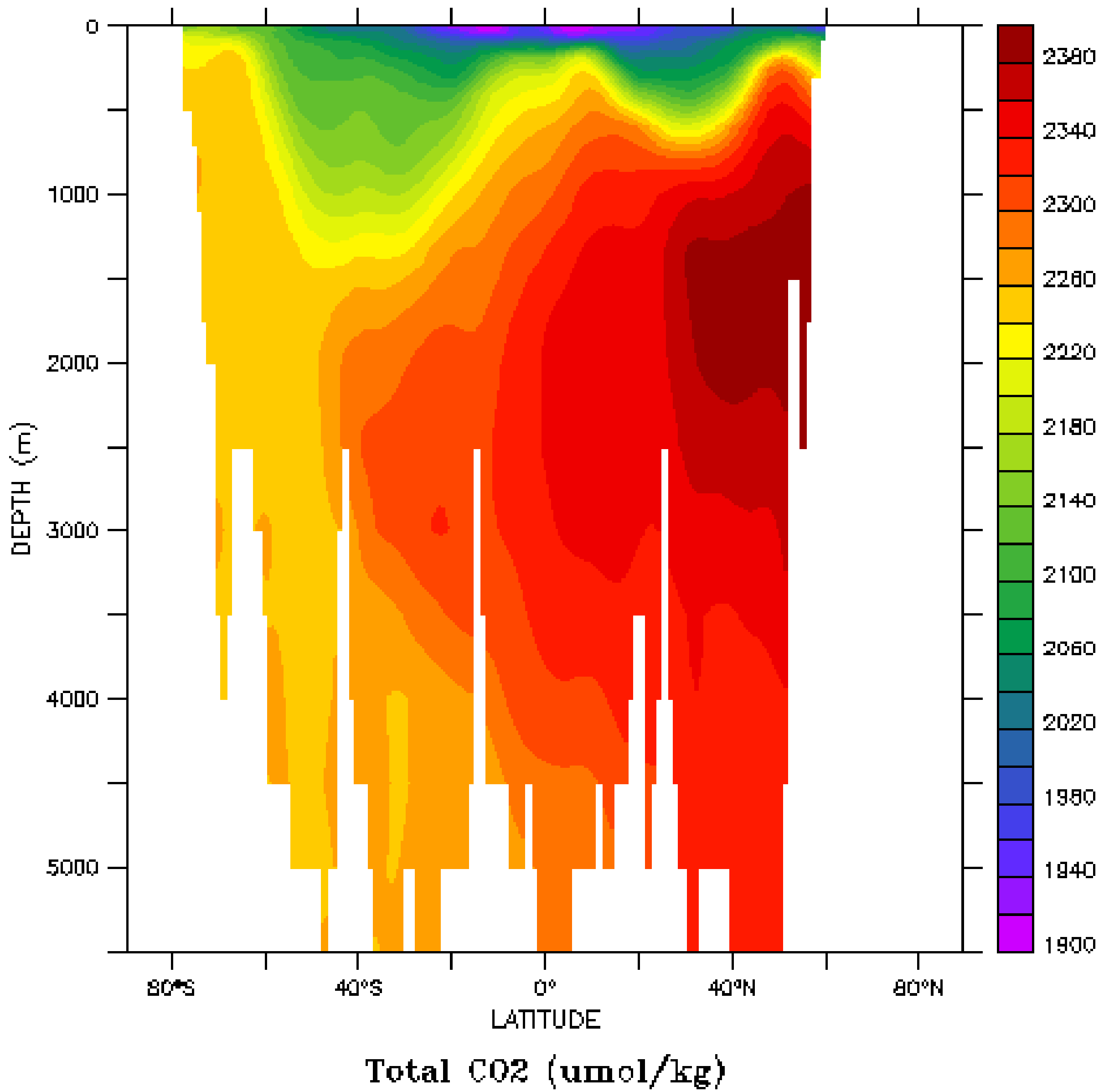
1) Large Scale Ocean Biogeochemical Features
2) Techniques for Modeling Biological Productivity
3) Skill Assessment
4) Global Carbon Cycle
5) Summary

NO_3 (a nutrient), O_2 (dissolved gas) Along Pacific Transect

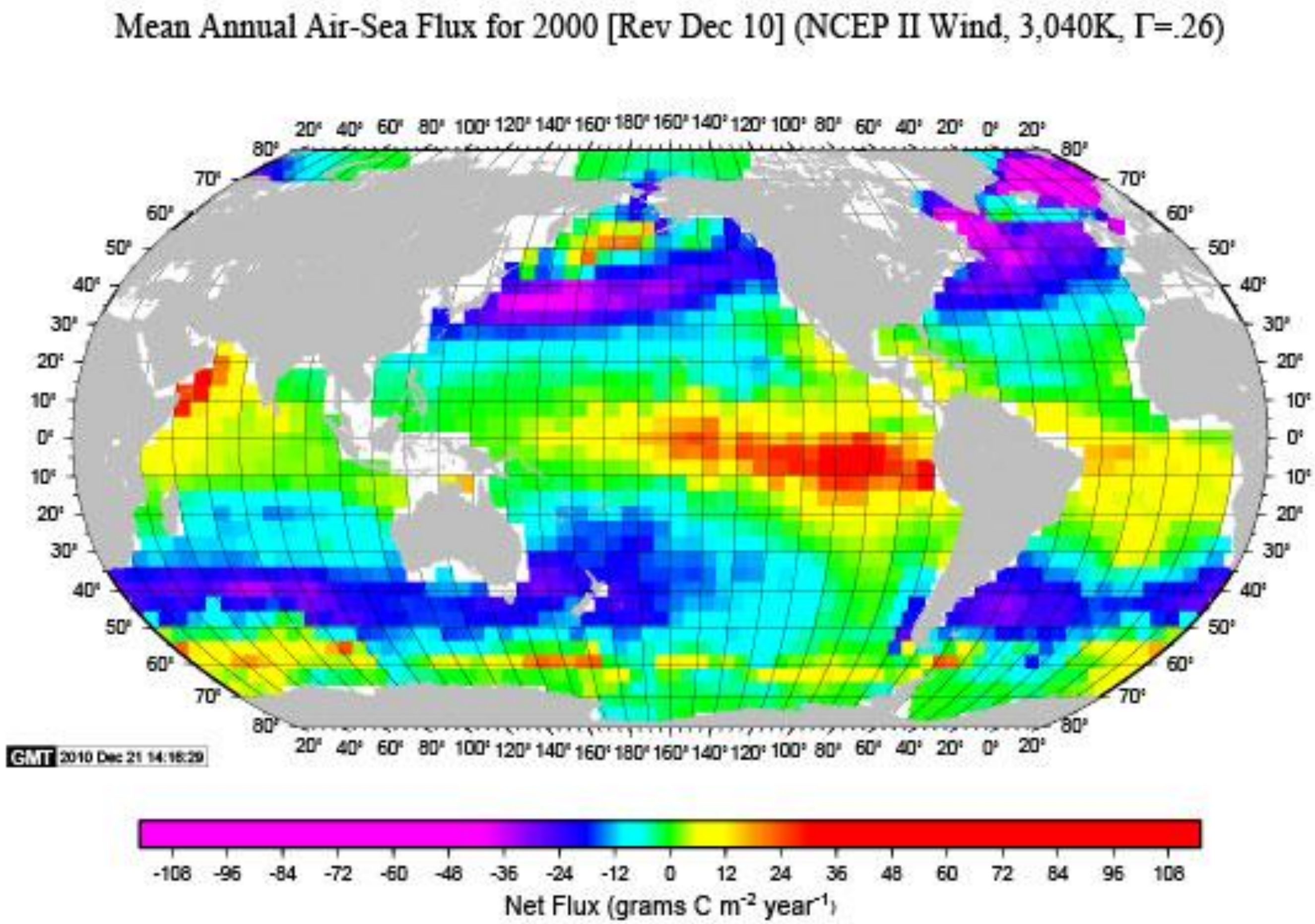




DIC (~CO_2) Along Same Pacific Transect



Takahashi Air-Sea CO_2 Gas Flux



Primary Processes Governing Distribution of Nutrients, O_2, Carbon, etc.

- Biological Productivity in Euphotic Zone
  - Consumes Nutrients & Inorganic Carbon
  - Produces Organic Matter & O_2
- Export of Organic Matter out of Euphotic Zone
  - Sinking Particles (e.g. detritus, $CaCO_3$ shells, …)
  - Circulation of Suspended Matter
- Remineralization of Organic Matter
  - ‘reverse’ of productivity, consumes O_2
- General Circulation
  - Advective Transport
  - Lateral & Vertical Mixing
- Temperature Dependent Air-Sea Gas Exchange

Other Processes, Smaller Global Impact, Locally Significant

- Atmospheric Nutrient Deposition
  - Fe, N, P, …
- Sedimentary Burial
- Riverine Inputs

Large Scale Ocean Carbon Cycle

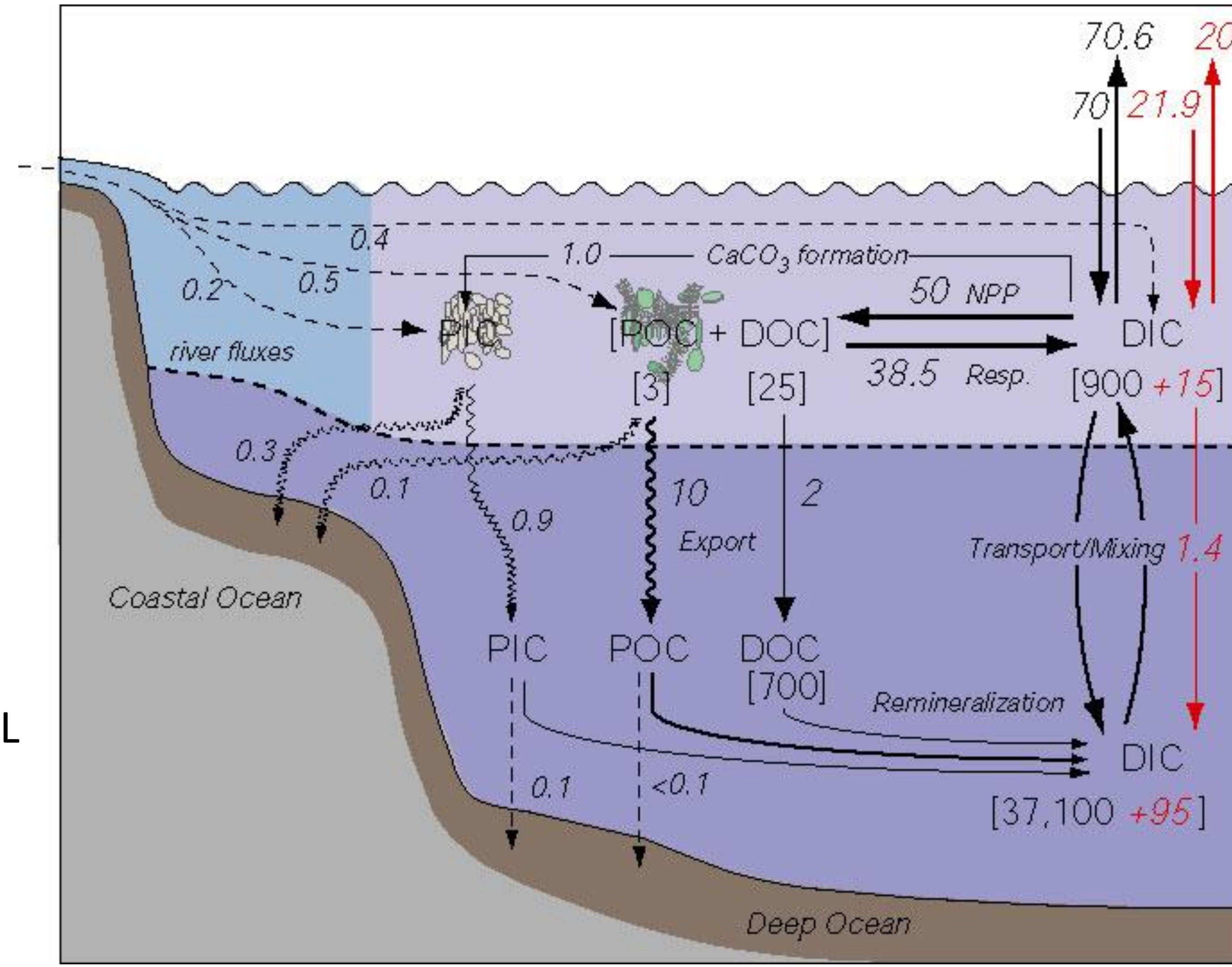
DIC
Diss. Inorganic C

DOC
Diss. Organic C

PIC
Part. Inorganic C

POC
Part. Organic C

Figure courtesy PMEL



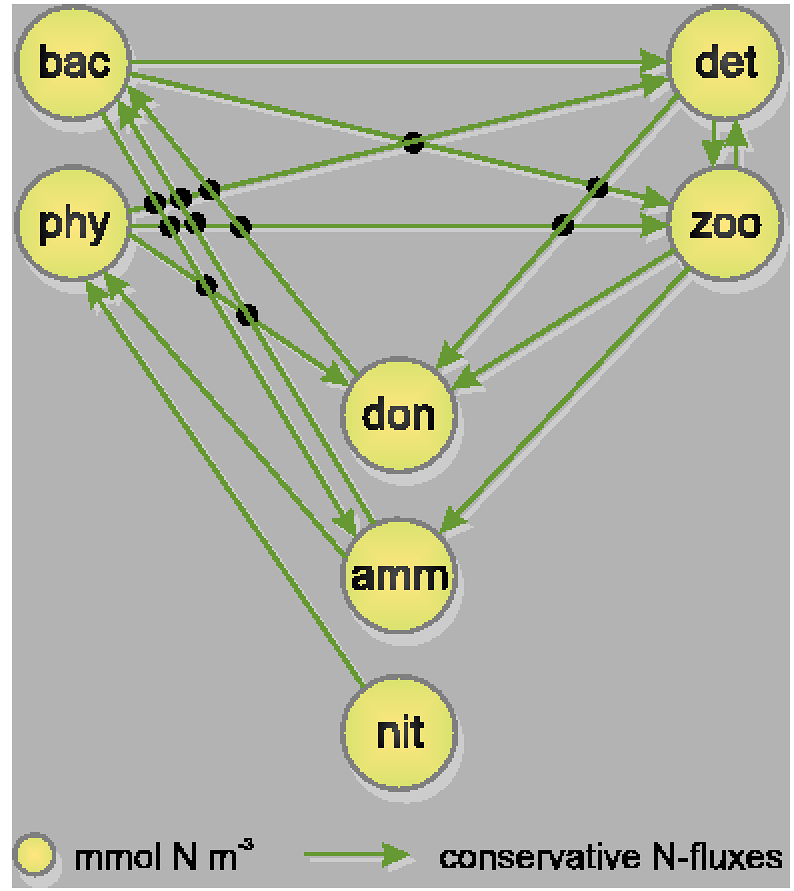
What is an NPZD model?

N Nutrient
    nitrate, ammonium,
    phosphate, silicate, iron, etc.
P Phytoplankton
    photosynthesizers
Z Zooplankton
    grazers
D Detritus

<u>Canonical Example</u>

Fasham, Ducklow, McKelvie, Journal of Marine Research, Vol. 48, pp. 591-639, 1990.

Many more variations are used…



Fasham model diagram from www.gotm.net

Simple NPZ Model

$$\frac{dP}{dt} = \mu_0\left(\frac{N}{k_N + N}\right)\left(1 - e^{\alpha E/\mu 0}\right)P - g\left(\frac{P}{k_P + P}\right)Z - m_P P$$

Nutrient limitation — Light limitation — Grazing — Mortality

$$\frac{dZ}{dt} = ag\left(\frac{P}{k_P + P}\right)Z - m_Z Z$$

$$\frac{dN}{dt} = -\mu_0\left(\frac{N}{k_N + N}\right)\left(1 - e^{\alpha E/\mu 0}\right)P + (1-a)g\left(\frac{P}{k_P + P}\right)Z + m_P P + m_Z Z$$

- Three coupled ordinary differential equations
- Mass conservation

How do you estimate parameters and functional forms?

- Laboratory & field incubations
  - P-I curves
  - Nutrient uptake curves
- Tune/Optimize against field data
- Previous Models

Plankton Functional Types (PFTs)

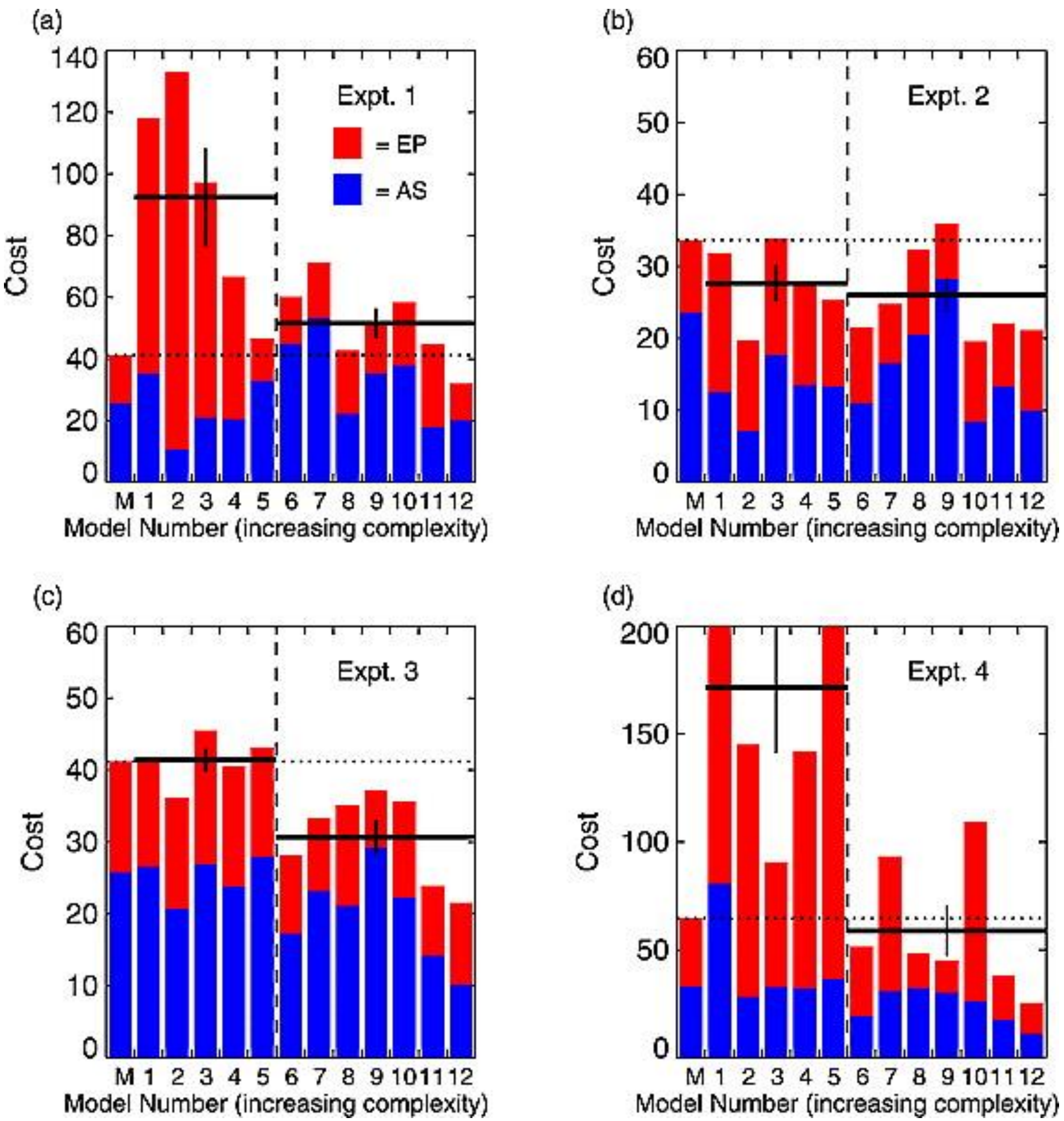
- Categorize plankton species by how they function and use representative types/groups
- Example definition from Le Quéré et al., Global Change Biology, Vol. 11, pp. 2016-2040, 2005.
  - Explicit biogeochemical role
  - Biomass and productivity controlled by distinct physiological, environmental, or nutrient requirements
  - Behavior has distinct effect on other PFTs
  - Quantitative importance in some region of the ocean

Skill & Portability in 12 Different NPZD models
Friedrichs et al., JGR-Oceans, 2007.

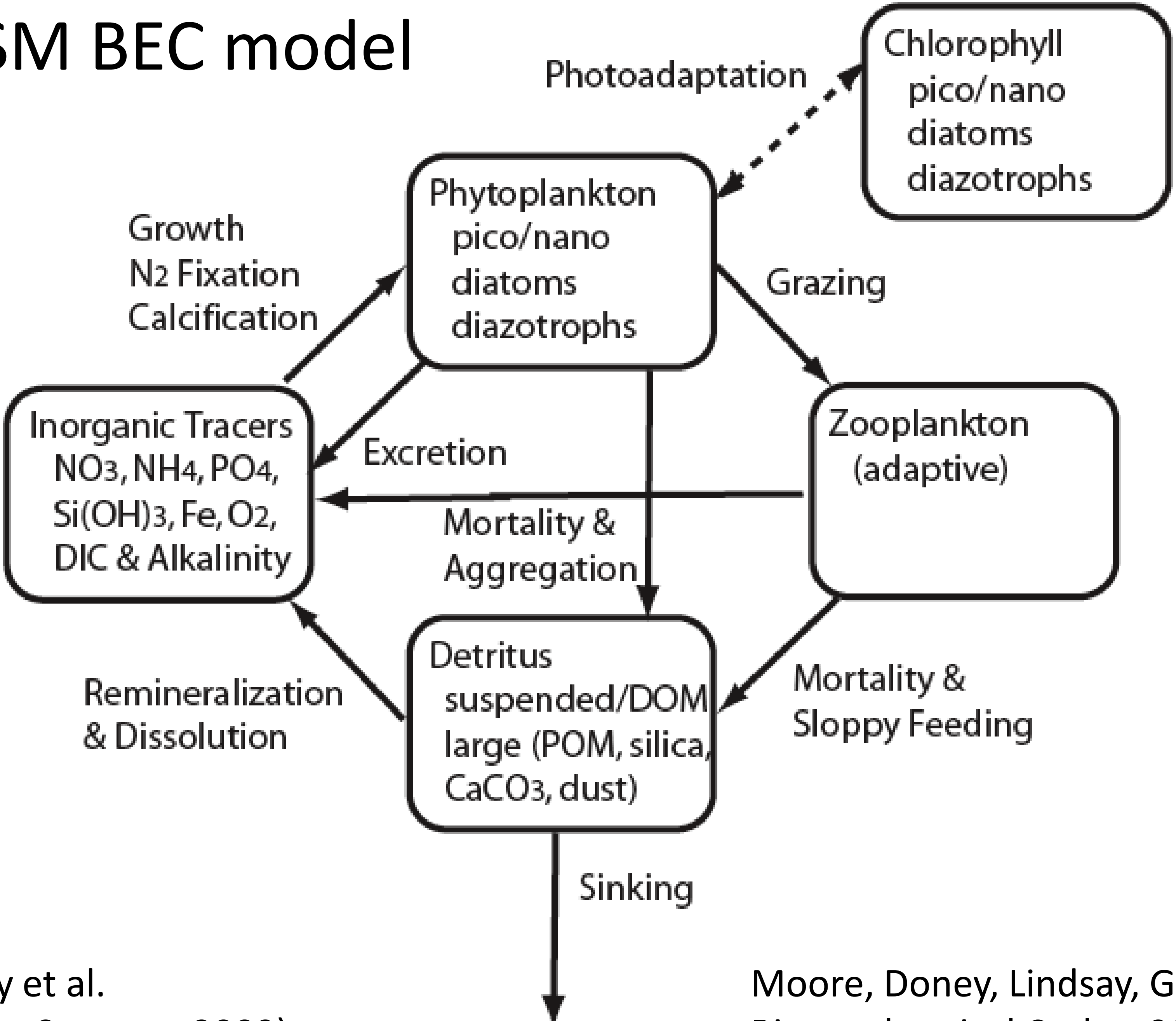
(b) Simple models do just as well as more complex models when tuned for specific sites.

(c) More complex models do better at multiple sites with single parameter sets.

(d) More complex models perform better at different sites when tuned for one site.



CCSM BEC model



Doney et al.
(J. Mar. Systems, 2009)

Moore, Doney, Lindsay, Global Biogeochemical Cycles, 2004.

Primary Features of CESM BEC Model

- 4 Plankton Functional Groups
  - 3 Autotrophs, 1 Grazer
  - Implicit coccolithophores
- Nutrients: N, P, Si, Fe
- Fixed C:N:P ratios in plankton (24 tracers)
- Variable Fe:C, Si:C, Chl:C ratios
- Fe cycle improved in Moore, Braucher, Biogeosciences, Vol. 5, 2008, pp. 631-656.

Known Gaps in Ocean BGC in CESM-(BGC)

- Calcification & $CaCO_3$ remineralization rates are independent of CO_3 saturation state.
- No riverine inputs of BGC tracers.
- No sediment model.
- No treatment of BGC in sea-ice.

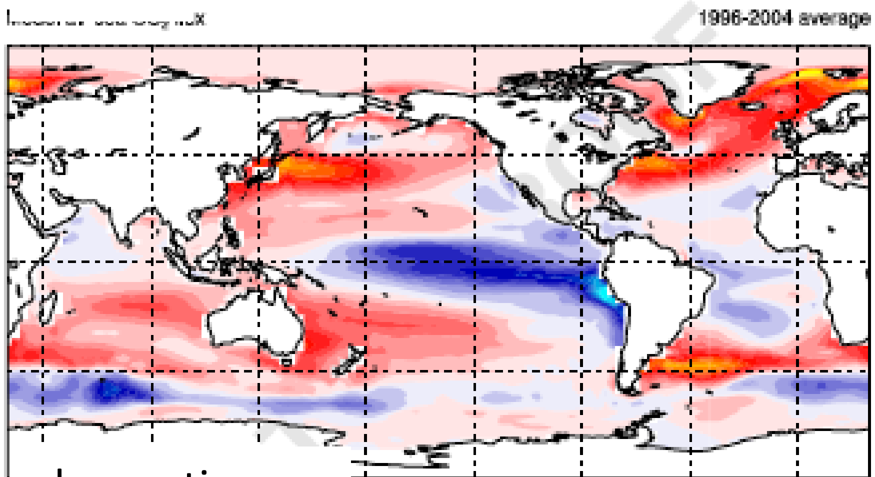
- Focus in on lower trophic levels.

Model Validation: Examples of Data Sets

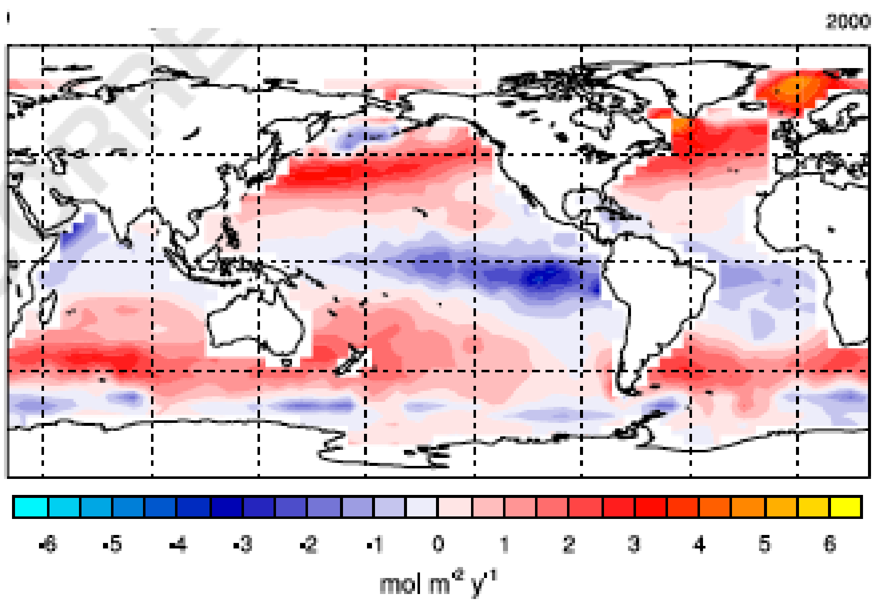
- Macronutrients (PO_4, NO_3, SiO_3) and O_2 from World Ocean Atlas
- DIC, ALK from GLODAP Analysis
- pCO_2 and CO_2 Flux assembled by Takahashi
- Surface Chl measured by satellite
- Productivity estimated from satellite
- JGOFS study sites
- HOTS & BATS timeseries

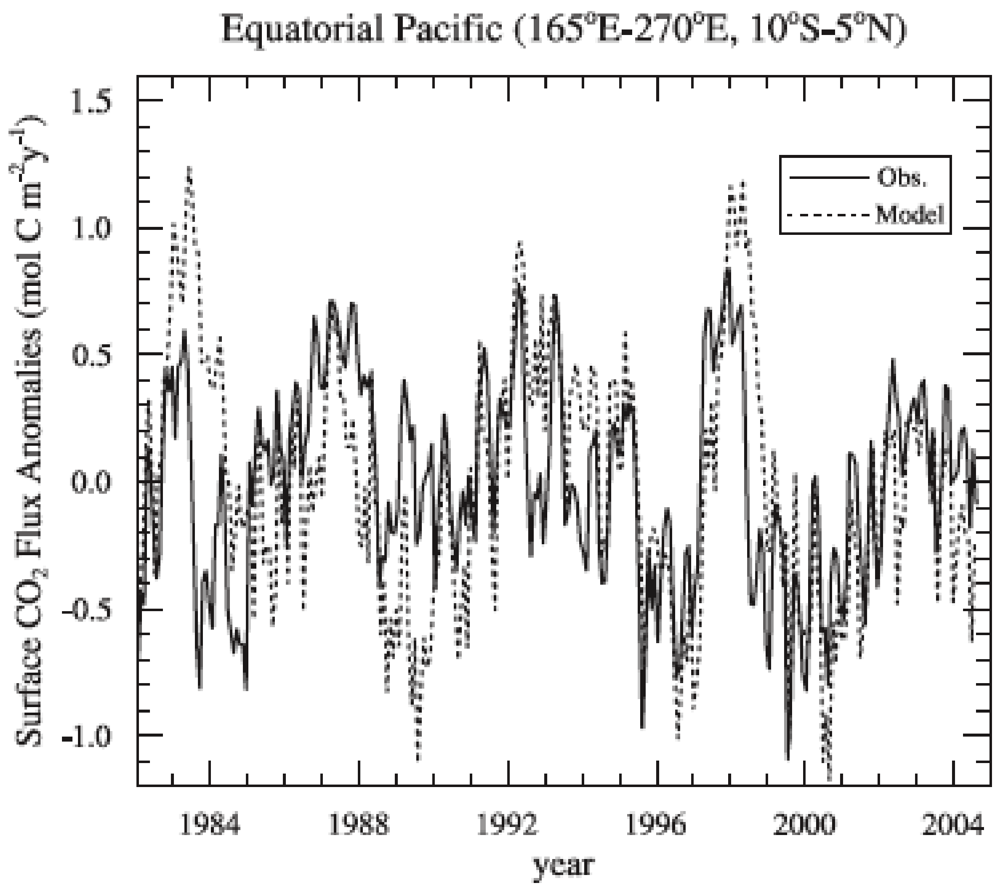
Air-sea CO_2 Flux

model



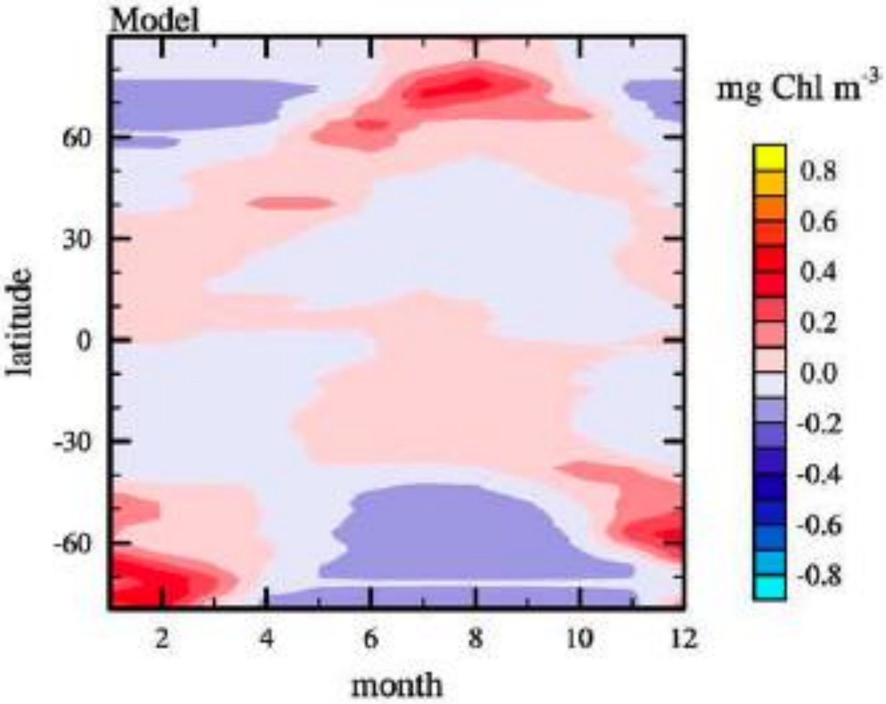
observations

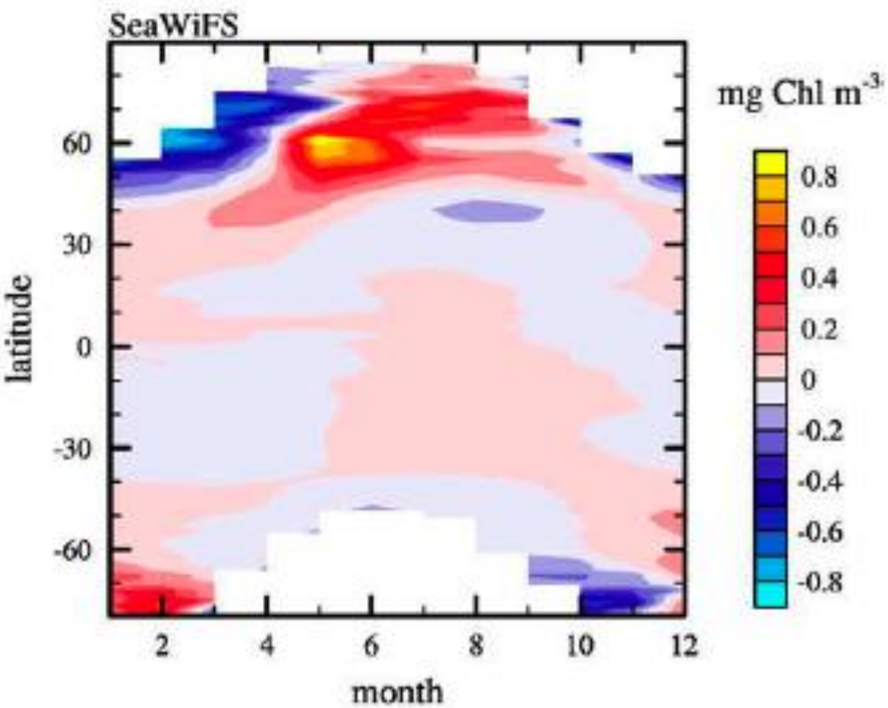


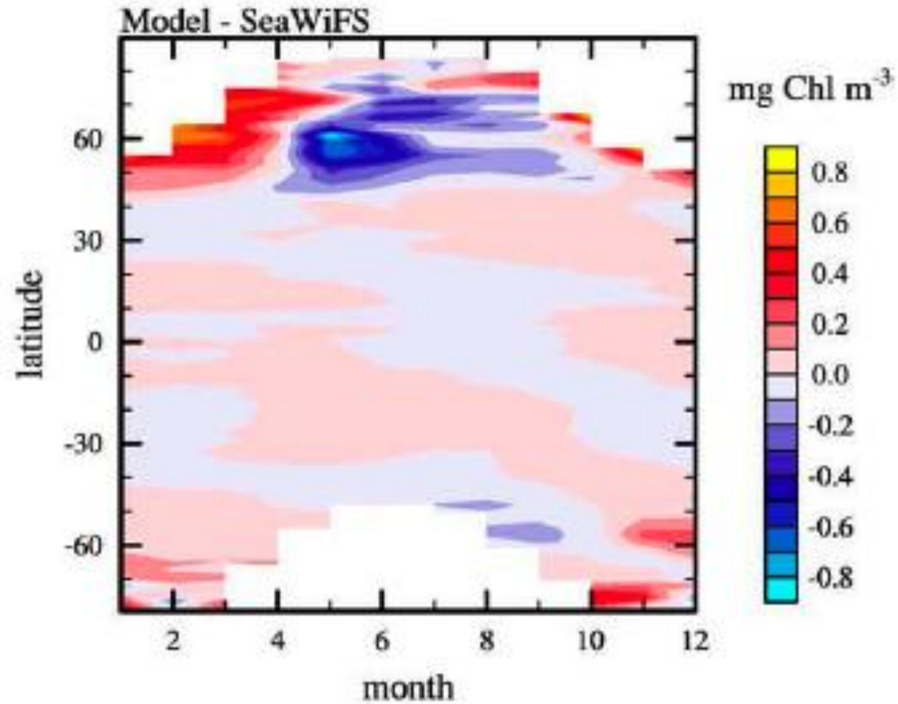


Doney et al. (Deep-Sea Res. II, 2009)

Satellite Ocean Color Comparison







Known Challenges

- Optimize BGC model parameters
  - Functional group approach increases uncertainty of parameters (i.e. multiple species, with different characteristics, are clumped together)
  - Don’t want to overtune too much to compensate for biases in physical model
- Given BGC model parameters and physical circulation, generate balanced BGC state
  - Need to deal w/ diurnal to millenial timescales
  - Using Newton-Krylov for this is a work in progress

Large Scale Global Carbon Cycle

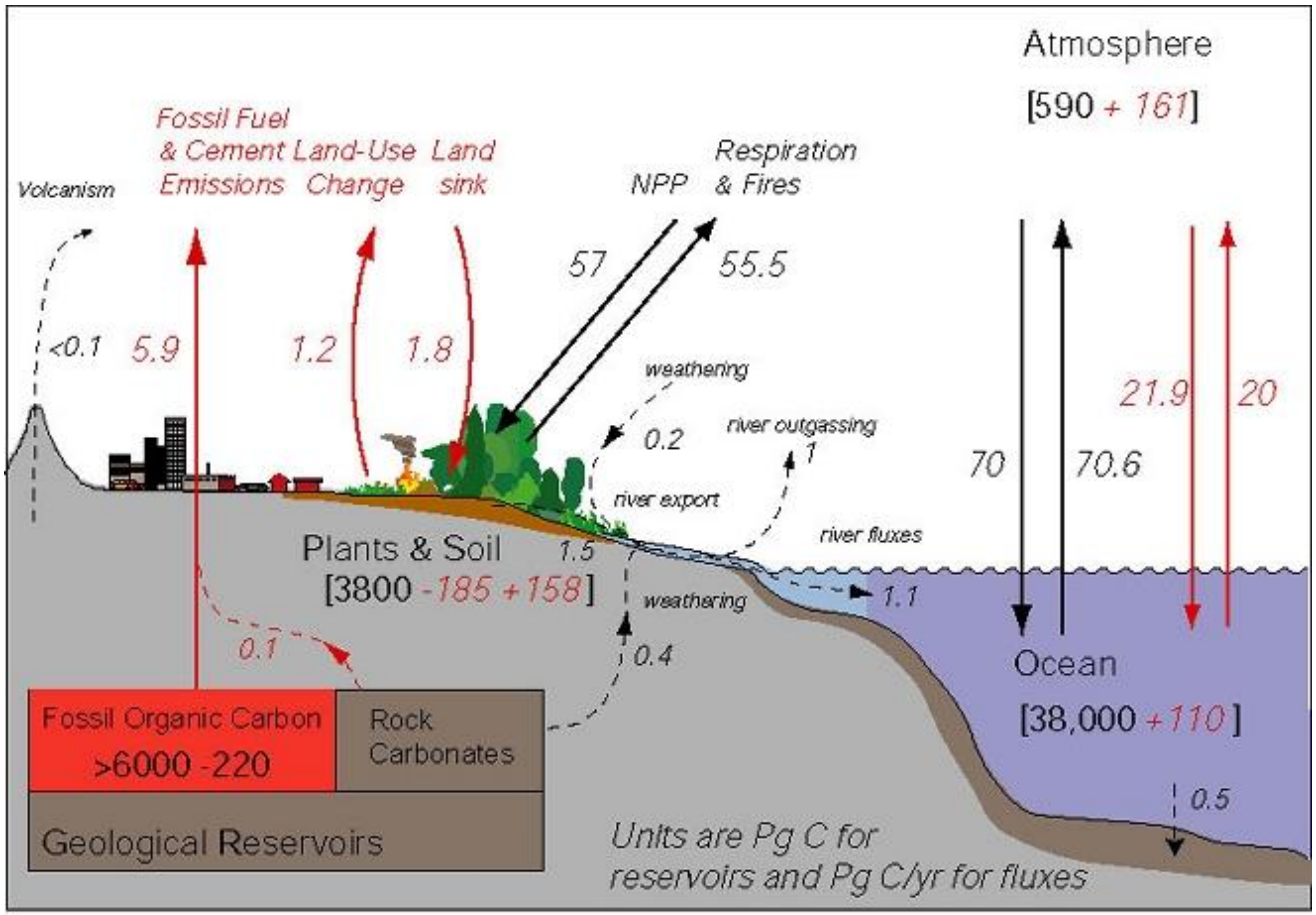
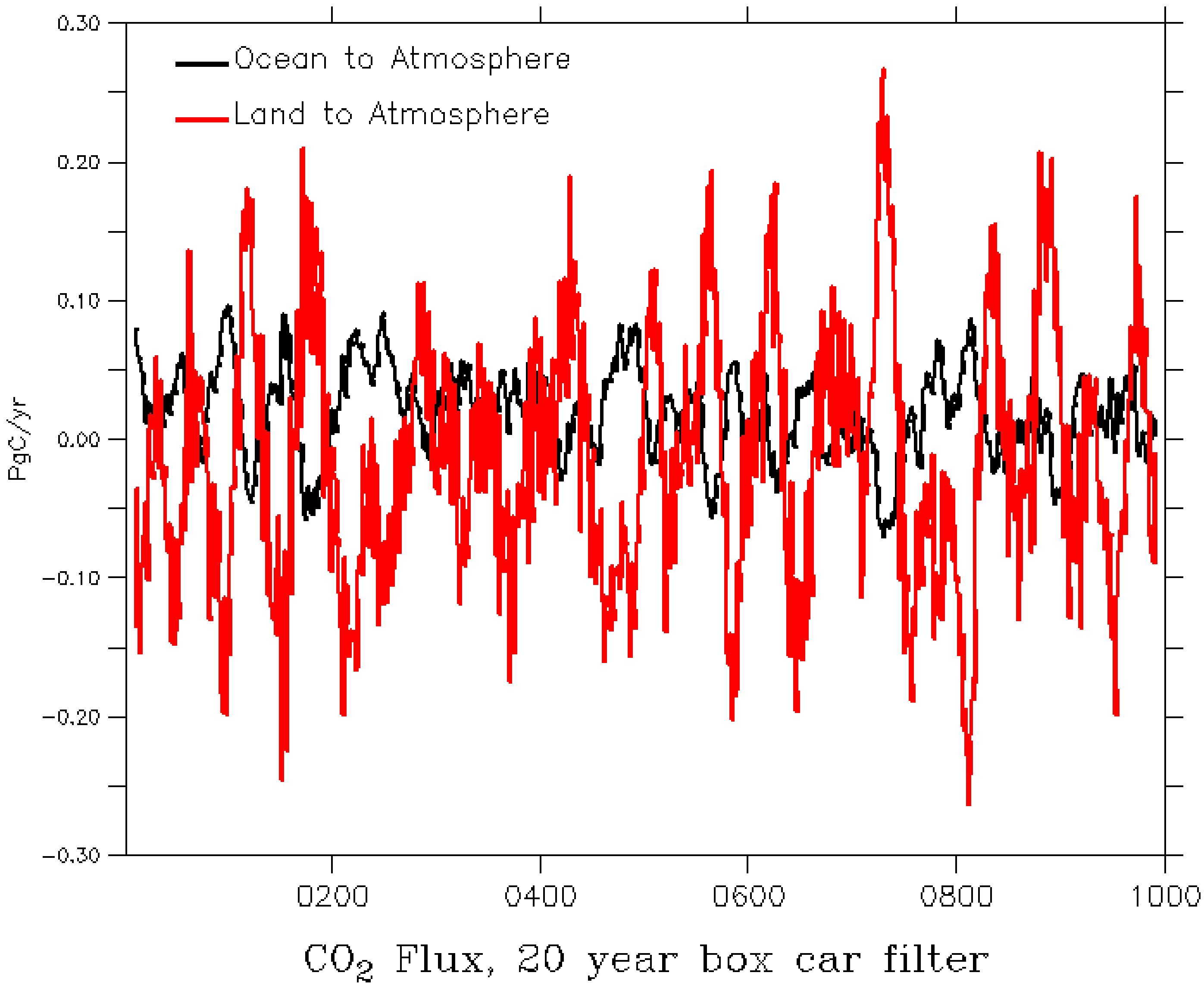
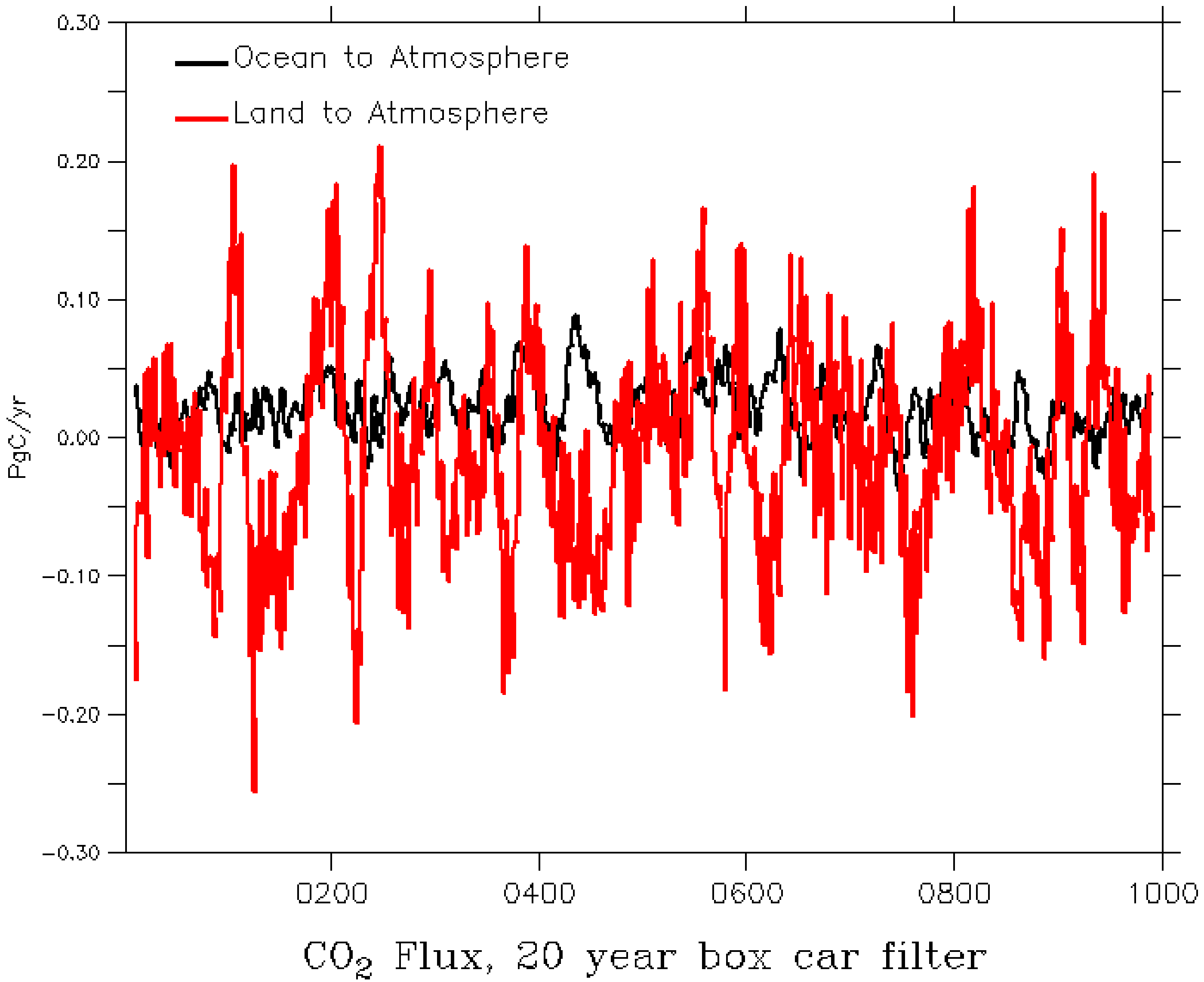


Figure courtesy PMEL

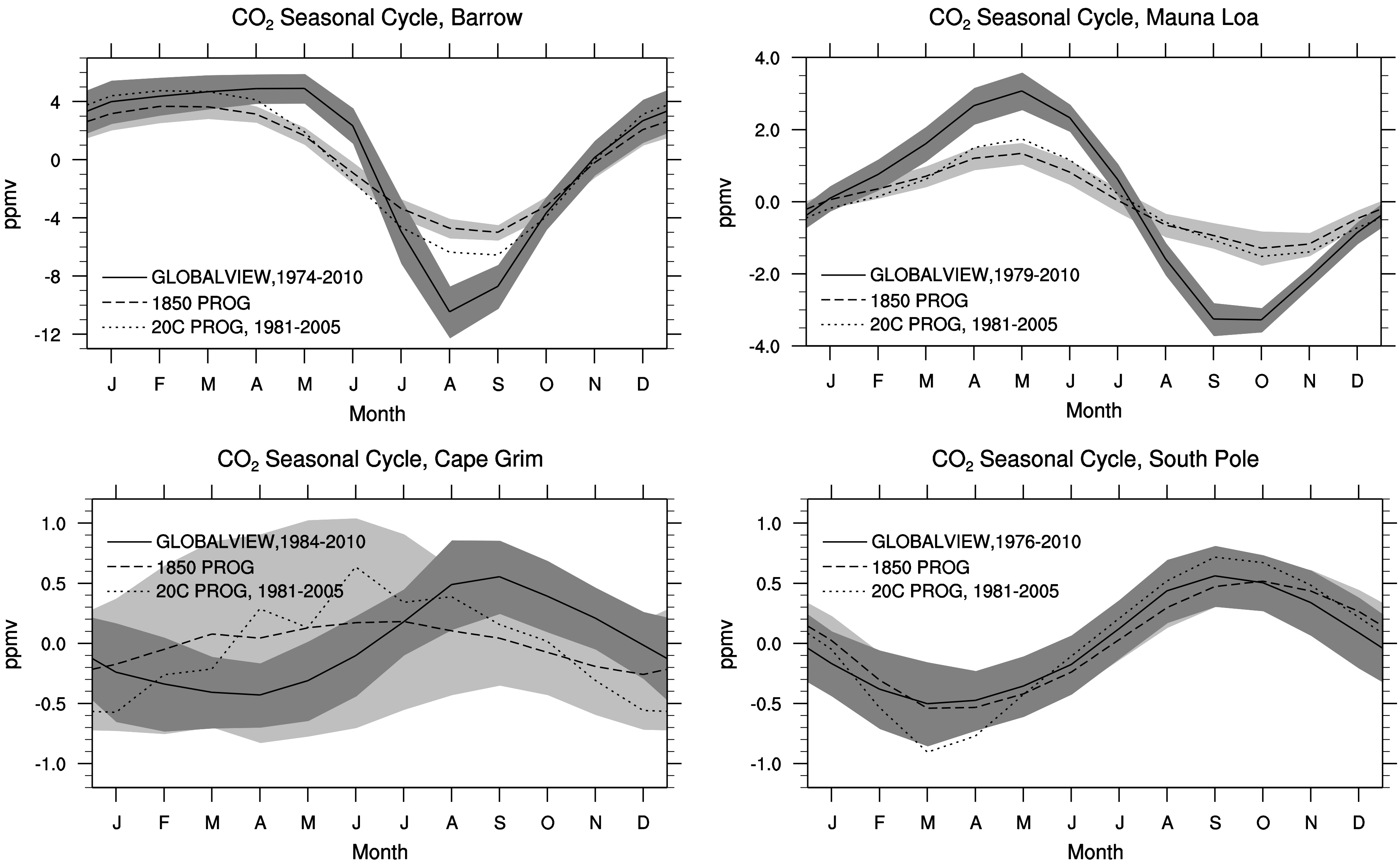
Land & Ocean CO_2 Fluxes from CESM1-BGC



Same plot with Fixed ATM CO_2



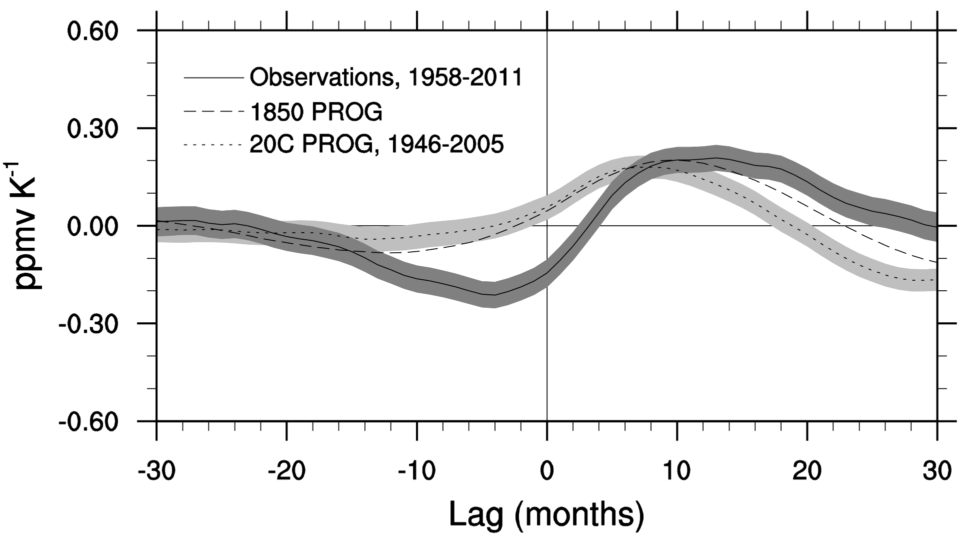
CO_2 Seasonal Cycle



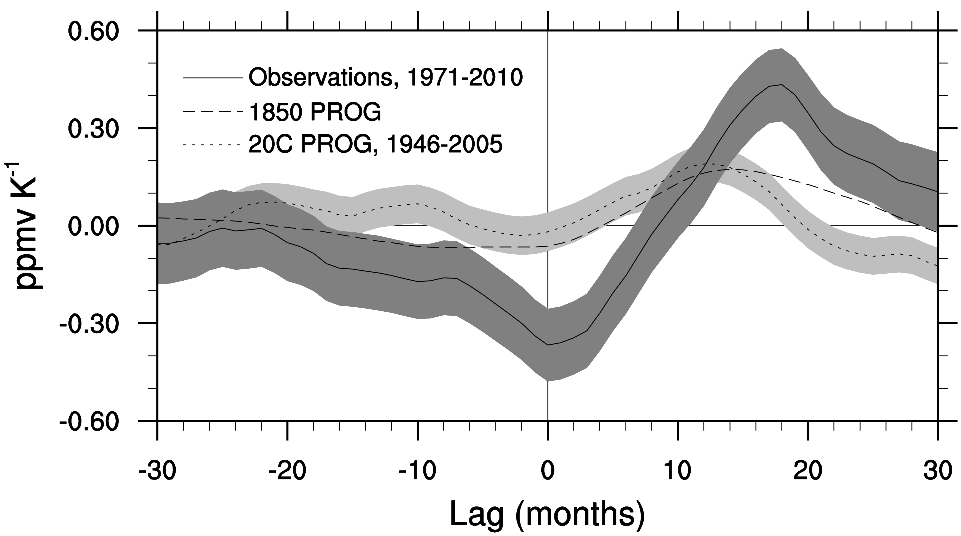
Lindsay et al., 2012, J Climate, submitted

CO_2 Response to ENSO

Mauna Loa, Hawaii

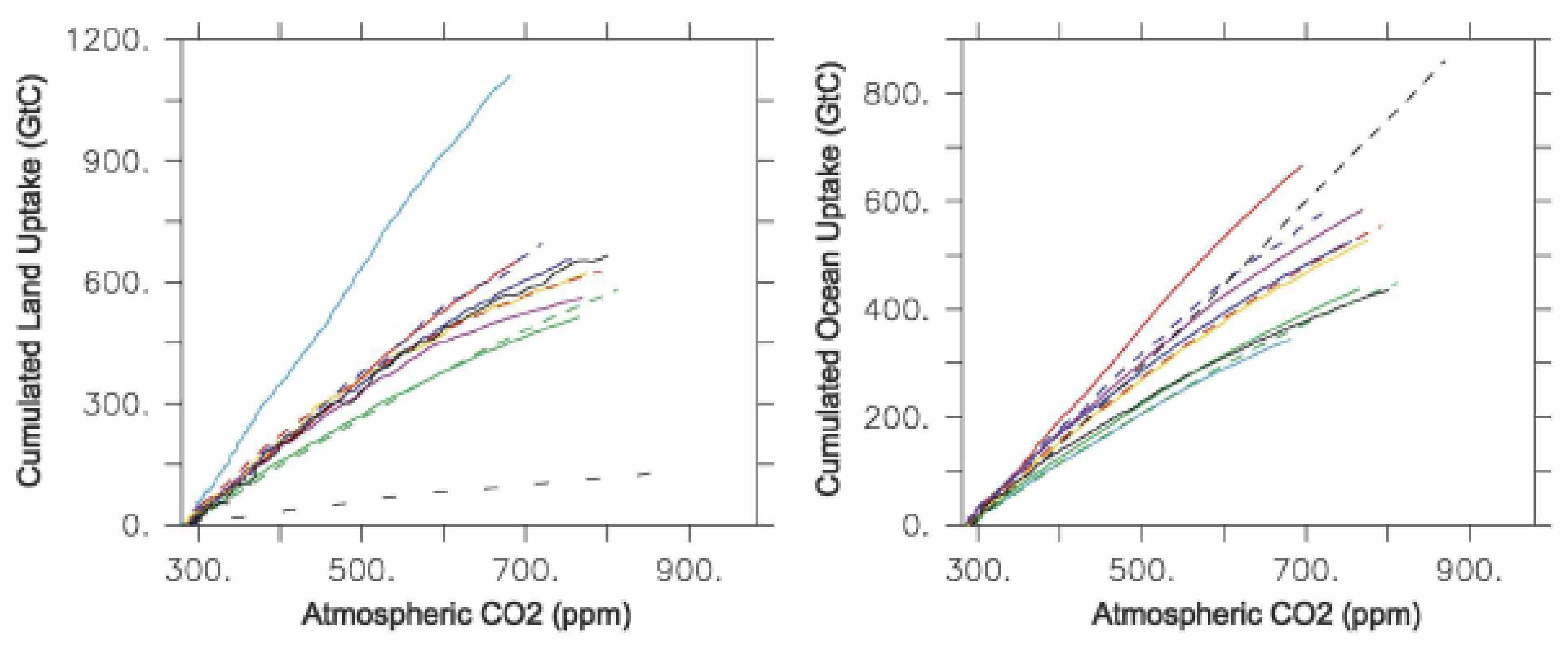


Point Barrow, Alaska



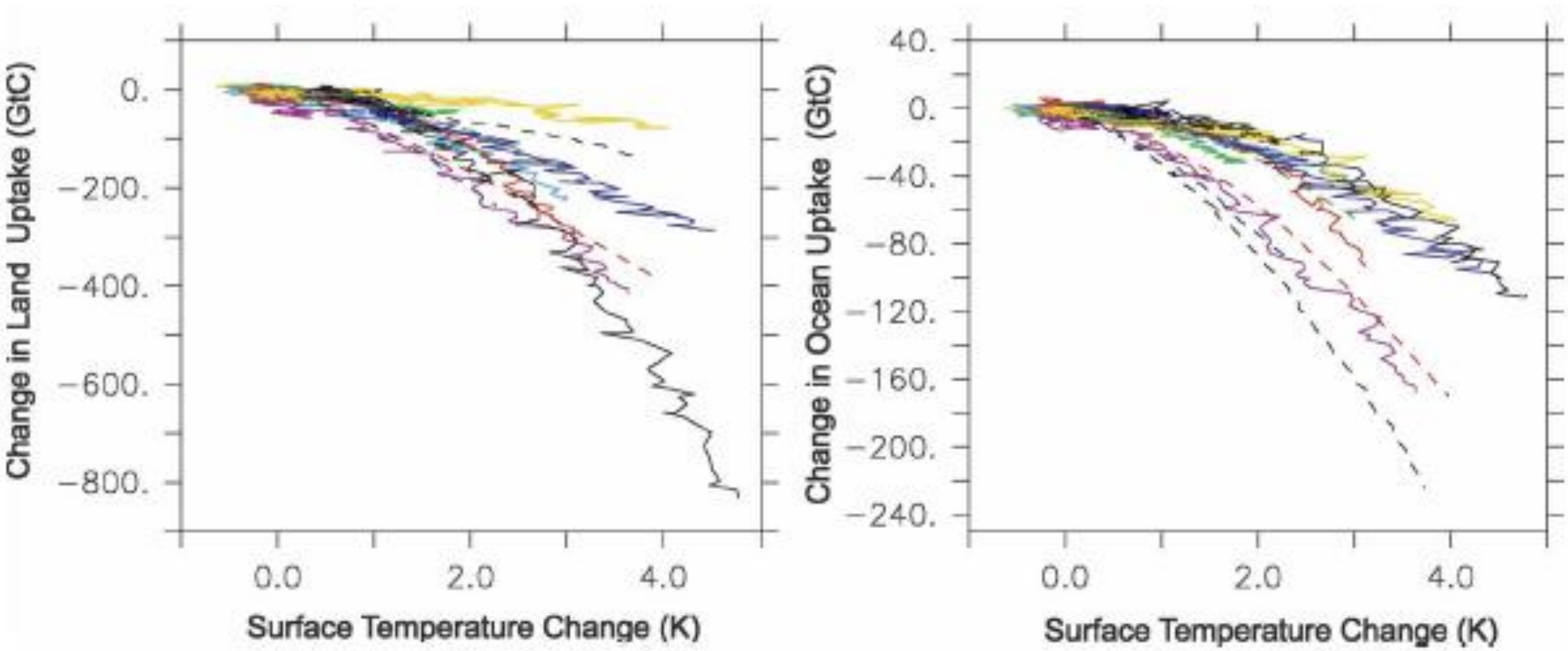
Lindsay et al., 2012, J Climate, submitted

Land & Ocean Uptake of Fossil Fuel Emissions



Friedlingstein et al, J. Climate, 2006

Impact of Climate Change on this Uptake



Friedlingstein et al, J. Climate, 2006

Summary

- Large scale ocean biogeochemical features are determined by handful of processes
- ‘Perfect’ ecosystem model doesn’t exist, many simplifications need to be made. Improving models is ongoing research. Scientific questions guide this process.

- Atmospheric CO_2 couples land and ocean carbon cycles, explaining some correlation. Climate variability does as well. Atmospheric CO_2 observations are valuable constraint on models.
- Land & ocean uptake of anthropogenic CO_2, particularly sensitivity to climate change is ongoing research. Modern models show considerable spread for land results.

- Practical Notes are available and will be presented in Land/BGC breakout