

Intro to Biogeochemical Modeling Ocean & Coupled

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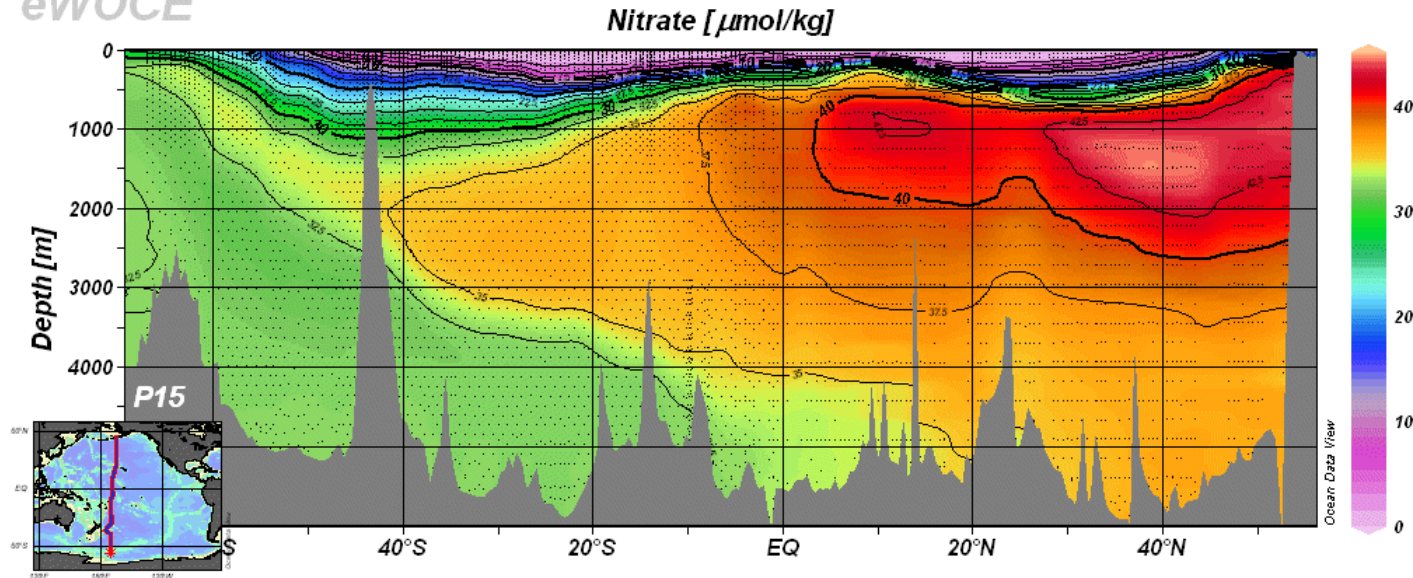


Lecture Outline

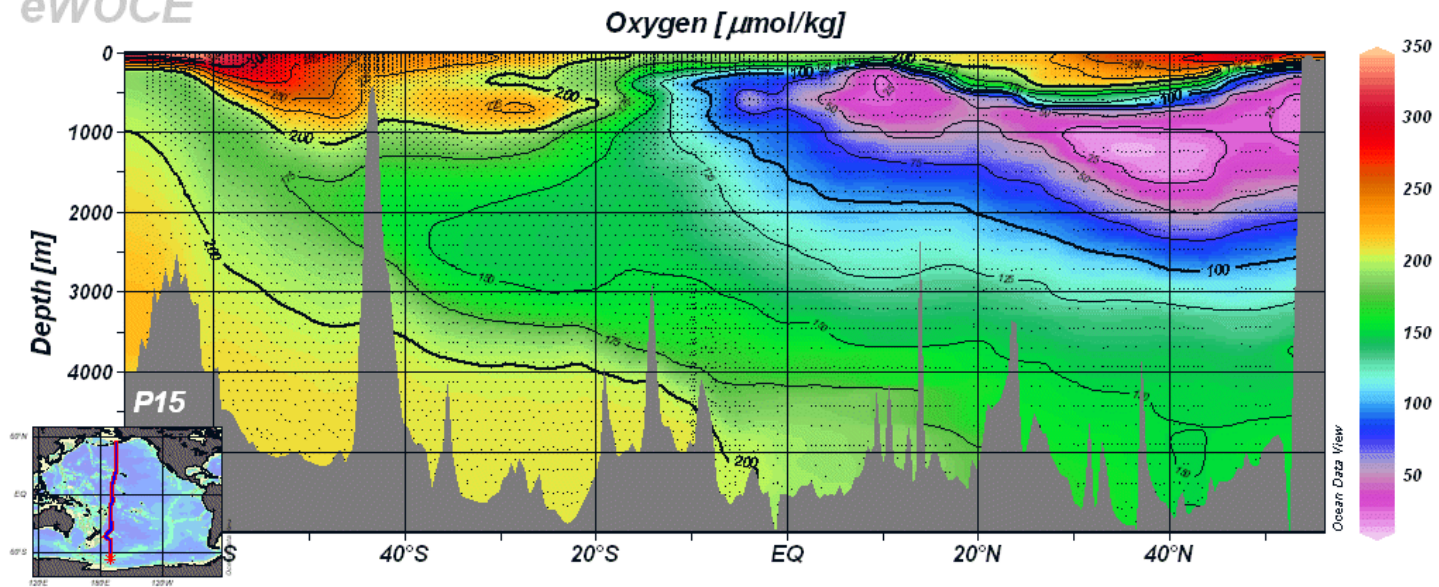
- 1) Large Scale Ocean Biogeochemical Features
- 2) Techniques for Modeling Biological Productivity
- 3) Skill Assessment
- 4) Global Carbon Cycle
- 5) Summary

NO₃ (a nutrient), O₂ (dissolved gas) Along Pacific Transect

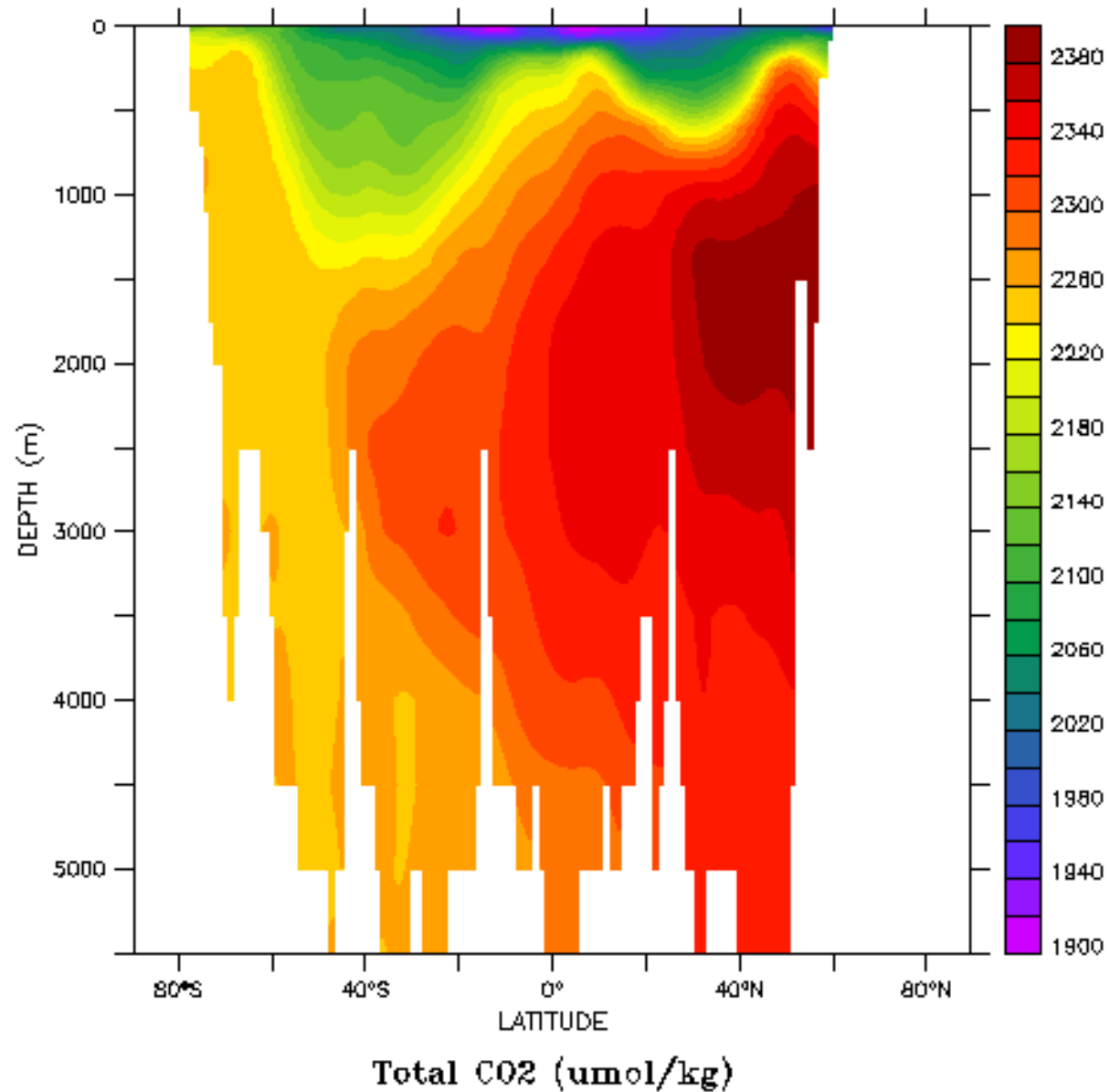
eWOCE



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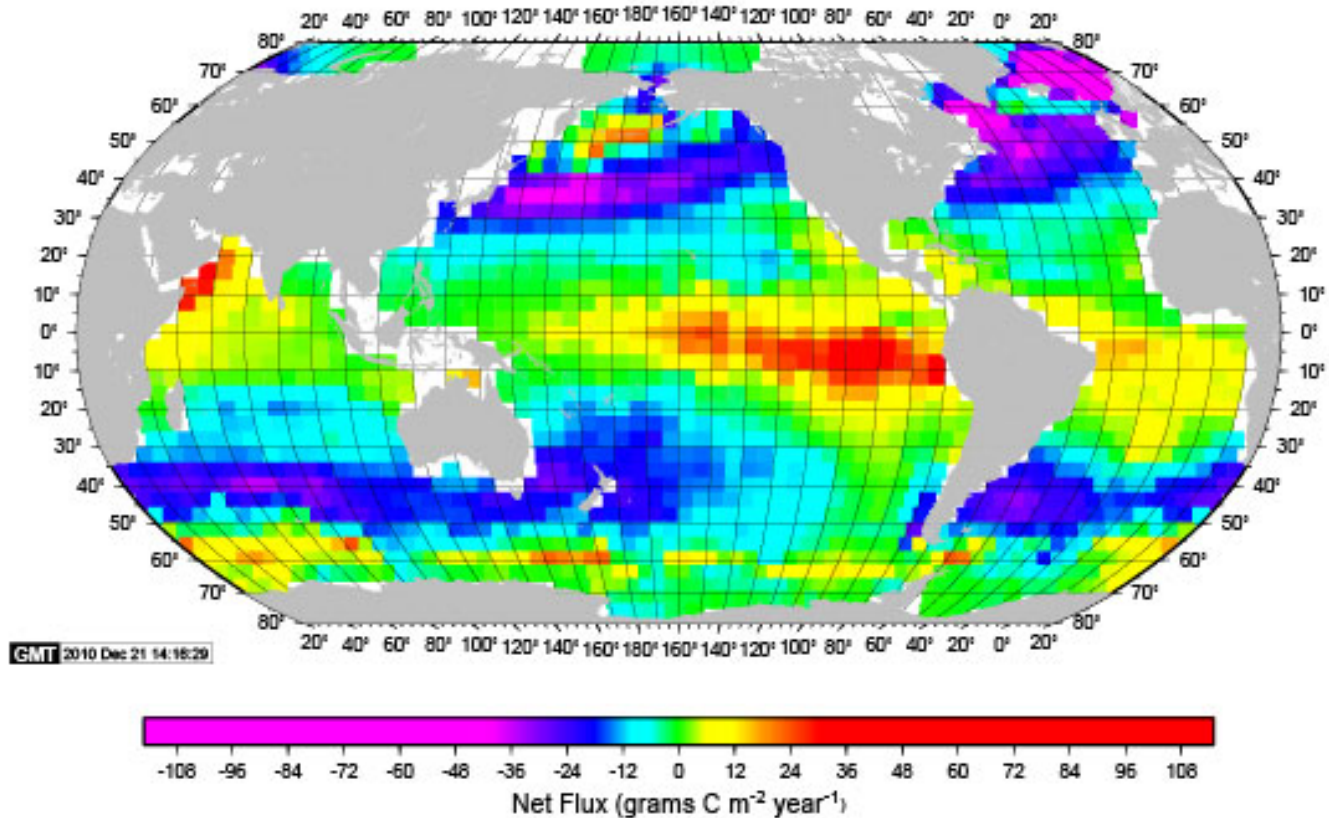


DIC ($\sim\text{CO}_2$) Along Same Pacific Transect



Takahashi Air-Sea CO₂ Gas Flux

Mean Annual Air-Sea Flux for 2000 [Rev Dec 10] (NCEP II Wind, 3,040K, $\Gamma=0.26$)



Primary Processes Governing Distribution of Nutrients, O₂, Carbon, etc.

- Biological Productivity in Euphotic Zone
 - Consumes Nutrients & Inorganic Carbon
 - Produces Organic Matter & O₂
- Export of Organic Matter out of Euphotic Zone
 - Sinking Particles (e.g. detritus, CaCO₃ shells, ...)
 - Circulation of Suspended Matter
- Remineralization of Organic Matter
 - ‘reverse’ of productivity, consumes O₂
- 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
- Nitrogen Fixation
 - Conversion of dissolved N_2 gas into NH_4
- Denitrification
 - Consumption of NO_3 during remineralization

Large Scale Ocean Carbon Cycle

- DIC
Diss. Inorganic C
- DOC
Diss. Organic C
- PIC
Part. Inorganic C
- POC
Part. Organic C

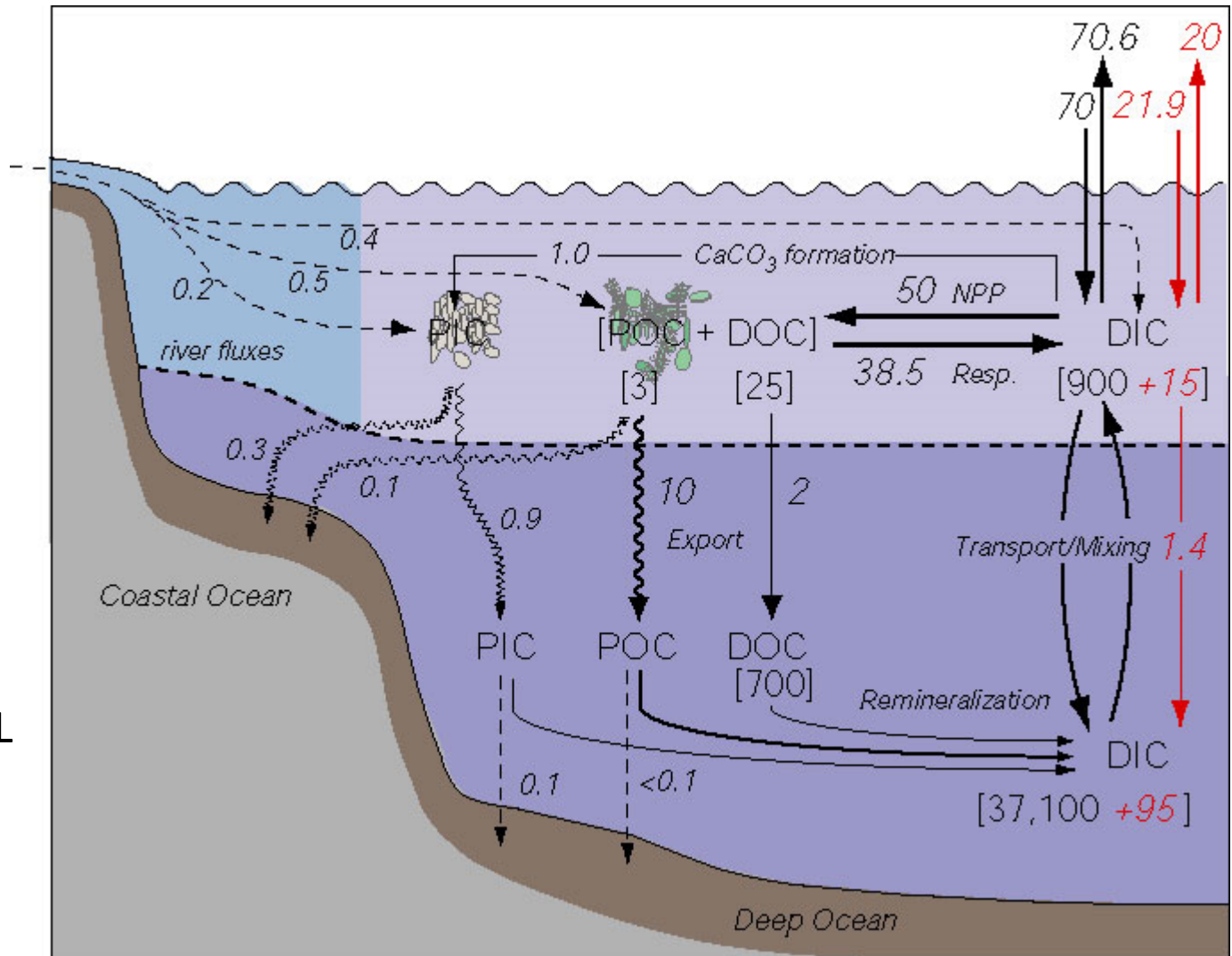


Figure courtesy PMEL

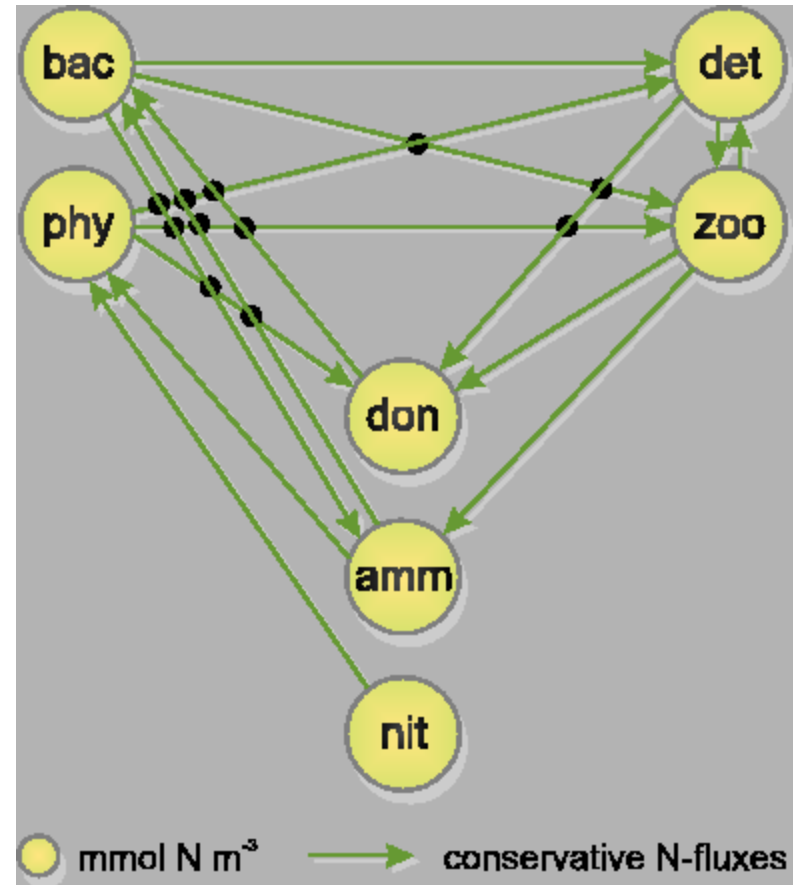
What is an NPZD model?

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

Canonical Example

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

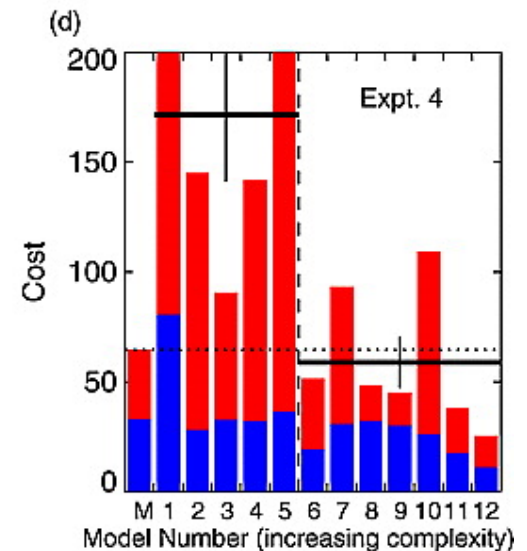
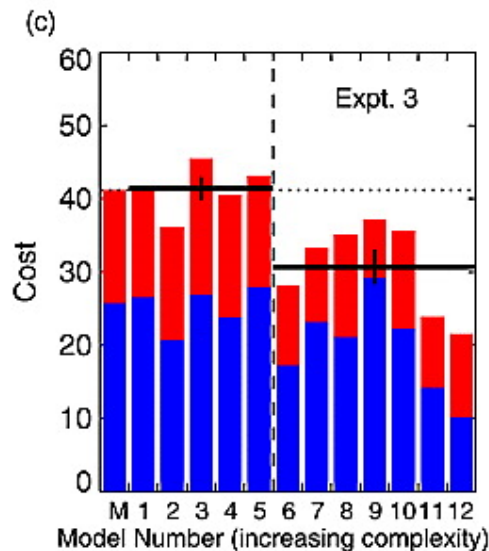
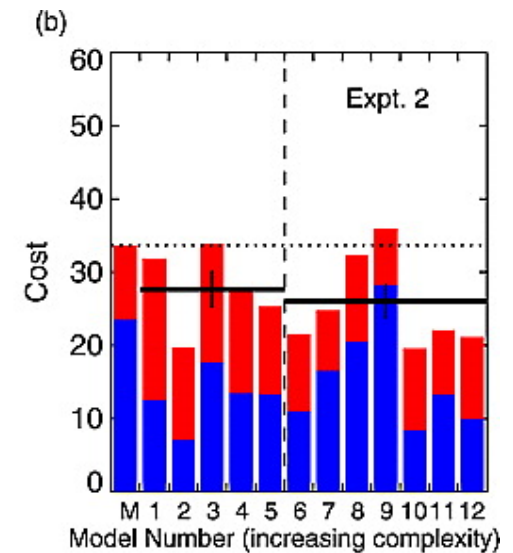
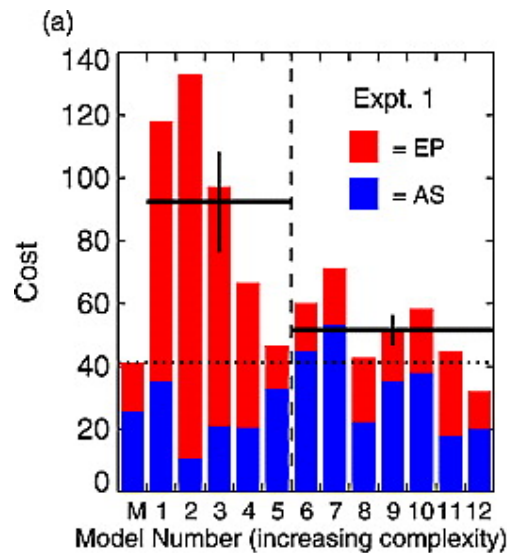
Skill & Portability in 12 Different NPZD models

Friedrichs et al., JGR-Oceans, 2007.

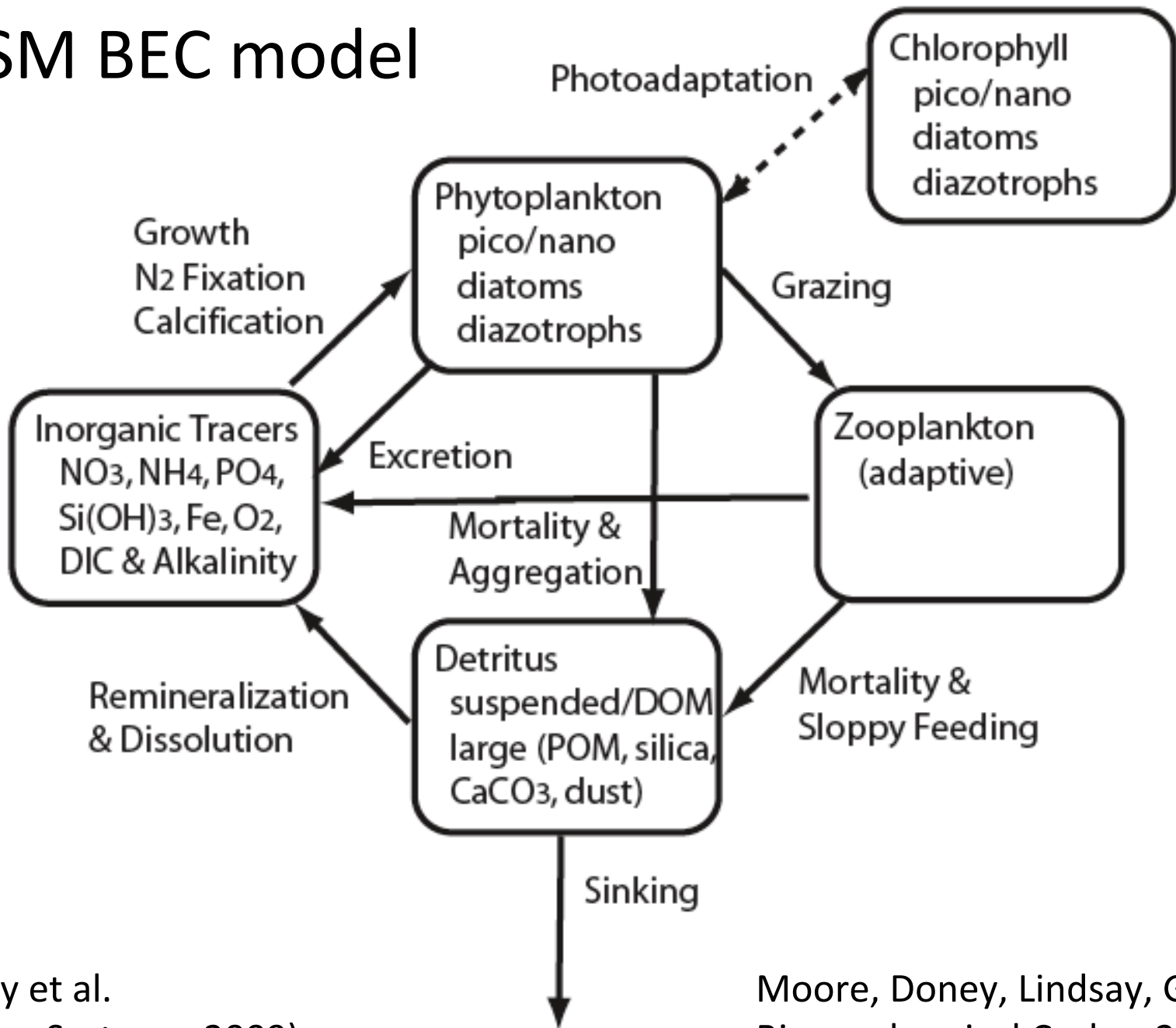
(b) Simple models do just as well as more complex models when tuned for specific sites.

(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 CESM1 BEC Model

- Nutrients: N, P, Si, Fe
- 4 Plankton Functional Groups
 - 3 Autotrophs, 1 Grazer
 - Implicit coccolithophores
 - 24 tracers in CESM 1.0, 1.1
 - 27 tracers in CESM 1.2
- Fixed C:N:P ratios in plankton
- Variable Fe:C, Si:C, Chl:C ratios

- Numerous enhancements introduced in CESM 1.2
 - Reduce excessively large OMZ bias

Known Gaps in Ocean BGC in CESM1-(BGC)

- Calcification & CaCO_3 remineralization rates are independent of CO_3 saturation state
- No riverine inputs of BGC tracers
 - Prescribed datasets introduced in 1.2
- No sediment model
 - Loss to sediments introduced in 1.2
- No treatment of BGC in sea-ice
- Focus in on lower trophic levels

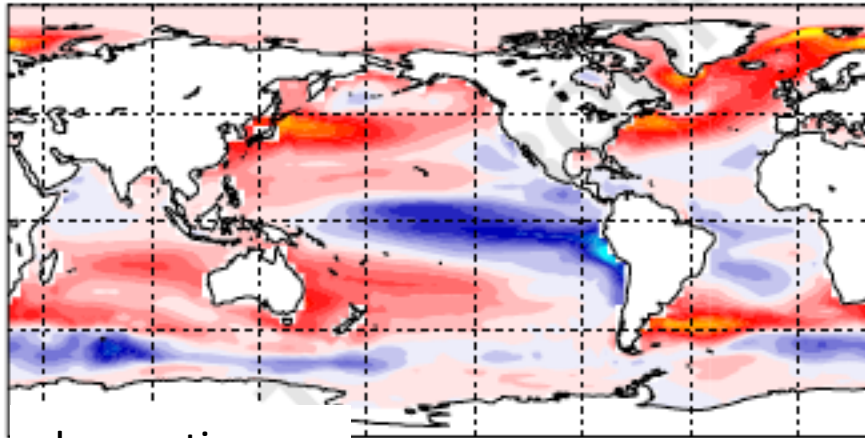
Model Validation: Examples of Data Sets

- 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 CO₂ Flux

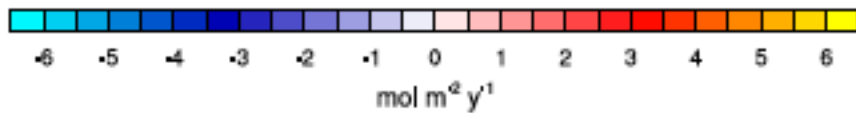
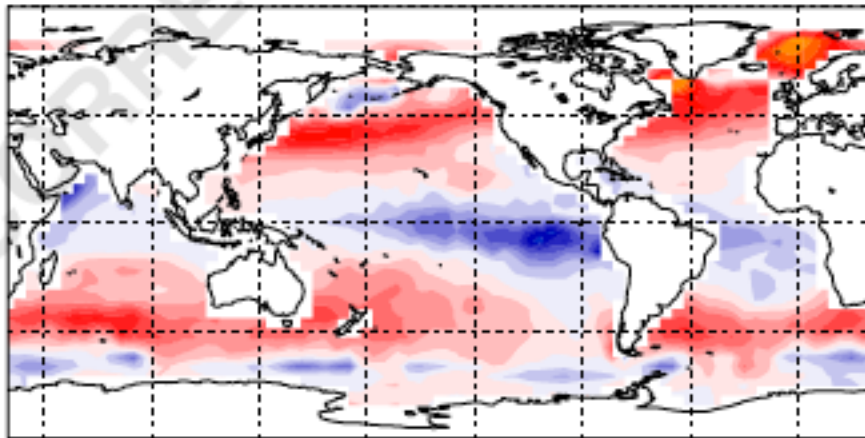
model

1996-2004 average

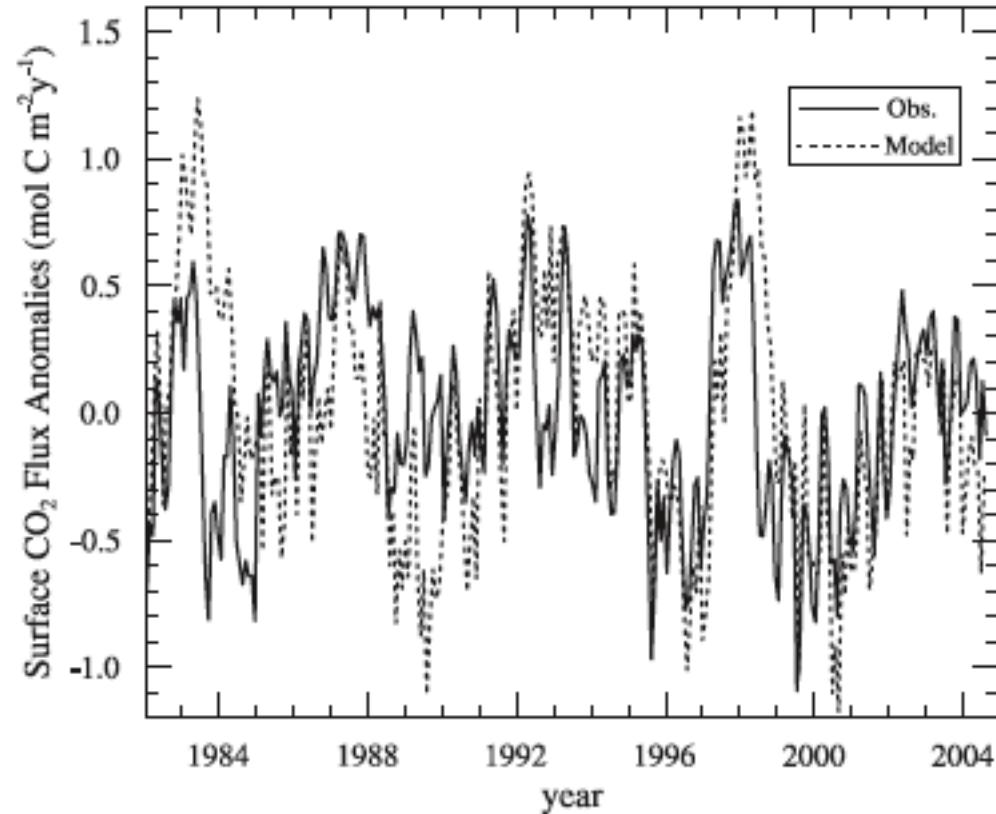


observations

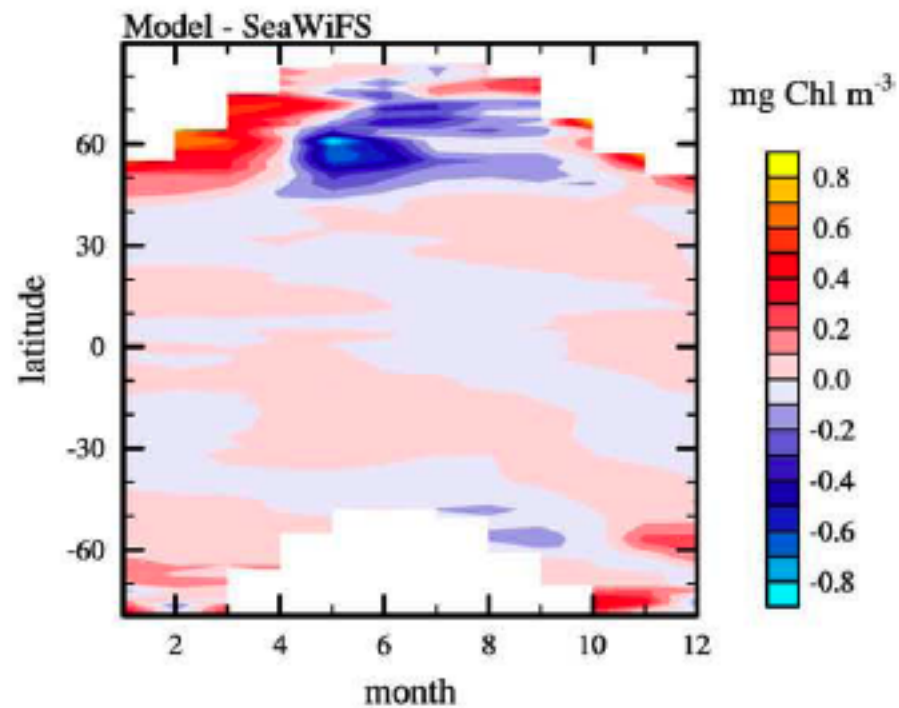
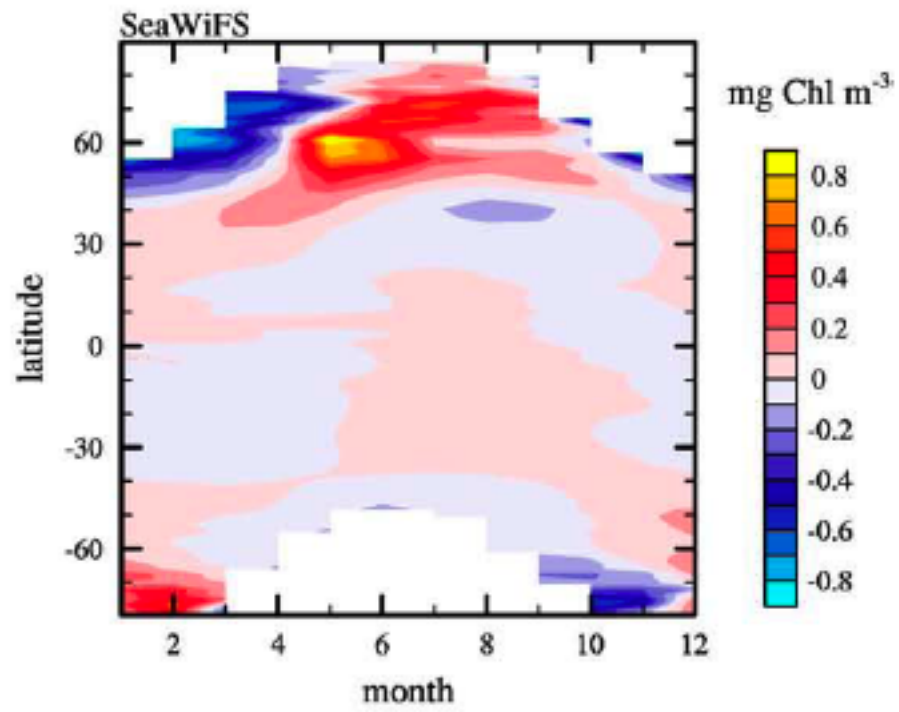
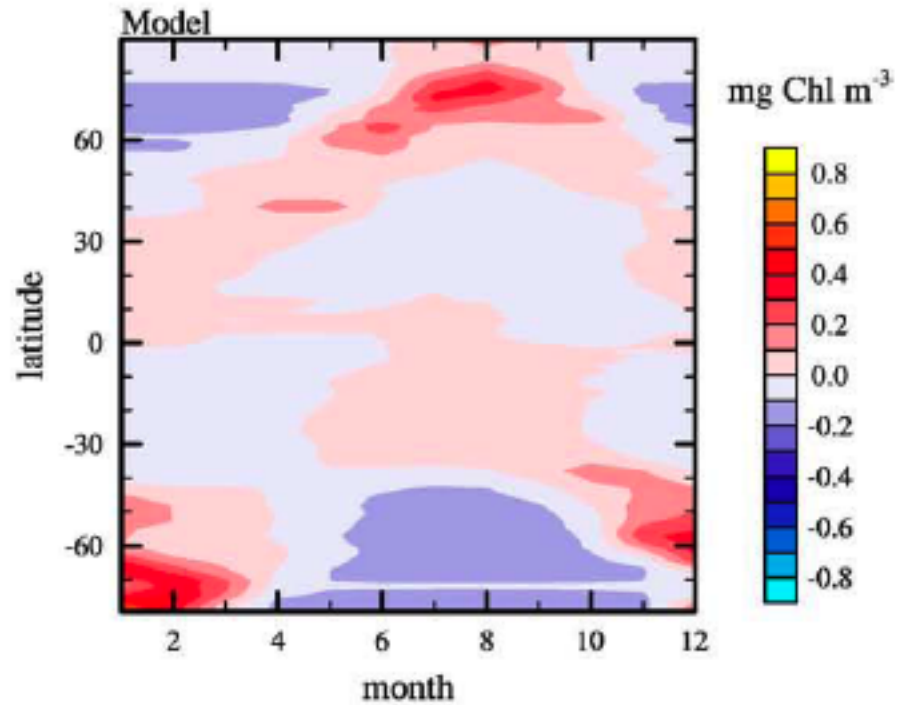
2000



Equatorial Pacific (165°E-270°E, 10°S-5°N)



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 millennial timescales
 - Using Newton-Krylov for this is a work in progress

Large Scale Global Carbon Cycle

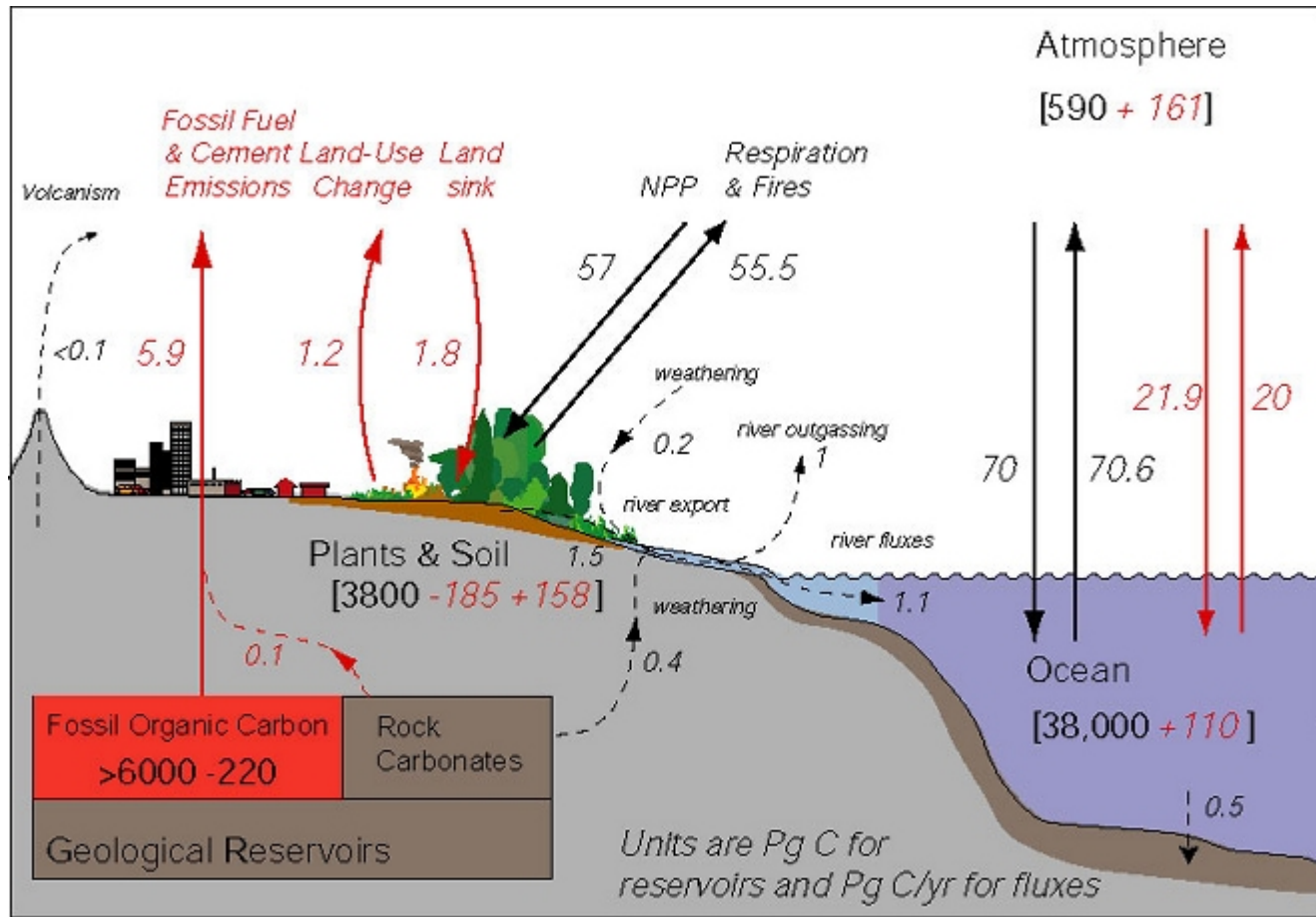
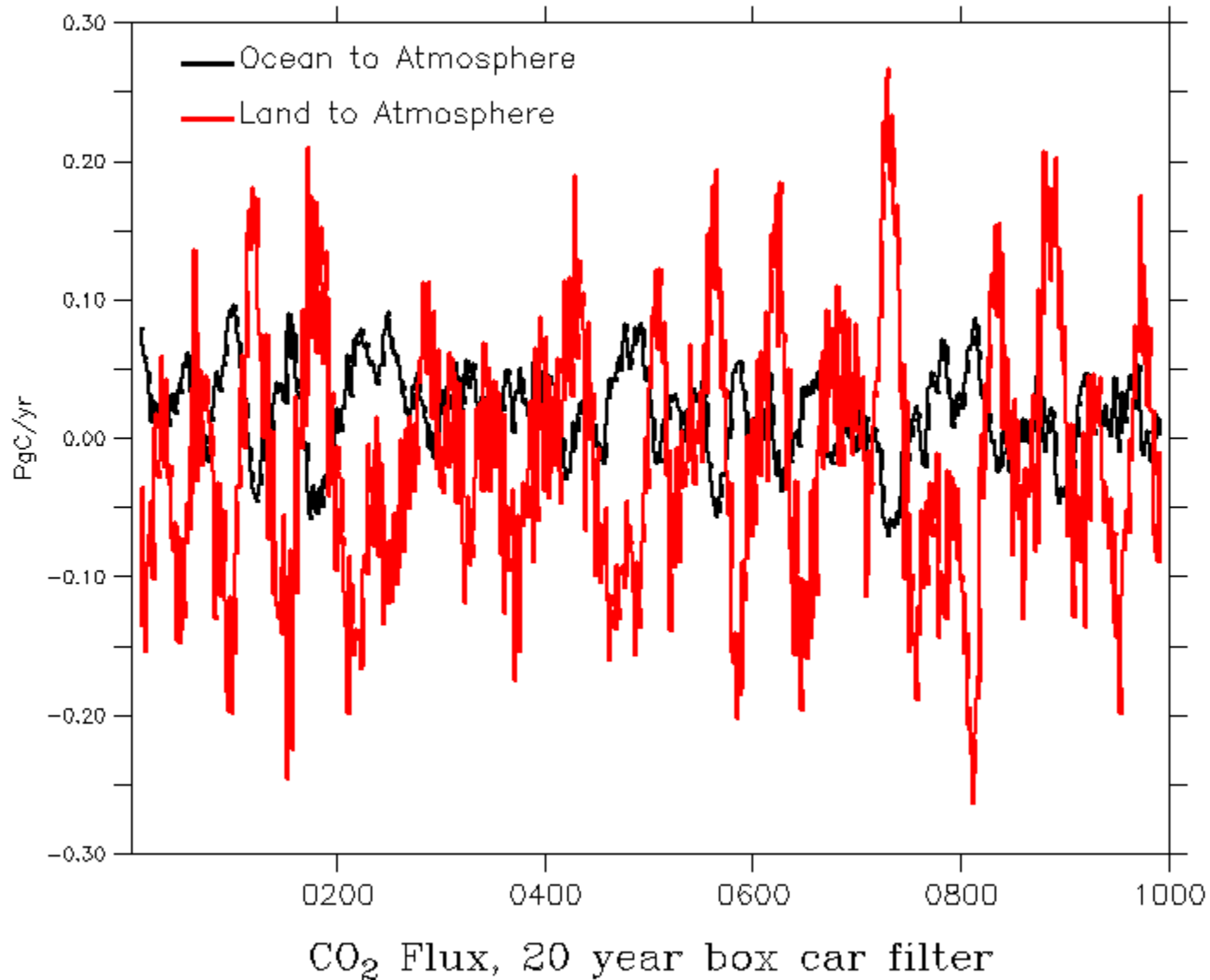
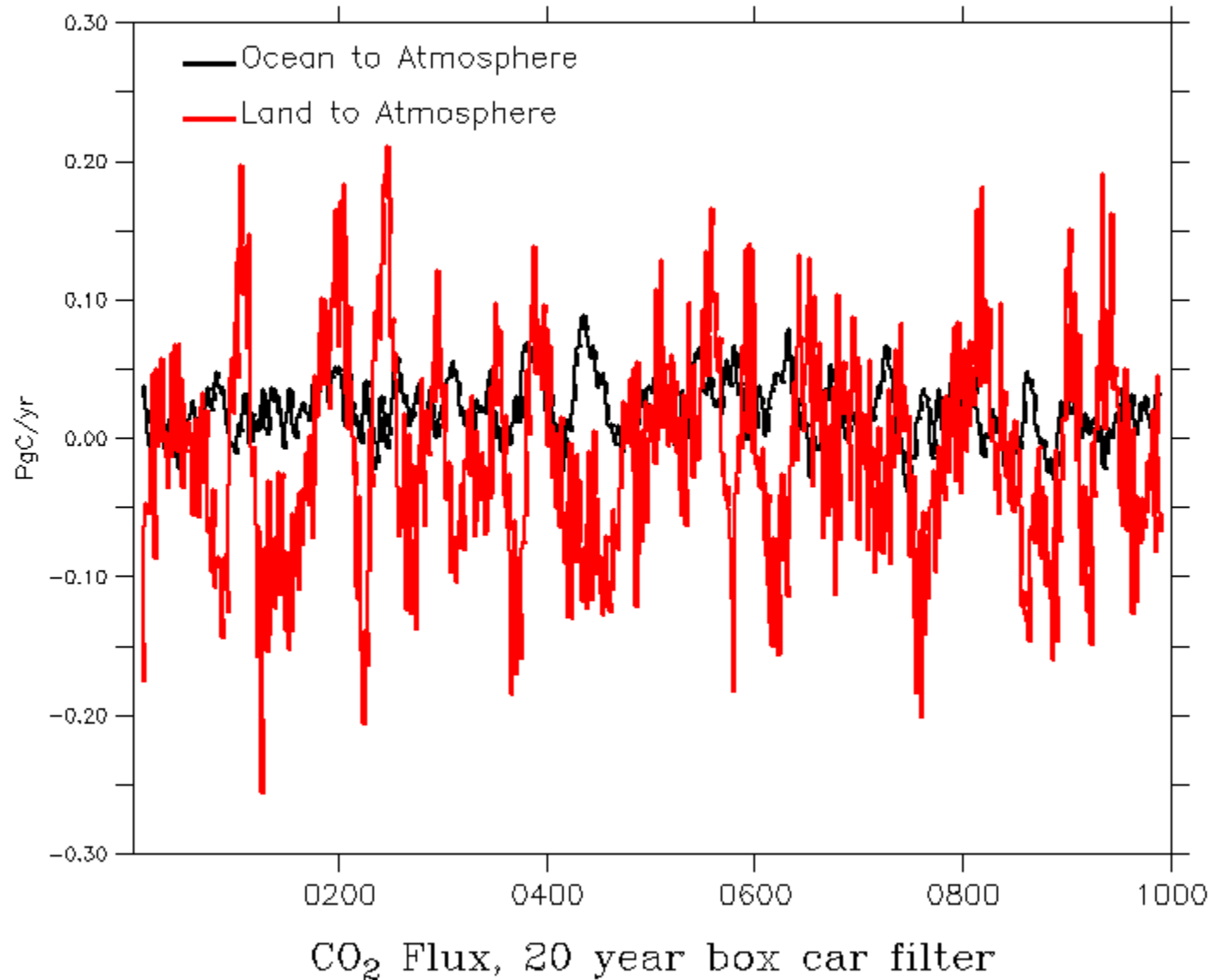


Figure courtesy PMEL

Land & Ocean CO₂ Fluxes from CESM1-BGC

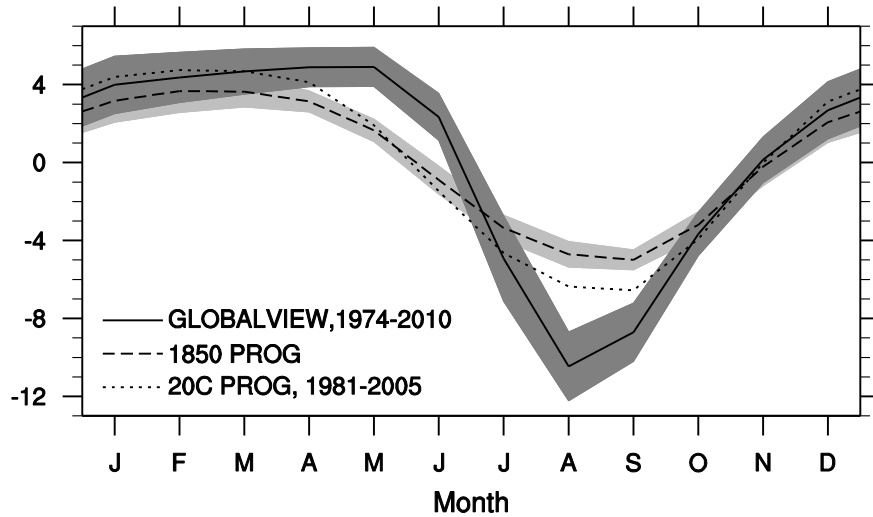


Same plot with Fixed ATM CO₂

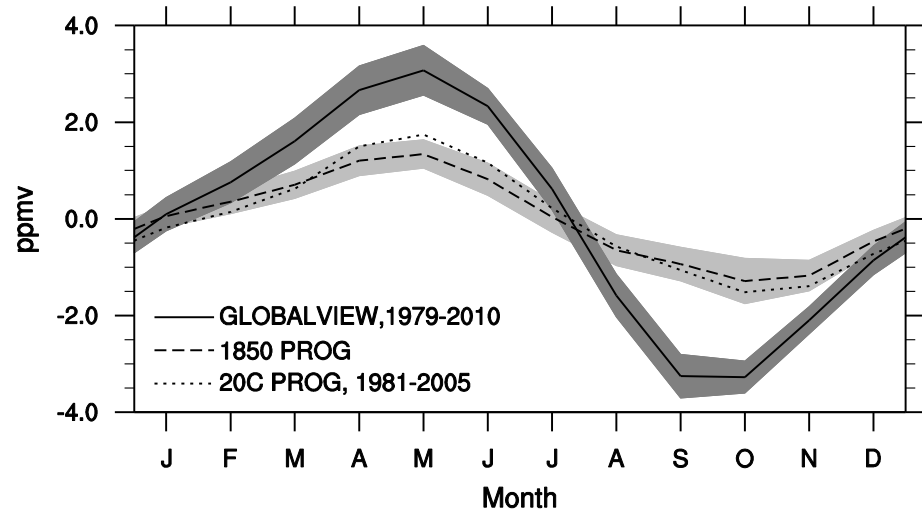


CO₂ Seasonal Cycle

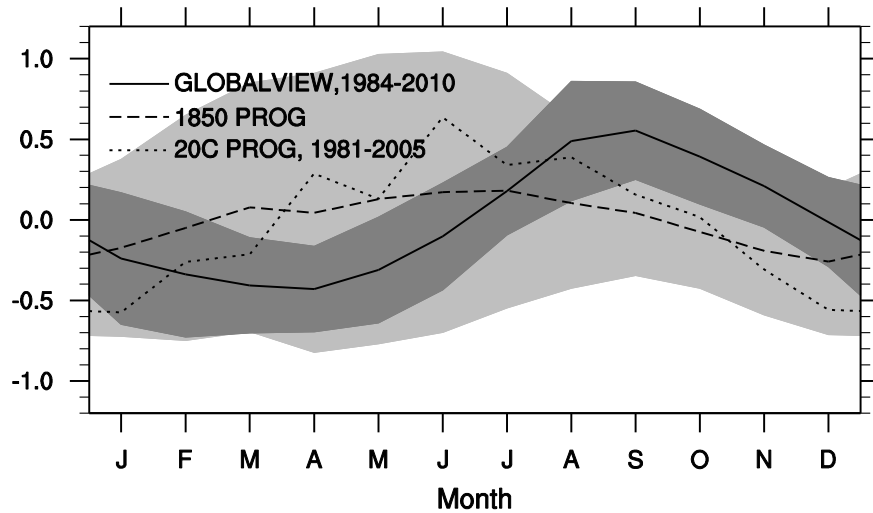
CO₂ Seasonal Cycle, Barrow



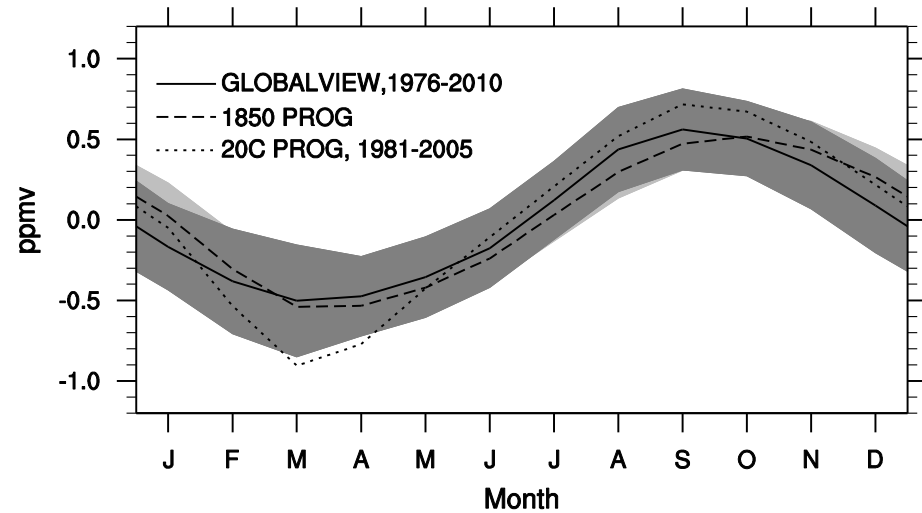
CO₂ Seasonal Cycle, Mauna Loa



CO₂ Seasonal Cycle, Cape Grim

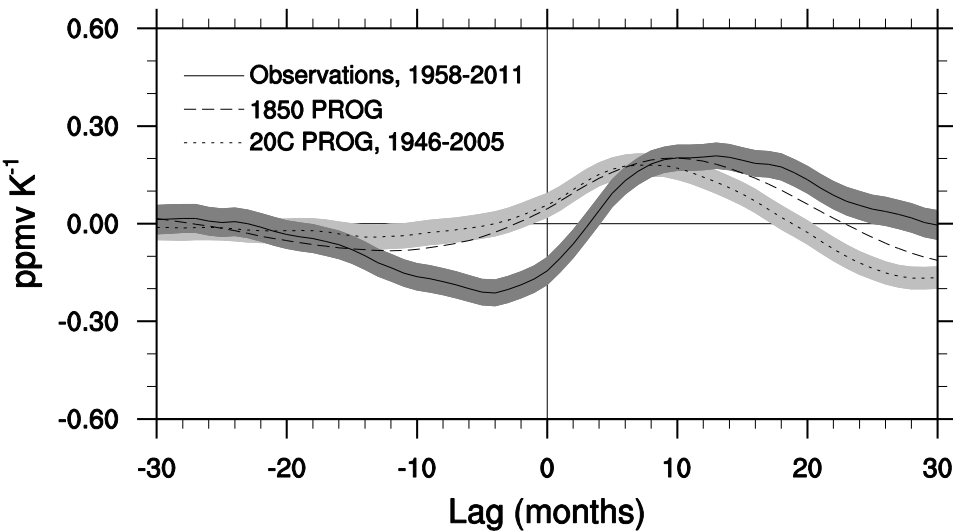


CO₂ Seasonal Cycle, South Pole

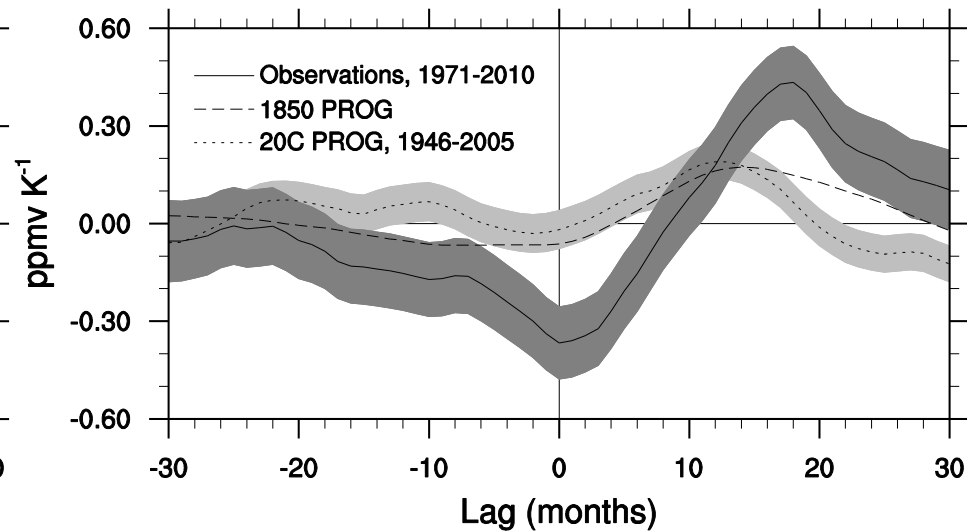


CO₂ Response to ENSO

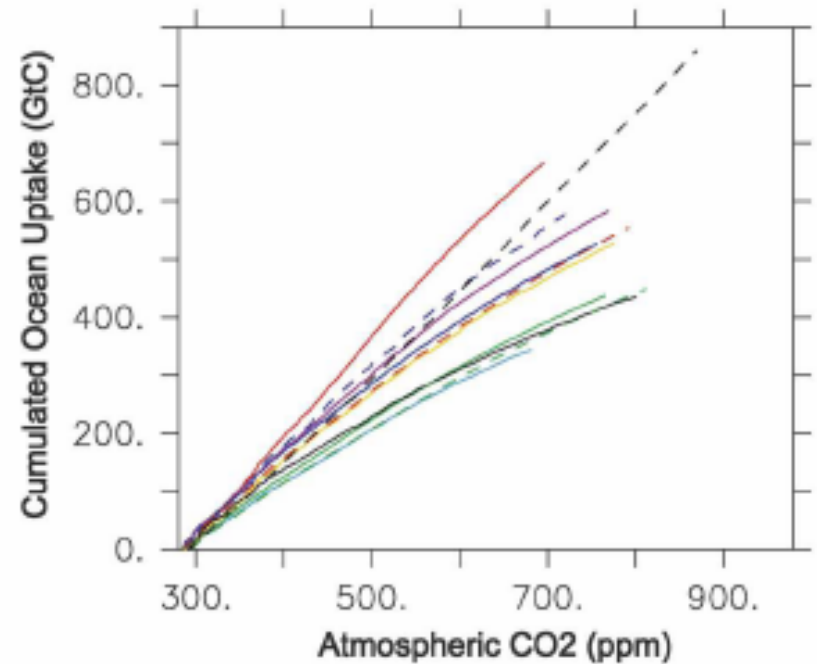
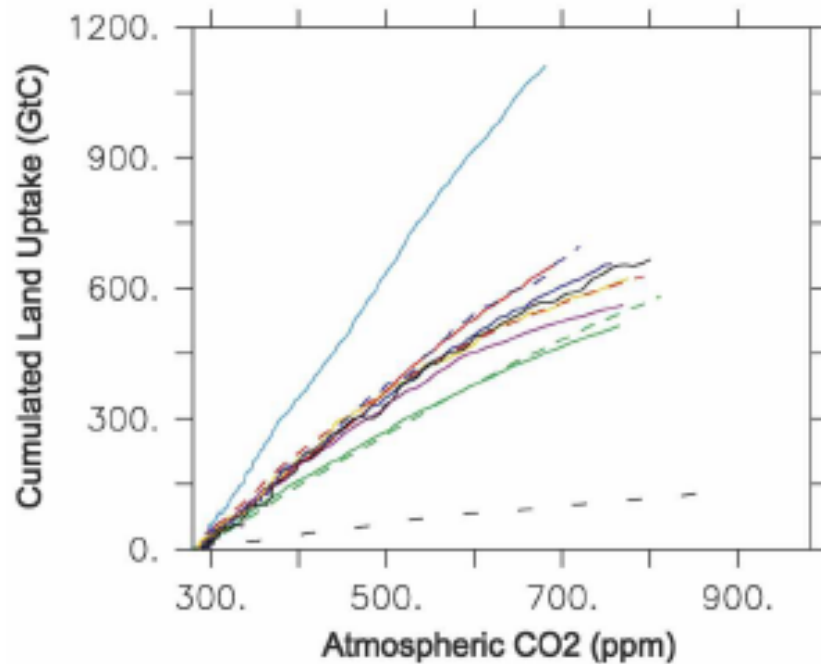
Mauna Loa, Hawaii



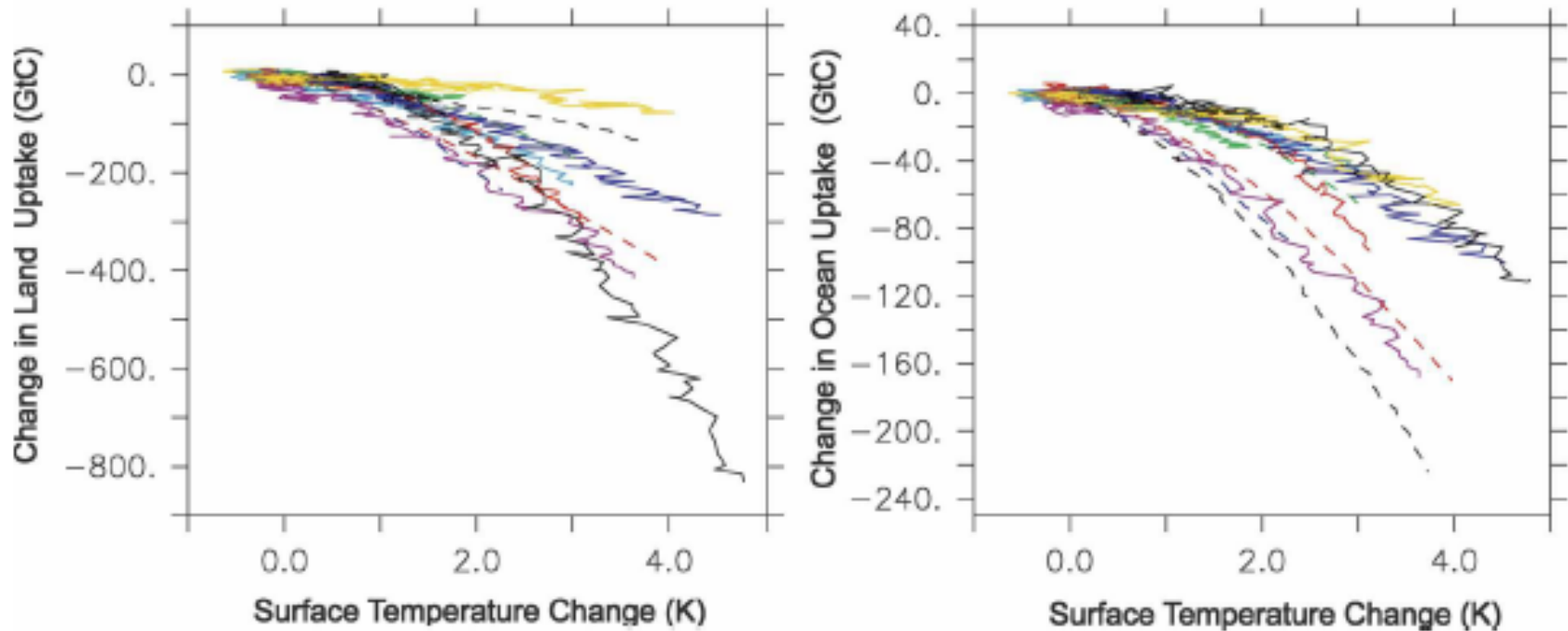
Point Barrow, Alaska



Land & Ocean Uptake of Fossil Fuel Emissions



Impact of Climate Change on this Uptake



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 CO₂ couples land and ocean carbon cycles, explaining some correlation. Climate variability does as well. Atmospheric CO₂ observations are valuable constraint on models.
- Land & ocean uptake of anthropogenic CO₂, 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