BioGeoChemical Coupling in the NASA-GISS Climate Model

Anastasia Romanou[1,2], Watson Gregg[3], Gavin Schmidt[2] and Rainer Bleck[1,2]

[1]Columbia U.

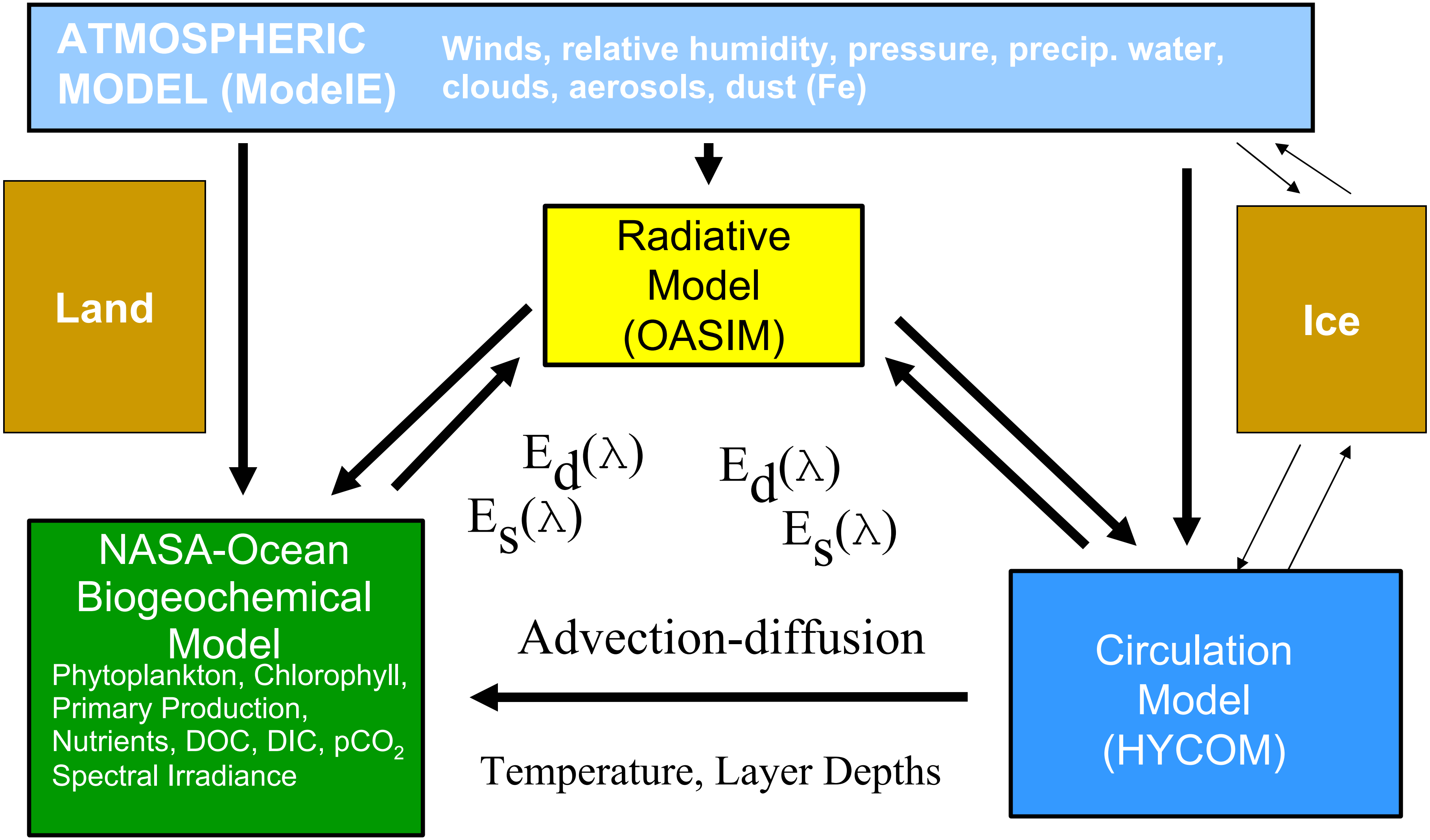
[2]NASA-GISS

[3]NASA-GSFC

Motivation-Objectives

- Resolve carbon cycle in the ocean
- Modeling the solubility, biological and carbonate pump in a climate system
- The role of coccolithophores in the carbonate pump (primary source of oceanic calcite)
- The role of light absorption by phytoplankton
- Climate change scenarios; natural vs anthropogenic sources

The NASA-GISS climate model



Model Description

AGCM: ModelE (*Schmidt et al, 2006*)

- 20layer, 4x5 degrees horizontal resolution
- full load of anthropogenic and natural aerosols
- greenhouse gases, volcanic activity, ozone, dust deposition

OGCM: HYCOM (*Bleck, 2002; Sun and Bleck, 2006*)

- 20 hybrid vertical coordinates
- 2x2cos(latitude) horiz grid & equatorial enhancement
- KPP mixing scheme
- bipolar grid patch
- ETOPO5 bottom topography

Model run specifications: 8 processors on an SGI Altix machine, run at NASA-GSFC computers, 2min/day(12hrs/model yr), MPI-OMP parallelization, ESMF capability available.

BioGeoChem Formulation

(Gregg et al, 2003; Gregg and Casey, 2007)

Nutrients

$$\frac{\partial C_{NO3}}{\partial t} = \nabla(K\nabla C_{NO3}) - \nabla \bullet \quad C_{NO3} - \underbrace{\frac{\Phi}{(C:N)}(\sum \mu_i P_i)}_{\text{chlorophyll growth}} + \underbrace{\frac{Ra_c D_c}{(C:N)}}_{\text{remineralization}}$$

$$\frac{\partial C_{NH4^+}}{\partial t} = \nabla(K\nabla C_{NH4^+}) - \nabla \bullet \quad C_{NH4^+} - \frac{\Phi}{(C:N)}(\sum \mu_i P_i) + \underbrace{\frac{\Phi}{(C:N)}\varepsilon(\gamma H + \eta_2 H^2)}_{\text{excretion}}$$

$$\frac{\partial C_{SiO2}}{\partial t} = \nabla(K\nabla C_{SiO2}) - \nabla \bullet \quad C_{SiO2} - \underbrace{\frac{\Phi}{(C:S_i)}\mu_1 P_1}_{\text{diatom growth}} + \underbrace{Ra_s D_s}_{\text{remineraliz.}}$$

$$\frac{\partial C_{Fe}}{\partial t} = \nabla(K\nabla DF) - \nabla \bullet \mathbf{V} C_{Fe} - \frac{\Phi}{(C:Fe)}\sum \mu_i P_i + \frac{\Phi}{(C:Fe)}\varepsilon(\gamma H + \eta_2 H_2) + Ra_{Fe} D_{Fe} + \underbrace{\frac{C_{Fe}^{atm}}{\delta h} + \theta C_{Fe}}_{\text{atmos. deposition and iron scavenging}}$$

….BGC formulation

Phytoplankton diatoms, chlorophytes, coccolith., cyanobact

$$\frac{\partial Pi}{\partial t} = \nabla(K\nabla P_i) - \nabla \bullet \mathrm{V} P_i - \nabla(w_{s_i} P_i) + \mu_i P_i - \gamma H - \kappa P_i$$

sinking — growth, grazing, aging

Herbivores

$$\frac{\partial H}{\partial t} = \nabla(K\nabla H) - \nabla \bullet \mathrm{V} H + (1-\varepsilon)\gamma \mathrm{H} - \eta_1 \mathrm{H} - \eta_2 \mathrm{H}^2 - \zeta \mathrm{H} - \Theta \mathrm{H}$$

heterotroph. loss rates — excretion to DOC and respiration

Detritus

$$\frac{\partial Dc}{\partial t} = \nabla(K\nabla Dc) - \nabla \bullet \mathrm{V} Dc - \nabla(w_{dc} Dc) - Ra_c Dc + \Phi(\kappa \sum P_i + \eta_1 H) + \Phi(1-\varepsilon)\eta_2 \mathrm{H}^2$$

phyto aging and zoo loss

$$\frac{\partial Ds}{\partial t} = \nabla(K\nabla Ds) - \nabla \bullet \mathrm{V} Ds - \nabla(w_{ds} Ds) - Ra_s Ds + \frac{\Phi}{(C:Si)}(\kappa P_1 + \gamma H)$$

$$\frac{\partial D_{\mathrm{Fe}}}{\partial t} = \nabla(K\nabla D_{\mathrm{Fe}}) - \nabla \bullet \mathrm{V} D_{\mathrm{Fe}} - \nabla(w_{d_{Fe}} D_{\mathrm{Fe}}) - Ra_{\mathrm{Fe}} D_{\mathrm{Fe}} + \frac{\Phi}{(C:Fe)}(\kappa \sum P_i + n_1 H) + \frac{\Phi}{(C:Fe)}(1-\varepsilon)\eta_2 \mathrm{H}^2 + \theta \mathrm{N}_{\mathrm{Fe}}$$

…more BGC formulation

Dissolved Organic Carbon

$$\frac{\partial \mathrm{DOC}}{\partial t} = \nabla(K\nabla \mathrm{DOC}) - \nabla \bullet \mathbf{V}\mathrm{DOC} + \underbrace{\Phi\delta\sum \mu_i P_i + \Phi\zeta H}_{\text{DOC exudation and herbiv. excretion}} + \underbrace{\lambda_D Dc - \phi \mathrm{DOC}}_{\text{detrital breakdown and bacterial degradation}}$$

DOC exudation and
herbiv. excretion

detrital breakdown and
bacterial degradation

Dissolved Inorganic Carbon

$$\frac{\partial \mathrm{DIC}}{\partial t} = \nabla(K\nabla \mathrm{DIC}) - \nabla \bullet \mathbf{V}\mathrm{DIC} - \Phi\sum \mu_i P_i$$

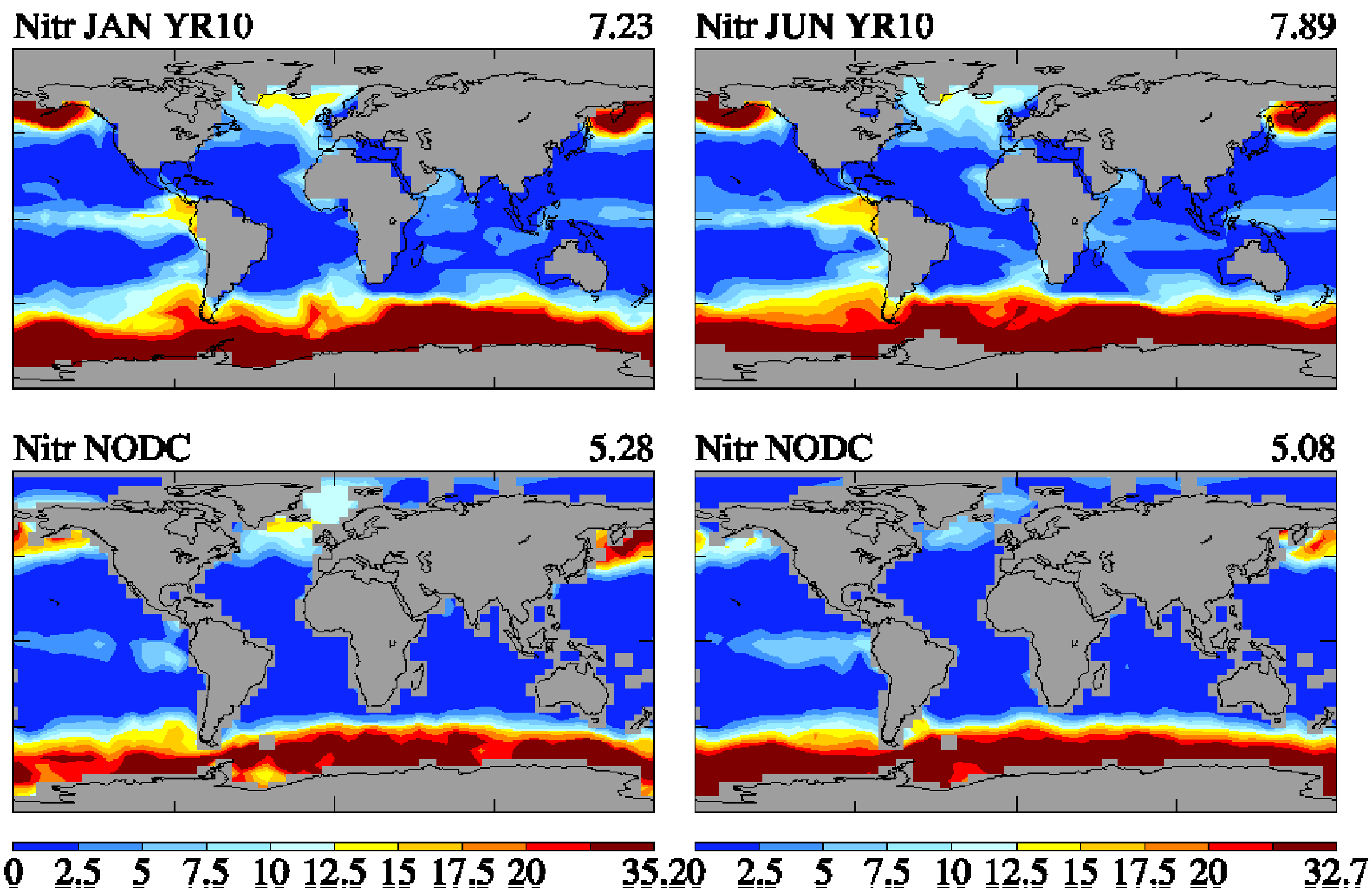
$$+ \underbrace{\Phi\Omega\sum \mu_i P_i + \Phi\Theta H}_{\text{phyto and herbiv. respiration}} + \underbrace{\phi \mathrm{DOC}}_{\text{bacterial degradation}} + \frac{R a_N Dc}{(C:N)} + \underbrace{\mathrm{Atm}CO_2}_{\text{Atmosph – oceanic equilibration}}$$

phyto and herbiv. respiration

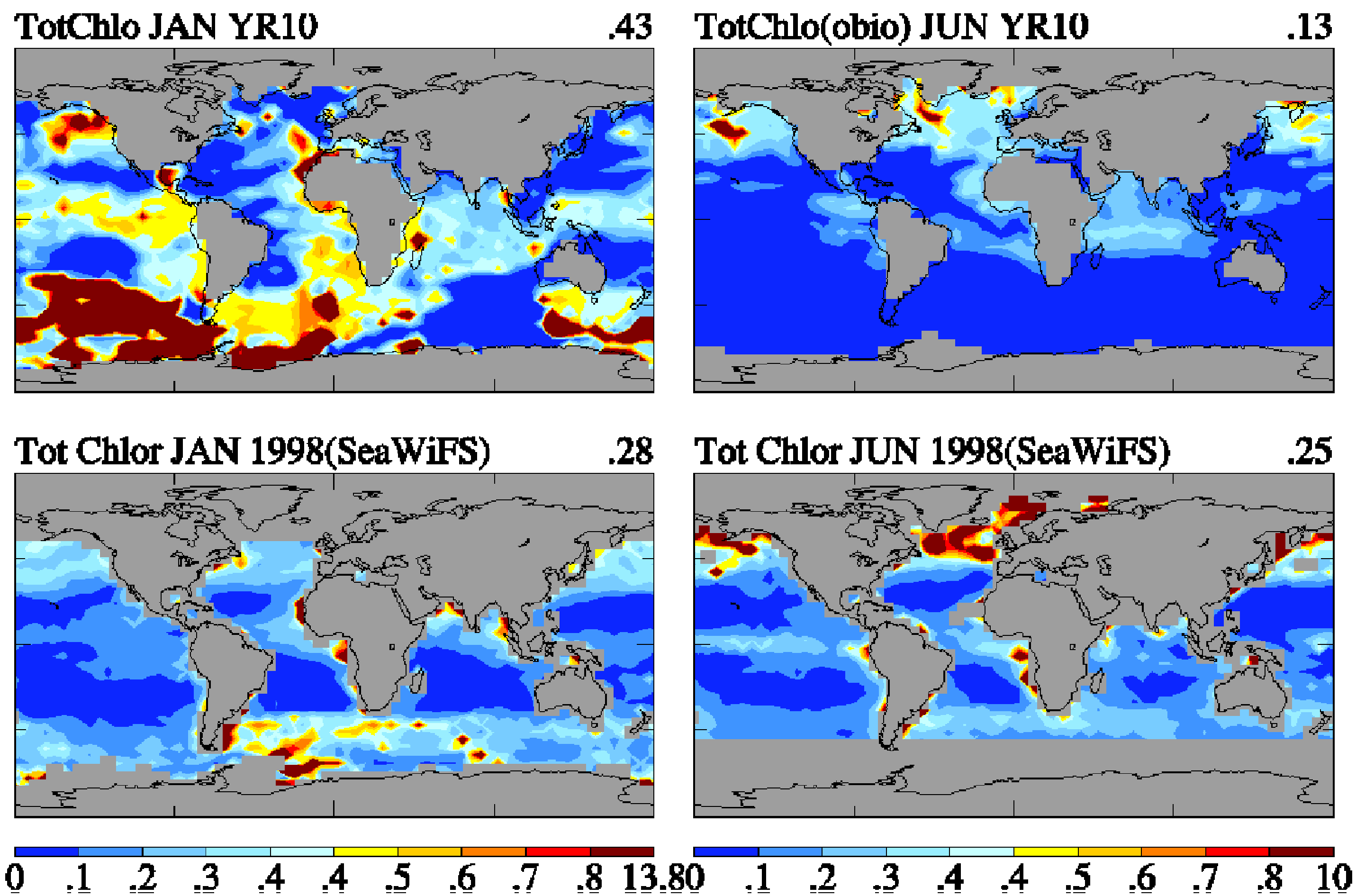
bacterial degradation

Atmosph – oceanic equilibration
solubility pump (depends on
SST, SSS, winds, alkalinity)

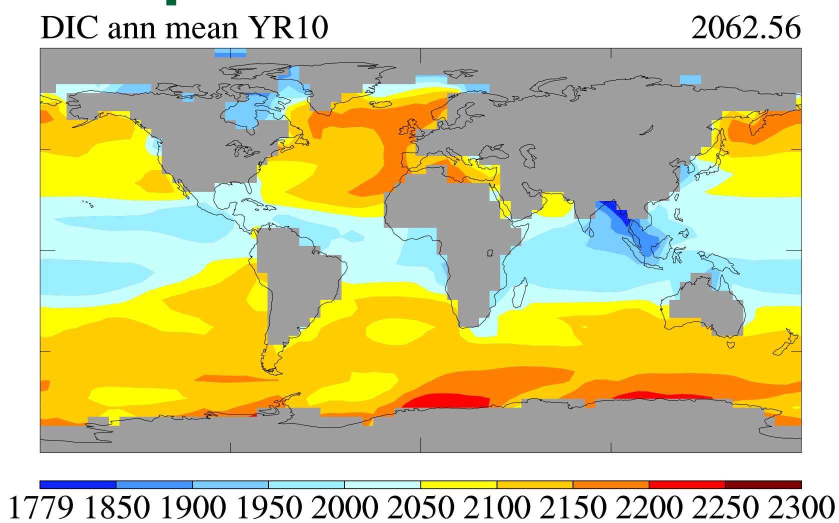
Control Experiment

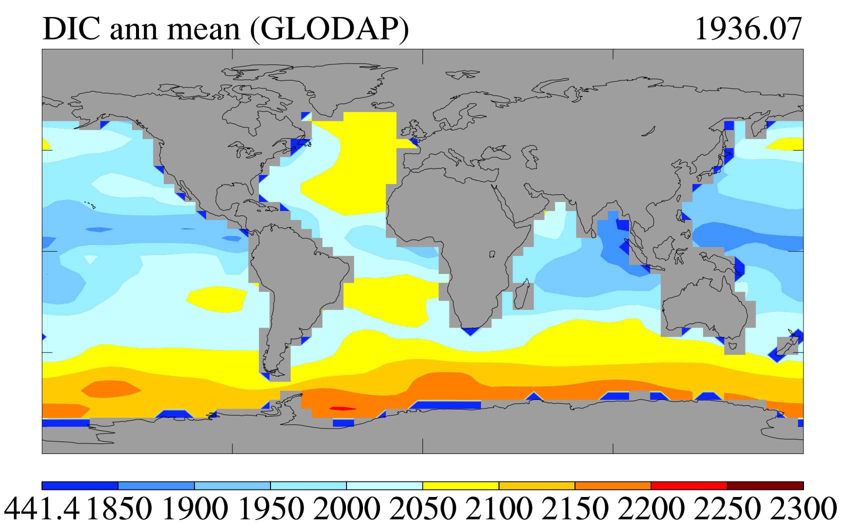


…Control expt

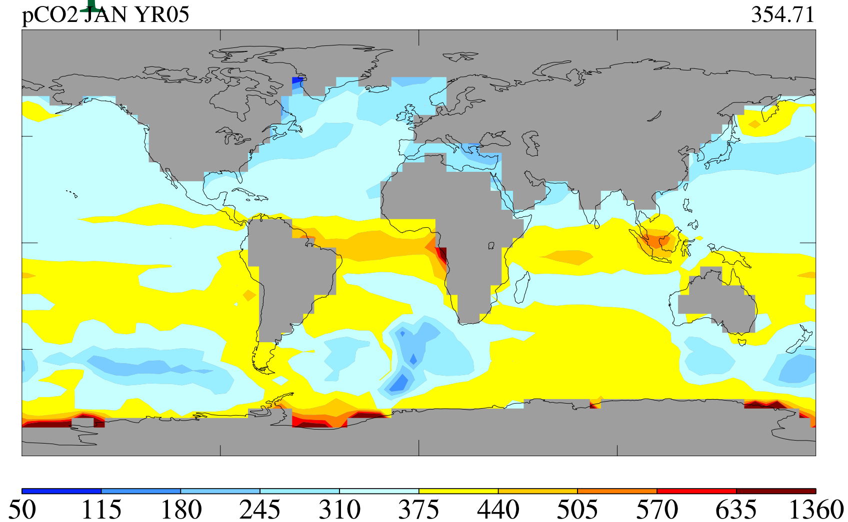


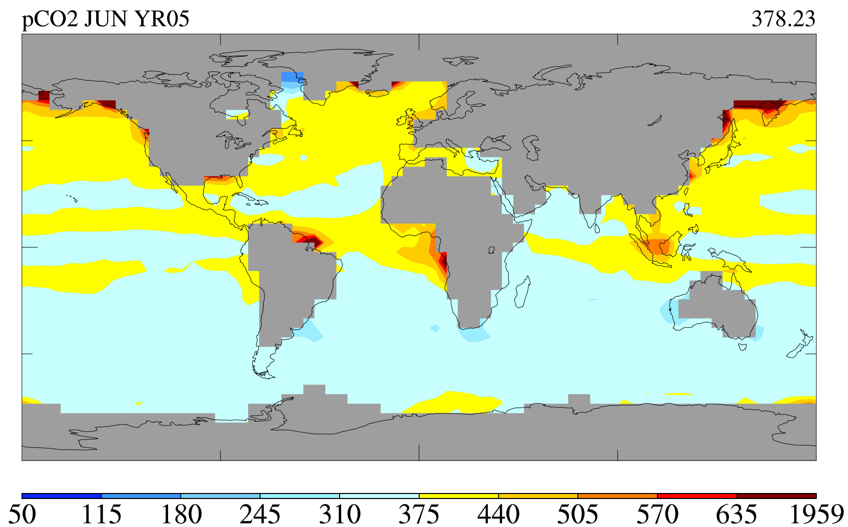
Control Experiment



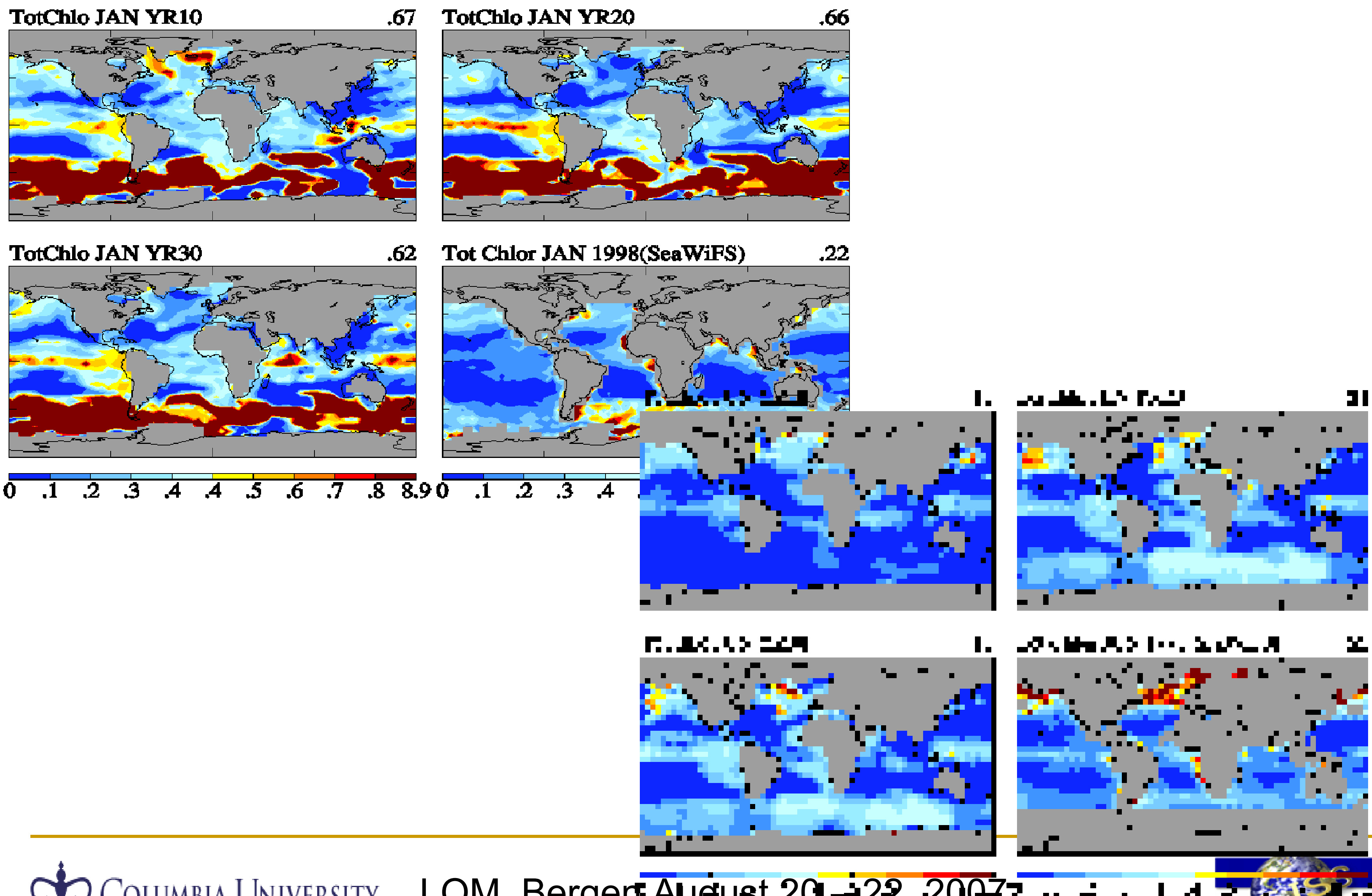


…control expt



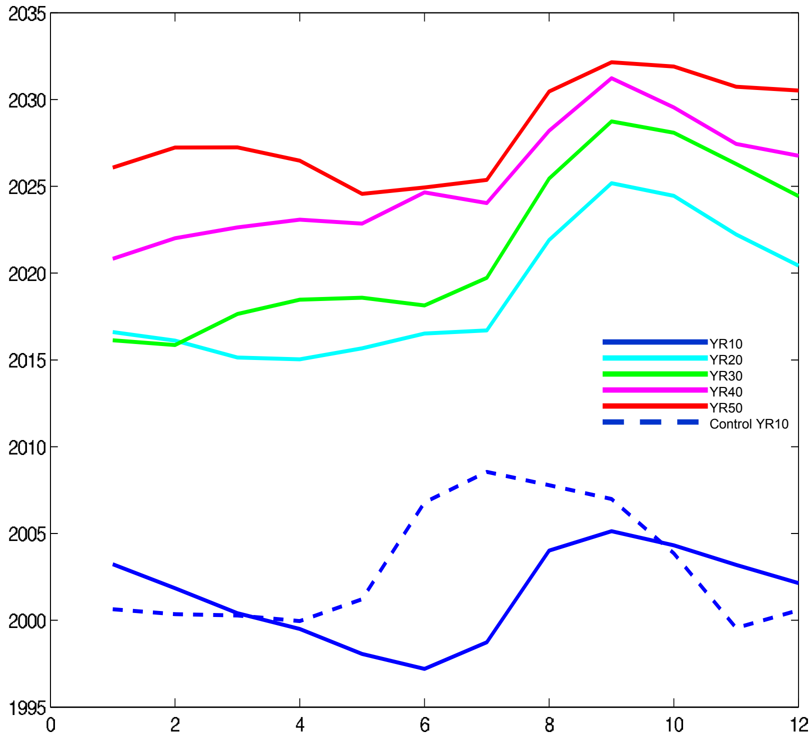


…iron fertilization expt

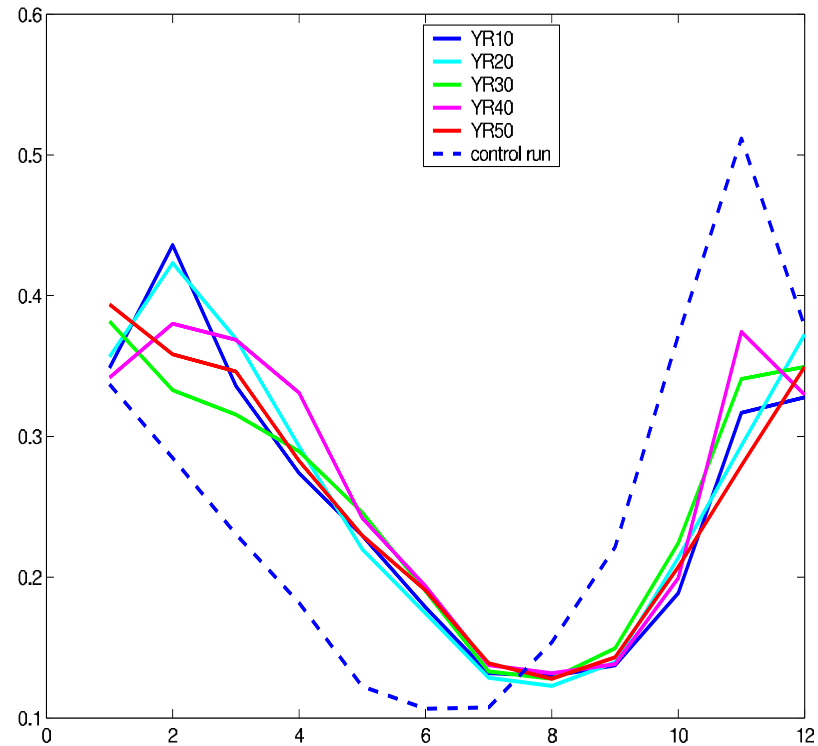


Seasonal Cycle in the Tropics

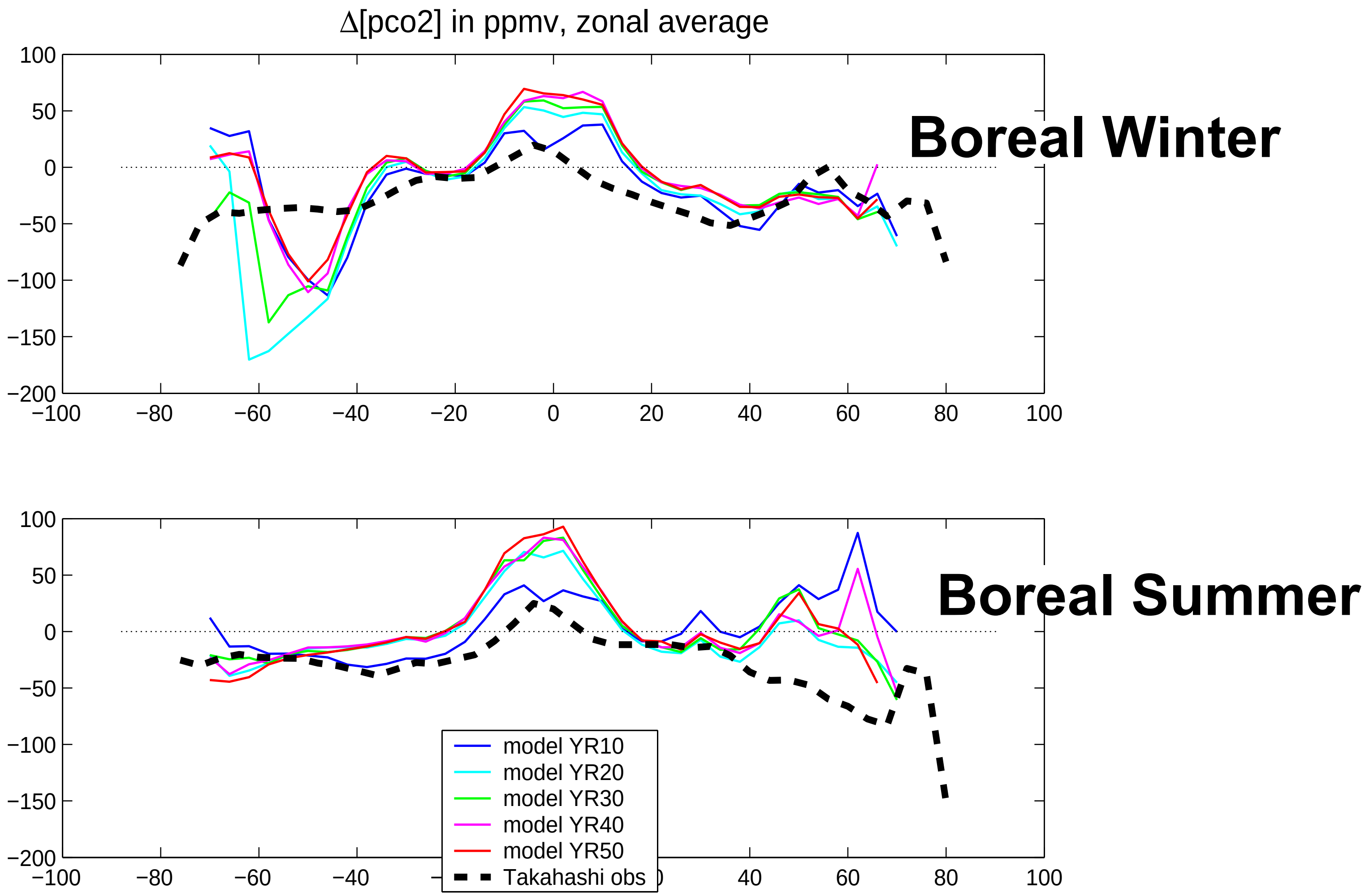
DIC – contrl & iron fertiliz run



Total Chlorophyll



Gas Exchange



Results

- Control expt
  - total chlorophyll (mostly diatoms in the Southrn Ocean, on the Pacific side) too high
  - Tropical chlorophyll is too high in the winter but low in the summer
  - DIC is increased everywhere, particularly in the subtropical gyres

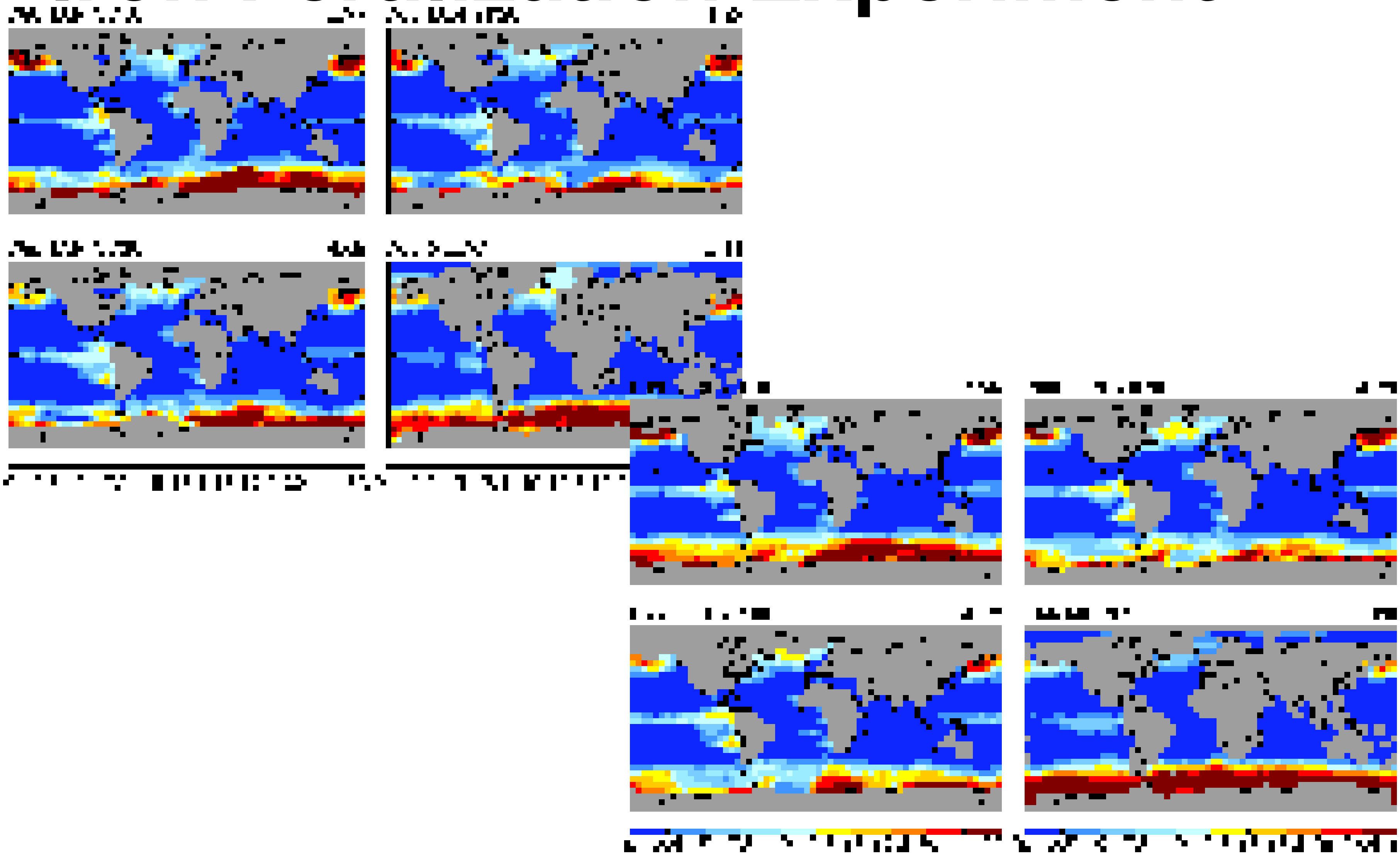
- Iron fertilization expt
  - mostly phase shift of the annual cycle in the tropics
  - Model is still not in equilibrium after 50years of integration
  - Mesoscale variability not well resolved compared to SeaWiFs

… More results

(iron fertilization expt)

- Air-sea pco2 flux is biased compared to Takahashi climatology mostly in subpolar and polar regions
- Δ(pco2) shows that in the model the ocean uptakes CO_2 in the Southern Ocean and in the Tropics there is degassing
- Observational data quality not sufficient to establish model fidelity.

Iron Fertilization Experiment



… Iron Fertilization Expt