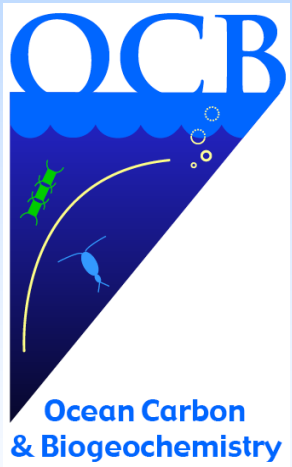
Simulating Southern Ocean Dynamics in Coupled Climate Models

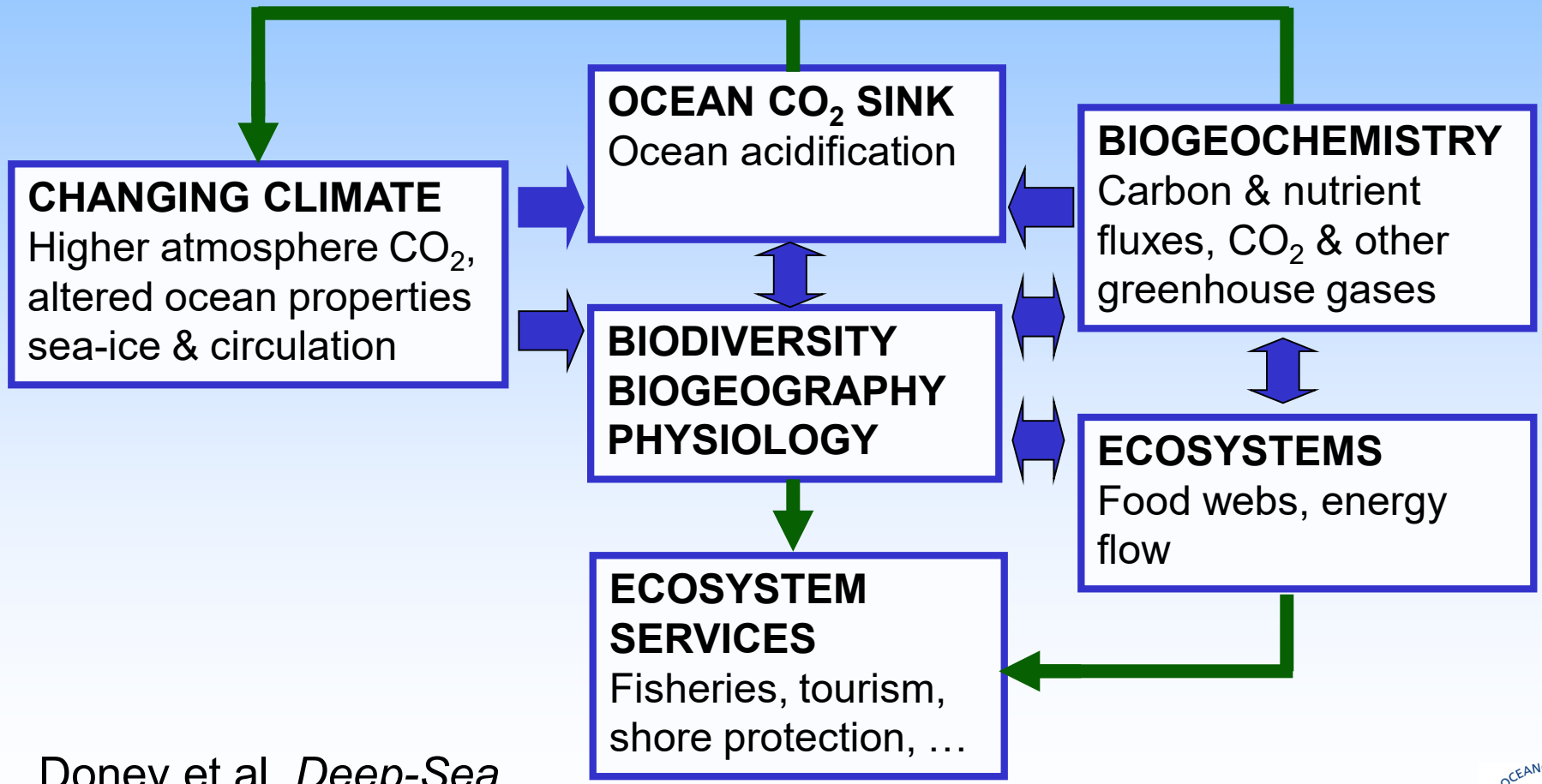
Scott Doney
(WHOI)



In collaboration with:
Ivan Lima (WHOI)
Keith Moore (UCI)
Keith Lindsay (NCAR)
Irina Marinov (U. Penn)
CCSM-3 BGC core group

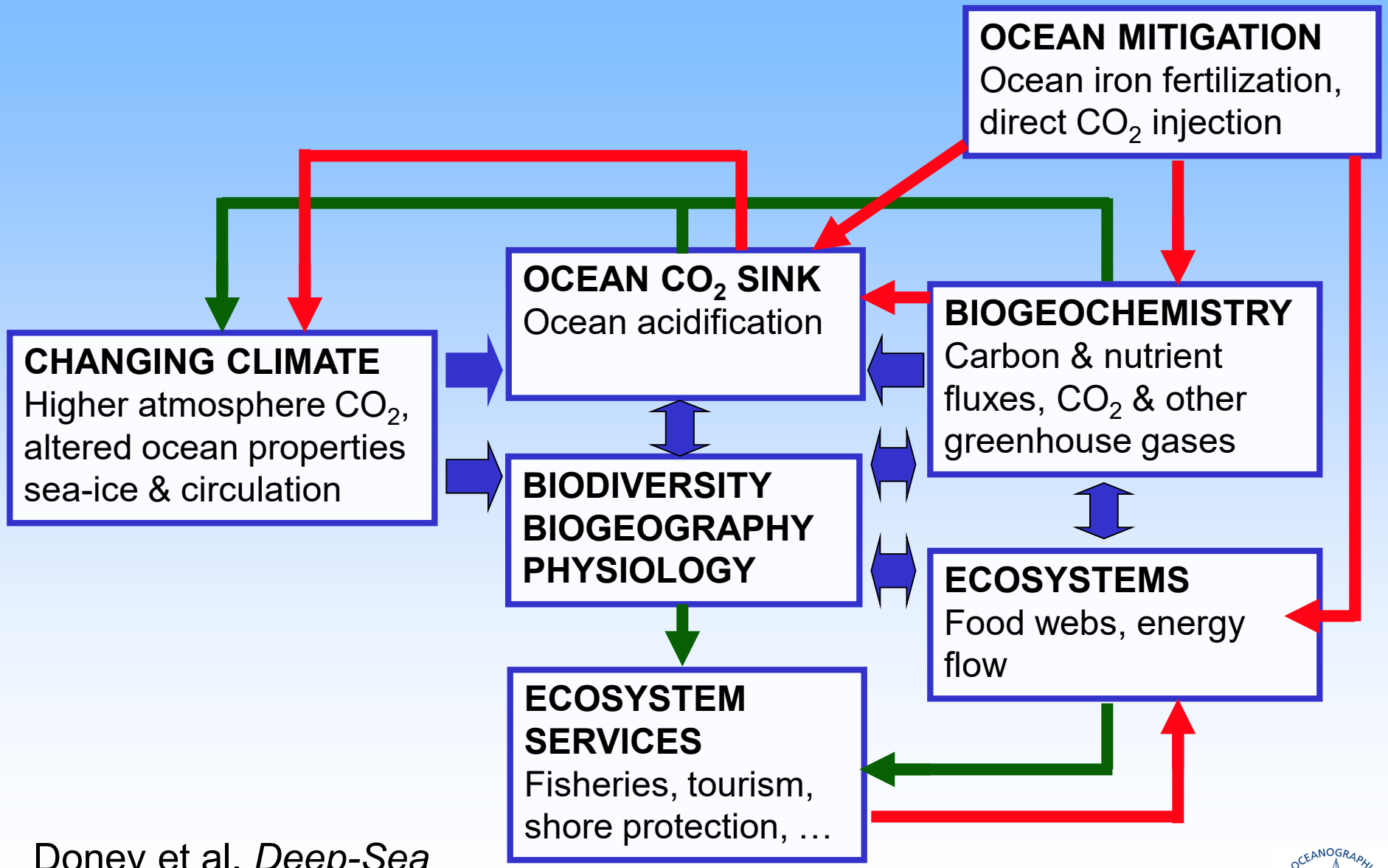
Supported by:

Ocean Climate Responses & Feedbacks



Doney et al. *Deep-Sea Res. II* 2009

Ocean Climate Responses & Feedbacks



Doney et al. *Deep-Sea Res. II* 2009

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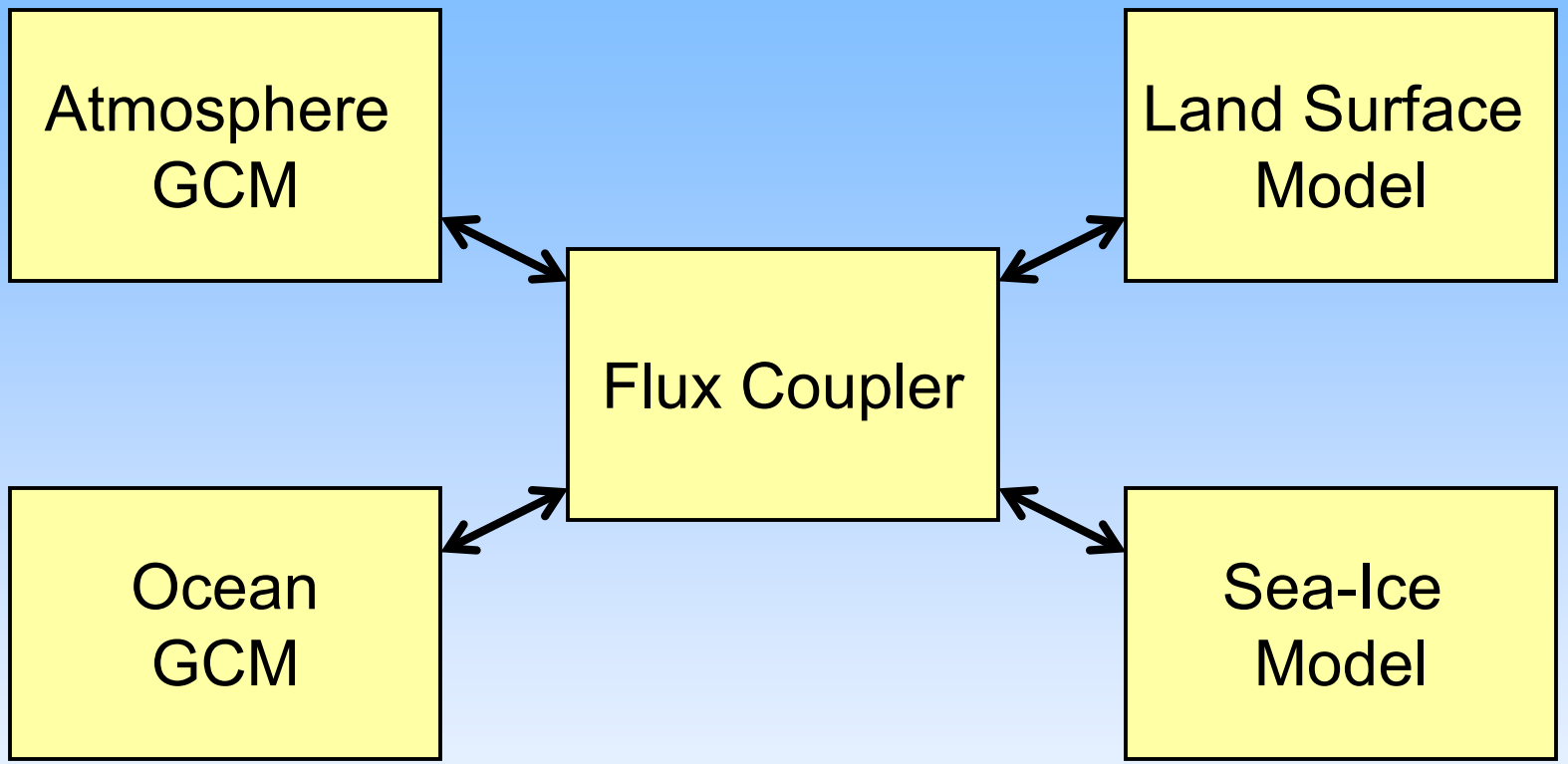
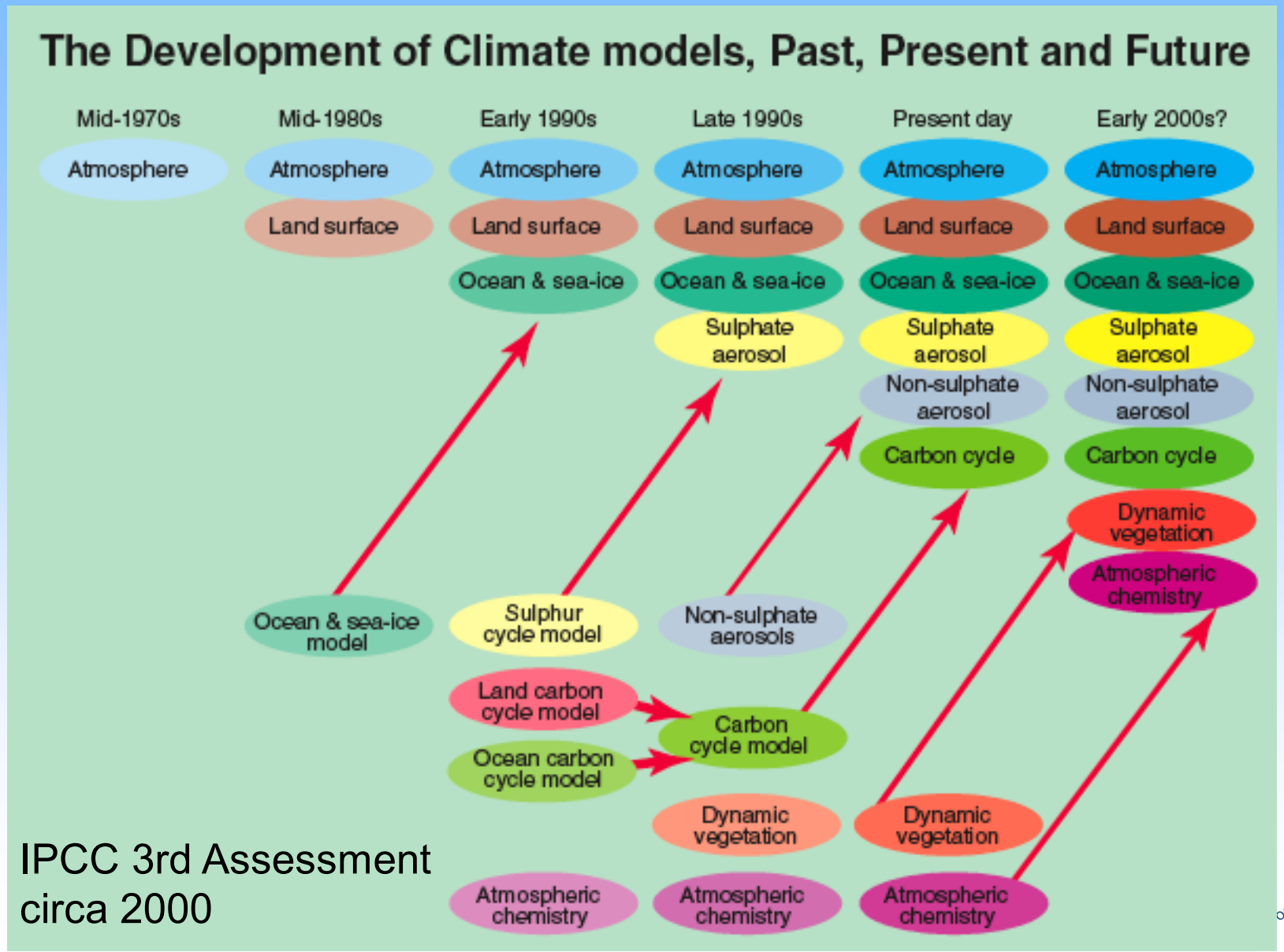
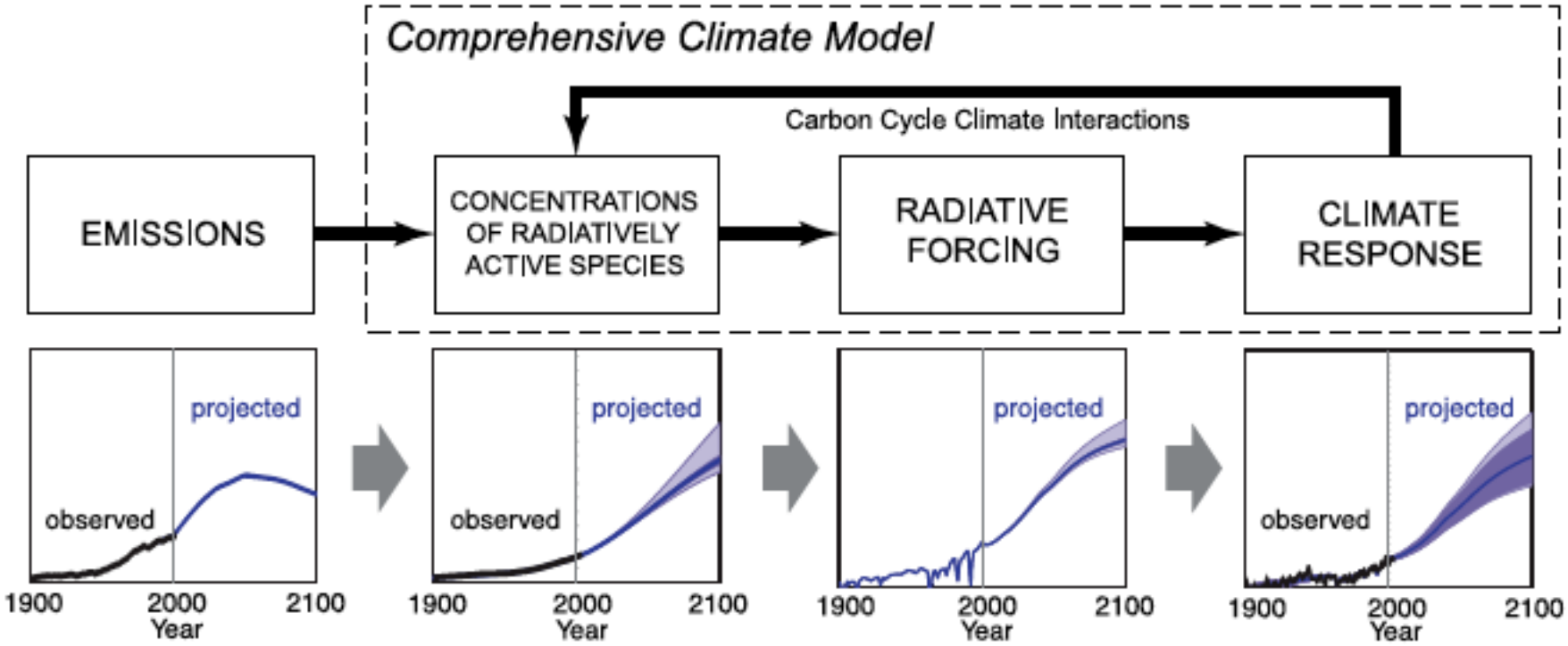
"IPCC-class" Coupled Climate Models

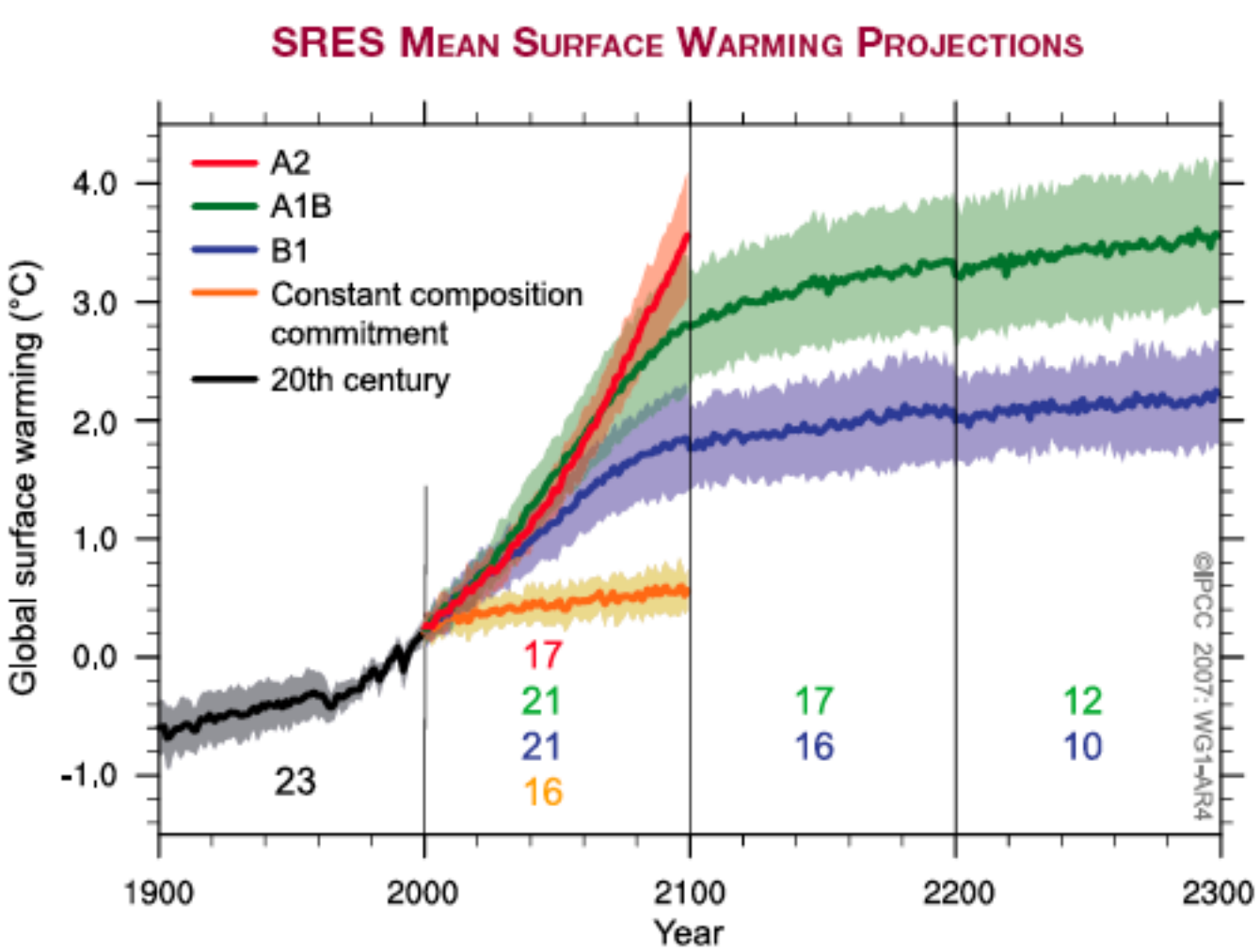


-energy and mass conserving
-internally driven climate variability
-external climate perturbations (e.g., fossil fuel CO_2)

Climate Models to Earth System Models




Comprehensive Climate Model
Carbon Cycle Climate Interactions
EMISSIONS
CONCENTRATIONS OF RADIATIVELY ACTIVE SPECIES
RADIATIVE FORCING
CLIMATE RESPONSE
observed
projected
1900
2000
2100
Year



Future Climate Projections

IPCC (2007)

Major uncertainties:

-CO_2 emissions (social, political, economic, geological)

-atmospheric CO_2 (carbon sinks, climate-carbon feedbacks)

-climate sensitivities (clouds, water vapor)

"IPCC-class" Climate Models

Opportunities

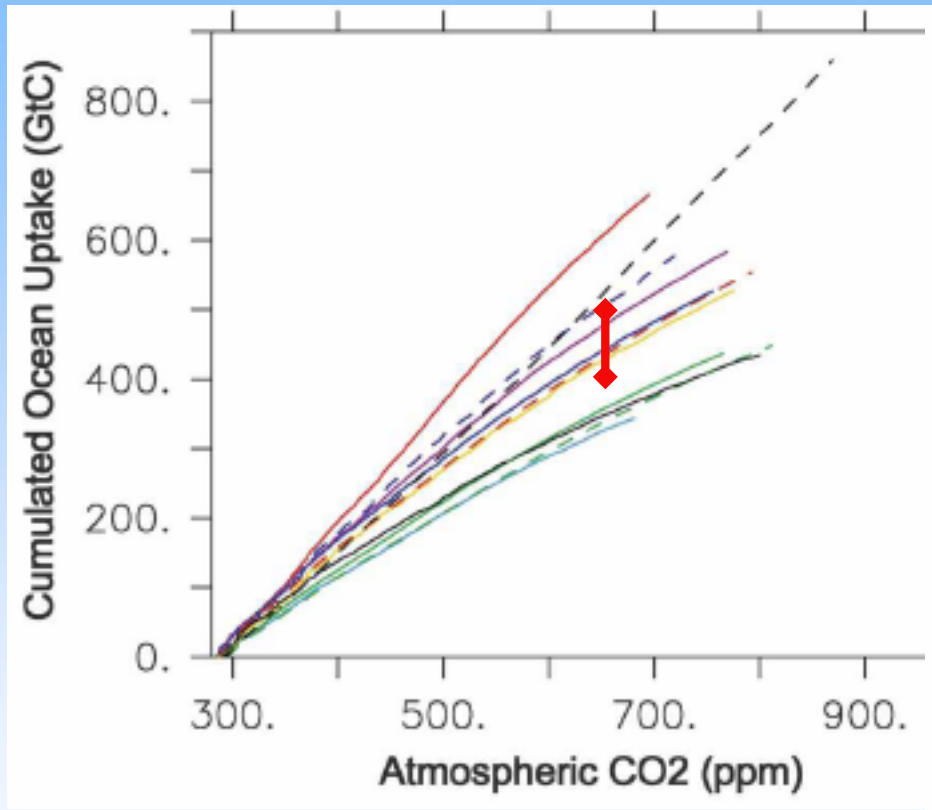
Coupled dynamics & modes - atm.-ocean-sea ice
Past & future projections - extend beyond reanalysis
Carbon-climate feedbacks - major source of uncertainty
Ecological impacts - climate & acidification
Flagship computations - computer resources, multi-model ensembles

Challenges

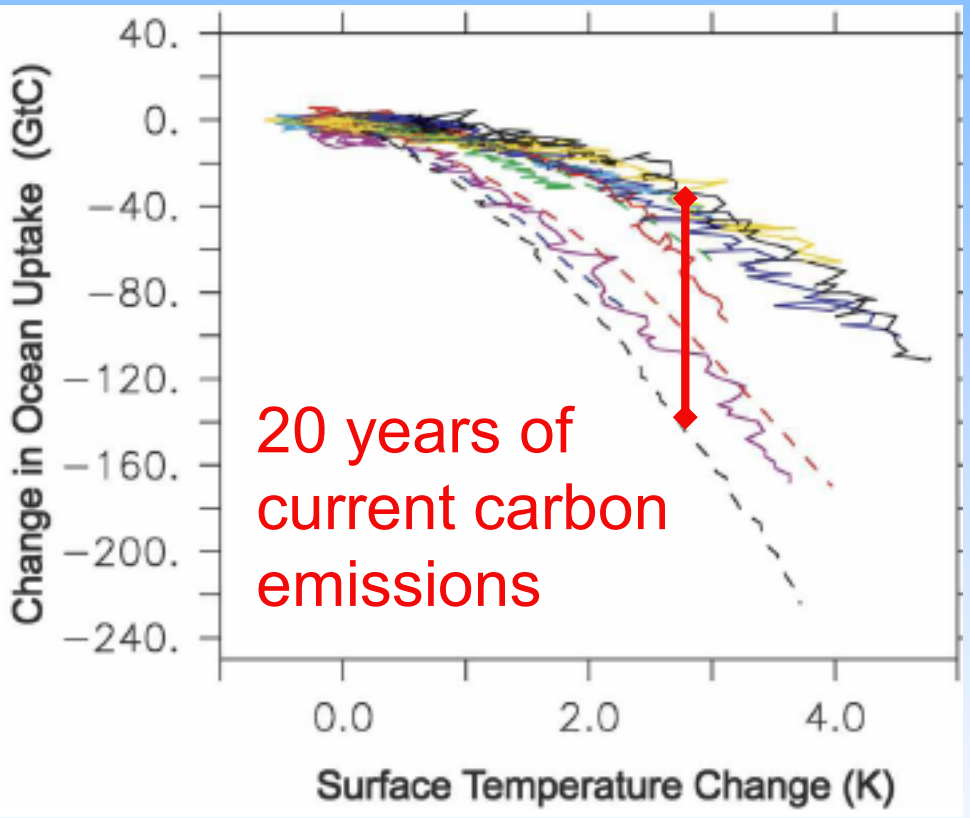
Coarse resolution - at best eddy-permitting
Internal variability - statistical matching with data
Coupled systems - large regional errors
Simplified biology - lower trophic levels

Coupled Model Uncertainties

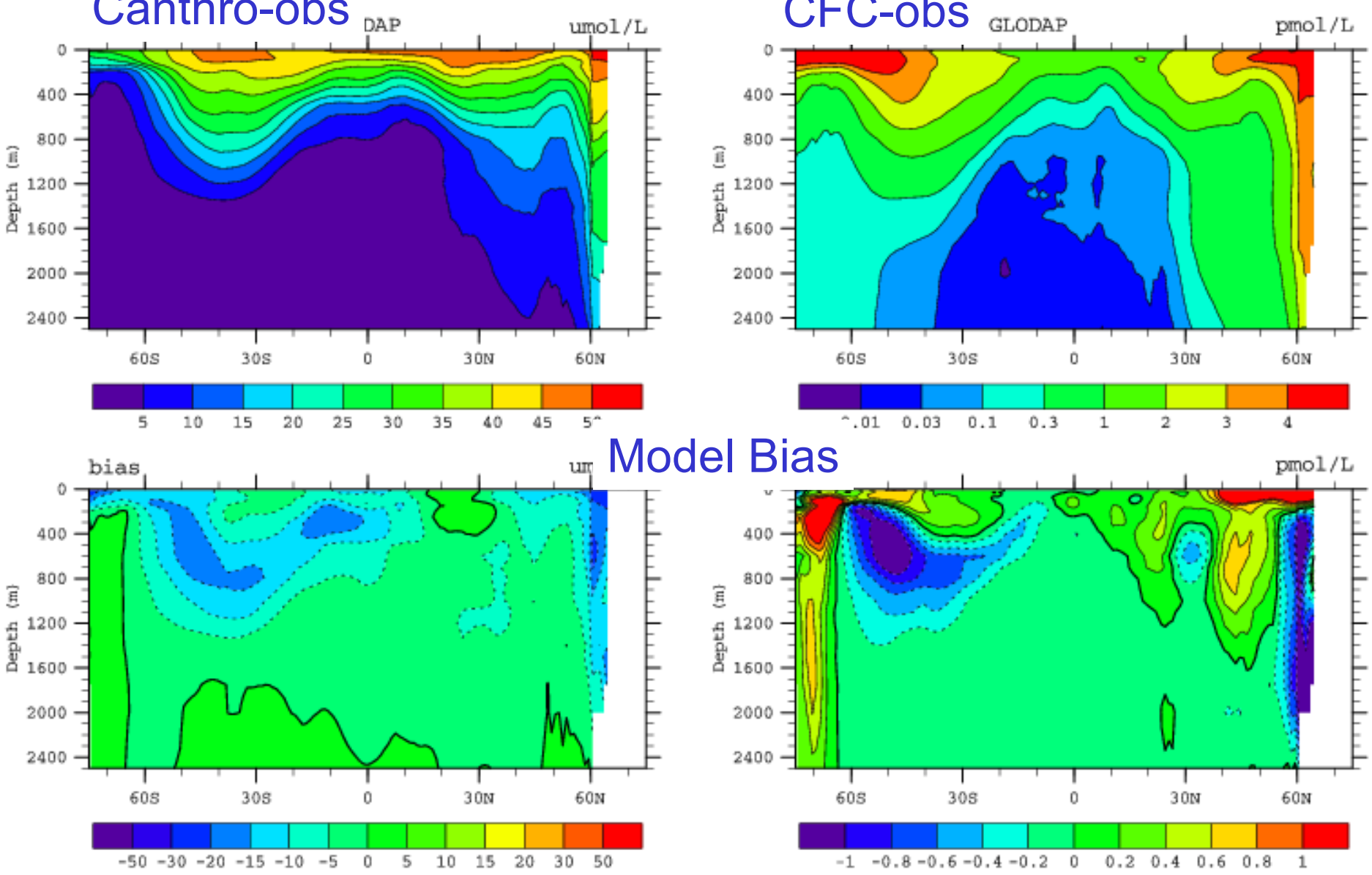
Strength of Ocean CO_2 Sink



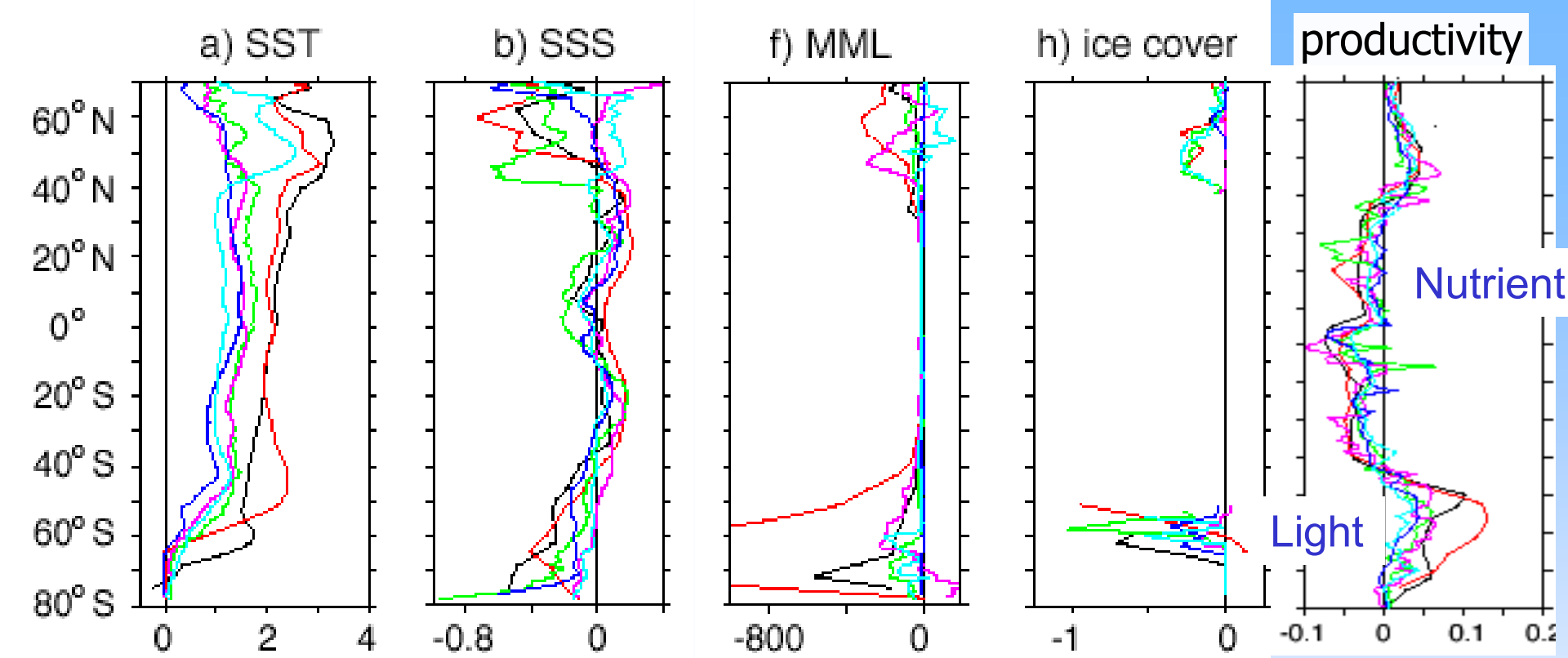
Sensitivity to Climate Warming



Friedlingstein et al. *J Climate* 2006



Thornton et al. *Biogeosci. Disc*. 2009

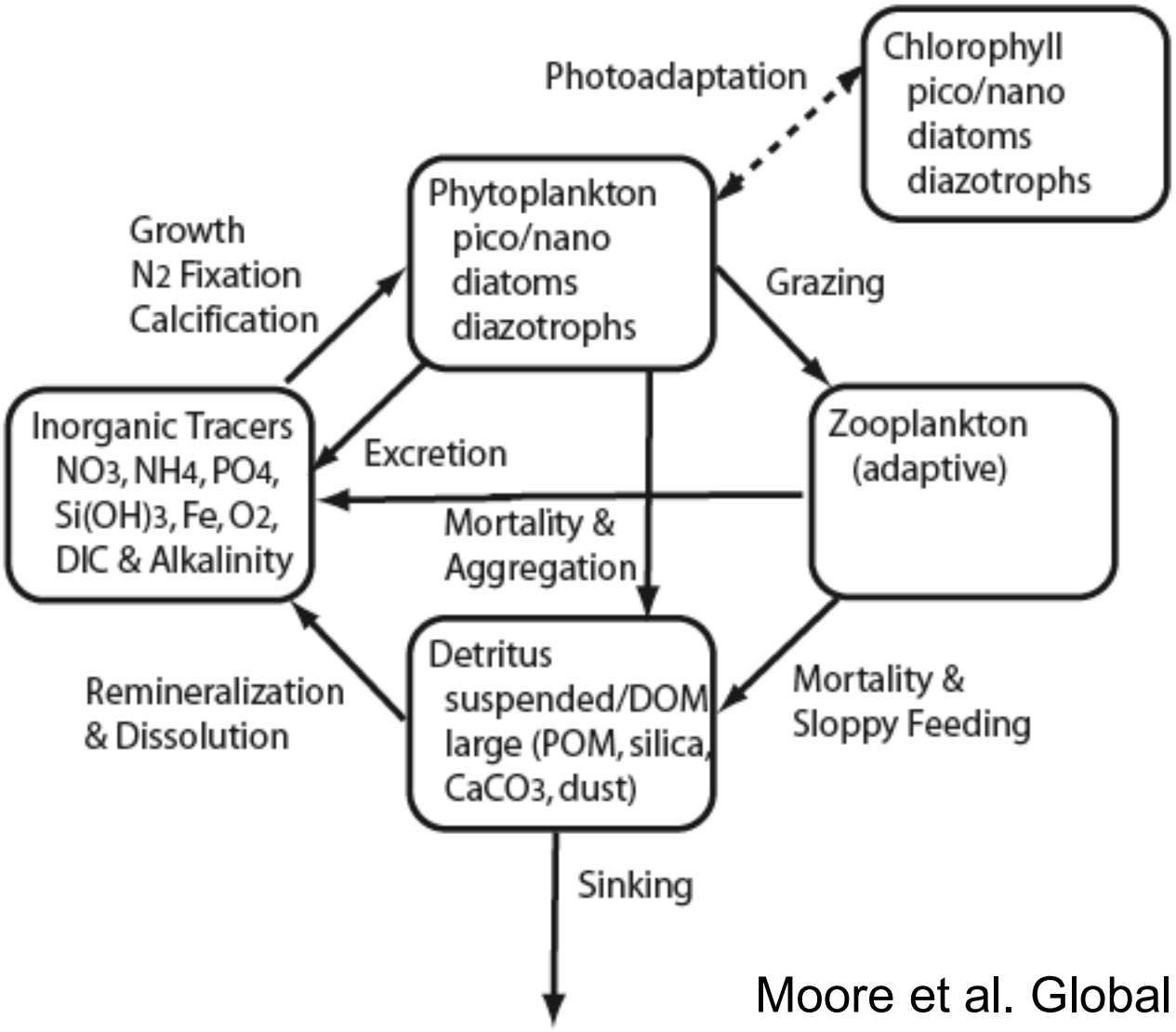


Sarmiento et al., Global Biogeo. Chem. (2004)

-stratification alters mixed layer depth (light) and nutrient supply

-primary productivity lower in subtropics, higher in subpolar gyres & polar regions

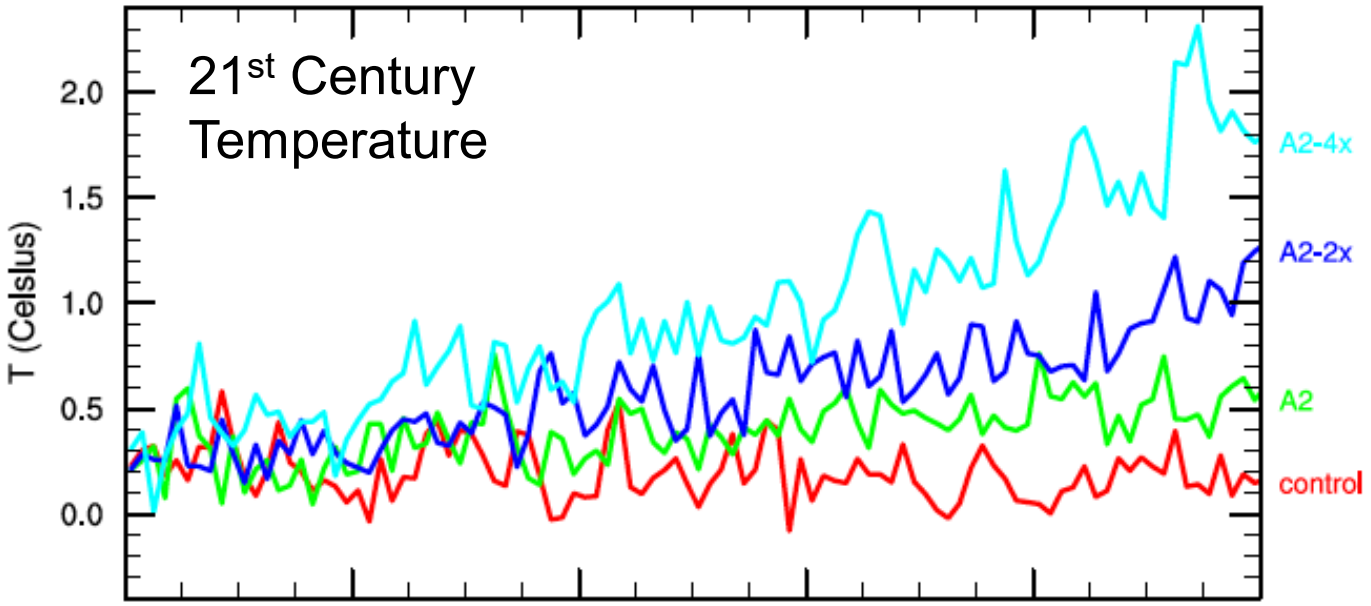
"Green-Ocean" Models



Multiple nutrients & phytoplankton functional groups

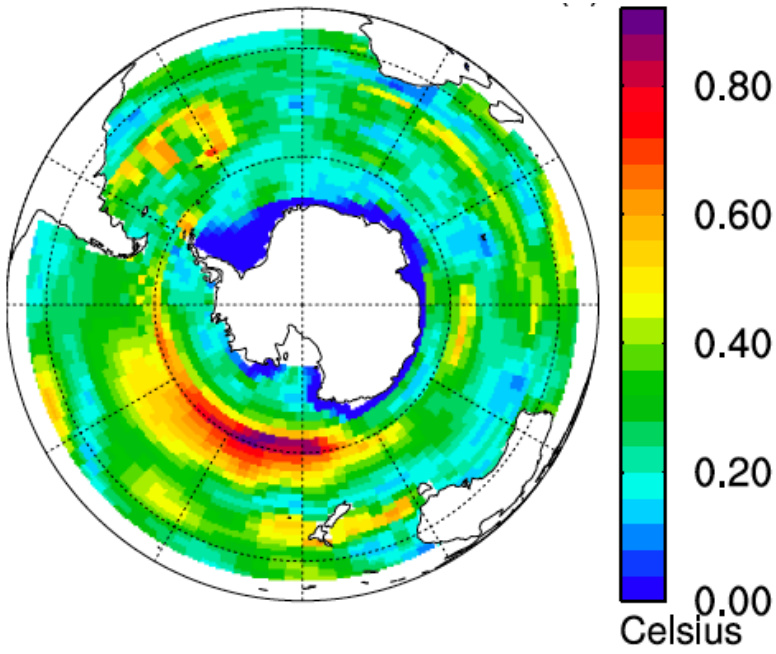
Moore et al. Global Biogeochem. Cycles (2004); Doney et al. J. Mar. Sys. (2009)

Atttribution & Detection

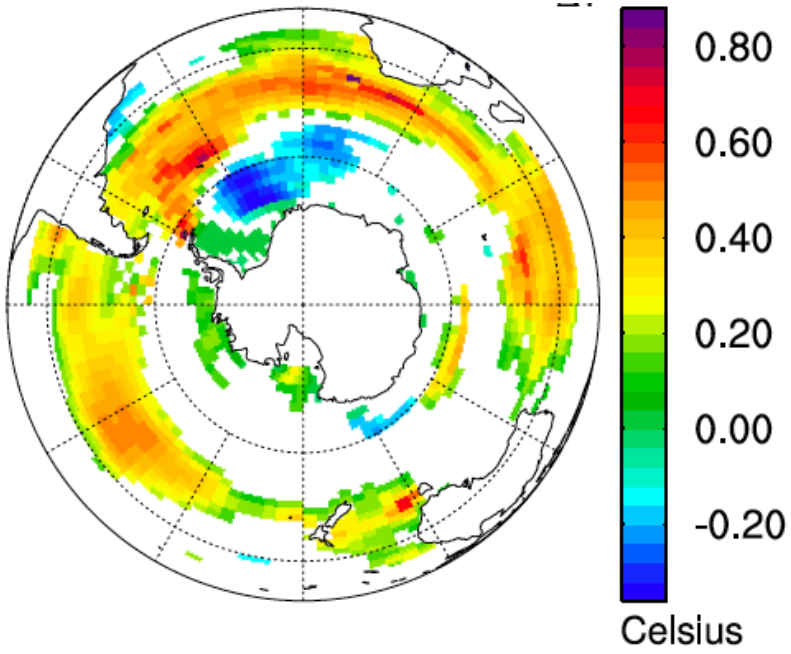


Boyd et al
Biogeosc. 2008

"RMS Interannual Variability"



"Decadal Trends" (20 years)



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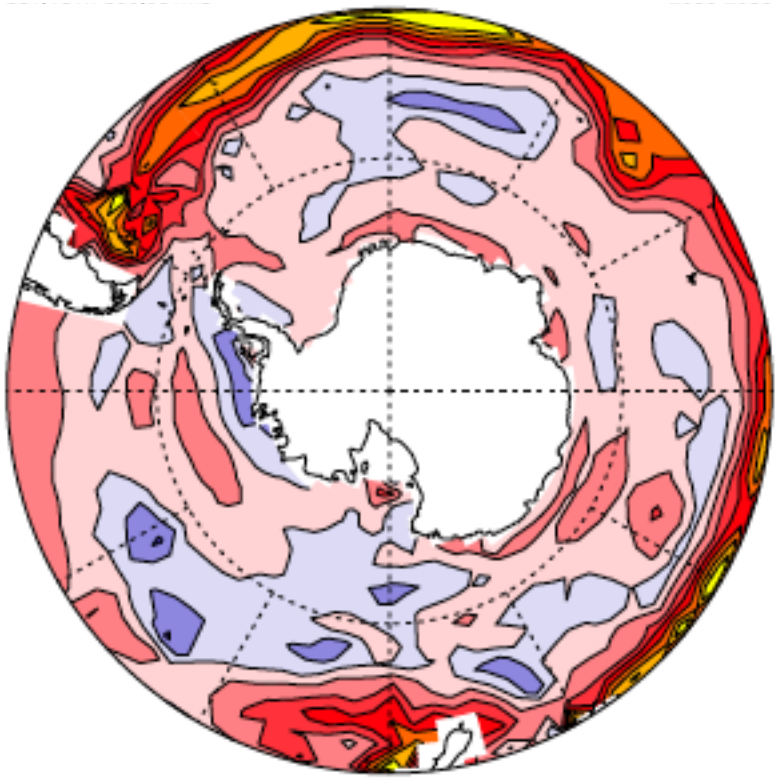
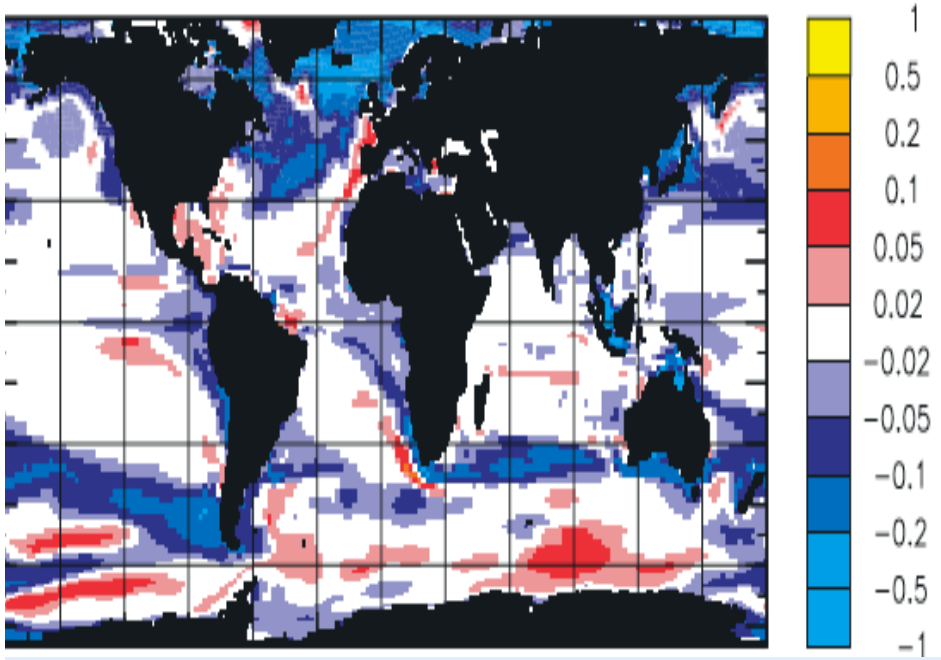
1930

ΔPrimary Production



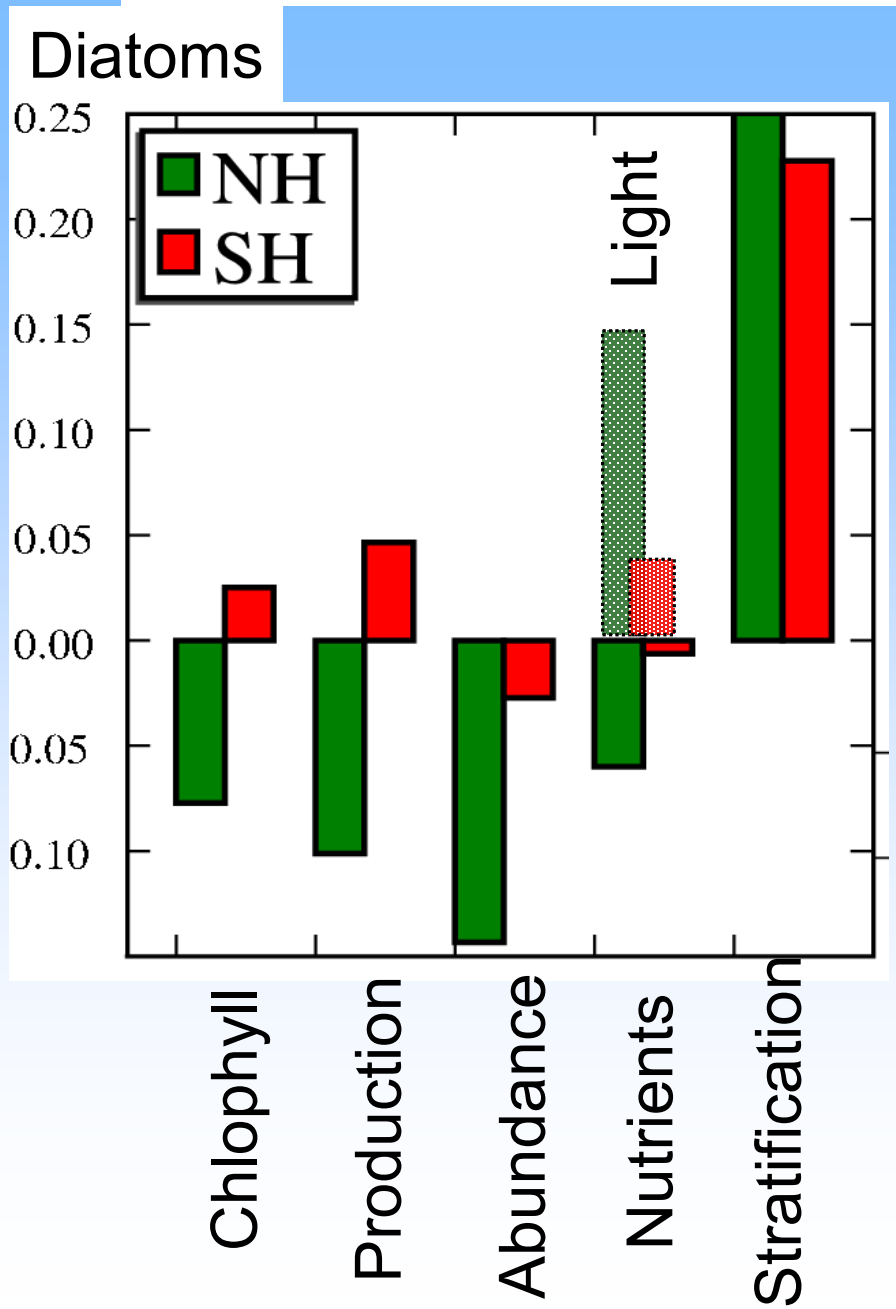
Marinov et al (in prep)

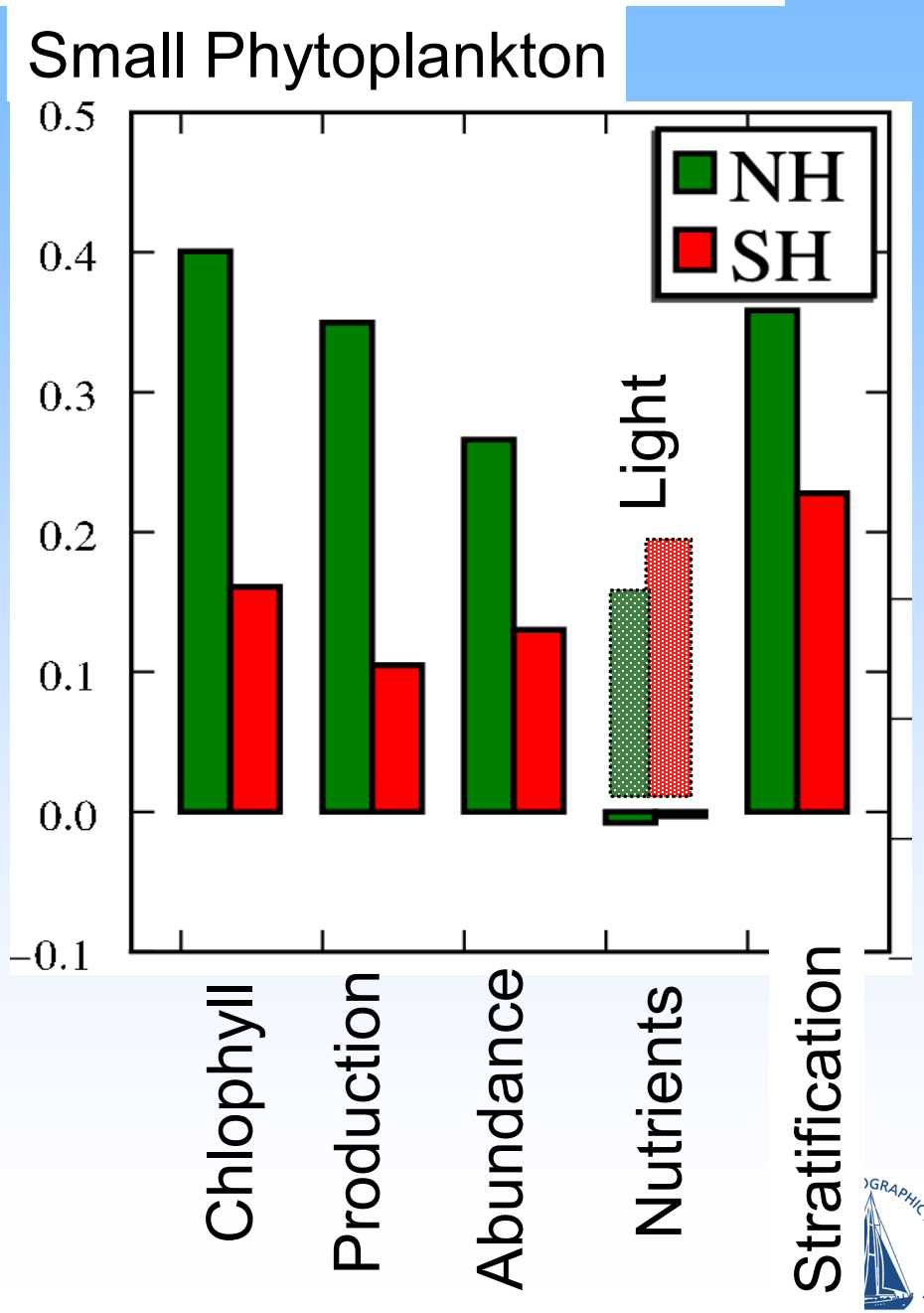
ΔDiatom Index



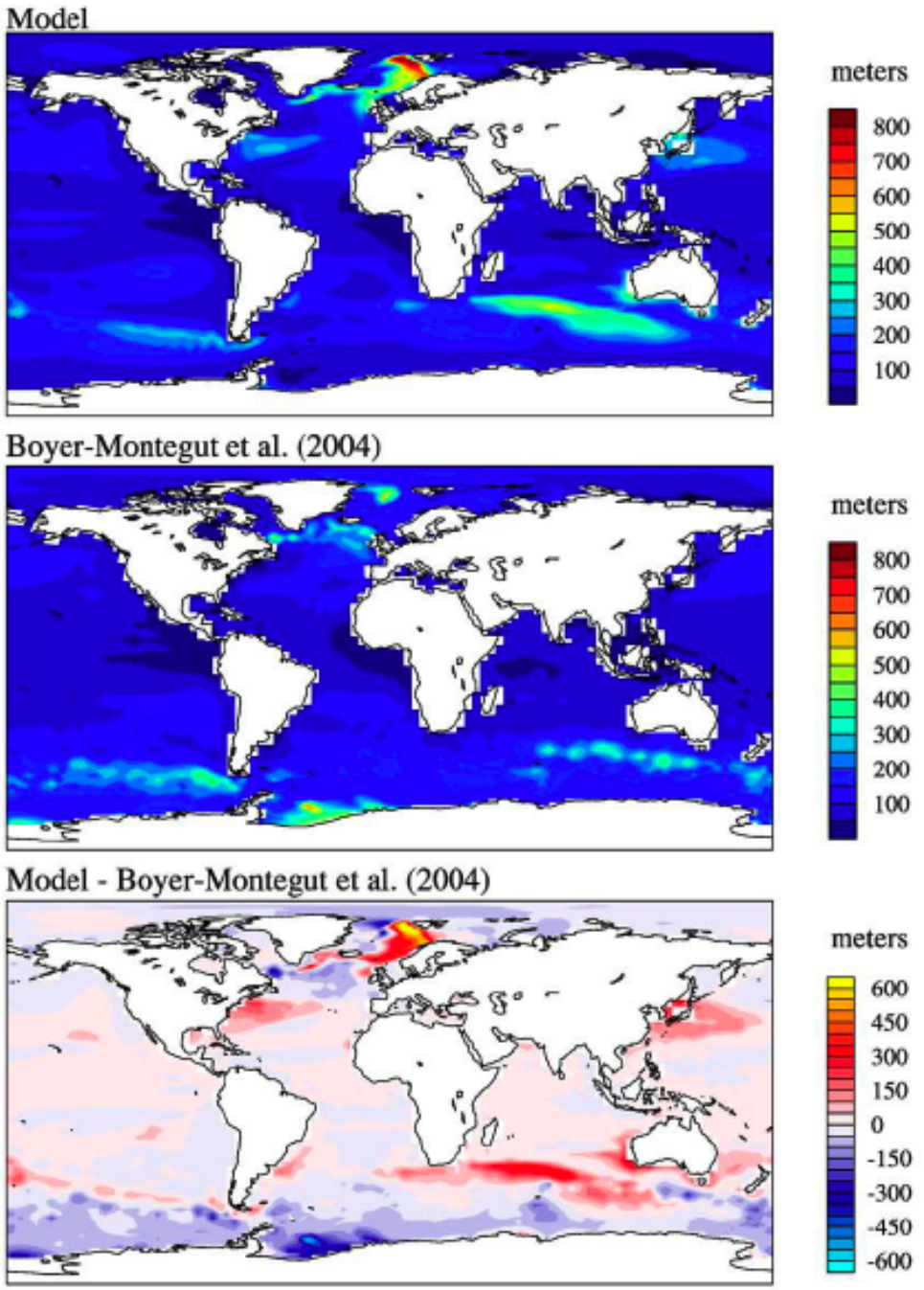
Bopp et al Geophys. Res. Lett. 2005

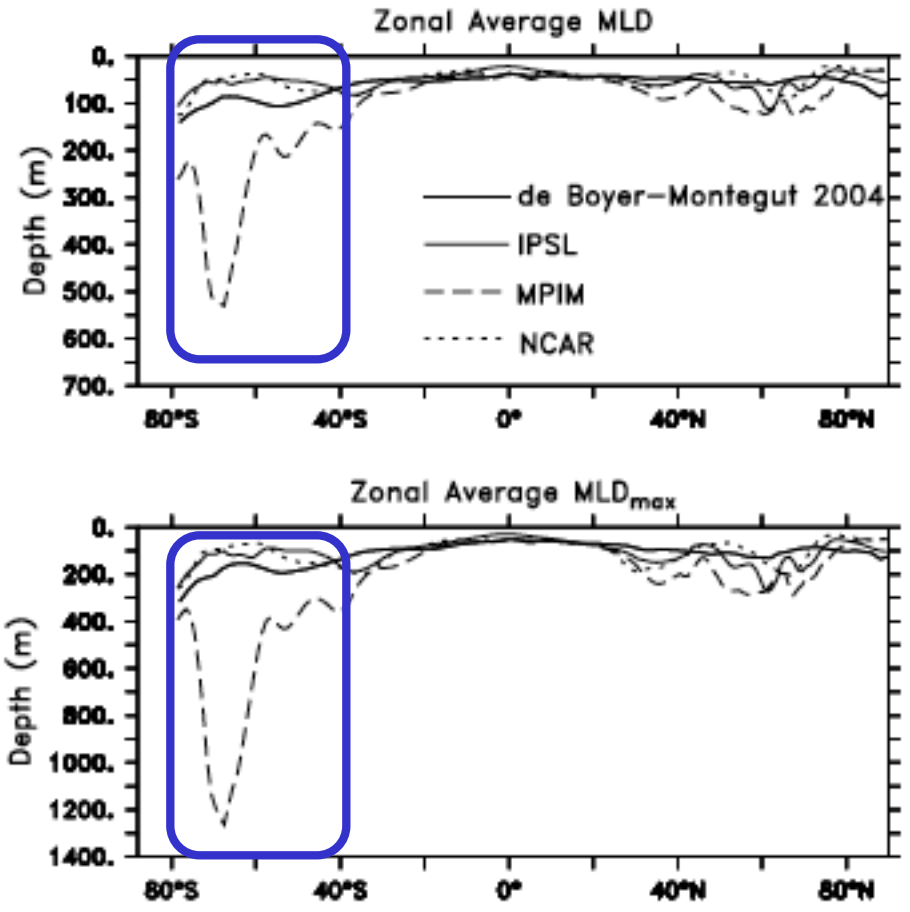
Climate Change & Biological Response in Ice Biome





Winter Mixed Layer Depth





Schneider et al.
Biogeosci. 2008

Doney et al.
J. Mar. Systems 2009

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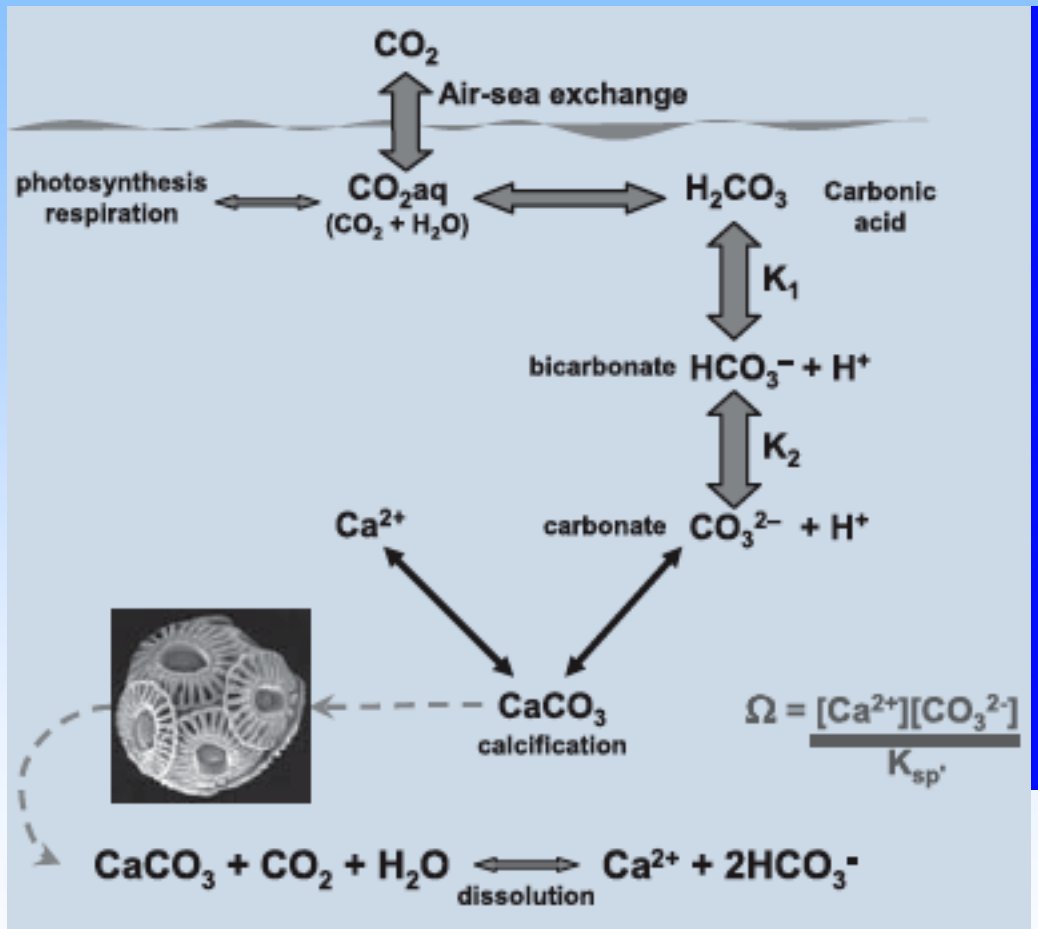
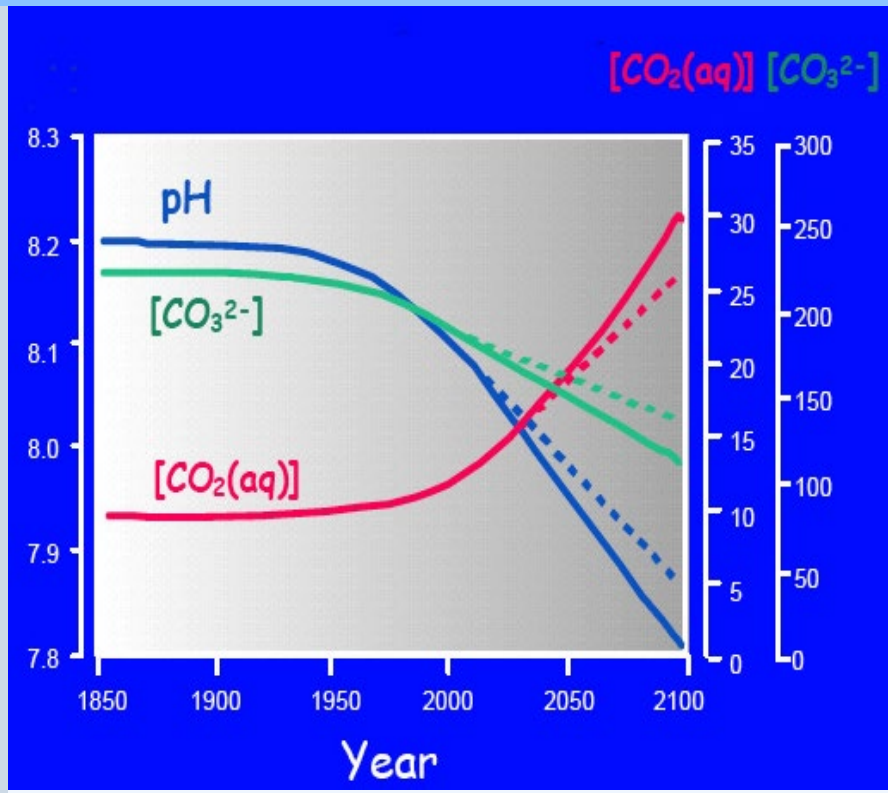
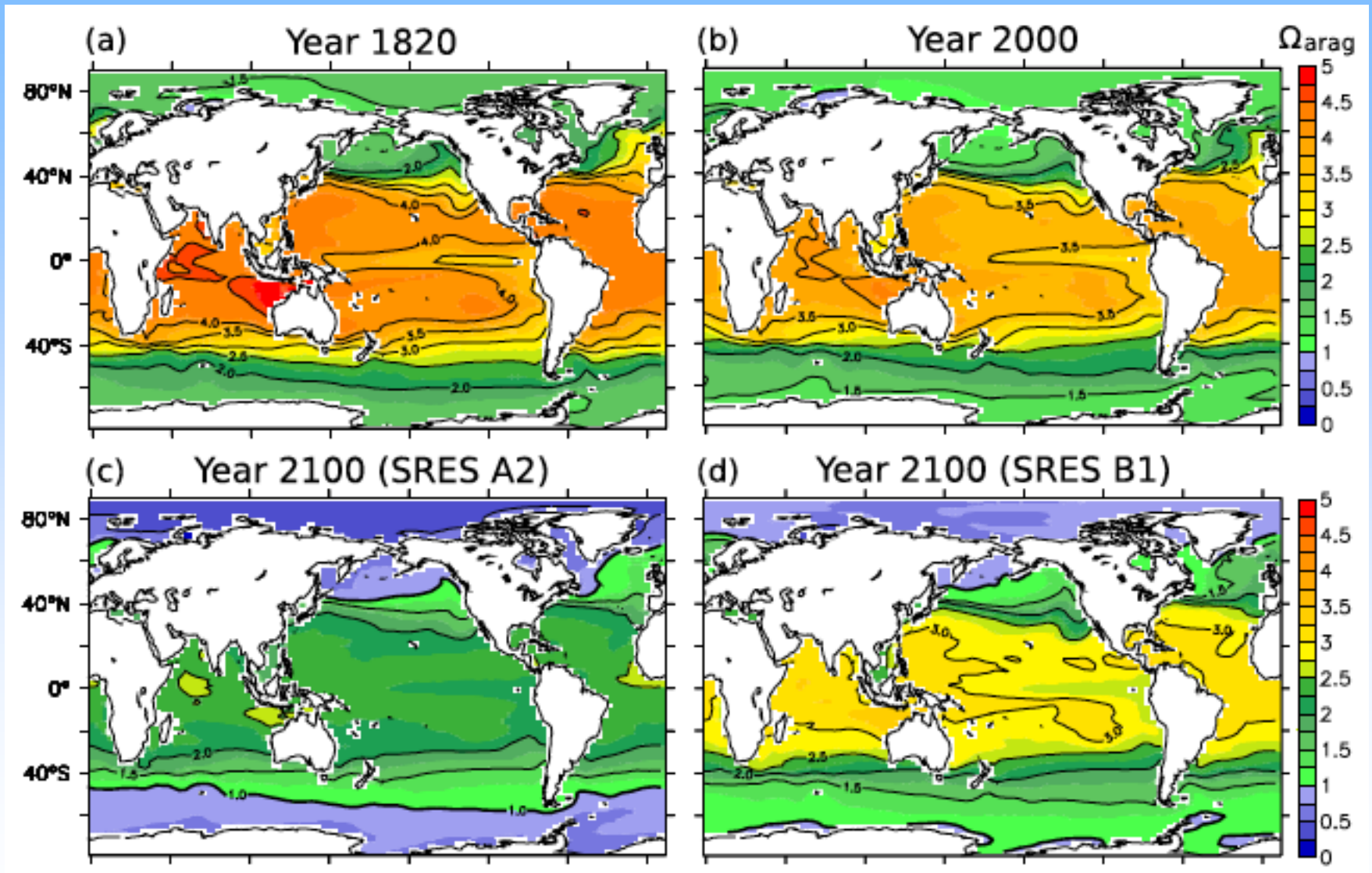
Rising CO_2 also leads to ocean acidification threatening shell-forming plants and animals





Aragonite Saturation State



Steinacher et al. *Biogeosciences* 2009

The new paradigm for coupled climate models

CMIP5 (IPCC 5th Assessment)

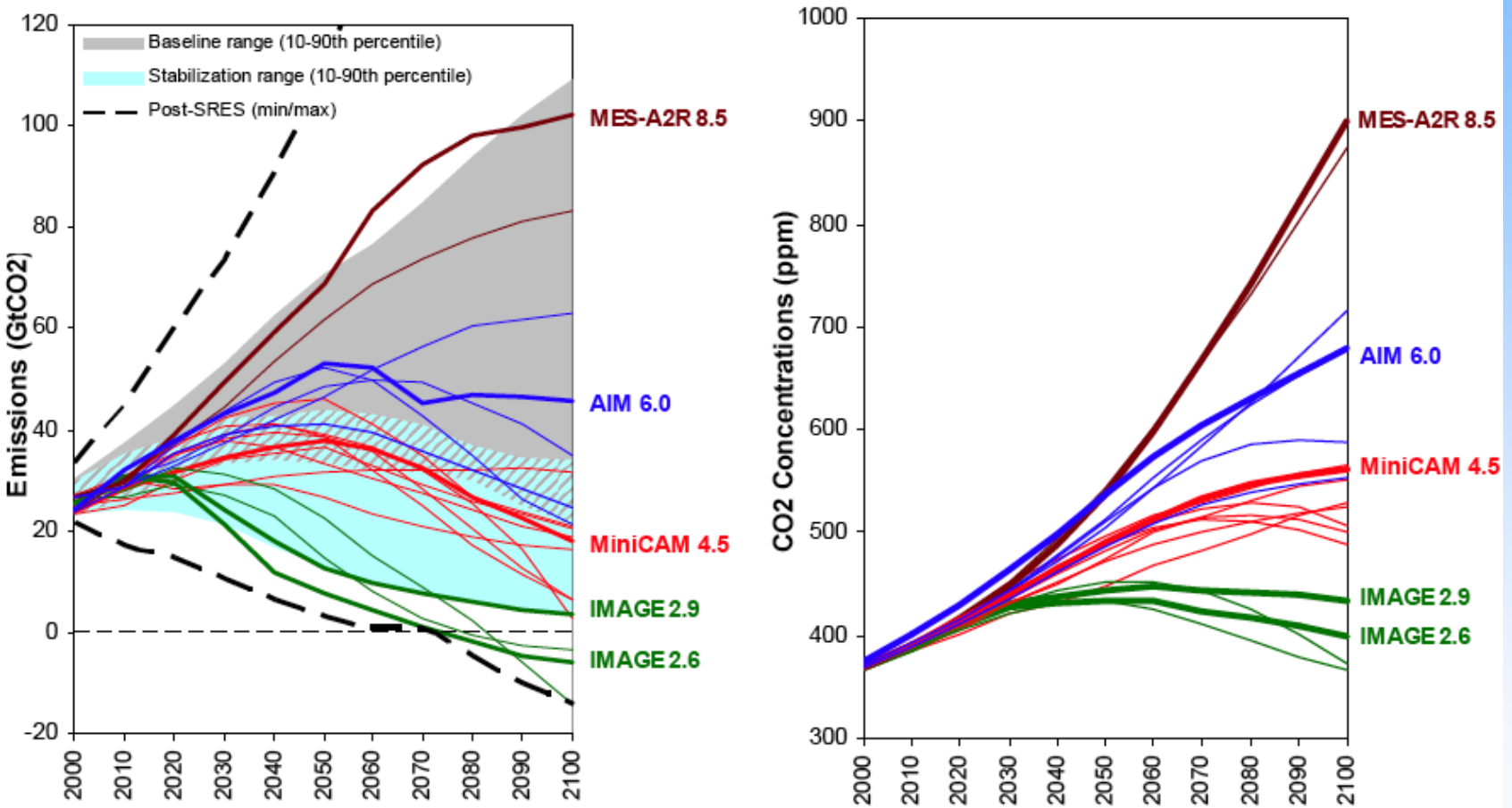
-Decadal Prediction

high resolution AOGCMs (~50km) initialized for near-term climate change over next 30 years

-Earth System Models (ESMs)

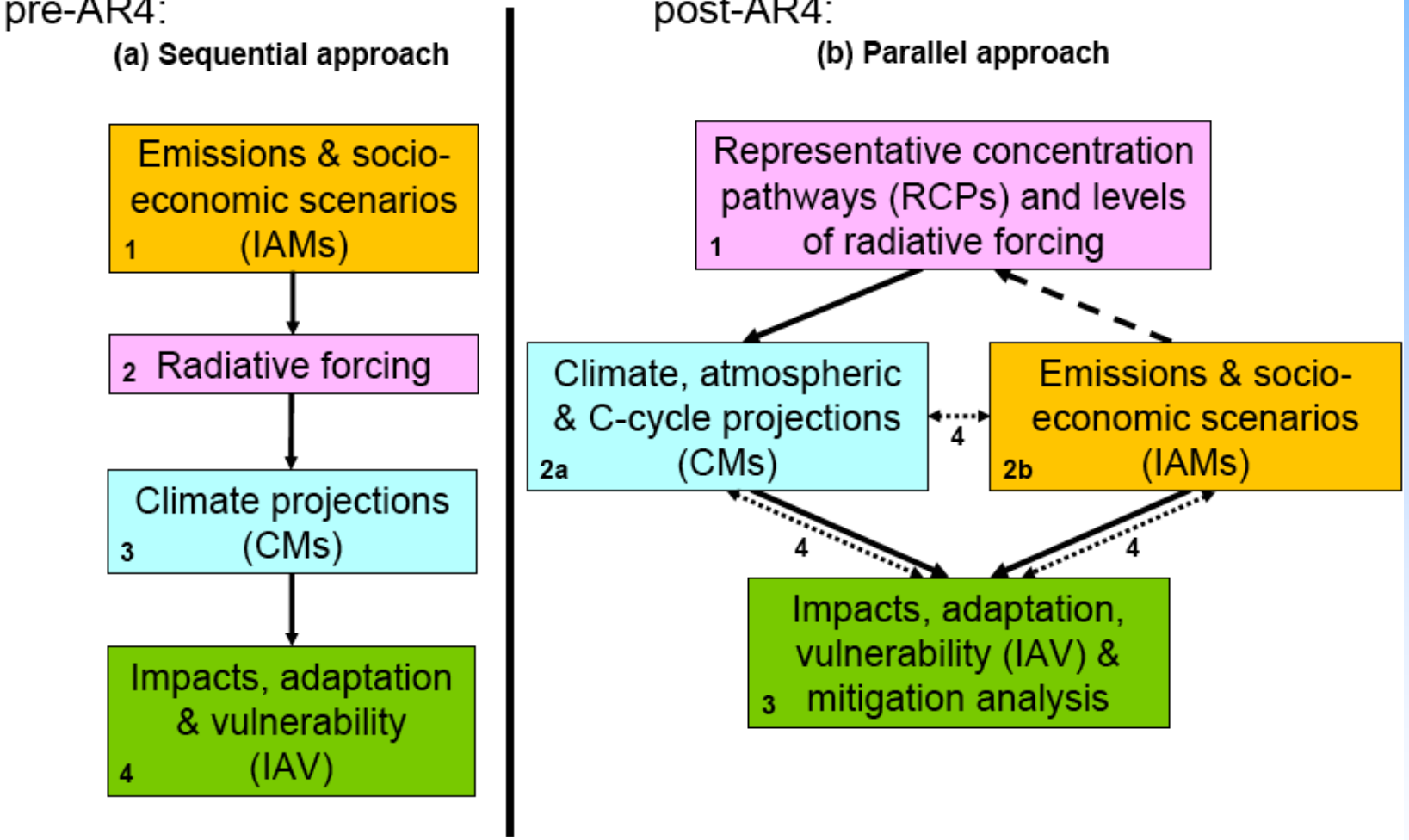
with coupled carbon cycle and intermediate resolution (~200km) to study longer term feedbacks

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)



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

-Skill of model physical projections?

- •Base-state and historical trends
- •Mixed layer depth, upwelling, sea-ice

-Magnitudes of biogoechemical feedbacks?

- •Carbon storage & trace gases
- •Climate/carbon mitigation

-Biological sensitivities & resilience to change in temperature, sea-ice, circulation & CO_2?

- •Thresholds, multiple-stressors & trophic mismatch

-Enhanced SO observing system

- •Oxygen, nutrient & carbon sensors/platforms
- •Mixed layer depth, stratification & upwelling
- •Biological rates & community composition

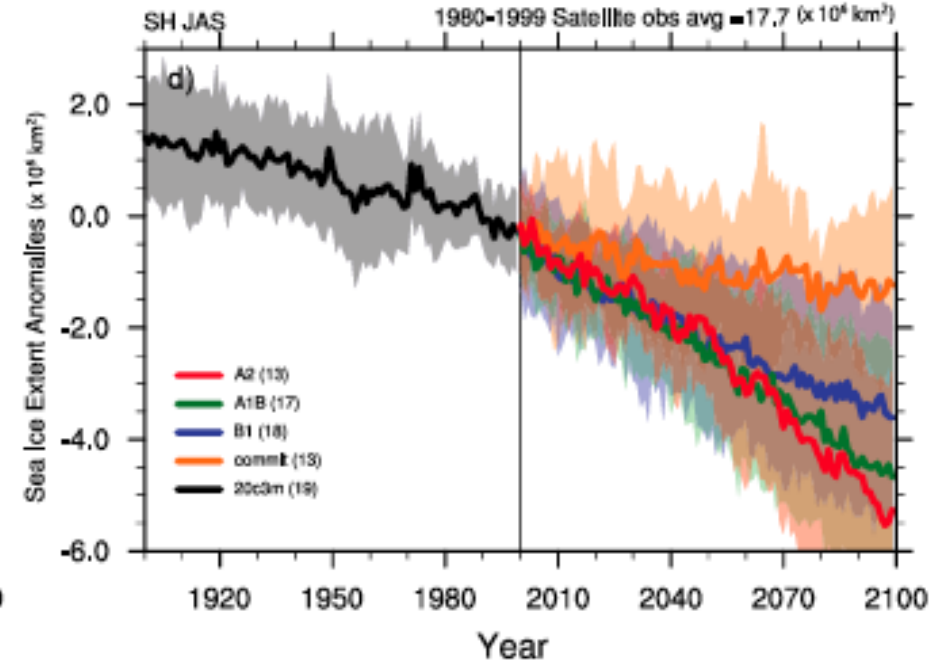
-Modelling advances & opportunities

- •Nested high-resolution regional atm-ocean models
- •Model-data skill metrics (NOAA CPT, MAREMIP, *J. Mar. Systems*, 2009, Vol. 76, Issue 1-2)
- •Biological food-web & impact models (embedded or one-way nested; physics data requirements?)

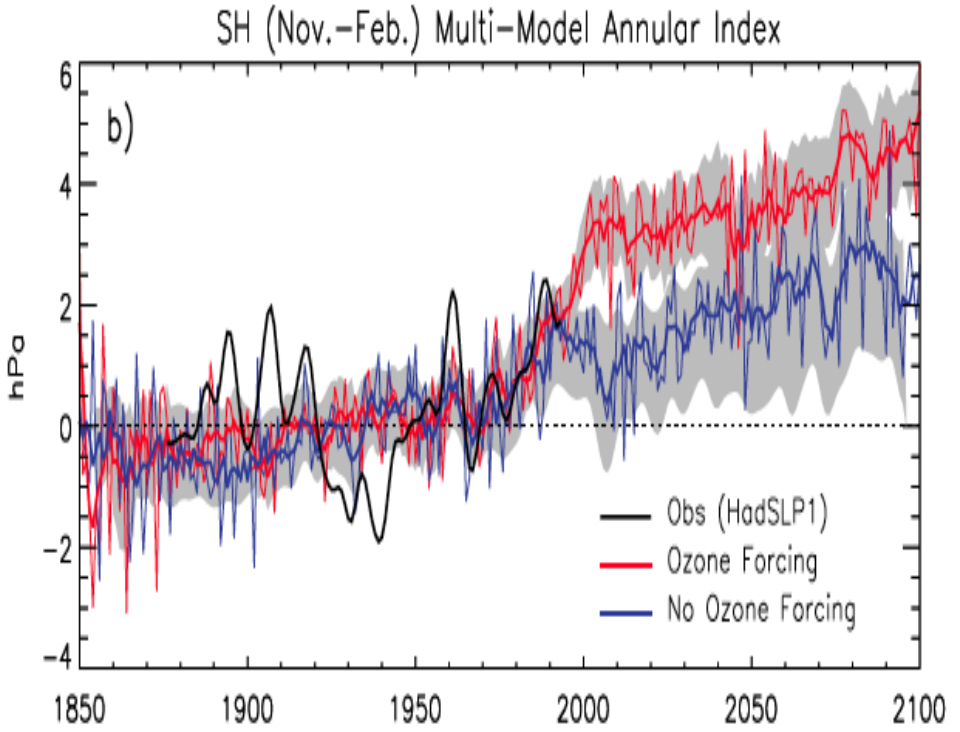
-Biological time-series & process studies

- •Multi-stressor experiments (ocean acidification, nutrients, trace metals, temperature)
- •Targeted process studies (lab & field)
- •Cross-ecosystem comparisons

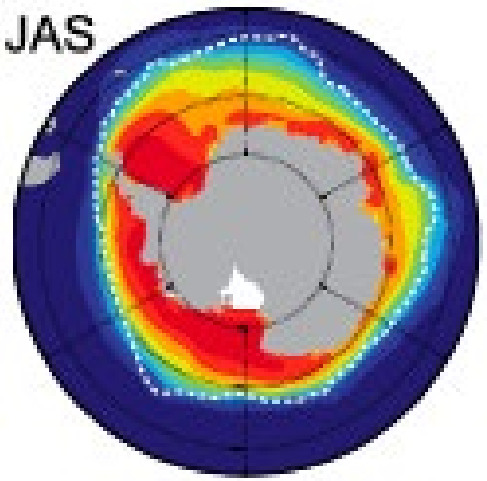
Reduced SH Sea-Ice



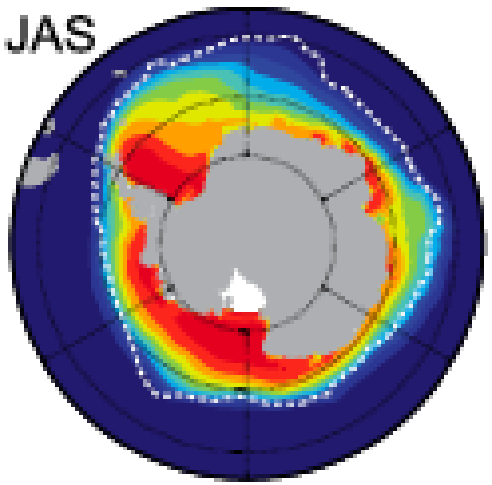
More Positive Southern Annular Mode



1980-2000



2080-2100



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J. Marine Systems Special Issue on
Skill Assessment for Coupled Biological / Physical Models of Marine Systems
Vol. 76, Issue 1-2, 2009

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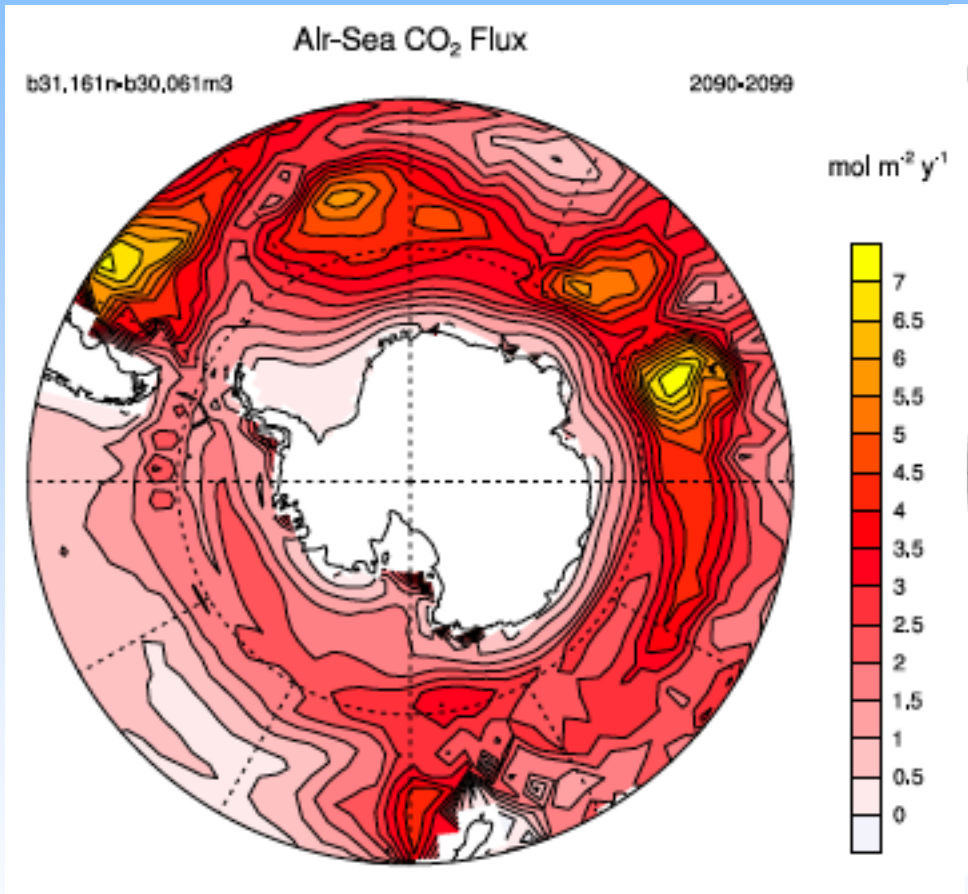

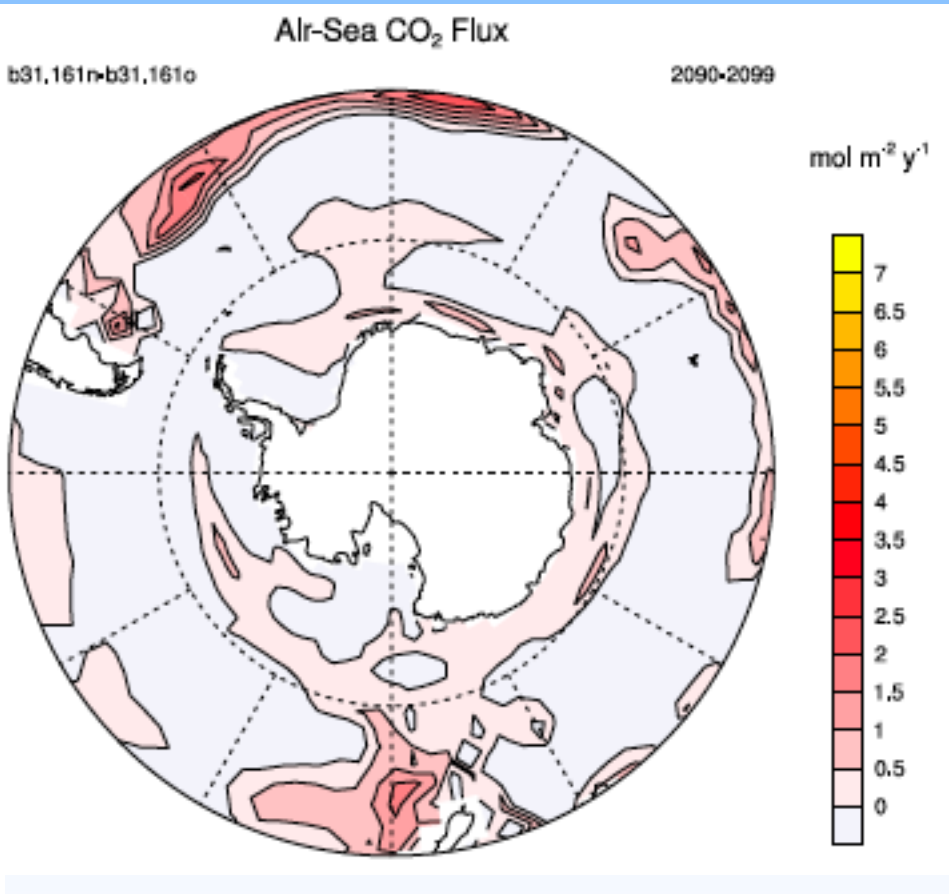

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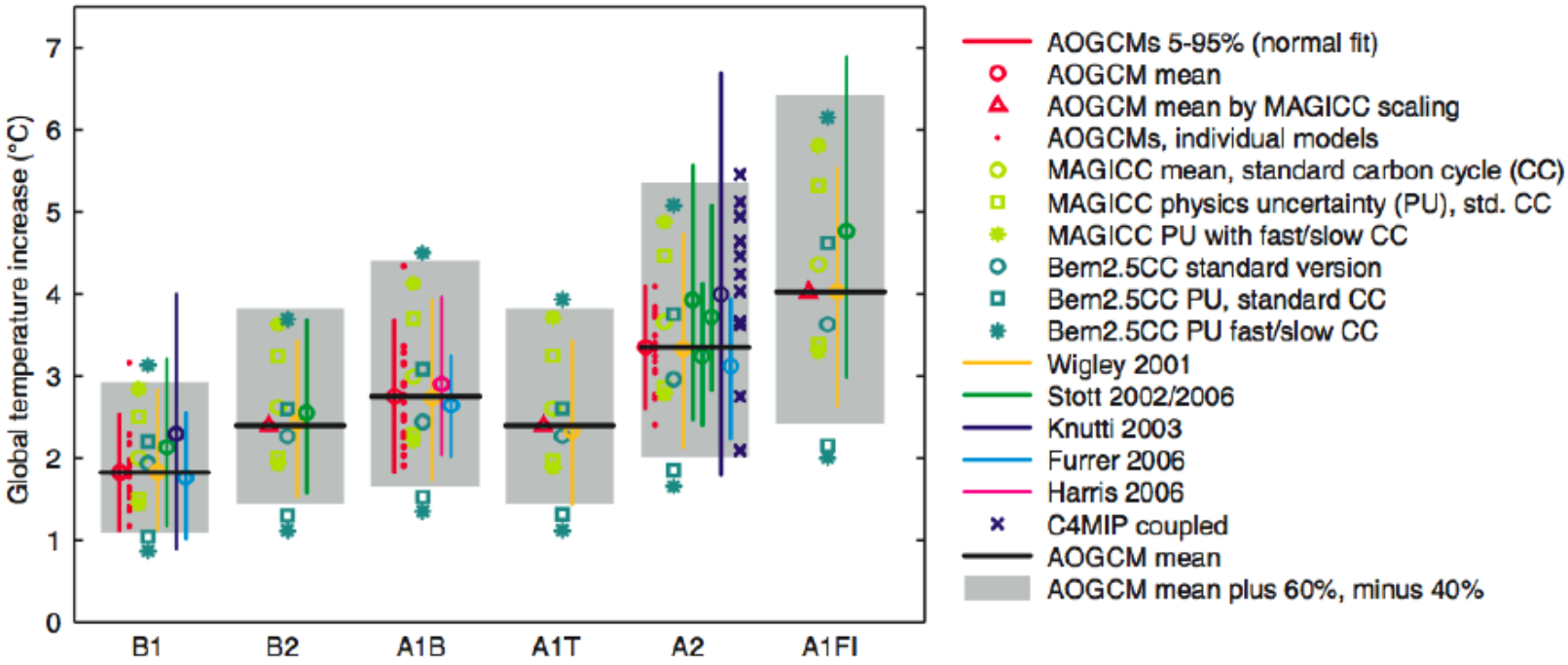
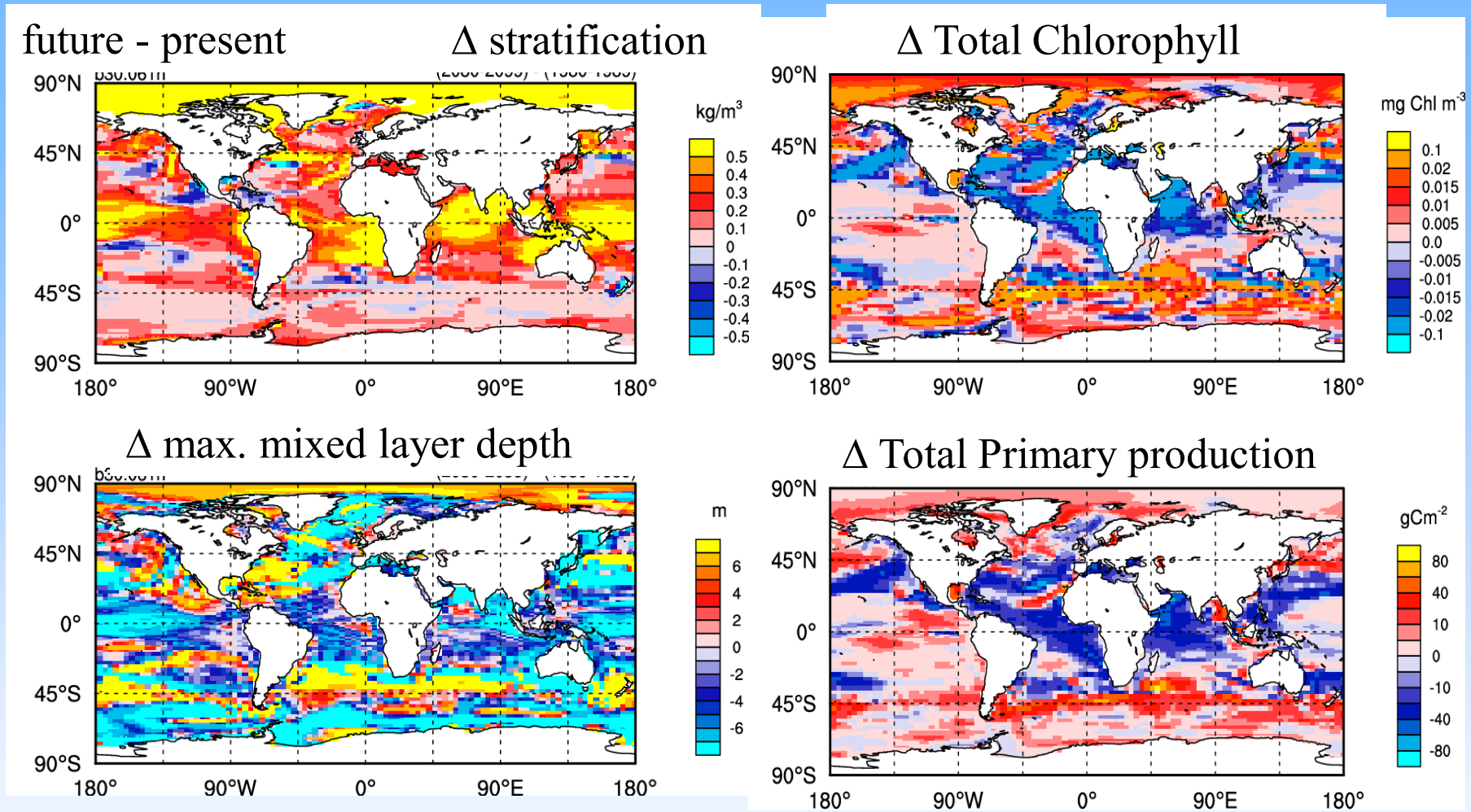


IPCC AR4 Fig. 10.29

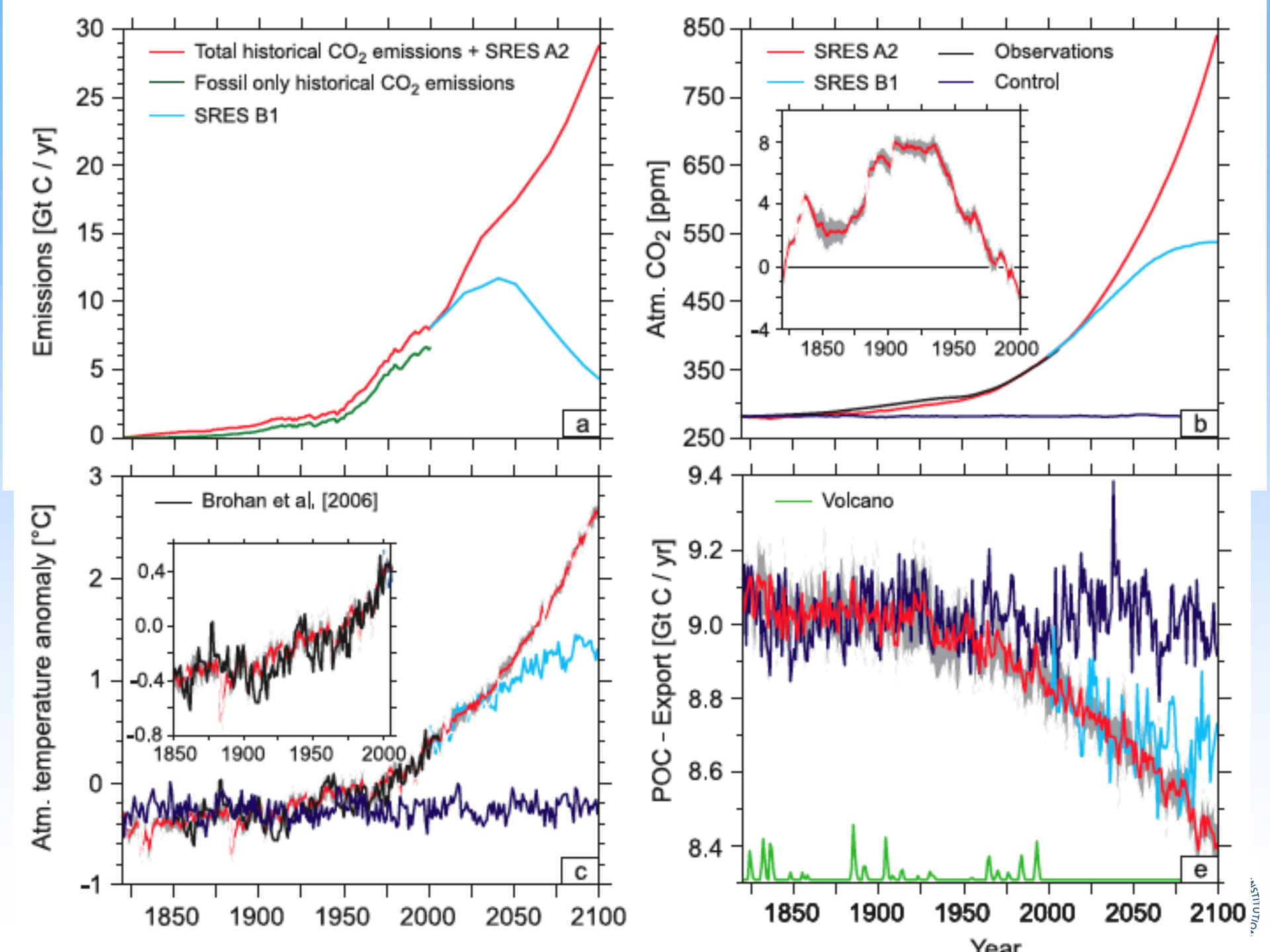
Greater uncertainty towards higher values due in part to uncertainty in the size and nature of the carbon cycle feedback



Marinov et al. (in prep)

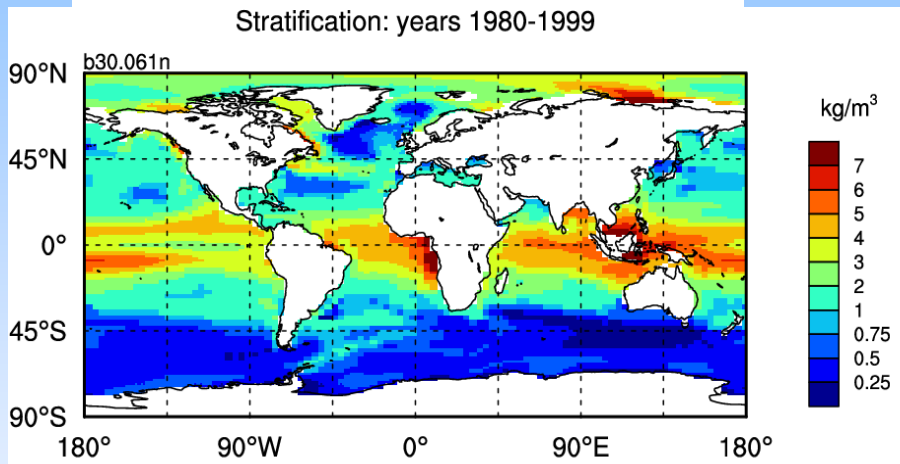
- Subtropical gyres: Climate change decreases NO_3 supply to the ocean surface, total Chl and Primary Production.

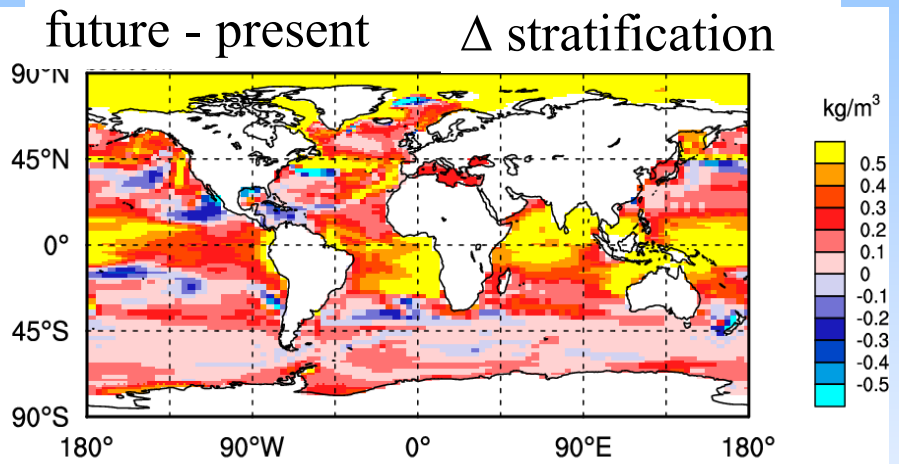
- Ice Biomes: Climate change increases light supply to phytoplankton, increasing total Chl and Primary Production

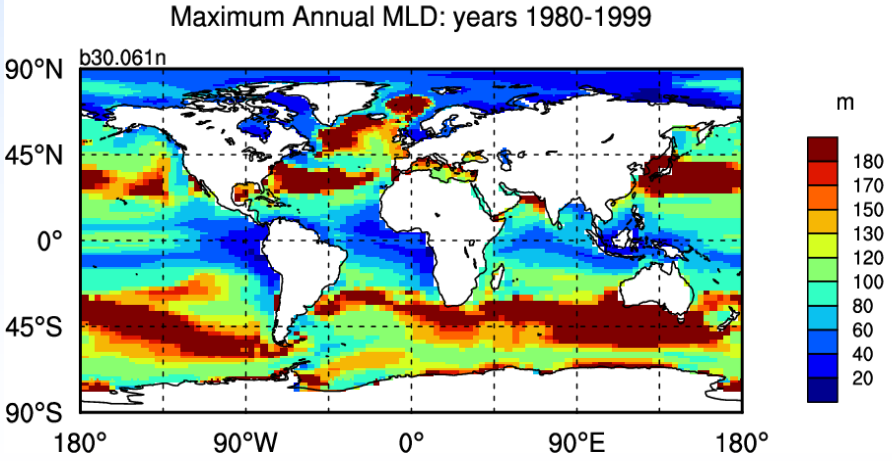

Total historical CO_2 emissions + SRES A2
Fossil only historical CO_2 emissions
SRES B1
Emissions [Gt C / yr]
a
SRES A2
SRES B1
Observations
Control
Atm. CO_2 [ppm]
b
Brohan et al, [2006]
Atm. temperature anomaly [°C]
c
Volcano
POC - Export [Gt C / yr]
e
Year

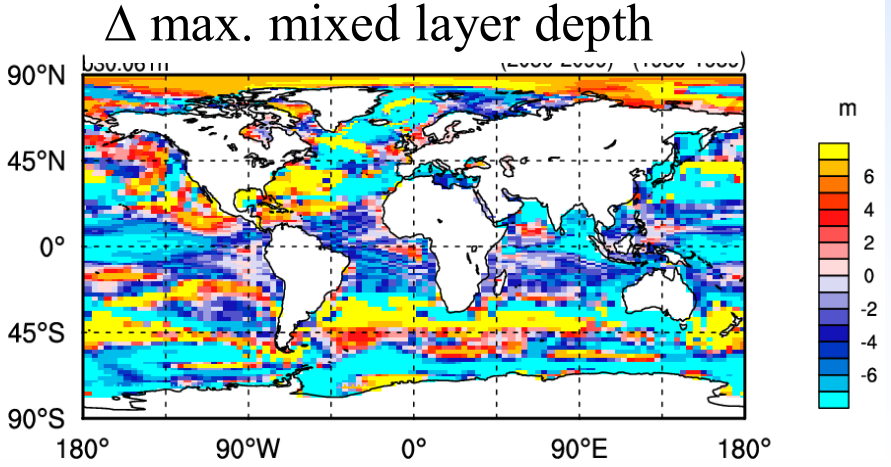
- Increased stratification over most of the ocean

- Less change in Southern Ocean stratification, because of the counteracting impact of stronger winds

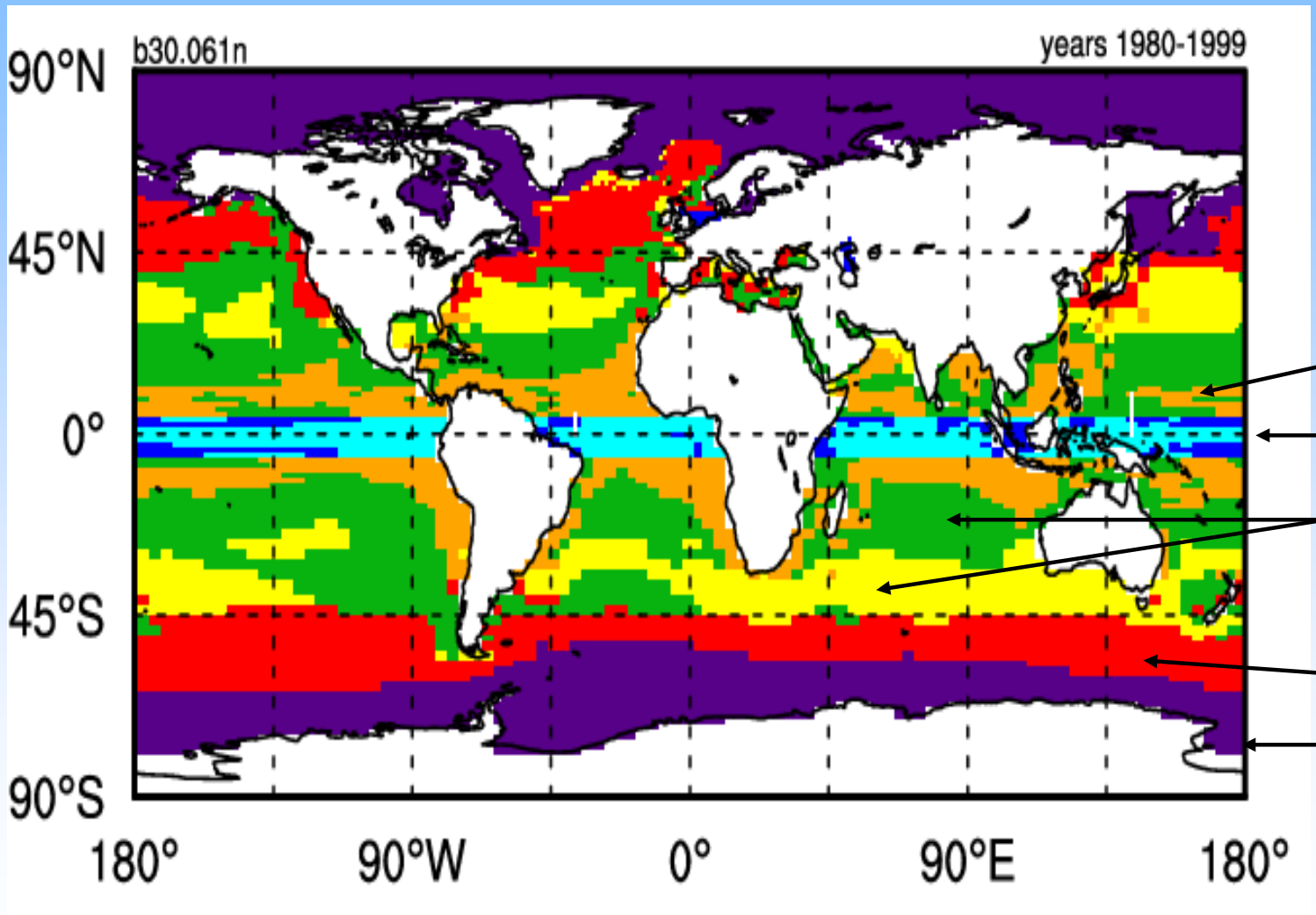








Separate ecological biomes (based on physical principles)



* technique as in Sarmiento et al. 2004