Marine Biogeochemistry

Coupling between marine biogeochemistry and climate

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Marine Biogeochemistry

Coupling between marine biogeochemistry and climate

1. Climate change and Marine productivity
2. Climate change and the ocean carbon cycle
3. Geoengineering options involving ocean biota

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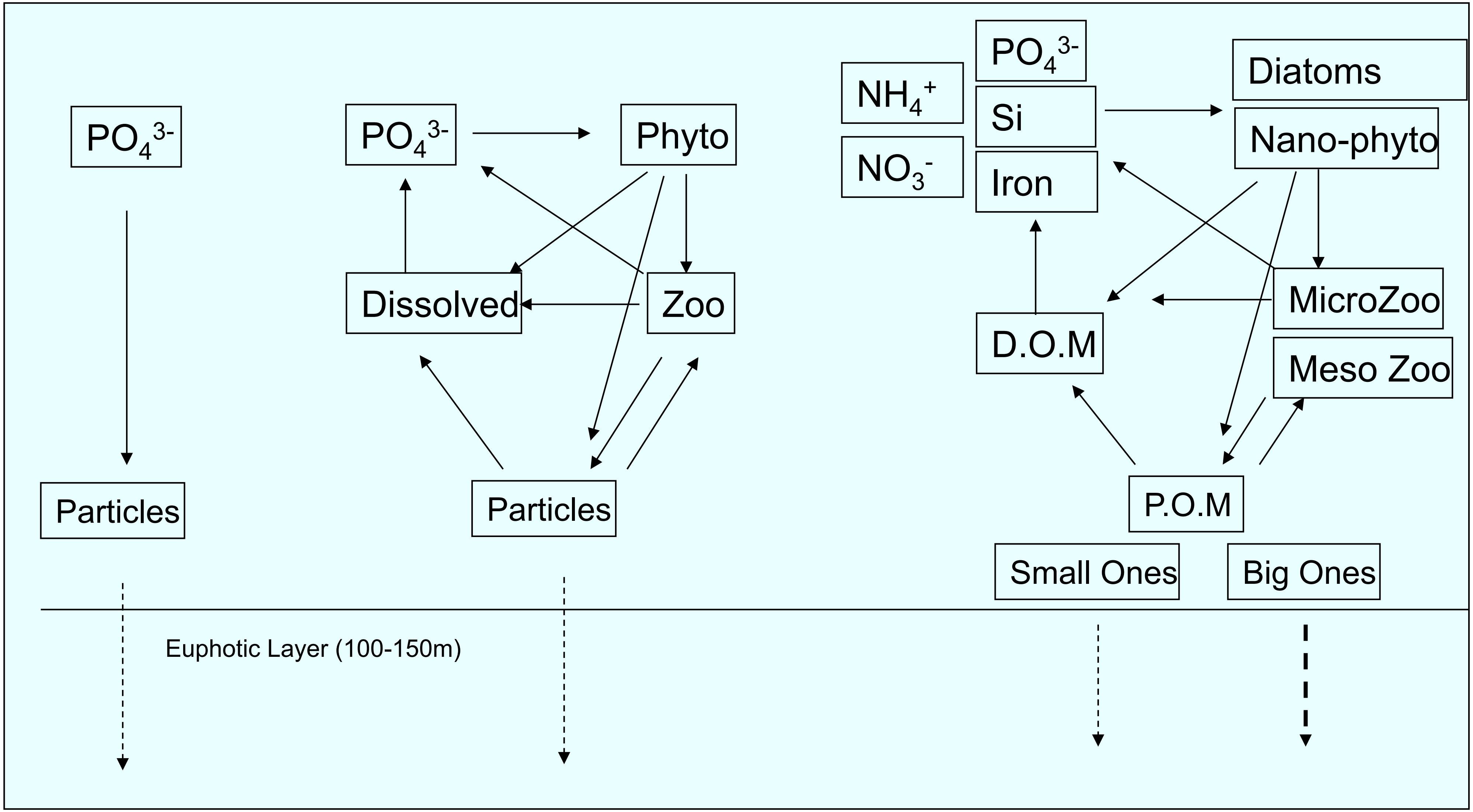
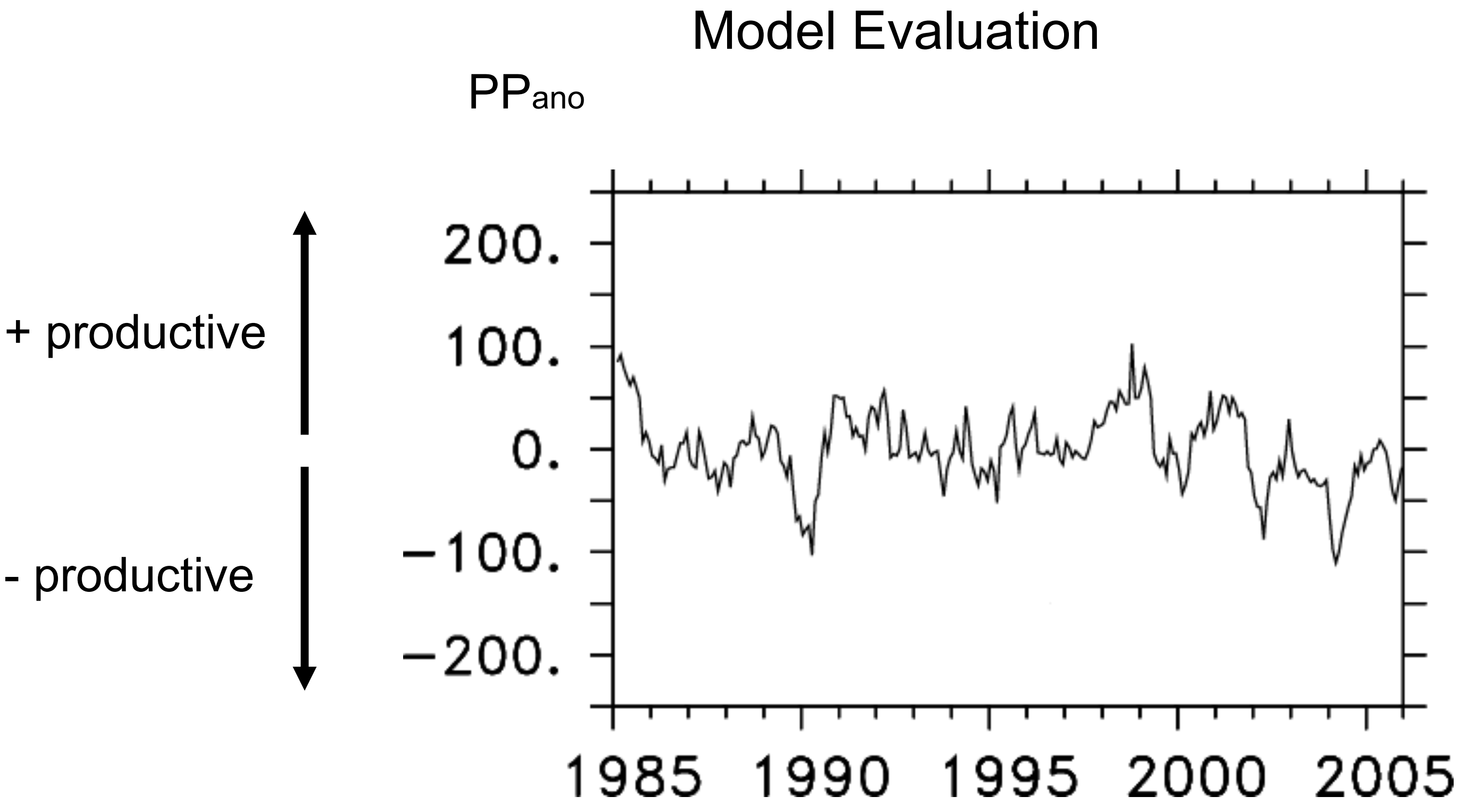
Marine Biogeochemical Models used in GCMs

Geochemical Models …… to ….. Simple Ecosystem Models



Climate variability and NPP



PP$_{ano}$ = anomaly of NPP (TgC/month)

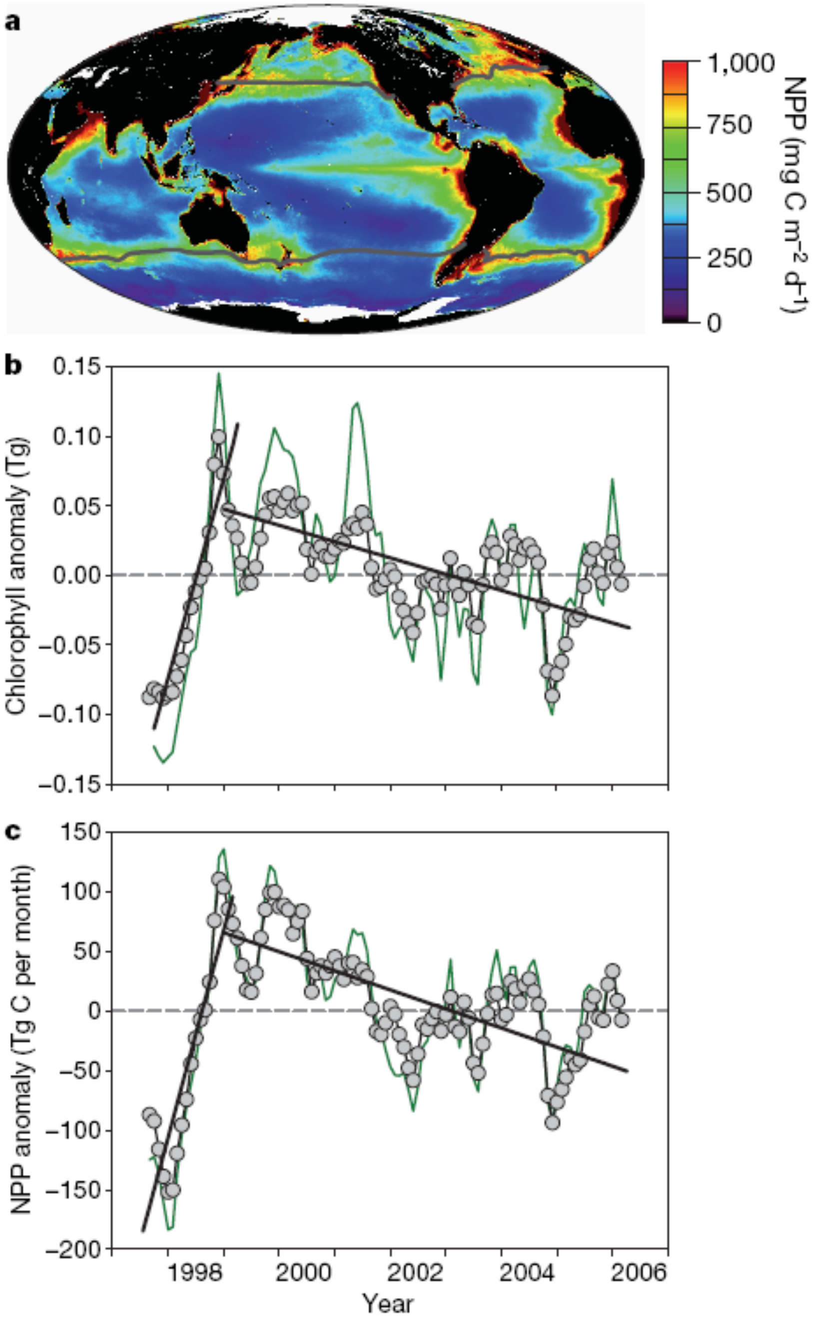
IPSL Model
(Schneider et al. 2008)

Climate variability and NPP

LETTERS

Climate-driven trends in contemporary ocean productivity

Michael J. Behrenfeld[1], Robert T. O'Malley[1], David A. Siegel[3], Charles R. McClain[4], Jorge L. Sarmiento[5], Gene C. Feldman[4], Allen J. Milligan[1], Paul G. Falkowski[6], Ricardo M. Letelier[2] & Emmanuel S. Boss[7]

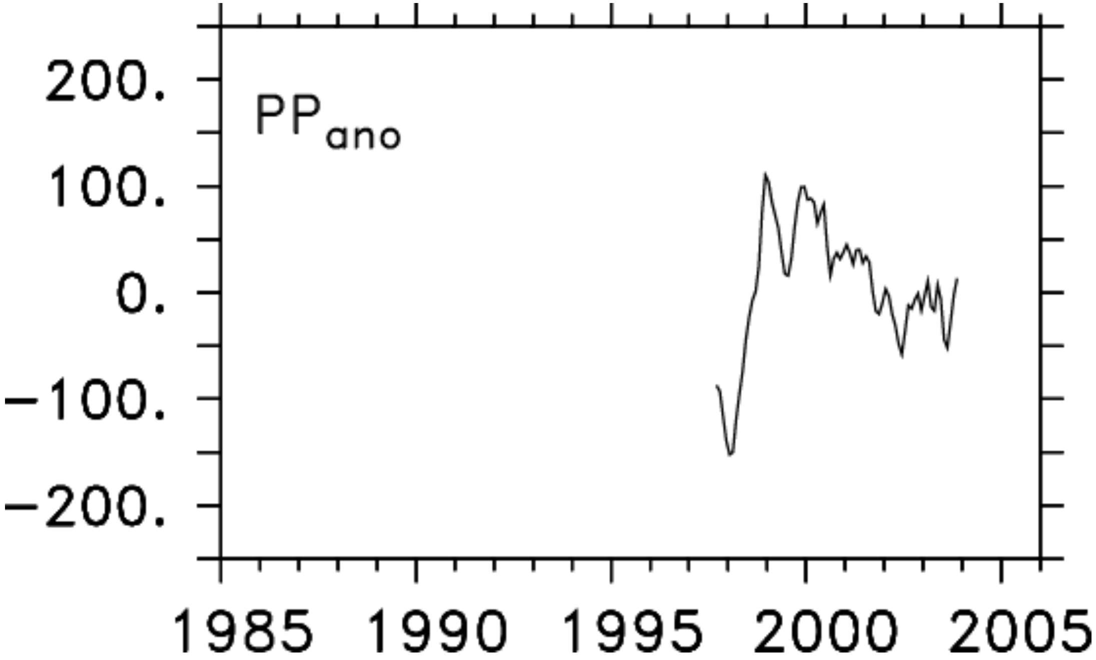


Climate variability and NPP : ENSO - Observations

PP_{ano}

+ productive

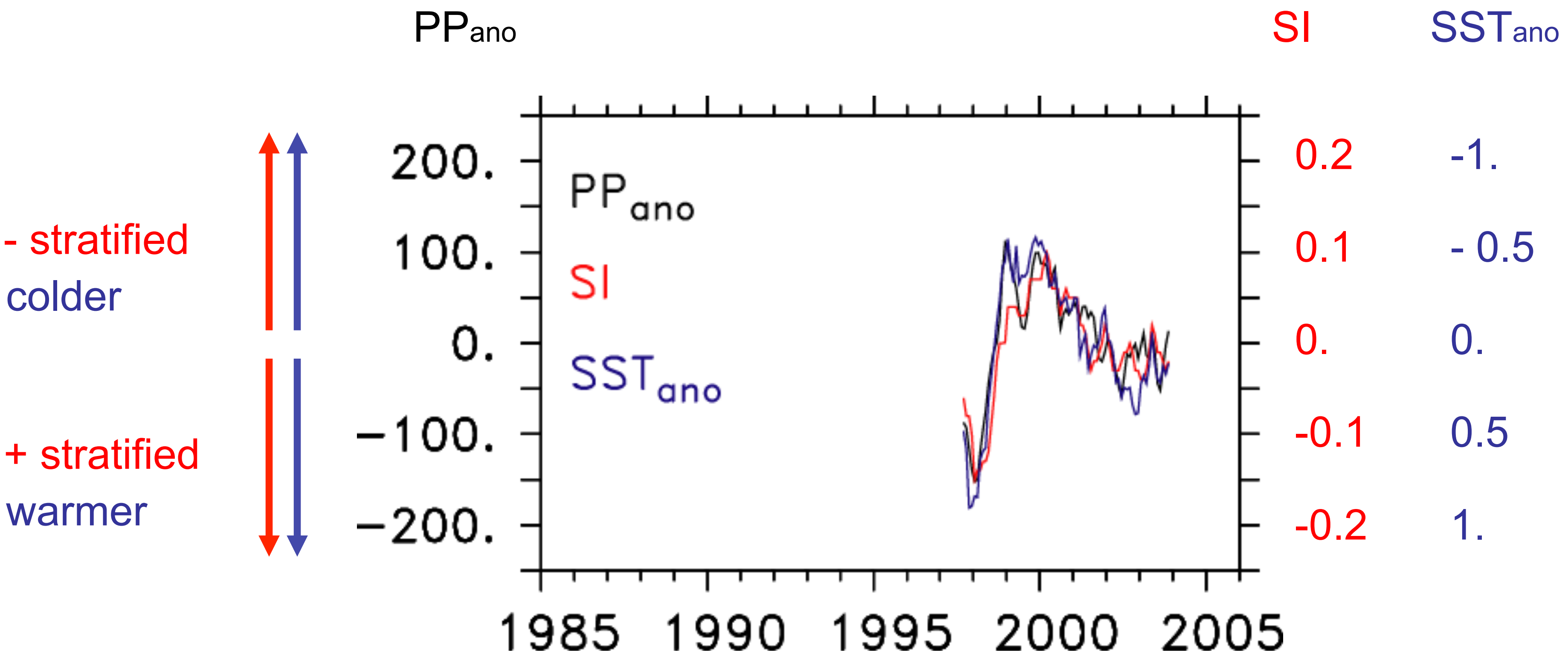
- productive



PP_{ano} = anomaly of NPP (TgC/month)

From SeaWifs (Behrenfeld et al. 2006)

Climate variability and NPP: ENSO - Observations

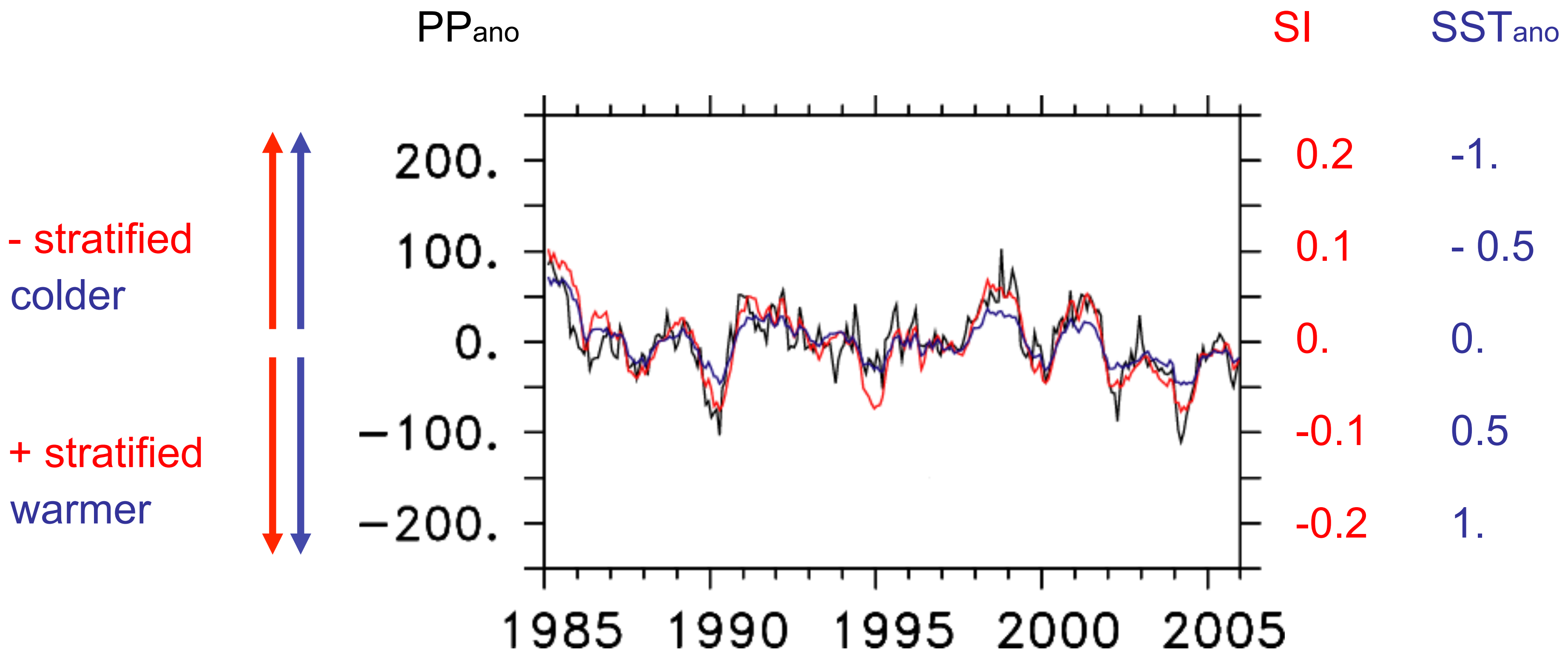


PP_{ano} = anomaly of NPP (TgC/month)

SI = stratification index : $\rho_{200} - \rho_{surf}$ (kg m-3)

SST_{ano} = anomaly of SST (°C)

Climate variability and NPP : ENSO - IPSL model



- stratified
colder

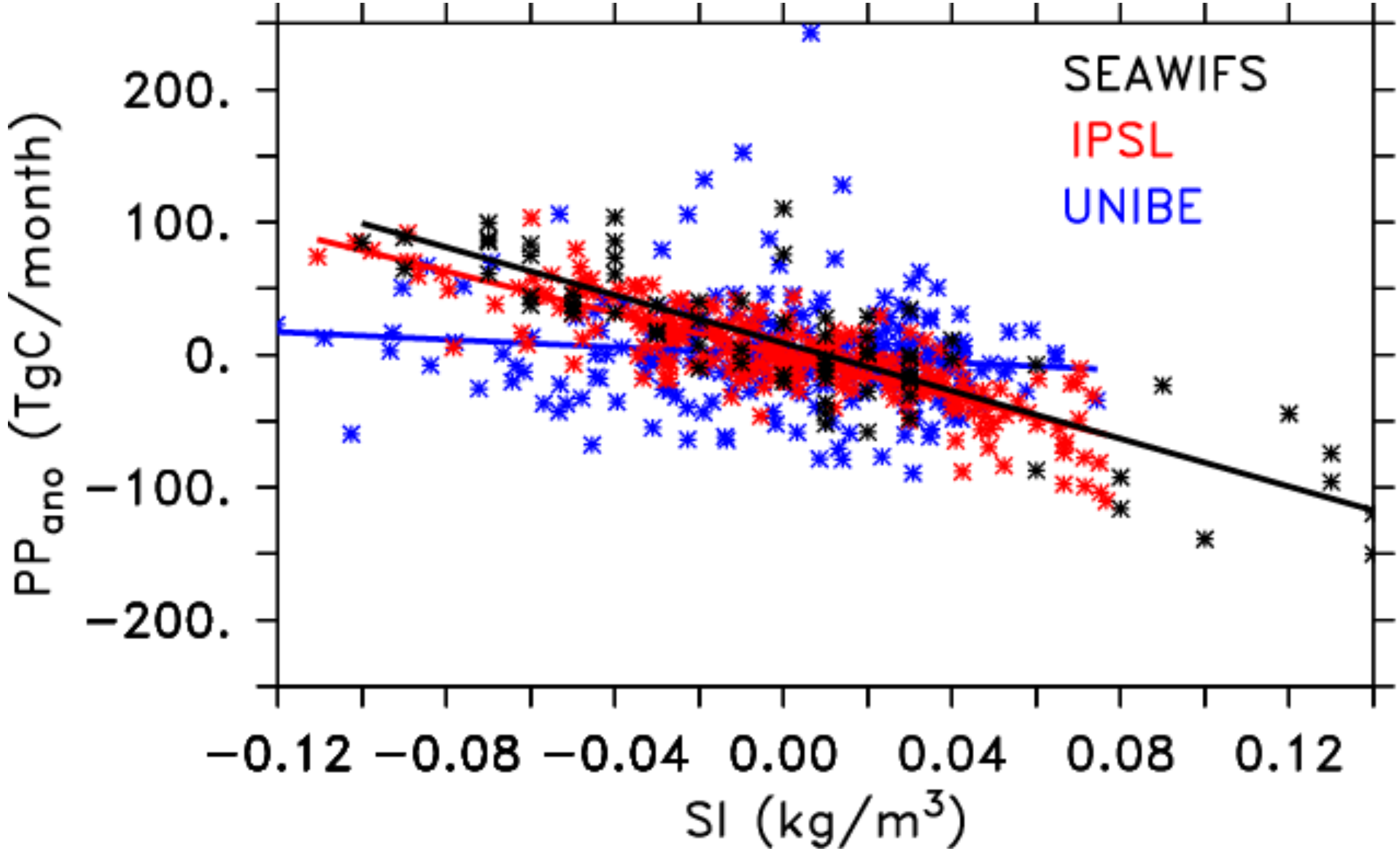
+ stratified
warmer

PP_{ano} = anomaly of NPP (TgC/month)

SI = stratification index : $\rho_{200} - \rho_{surf}$ (kg m-3)

SST_{ano} = anomaly of SST (°C)

Climate variability and NPP: ENSO

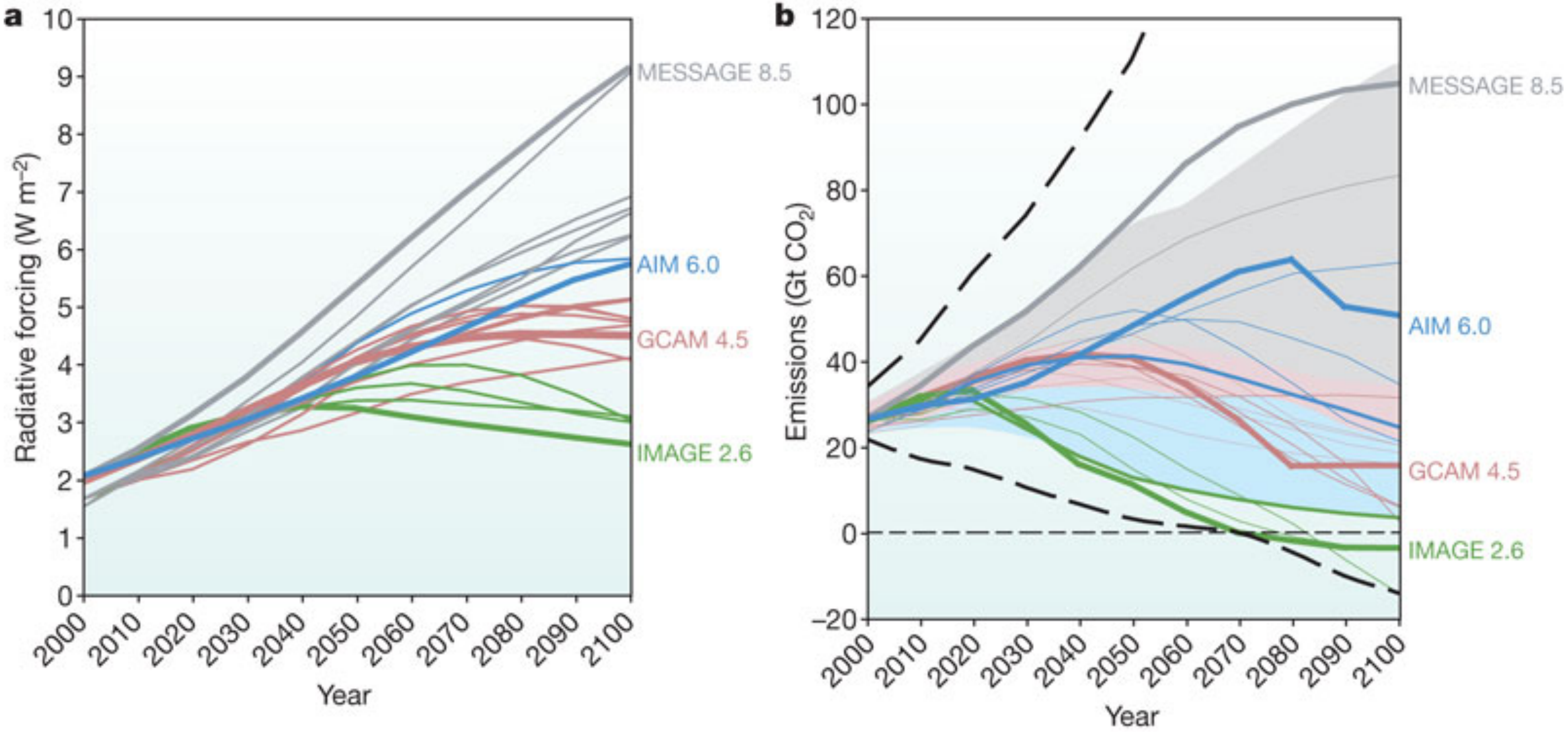


PP dependence on stratification

SEAWIFS -876 TgC month^{-1} kg^{-1} m^{3}; R^2=0.69
IPSL -787 TgC month^{-1} kg^{-1} m^{3} ; R^2=0.70
UNIBE -143 TgC month^{-1} kg^{-1} m^{3} ; R^2=0.02

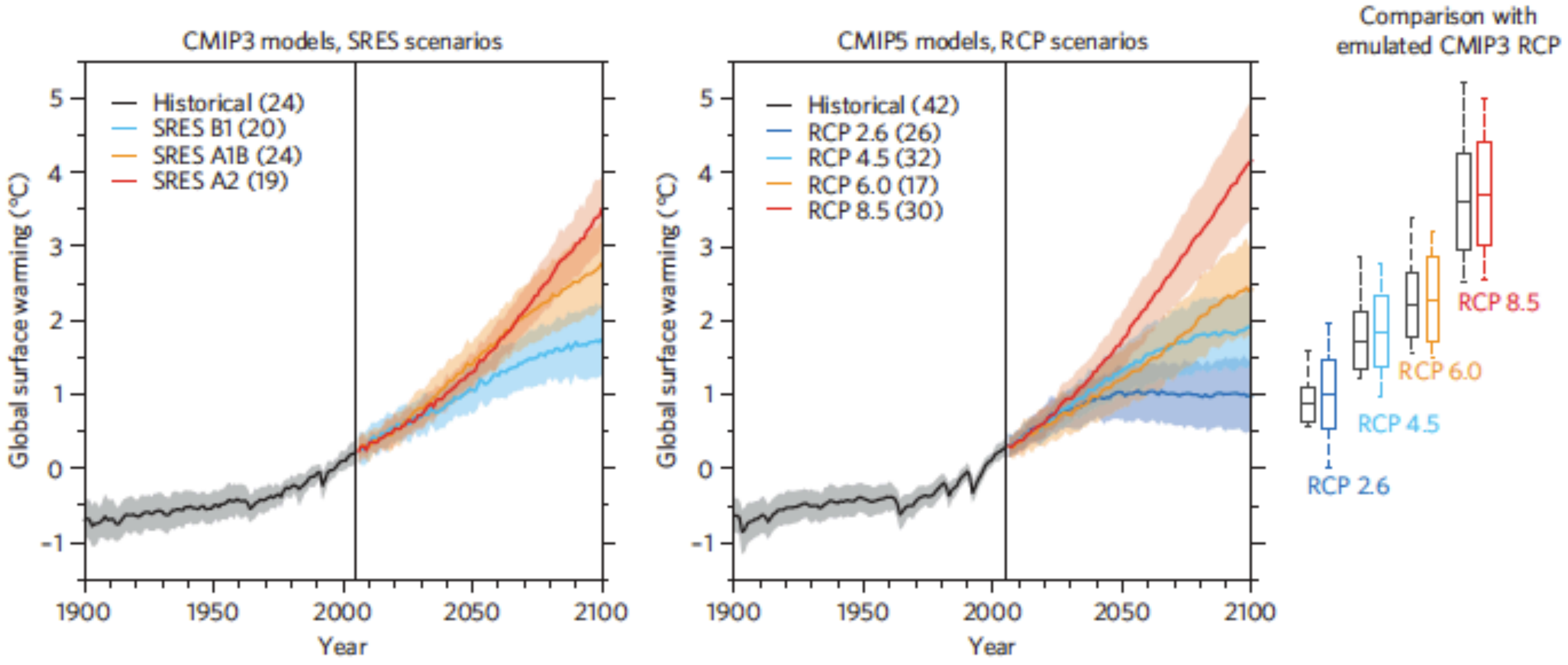
Scenarios for projections

Representative concentration pathways.



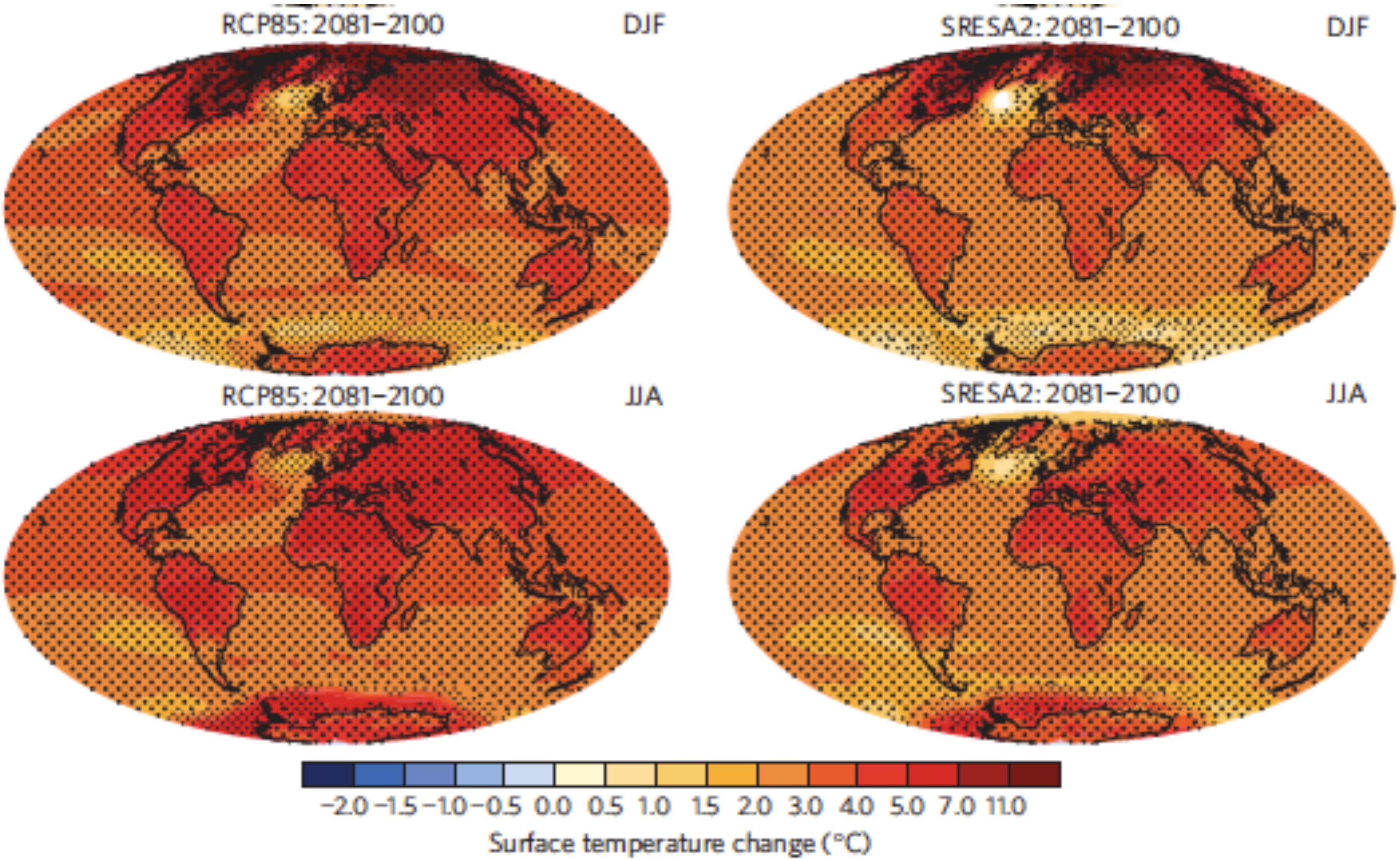
RH Moss *et al. Nature* **463**, 747-756 (2010) doi:10.1038/nature08823

Projections: Global Mean Temperature



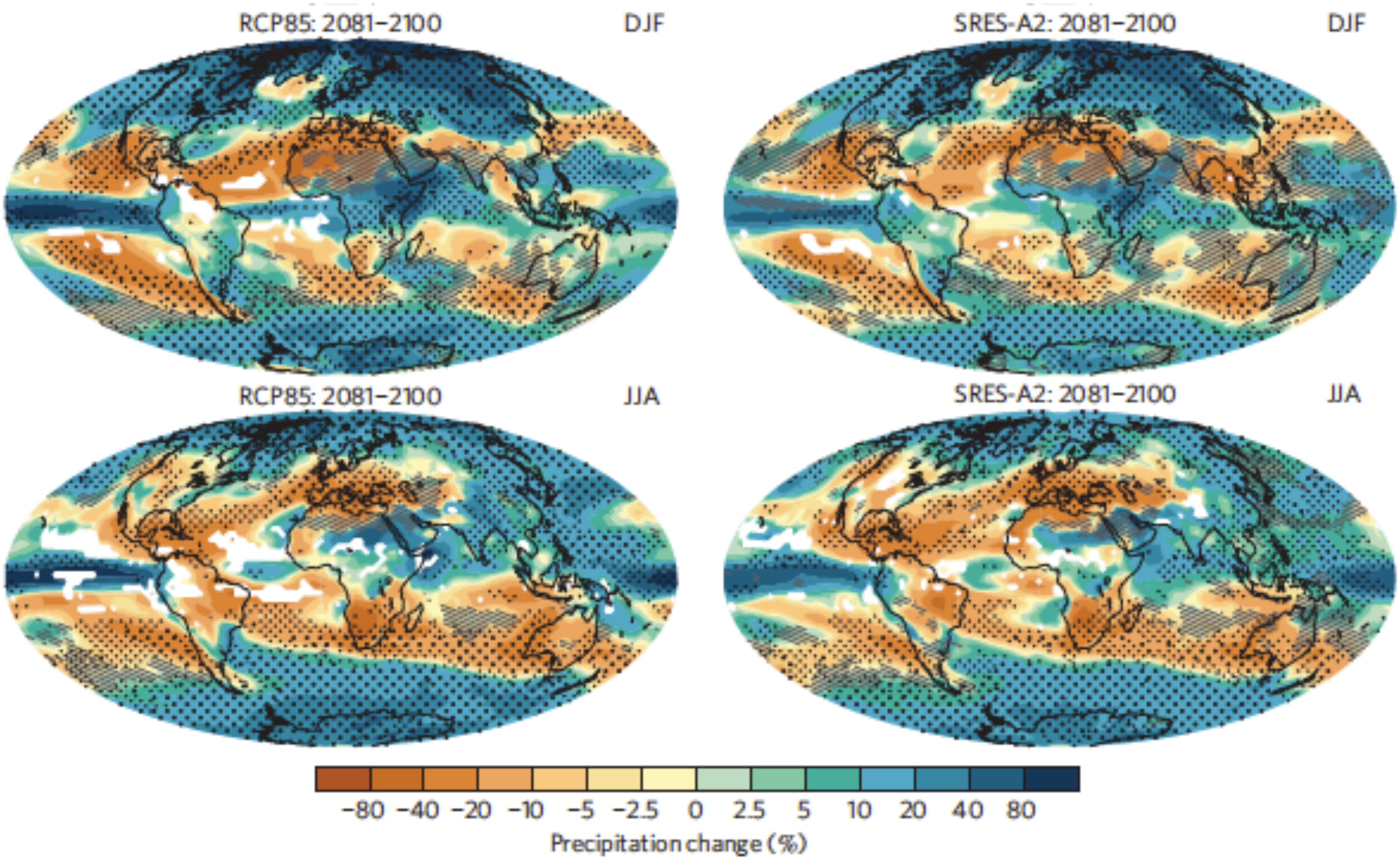
Knuti and Sedlacek, NCC, 2012

Temperature Changes



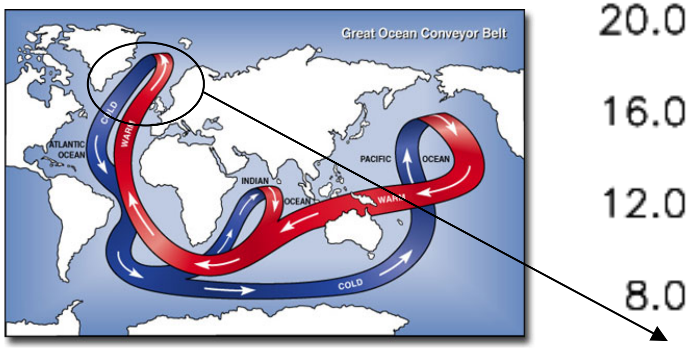
Knuti and Sedlacek, NCC, 2012

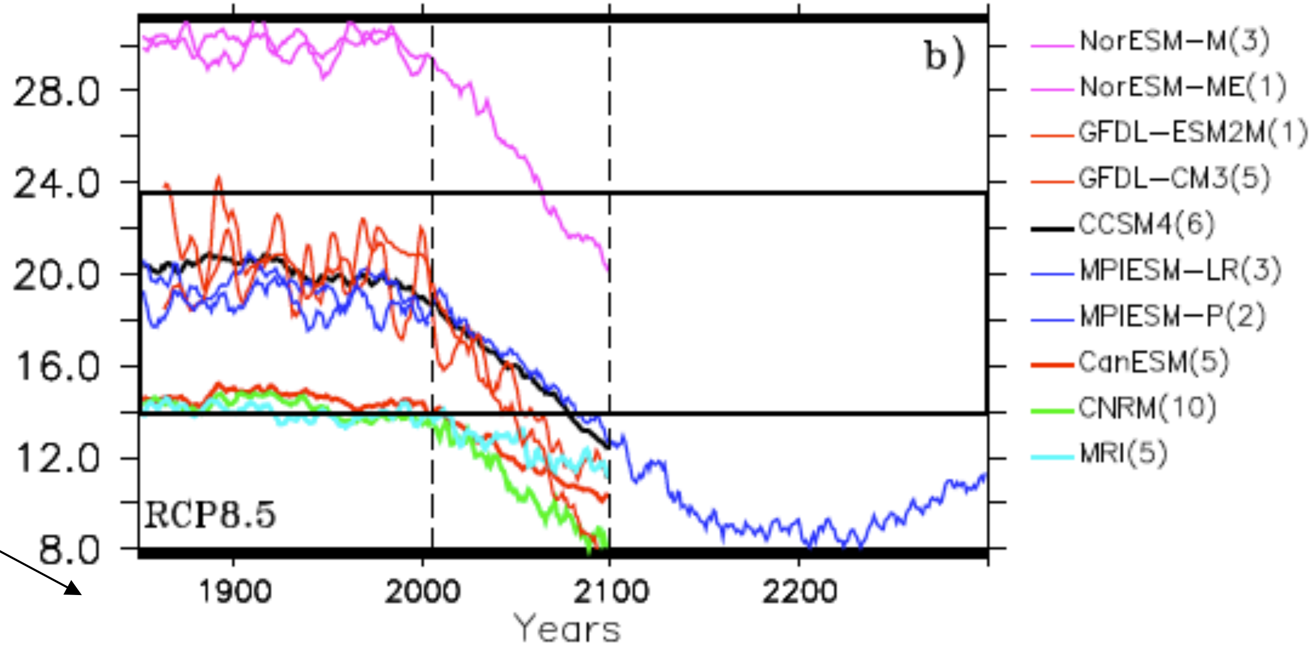
Precipitation Changes

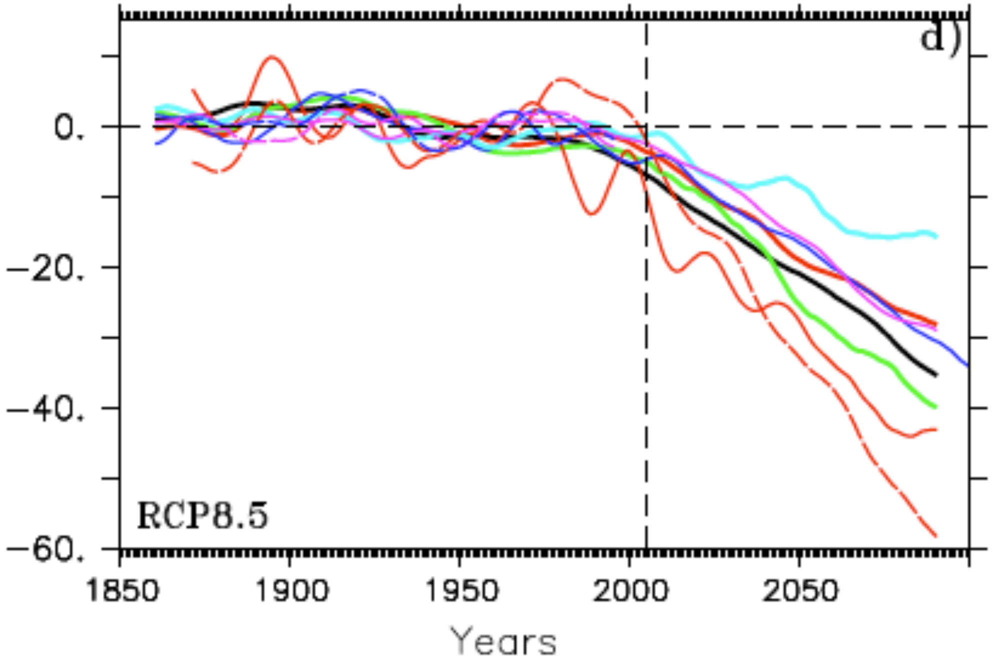


Knuti and Sedlacek, NCC, 2012

Atl. Meridional Overturning CIrculation



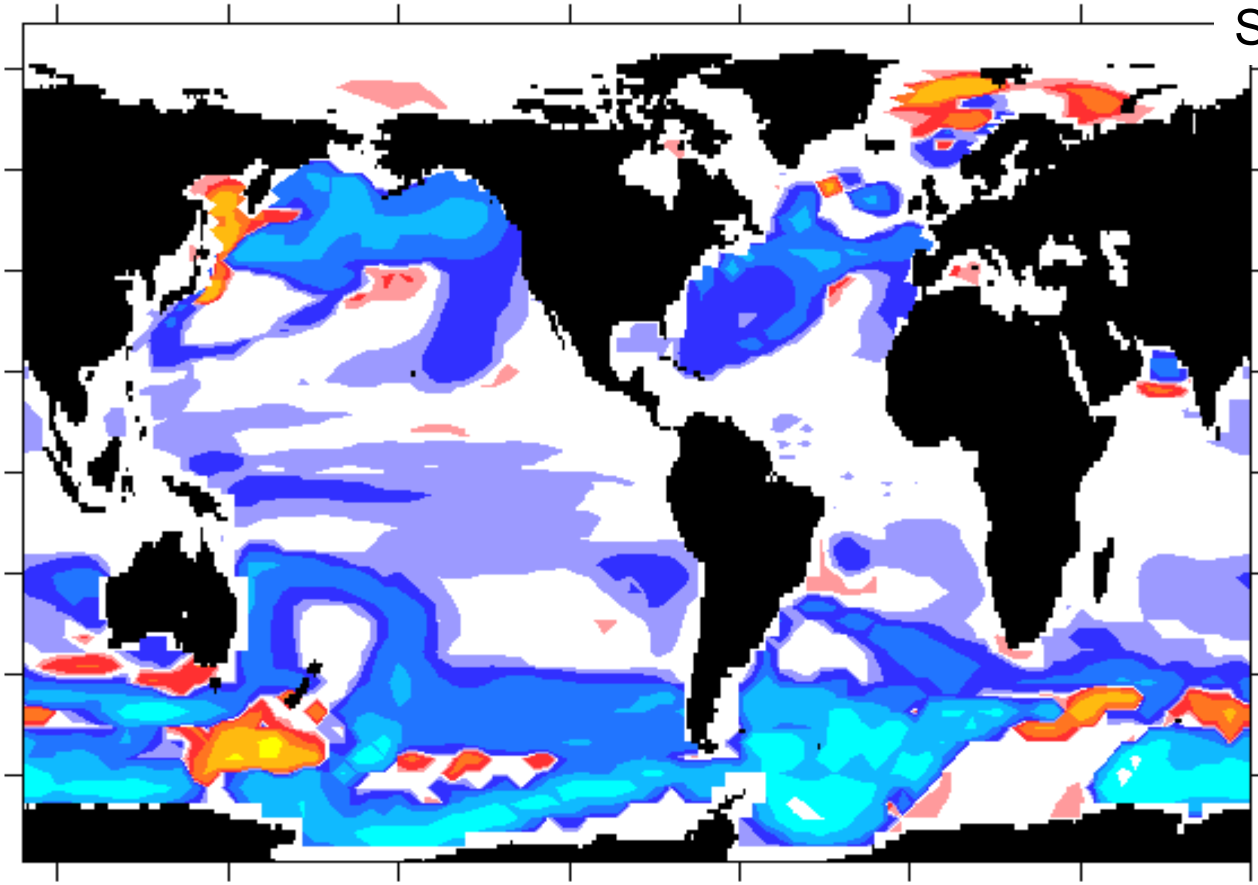




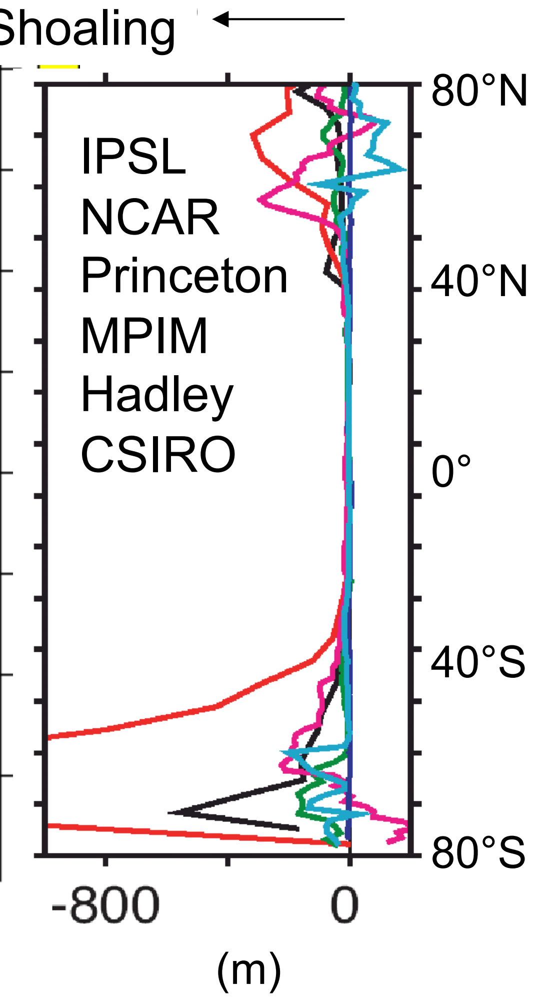
Cheng et al. sub.

Stratification

- Shoaling of Mixed Layer Depth w/ climate change



IPSL-CM2, MML, 2075-Present

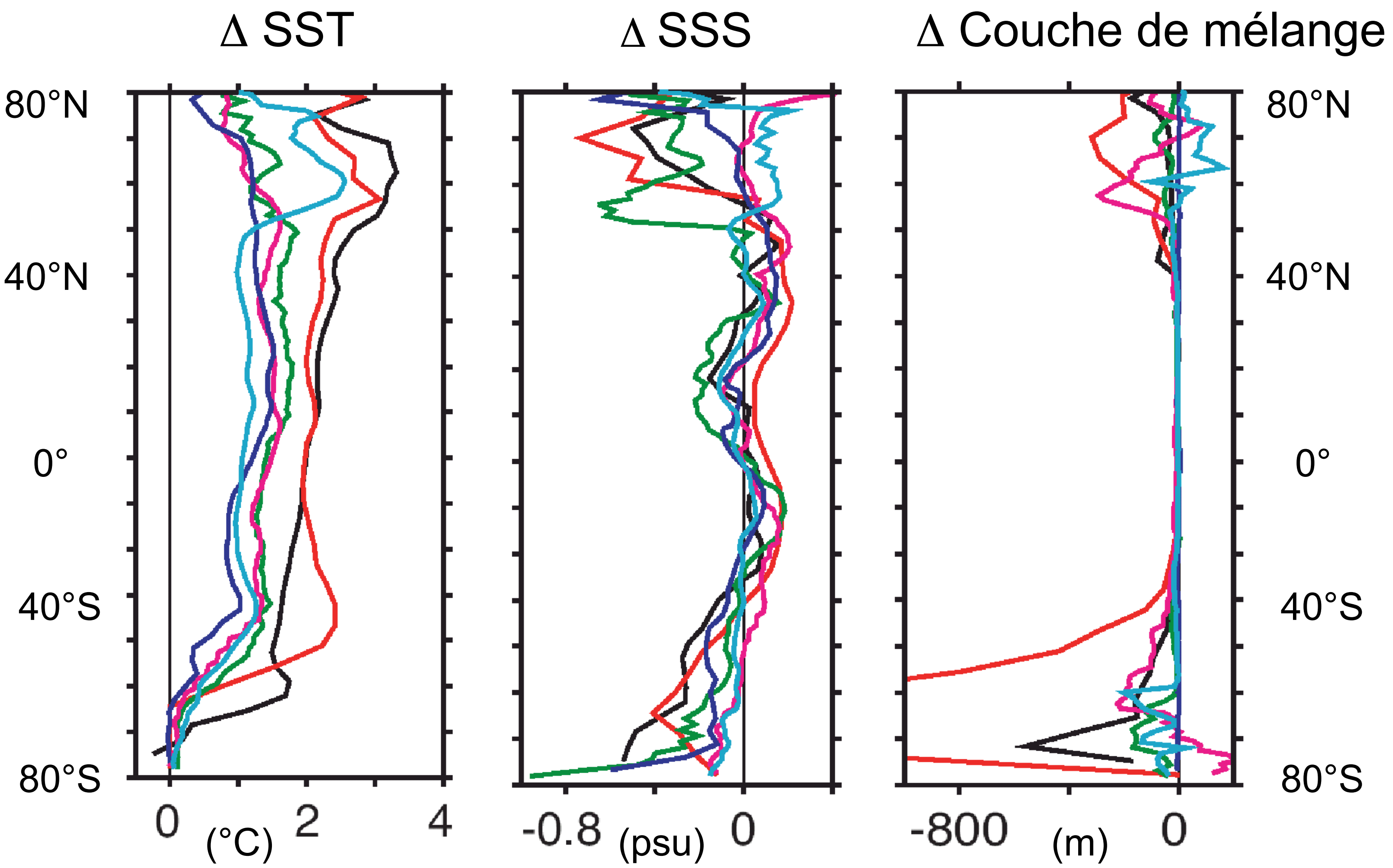


Sarmiento et al. 2004

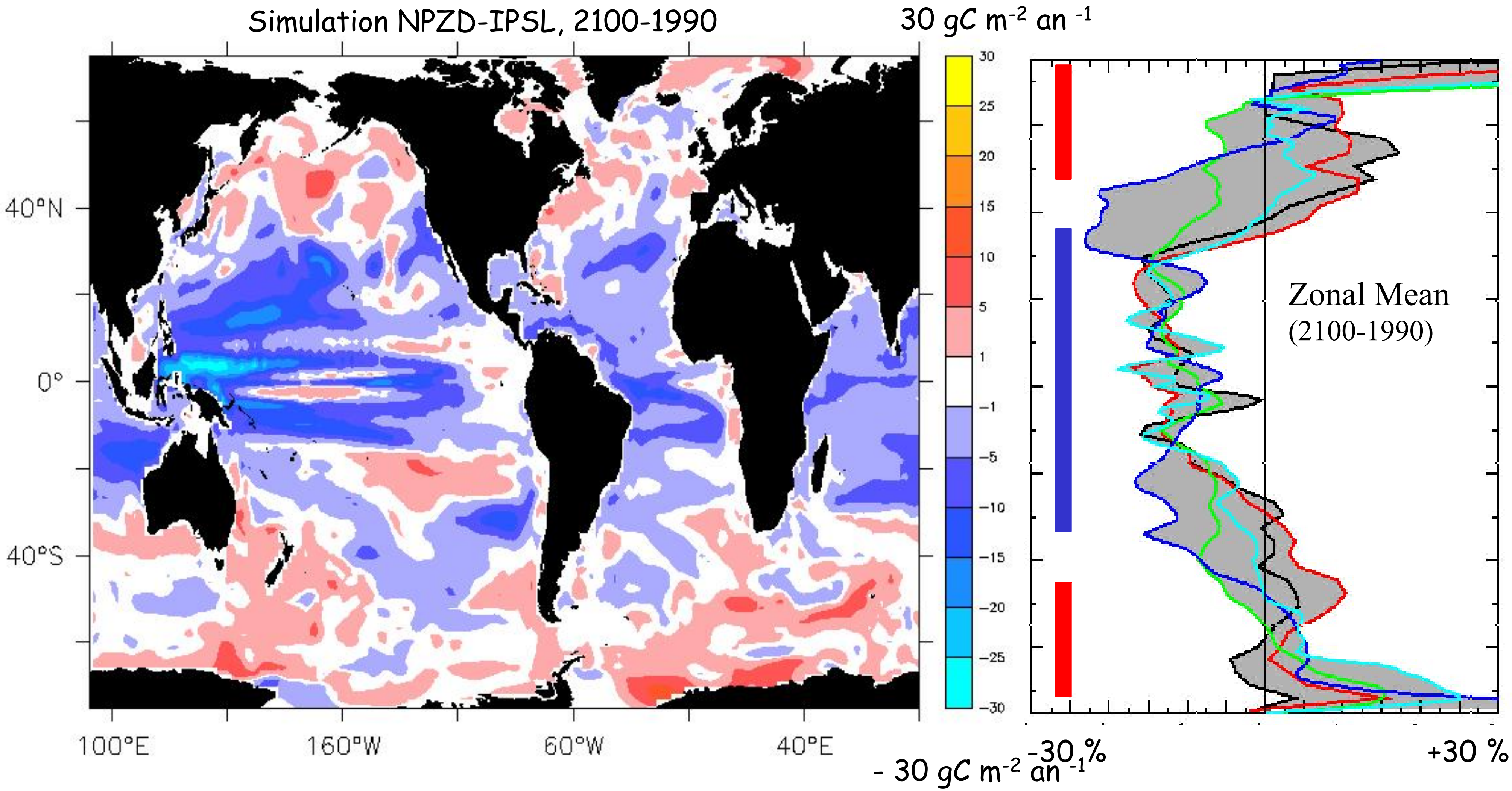
Stratification

- Mecanisms

Sarmiento et al. 2004

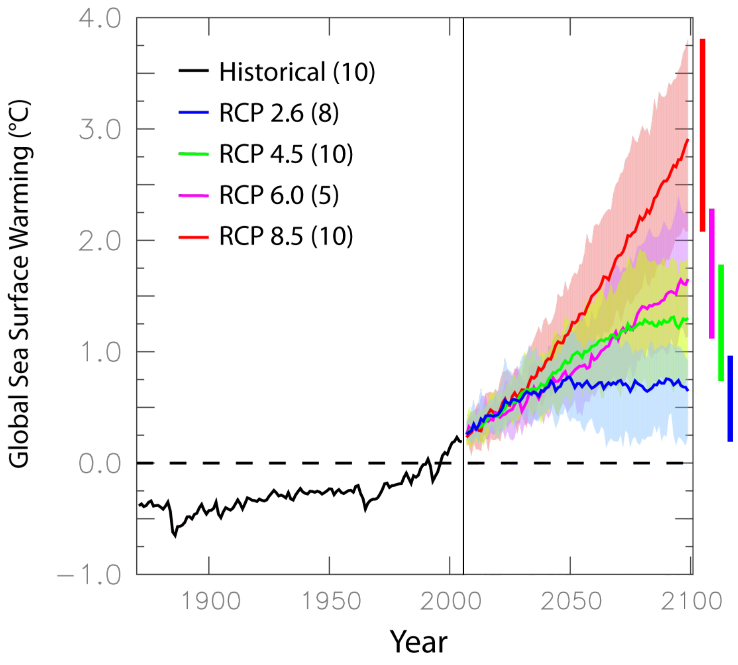


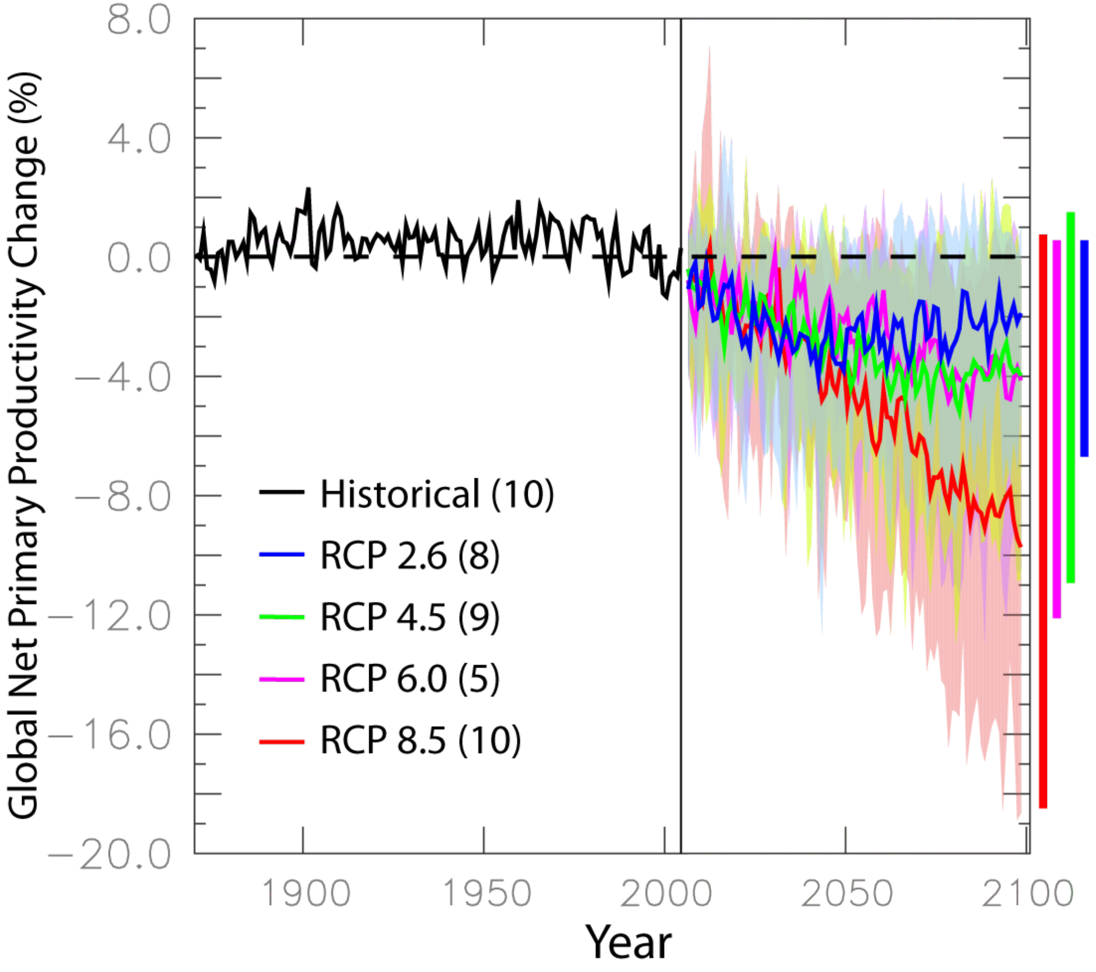
Changes in Marine NPP



- Global decrease (-5/10%), but increase at high latitudes (+20/30%)

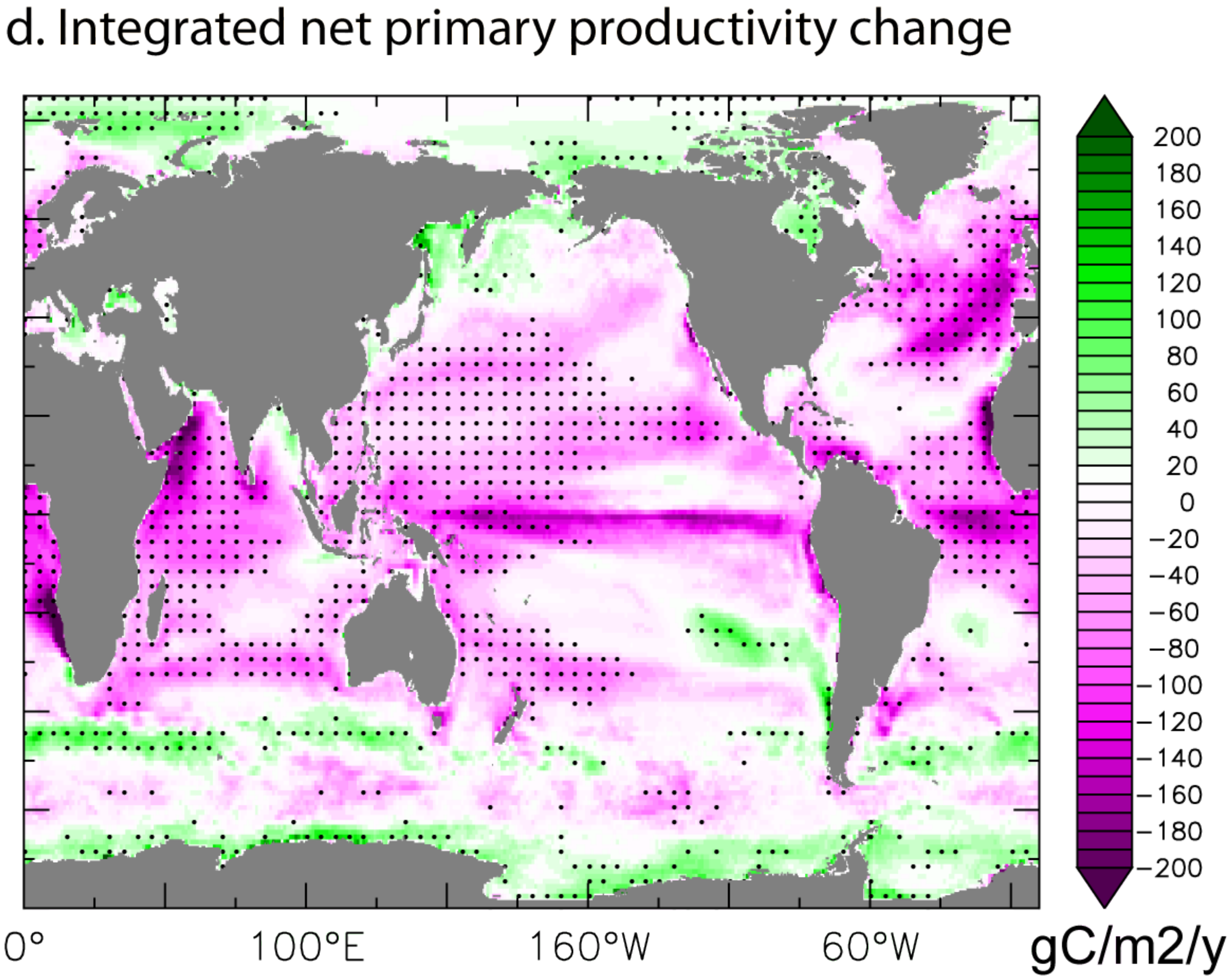
- Similar responses with different models (Bopp et al. 2001)





Bopp et al. 2013

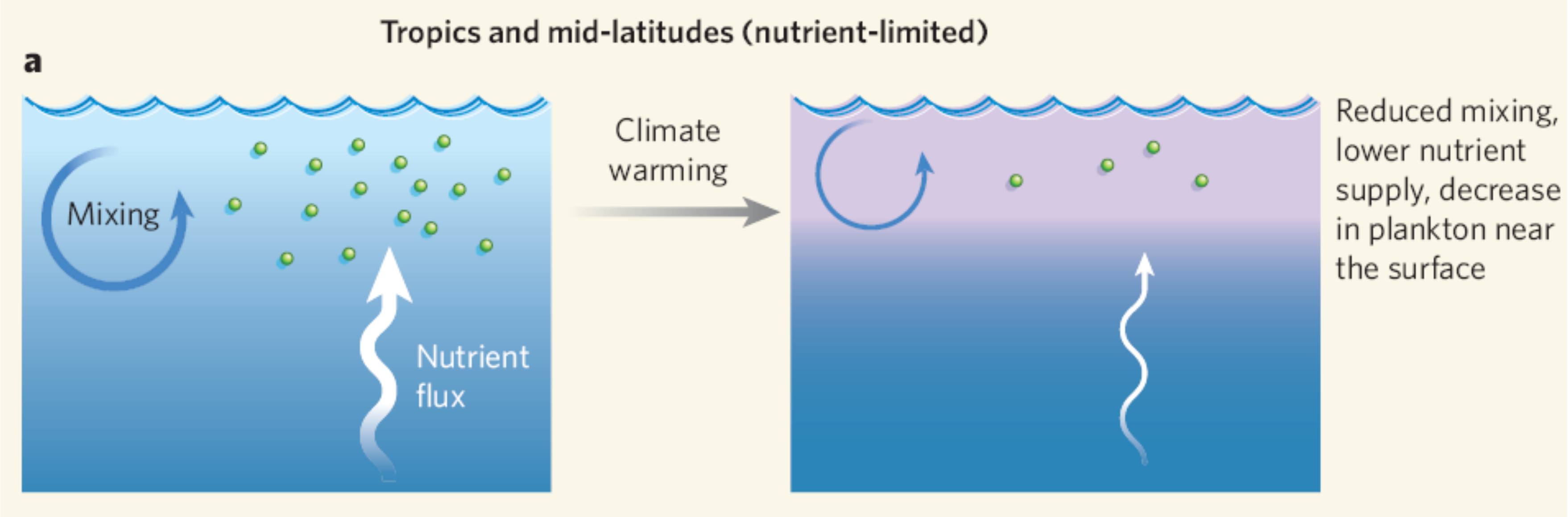
Changes in Marine Productivity



Bopp et al. 2013

Impact of climate change

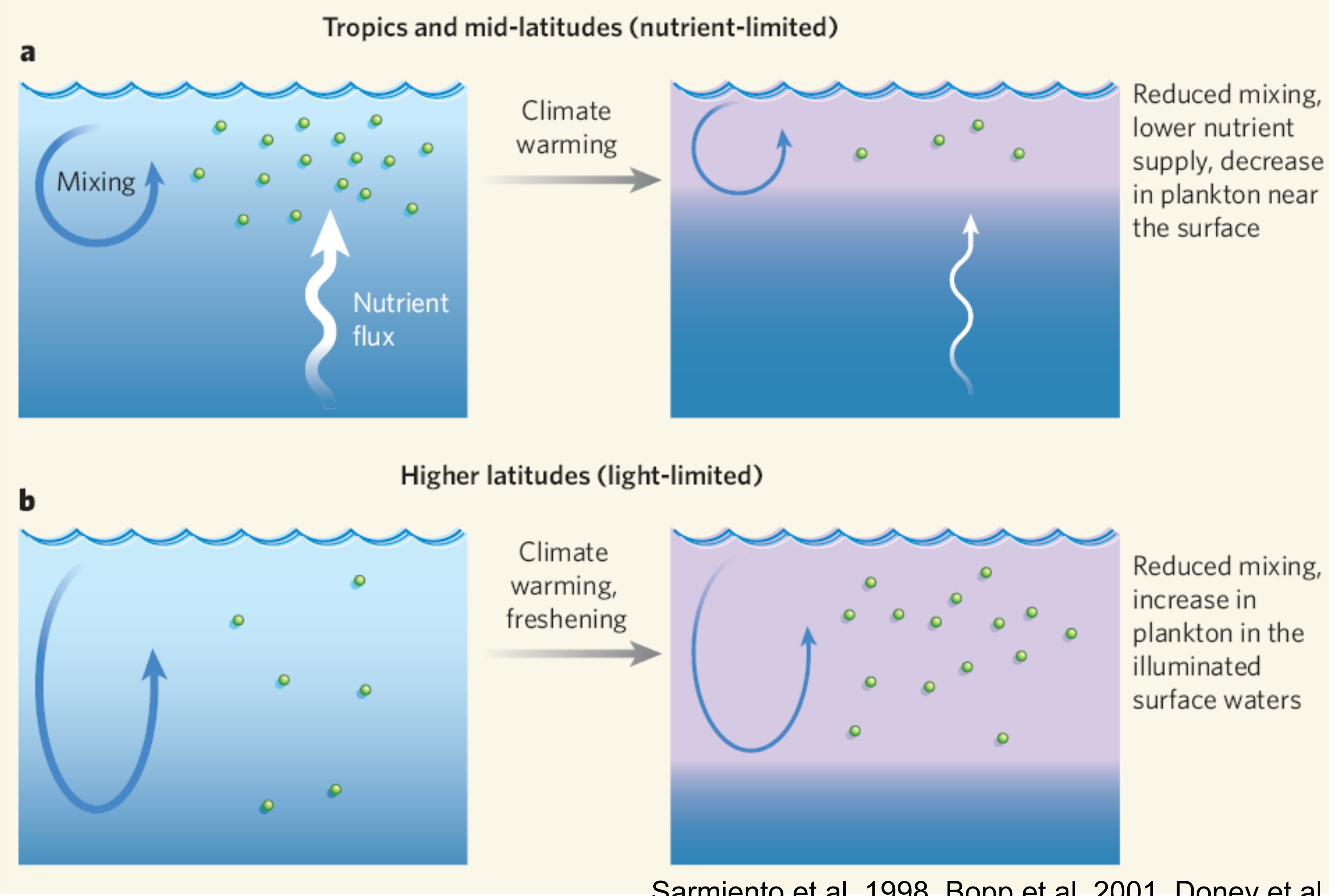
- **Climate Change impact** on marine productivity : mechanisms



Sarmiento et al. 1998, Bopp et al. 2001, Doney et al. 2006

Impact of climate change

- **Climate Change impact** on marine productivity : mechanisms



Sarmiento et al. 1998, Bopp et al. 2001, Doney et al. 2006

Marine Biogeochemistry

Coupling between marine biogeochemistry and climate

1. Climate change and Marine productivity
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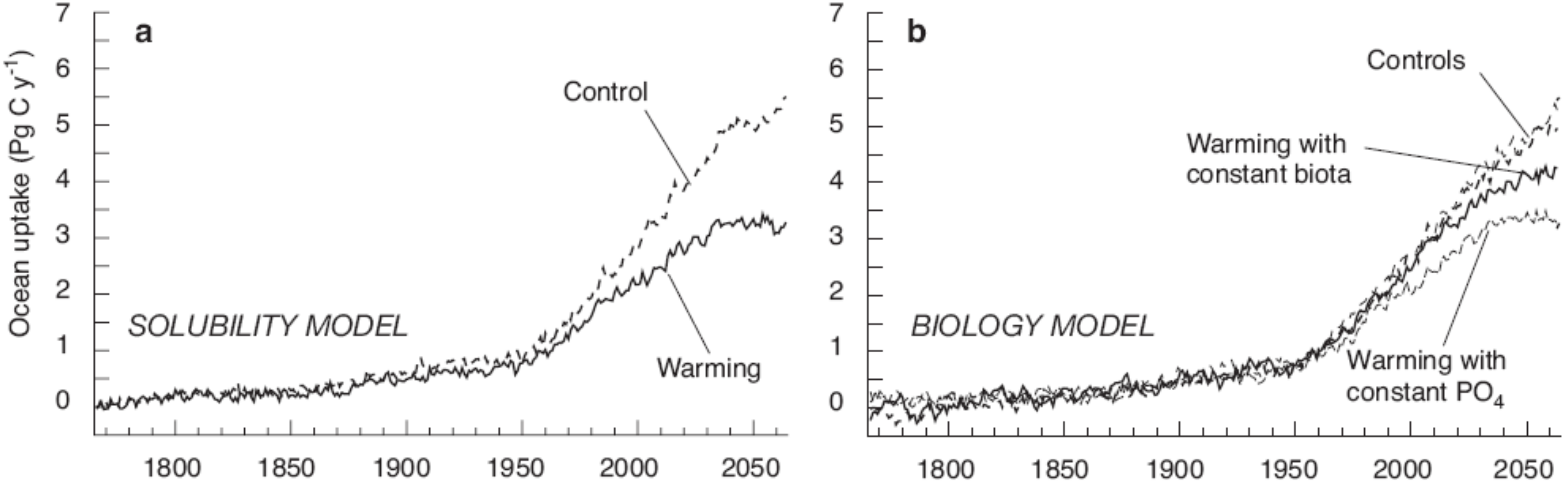
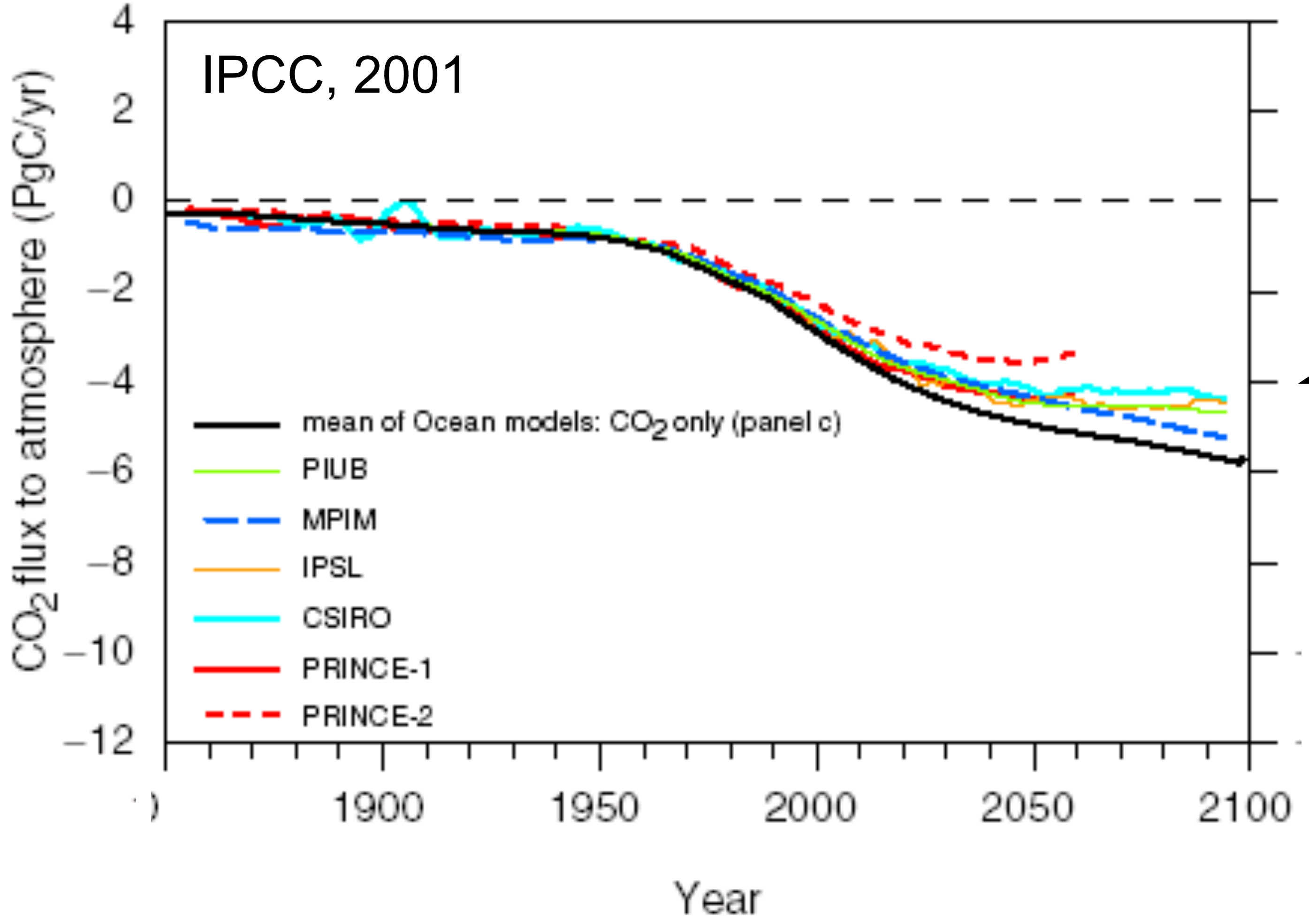
2. Climate and Marine Biogeochemistry : Carbon Fluxes

First Studies w/ GCMs : Maier-Reimer et al. (1996), Sarmiento et al. (1996, 1998)

Sarmiento et al. 1998



2. Climate and Marine Biogeochemistry : Carbon Fluxes


IPCC, 2001

Climate
Change
Impact

- Climate Change reduces ocean CO_2 sink
  (from –6% to –25% in 2050)

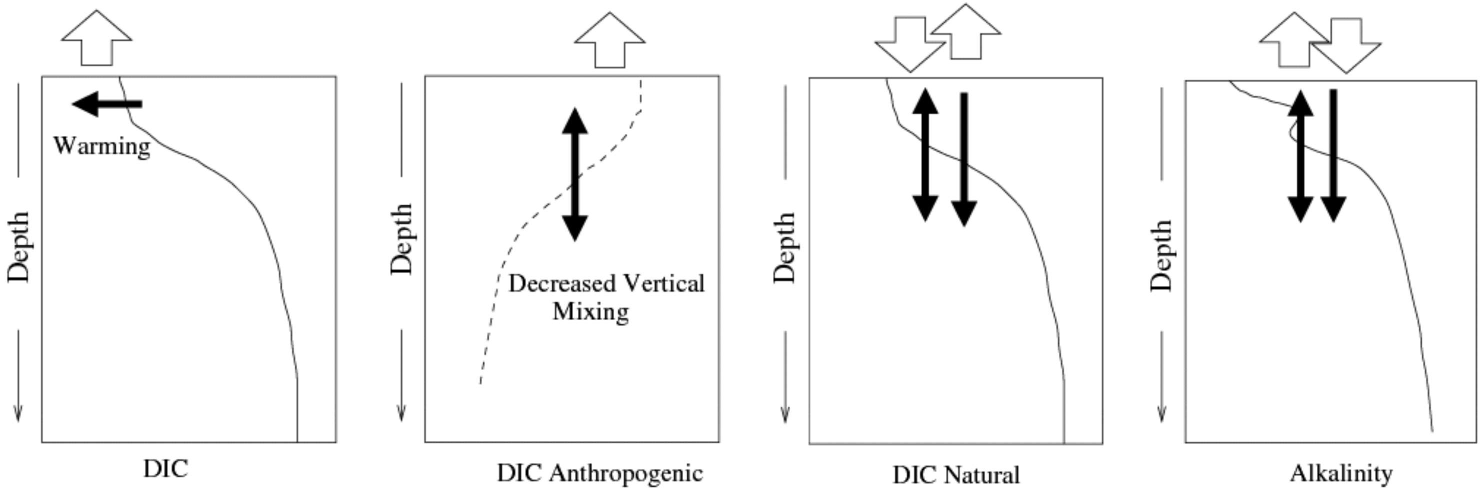
2. Climate and Marine Biogeochemistry : Carbon Fluxes

- Mechanisms

Thermal

Circulation

Re-Organisation of the Natural C Cycle



2. Climate and Marine Biogeochemistry : Carbon Fluxes

Potential Retroactions?

	Direction	& Uncertainty
1. Chemical: Acidification reduces the ability of the oceans to absorb anthopogenic CO2	+	Certain
2. Thermal: Warming decreases solubility, which leas to CO2 outgassing	+	Certain

2. Climate and Marine Biogeochemistry : Carbon Fluxes

Potential Retraoctions?

Sens et certitude

3. Physical : + Likely

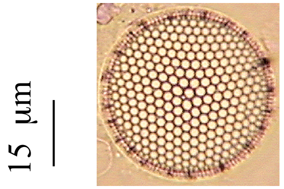
Warming induced stratification and reduced ventilation prevents anthropogenic carbon to penetrate into deeper oceanic layers

4. Biological : + / - ?

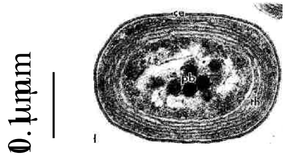
Organic C export
Planctonic ecosytem strtucture

4. Biological : + / - ?

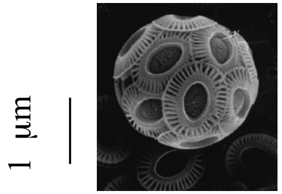
Production / Export de C
Structure de l’écosystème planctonique



Diatomées :
grosses cellules
à tests siliceux



Prochlorococcus :
petites cellules, recyclées
en surface



Coccolithophoridés :
tests calcaires
cycle des carbonates

Ocean C uptake simulated by the CMIP5 ESMs for the historical period and the 4 RCPs

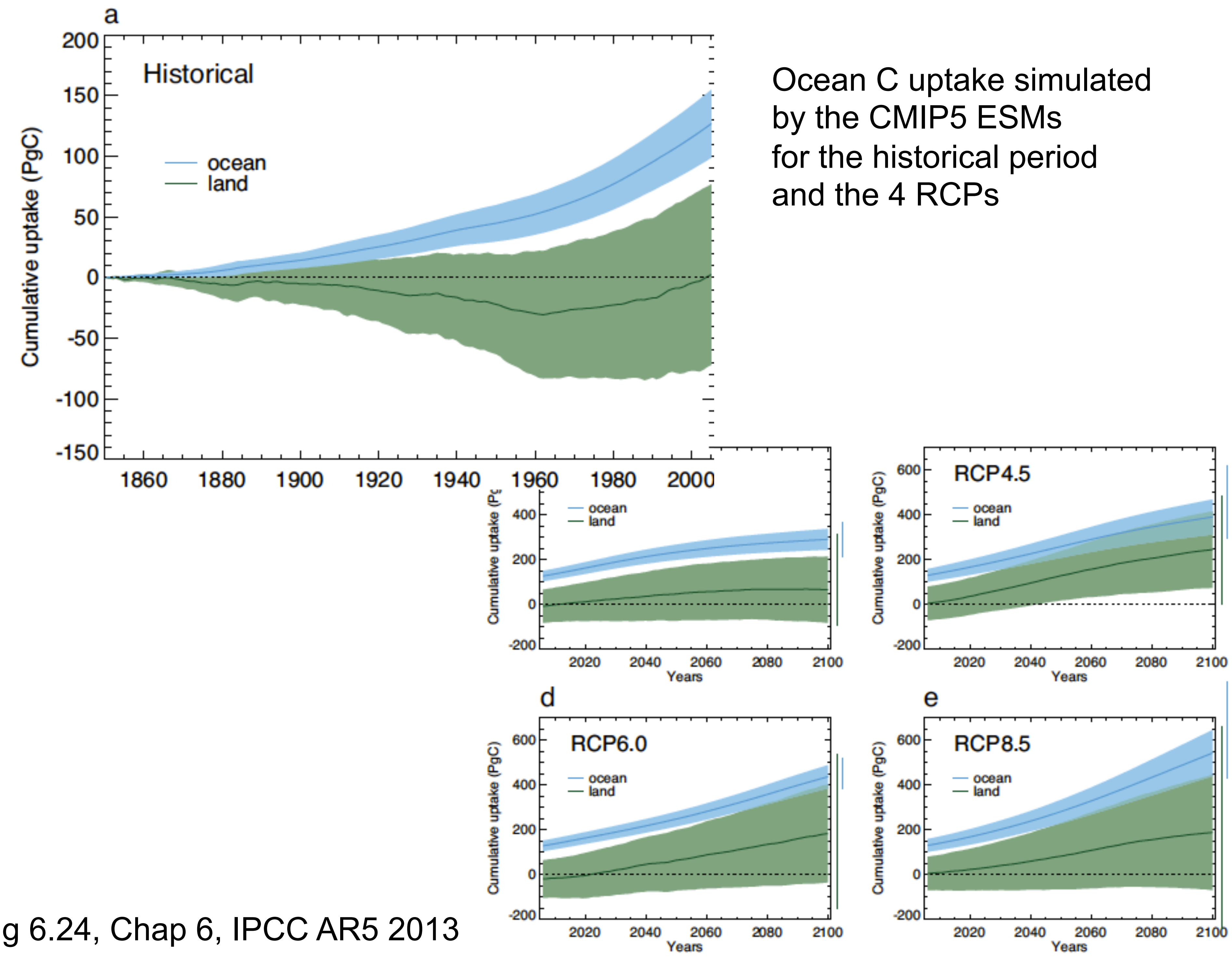


Fig 6.24, Chap 6, IPCC AR5 2013

Feedback Linear Analysis

$\Delta CO_2 = \text{emissions} - \Delta F_{ao} - \Delta F_{ab}$ (1)

$\Delta T = \alpha \Delta CO_2 + \Delta T_{ind}$ (2)

with:

$\Delta F_{ao} = \beta_{ao} \Delta CO_2 + \gamma_{ao} \Delta T$ (3)

$\Delta F_{ab} = \beta_{ab} \Delta CO_2 + \gamma_{ab} \Delta T$ (4)

$\Delta T = 1/(1-g) \Delta T_{unc}$

with:

$g = \alpha (\gamma_{ao} + \gamma_{ab})/(1+ \beta_{ao} + \beta_{ab})$

g is the gain of the retraoction

Climate Carbon Feedbacks

(Section 6.4.2)

Carbon-concentration effect (β)

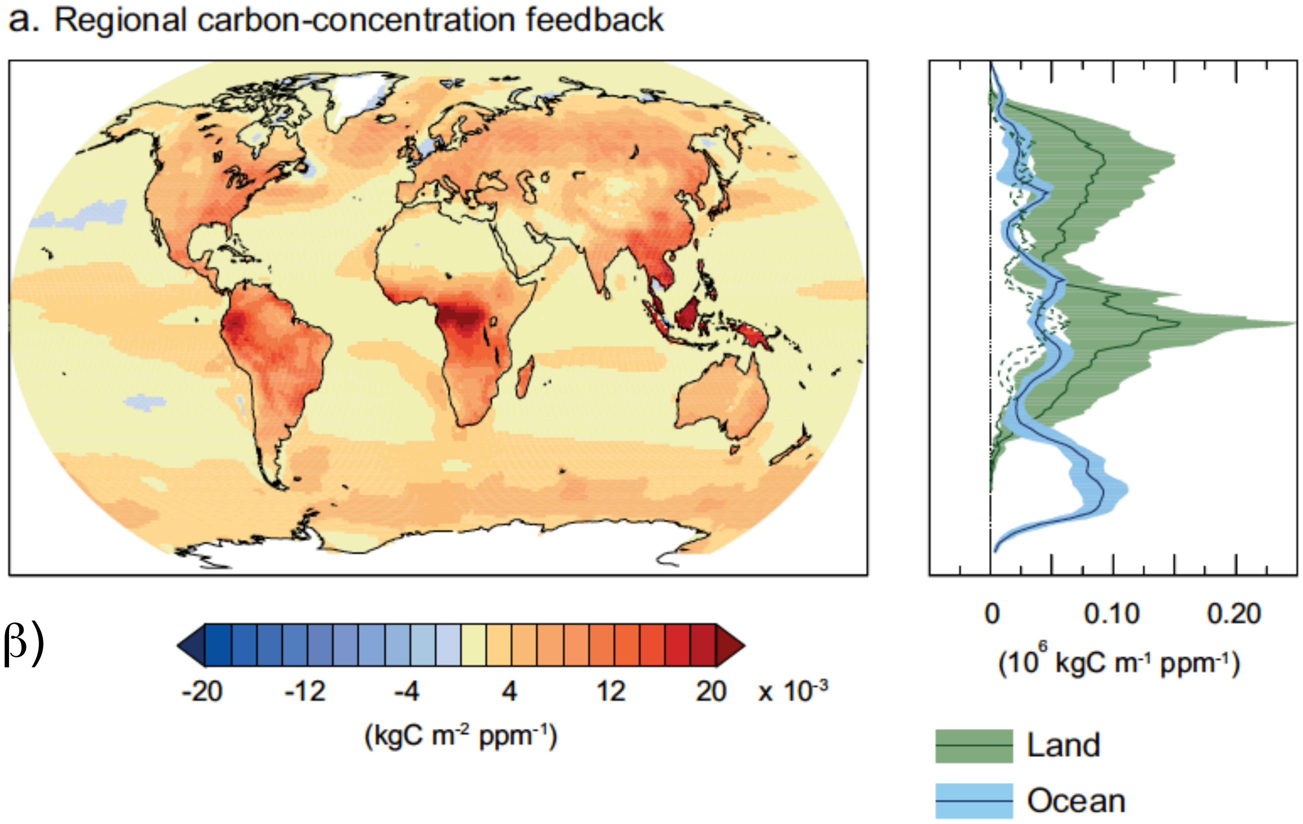
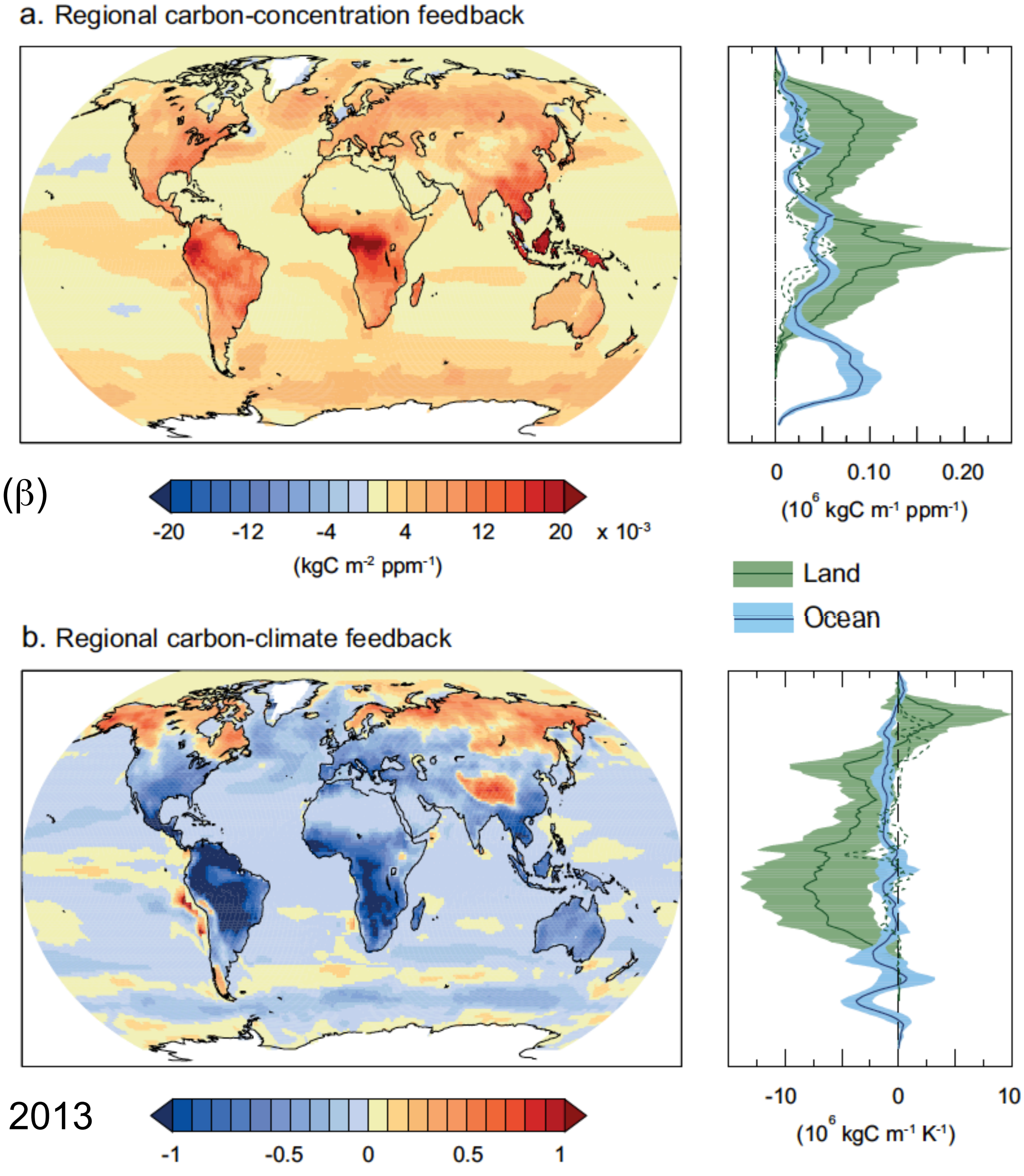


Fig 6.22, Chap 6, IPCC AR5 2013 (climate-carbon feedbacks analysed as in Roy et al. 2011)

III. Climate Carbon Feedbacks

(Section 6.4.2)



Carbon-concentration effect (β)

Carbon-climate effect (γ)

Fig 6.22, Chap 6, IPCC AR5 2013

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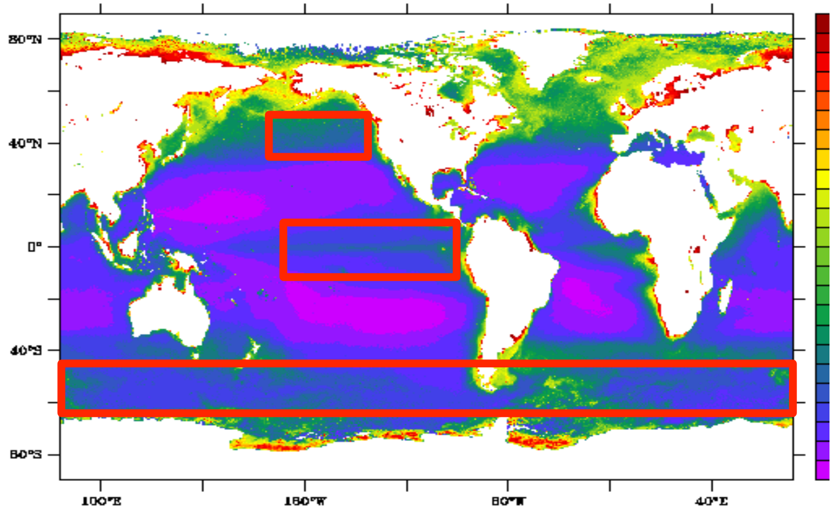
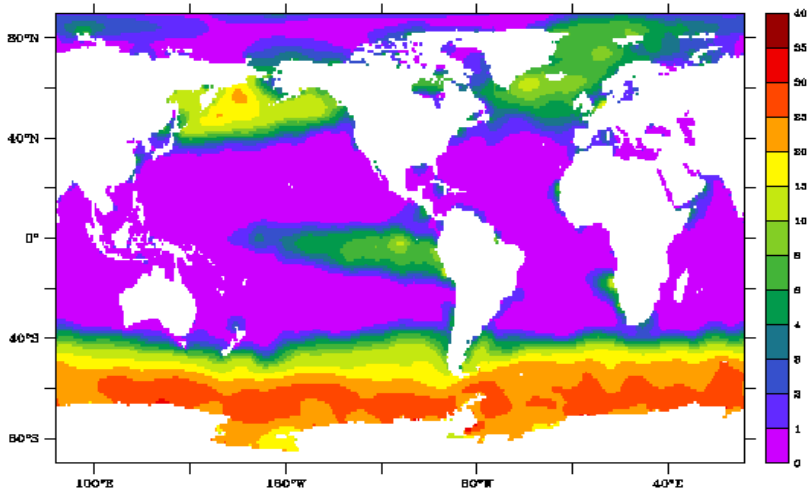
Iron cycle and the HNLC regions

- Principal paradigm: if nutrient are abundant and light not limiting….

Chla, SEAWiFS



Nitrates, WOA2001

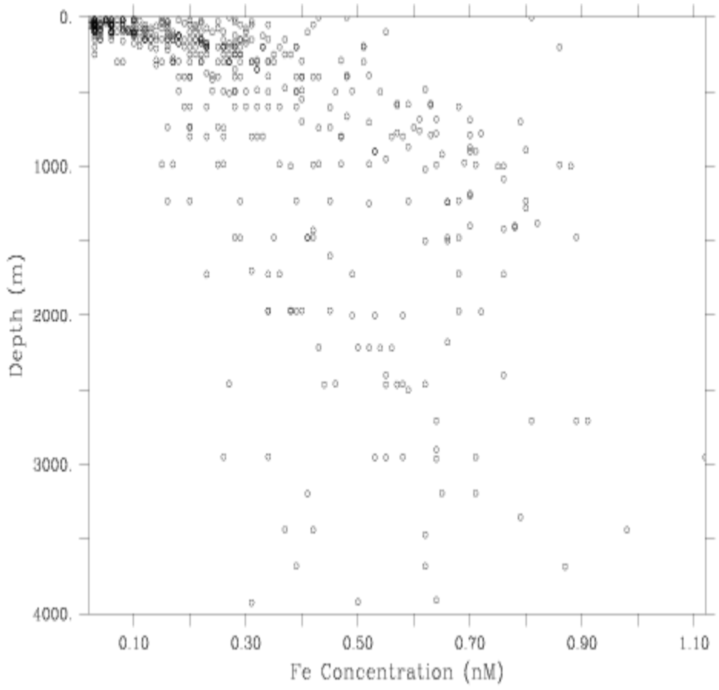


Iron cycle and the HNLC regions

- 3 hypothesis
  - Light limitation, essentially for the Southern Ocean
  - Limitation by grazing, essentially for the North Pacific (Frost, 1993)
  - Iron- or silicate limitation (Gran, 1931; J. Martin, 1985-1990)

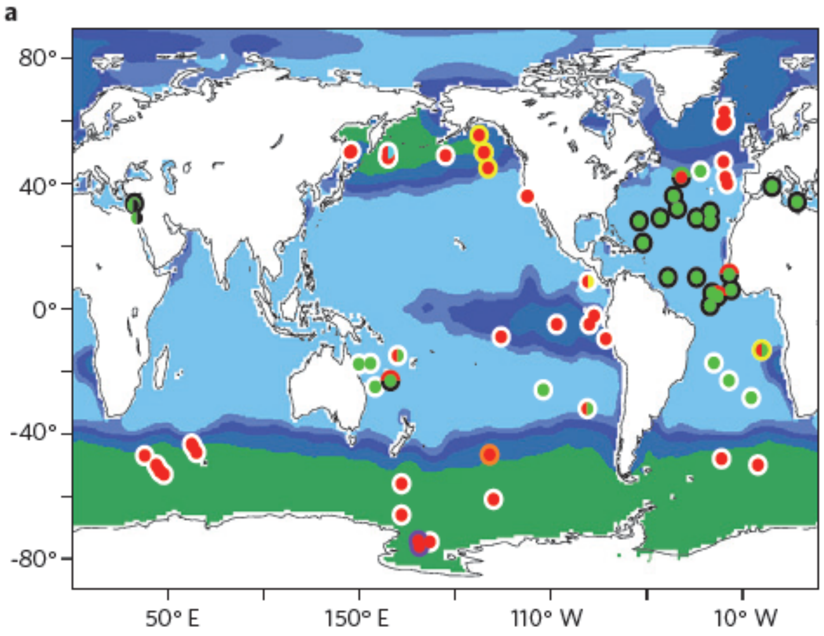
Iron Cycle

- From 1930 to 1980, all attempts to measure dissolved iron have failed
  - Very low concentrations (~ nM)
  - Contaminations (ultra-clean techniques are needed)
- Since 1980, 13,000 measurements of dissolved iron



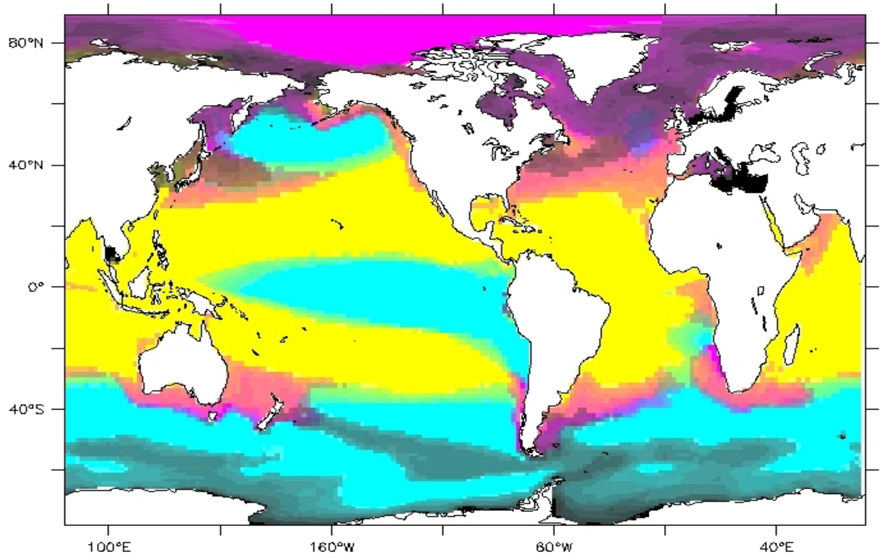
- Generally less than 1 nM
- Nutrient-type vertical profile
- But no increase in concentration from the deep atlantic to the deep pacific
- Deep concentrations generally less than < 0.8 nM

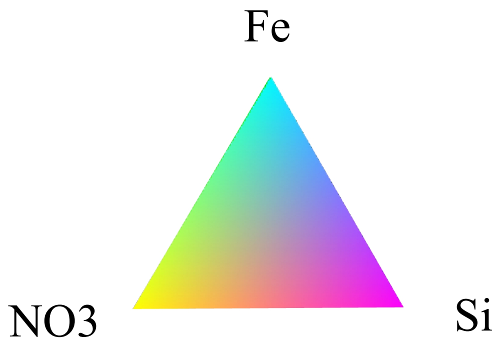
Co-limitations – Spatial distribution



Symbols indicate the primary (central circles) and secondary (outer circles) limiting nutrients as inferred from chlorophyll and/or primary productivity increases following artificial amendment of
N (green), P (black), Fe (red), Si (orange),
Co (yellow), Zn (cyan) and vitamin B12 (purple)

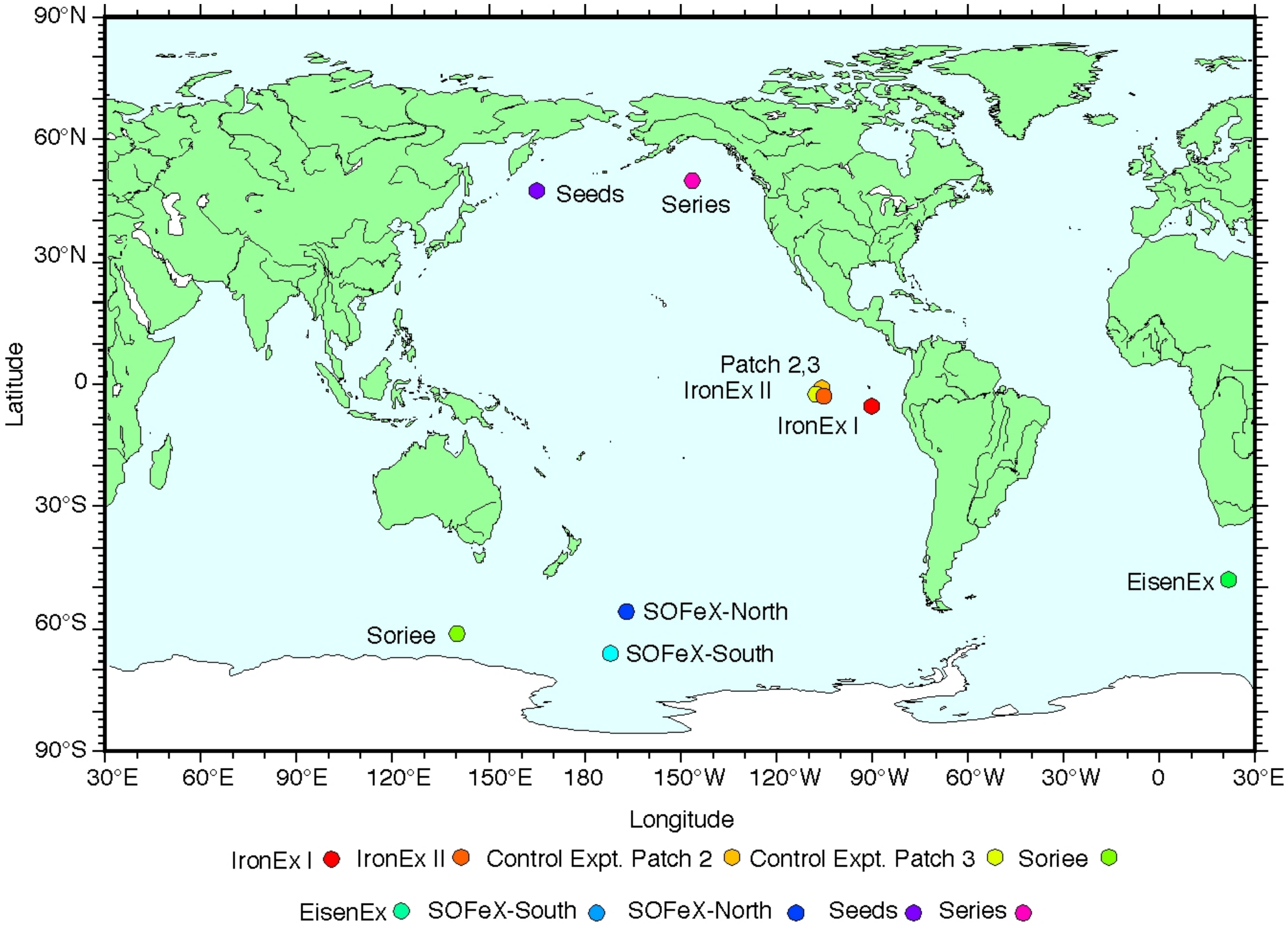
(Moore et al. 2013)





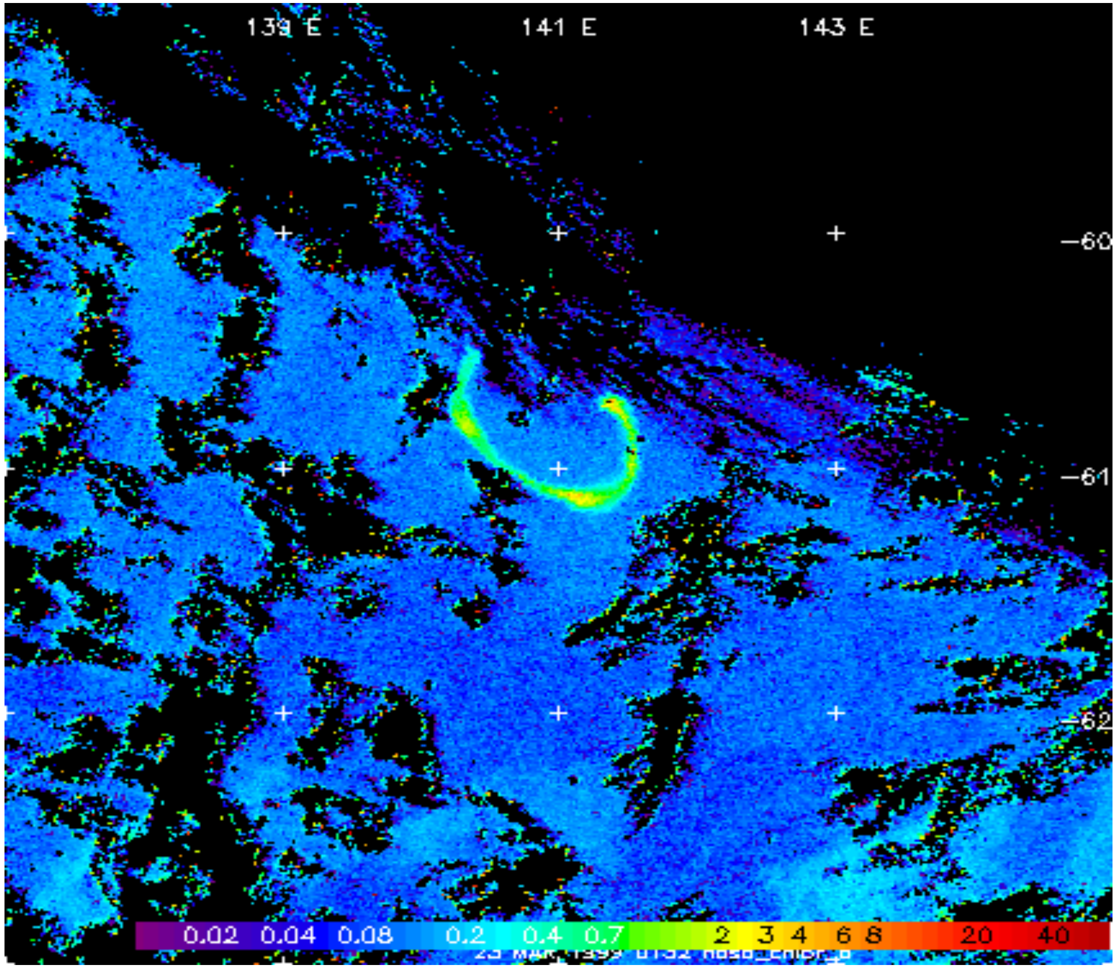
Diatoms co-limitation in PISCES

In-situ iron fertilization experiments



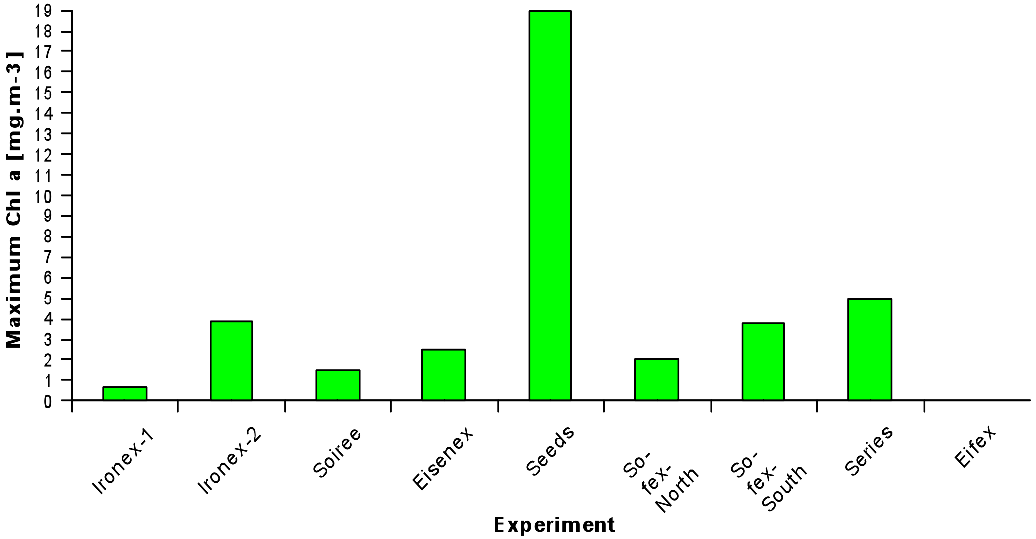
In-situ iron fertilization experiments

SOIREE after 42 days
SeaWiFS
Abraham et al., 2000

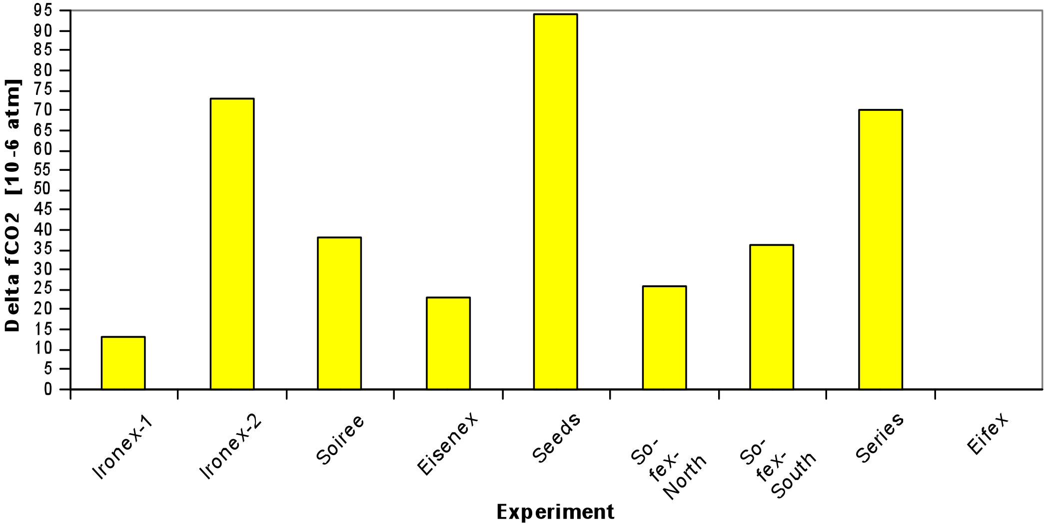


In-situ iron fertilization experiments: effects on Chl and pCO2

- Increase in Chla

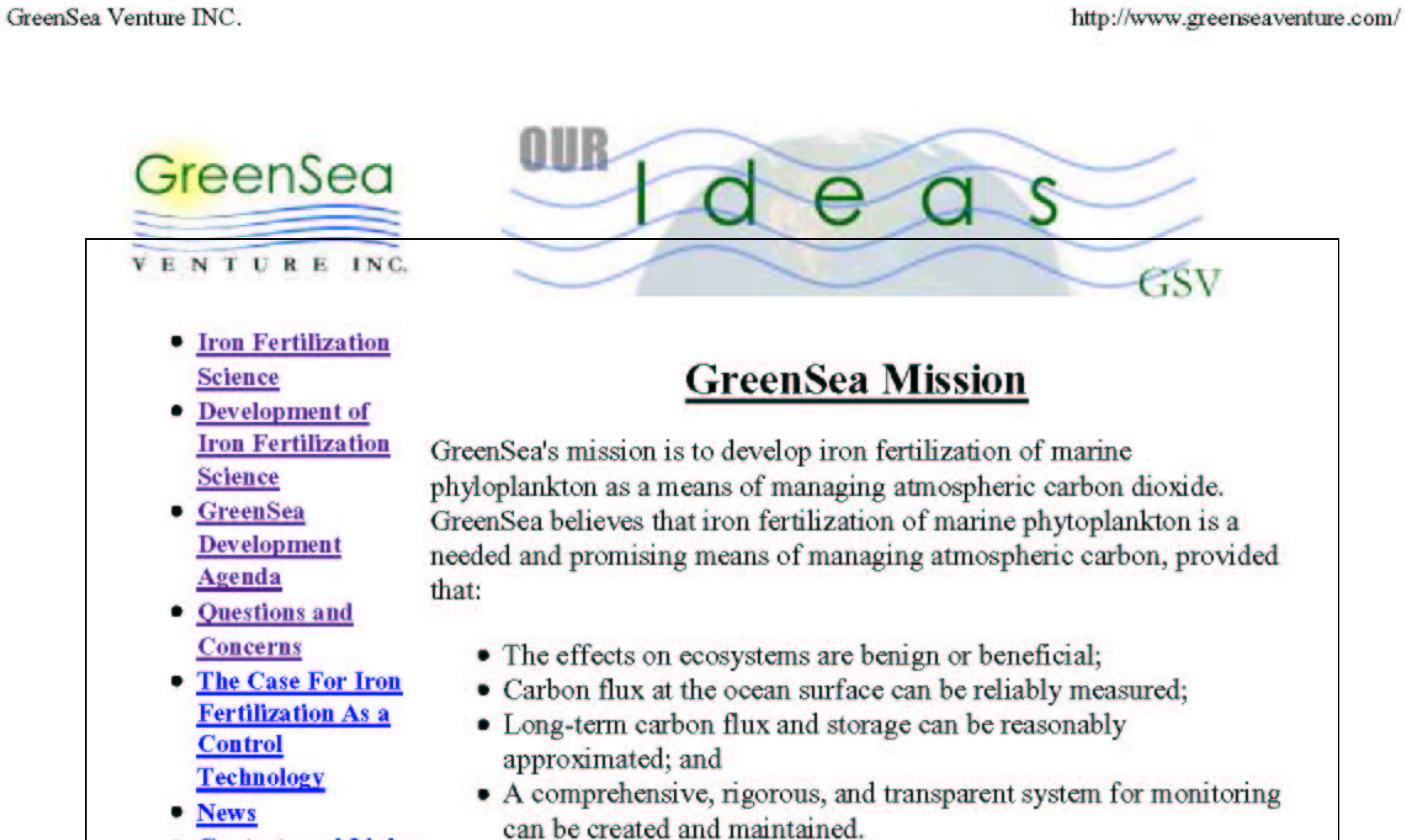


- Decrease in surface pCO2



Several private companies - Patents

Planktos
Ocean Farming Inc.
GreenSea Venture Inc …



GreenSea Venture INC.   http://www.greenseaventure.com/

- Iron Fertilization Science
- Development of Iron Fertilization Science
- GreenSea Development Agenda
- Questions and Concerns
- The Case For Iron Fertilization As a Control Technology
- News

GreenSea Mission

GreenSea's mission is to develop iron fertilization of marine phyloplankton as a means of managing atmospheric carbon dioxide. GreenSea believes that iron fertilization of marine phytoplankton is a needed and promising means of managing atmospheric carbon, provided that:

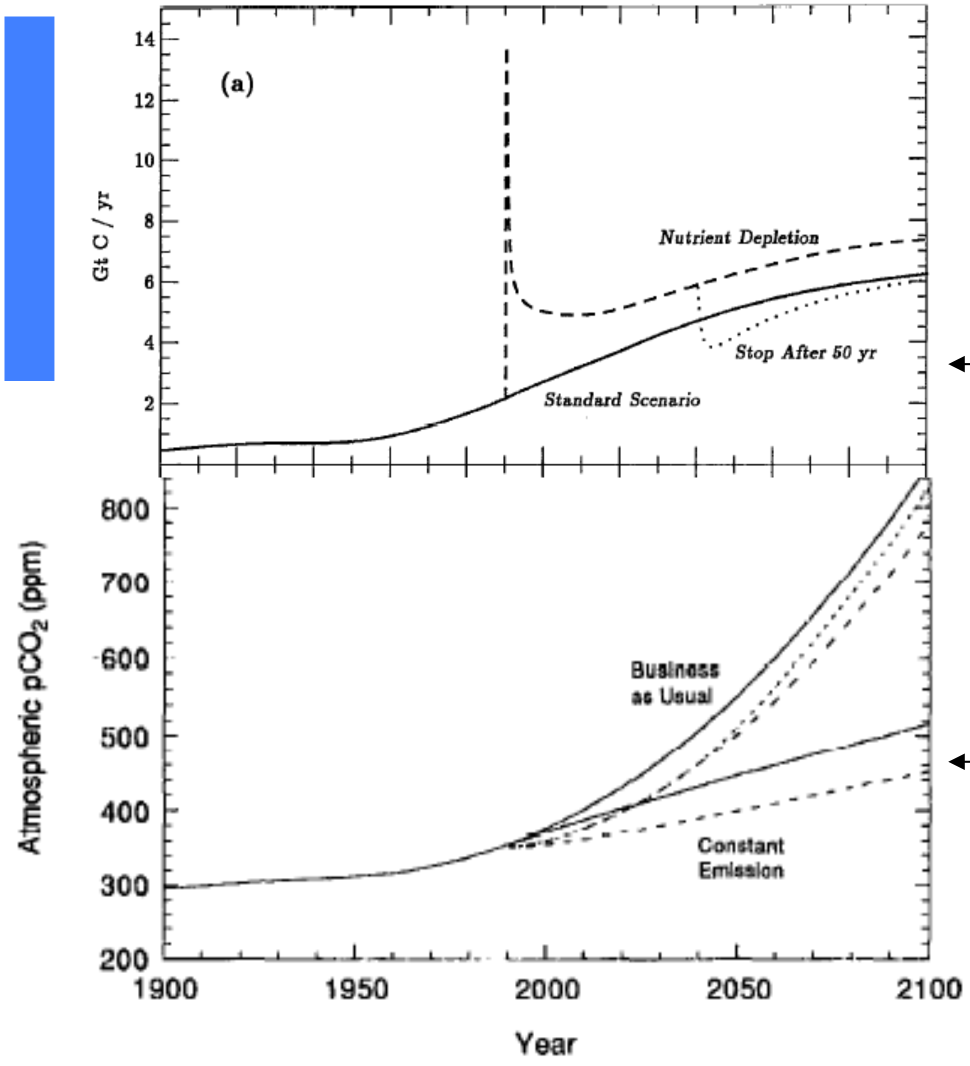
- The effects on ecosystems are benign or beneficial;
- Carbon flux at the ocean surface can be reliably measured;
- Long-term carbon flux and storage can be reasonably approximated; and
- A comprehensive, rigorous, and transparent system for monitoring can be created and maintained.

Iron Fertilization: Nutrient Depletion Experiment

Early 90s papers: **Physical Model:** Box (Broecker and Peng (1991), Joos et al. (1991)) or OGCM (Sarmiento and Orr (1991))

Biogeochemical Model: PO_4 → Export of OM

Hypothesis: Fe fertilization able to deplete surface PO_4 entirely…



Ocean Carbon Uptake (PgC/yr)

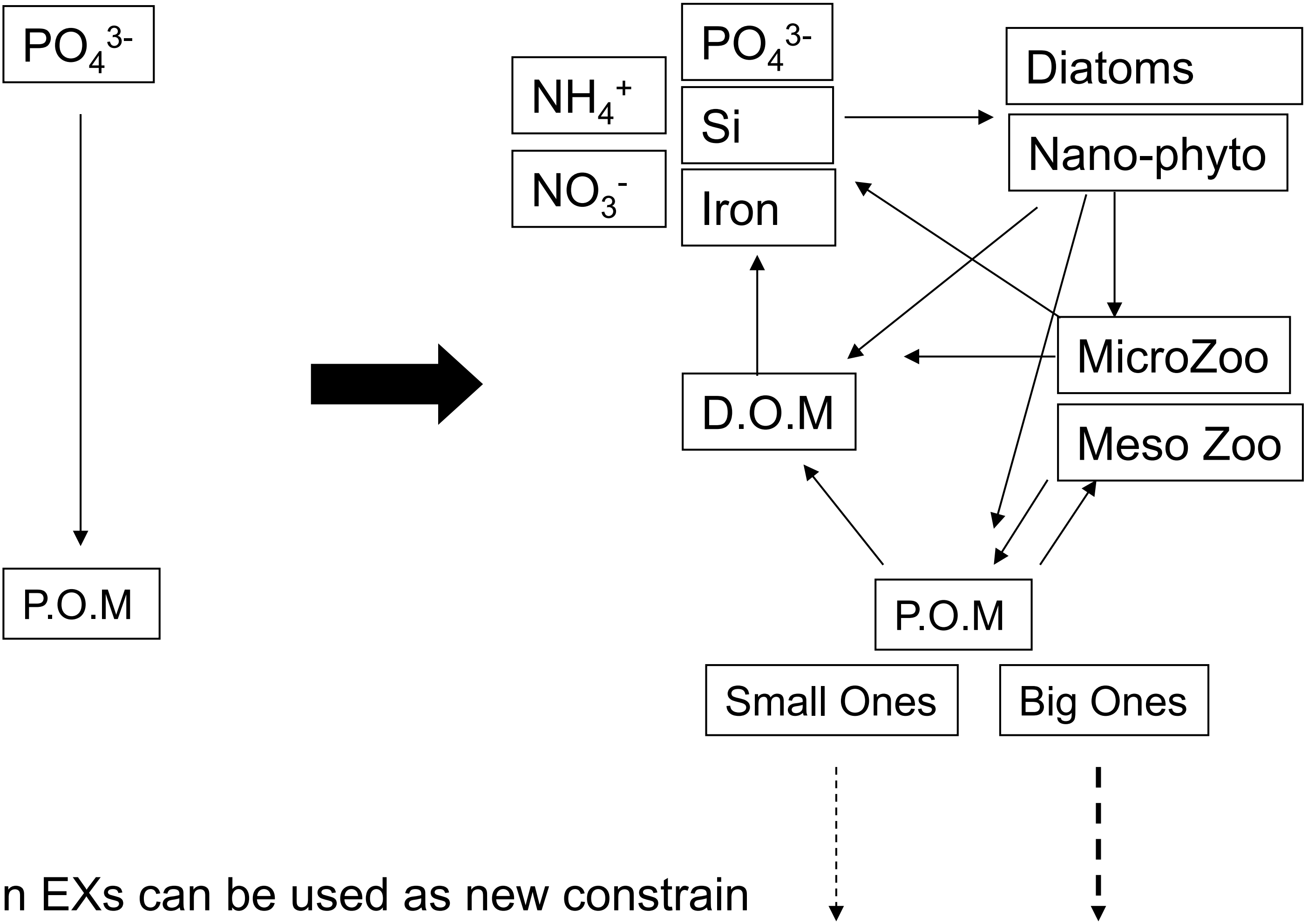
Atmospheric CO_2 (ppm)

(Sarmiento and Orr, 1991)

Modelling Iron Fertilization: What’s new?

- Biogeochemical Models have been complexified

PISCES
(Aumont and Bopp, 2006)



PO_4^{3-}

P.O.M

NH_4^+

NO_3^-

PO_4^{3-}

Si

Iron

Diatoms

Nano-phyto

MicroZoo

Meso Zoo

D.O.M

P.O.M

Small Ones

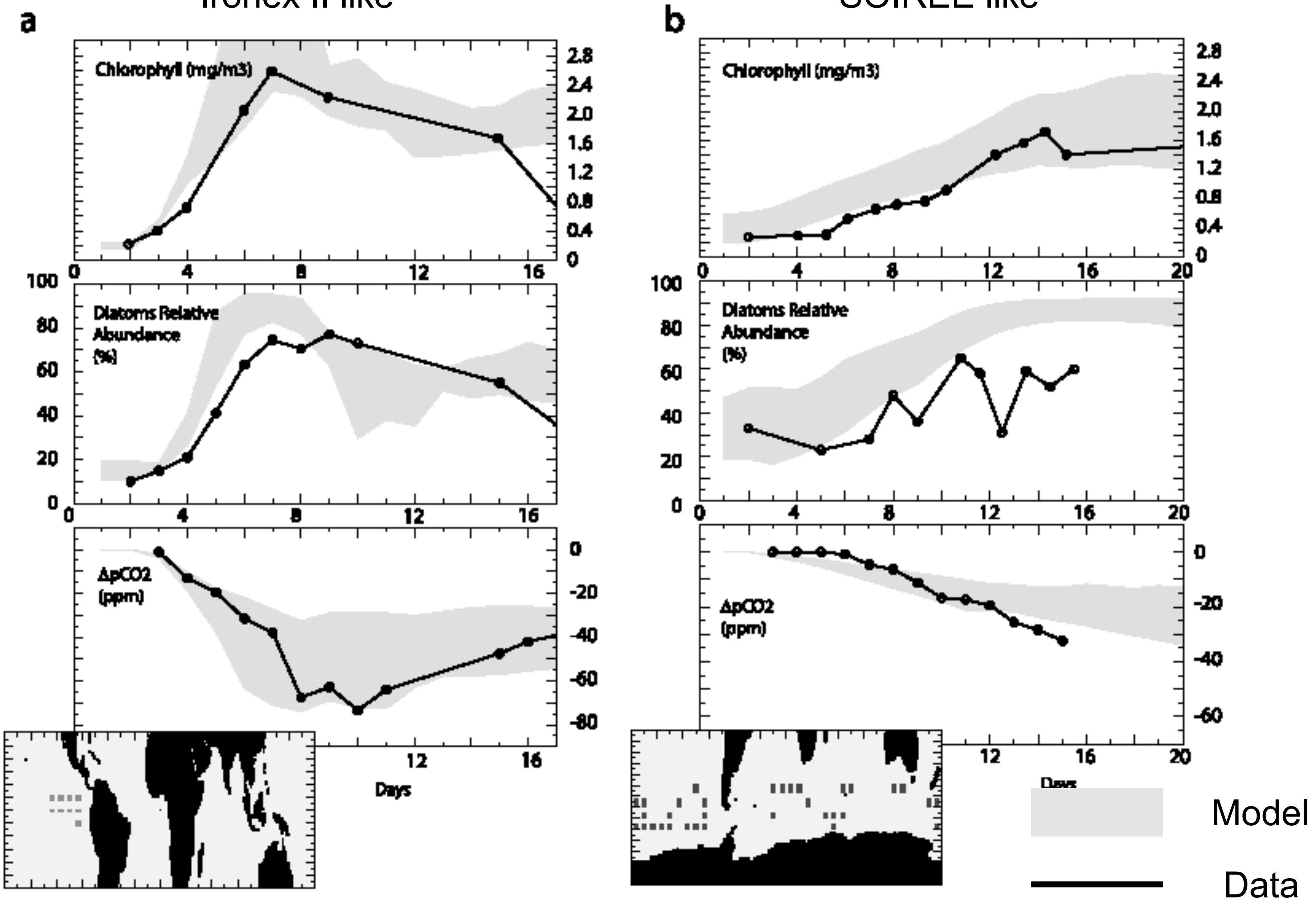
Big Ones

-All the iron fertilization EXs can be used as new constrain
 on models’ behaviour

Patchy Iron Fertilization Experiment

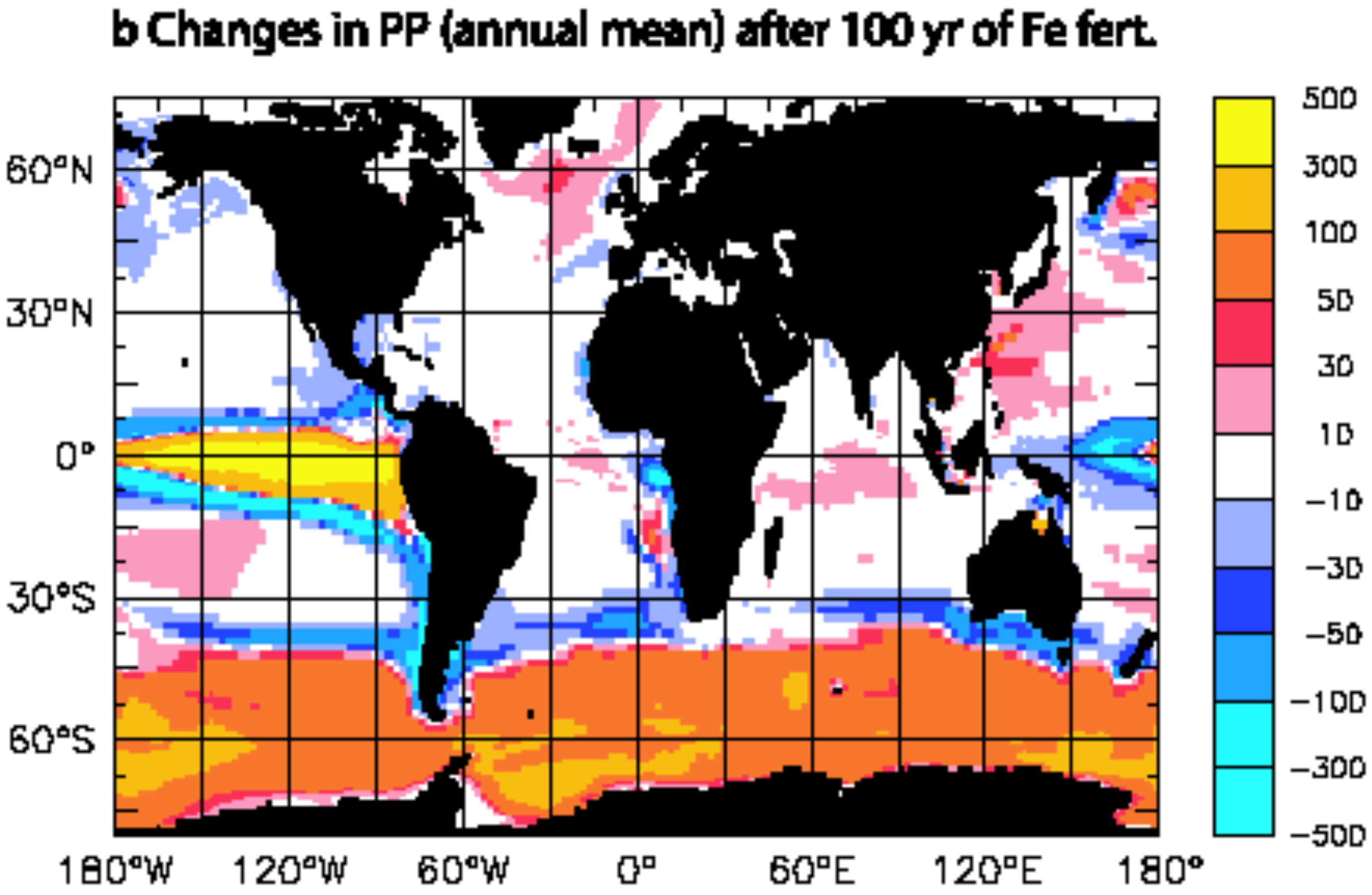
Ironex II like

SOIREE like



Long Term Iron Fertilization Experiment

- [Fe] set at 2 nM everywhere for 100 yrs



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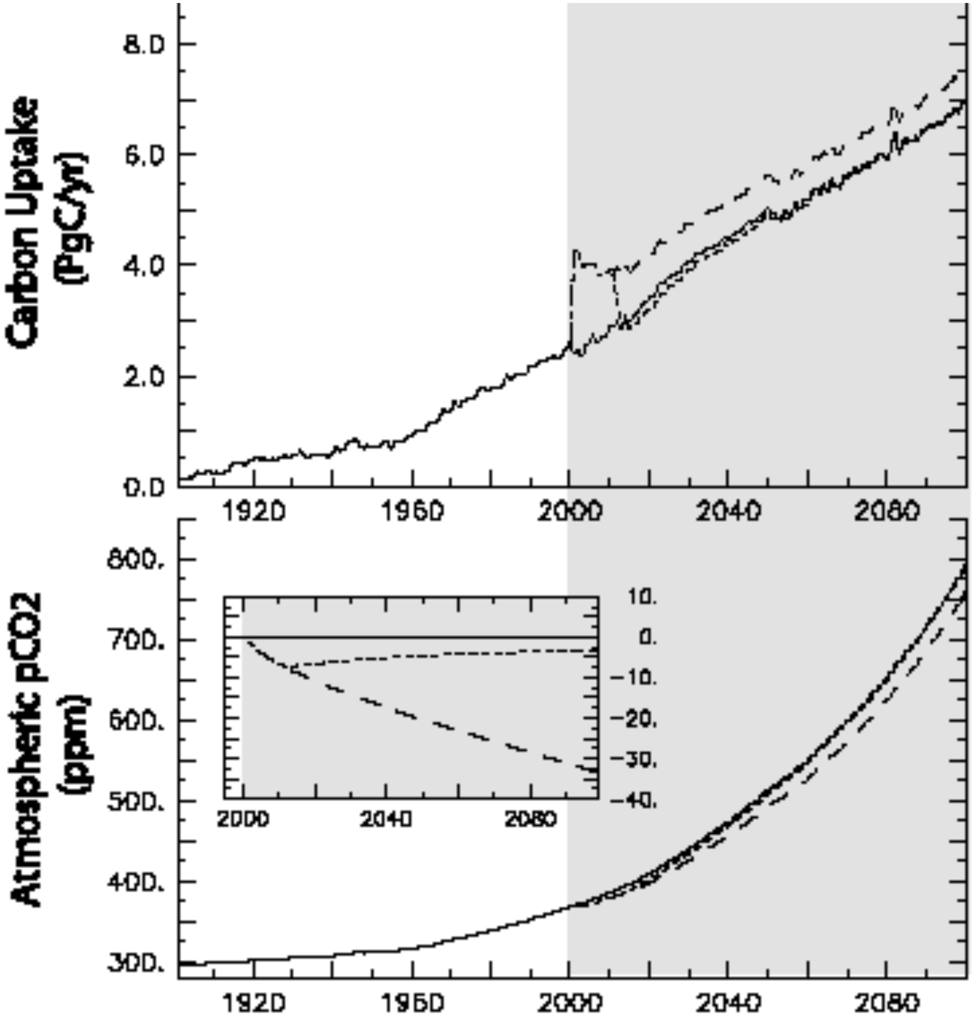


Long Term Iron Fertilization Experiment

- [Fe] set at 2 nM everywhere for 100 yrs

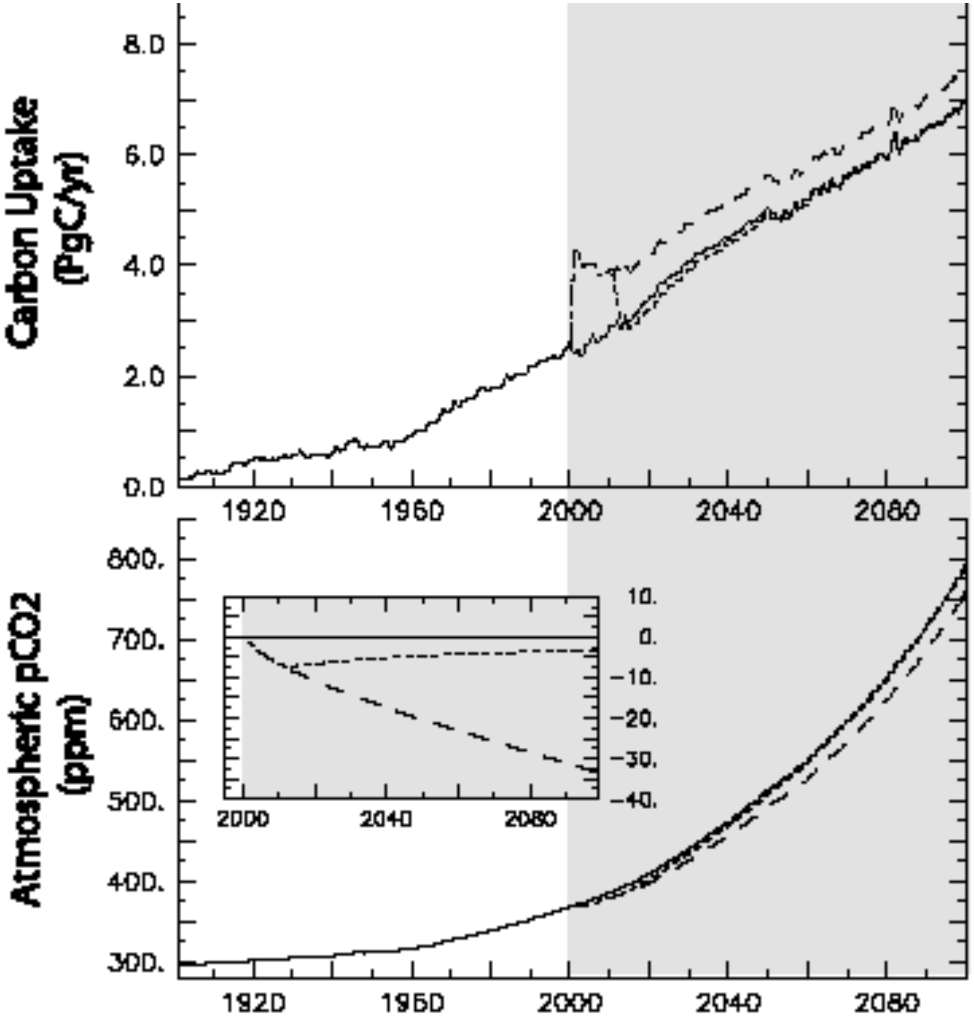
- Primary Prodcutivity (PP) increases
  by up to +50 % then
  decreases gradually

- Maximum effect on atmospheric
  pCO2 is -33 ppm after 100yr,
  -7 ppm after 10.

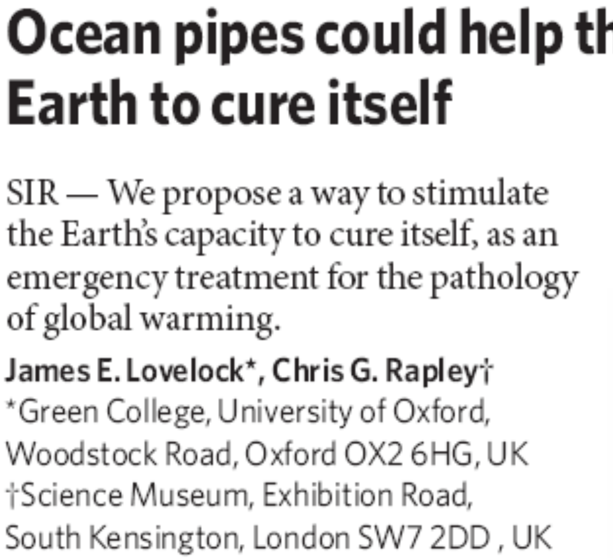
- 33% of export carbon comes from
  the atmosphere

- Only fertilizing SO is (very moderatly)
  efficient

- If fertilization is stopped, PP decreases
  sharply below previous levels
  and effect on pCO2 is decreased.



Modelling Ocean Pipes



Ocean pipes could help the Earth to cure itself

SIR — We propose a way to stimulate the Earth's capacity to cure itself, as an emergency treatment for the pathology of global warming.

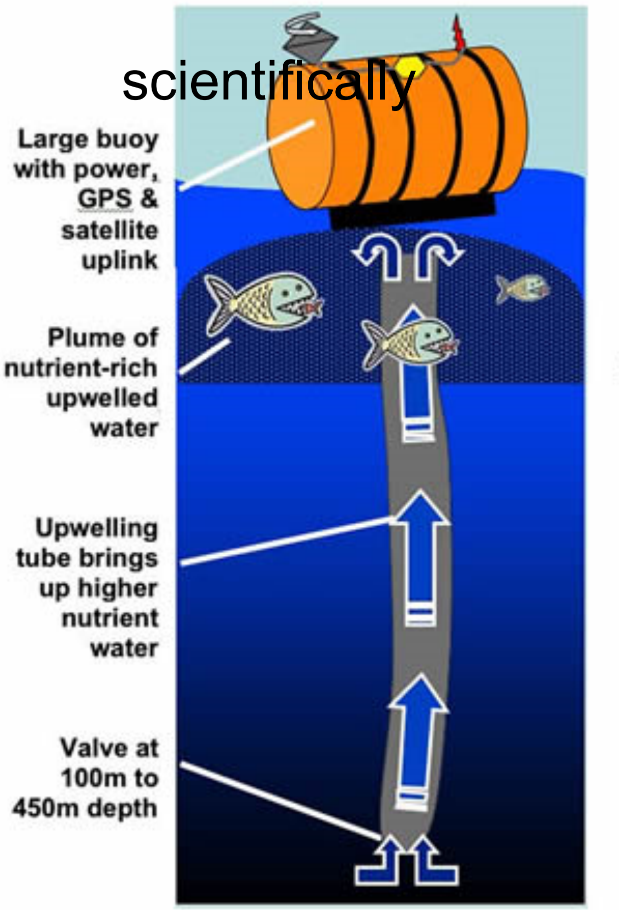
James E. Lovelock*, Chris G. Rapley†

*Green College, University of Oxford, Woodstock Road, Oxford OX2 6HG, UK

†Science Museum, Exhibition Road, South Kensington, London SW7 2DD , UK

Nature, 2007

- Fertilize the biological pump via an artificial « upwelling » of deep nutrients
- Increase uptake of atmospheric CO_2
- Already being investigated commercially / scientifically



Modelling Ocean Pipes

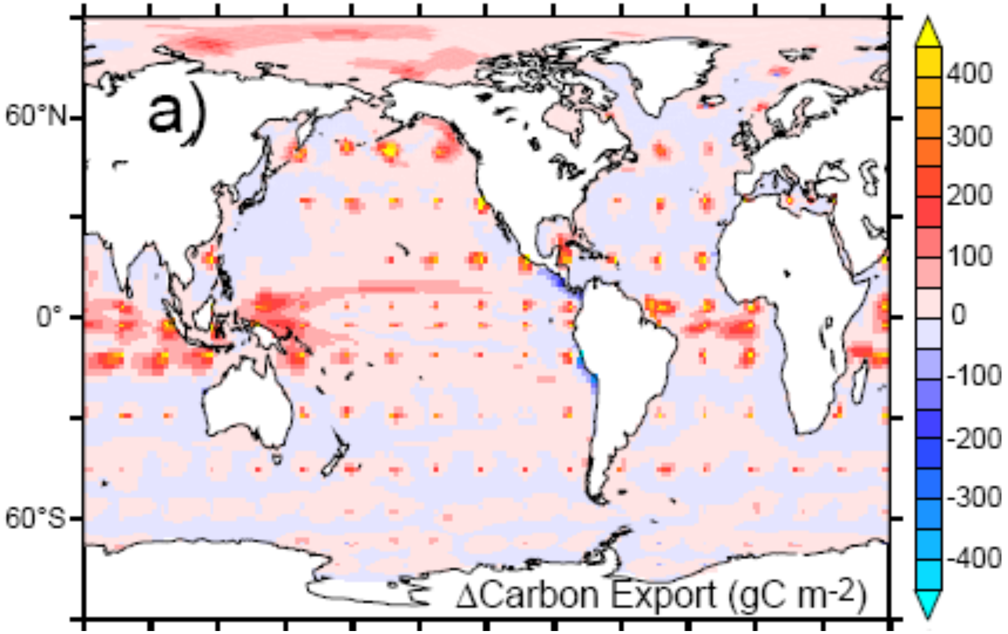
- 2 modelling studies so far (Yool et al. 2009, **Dutreuil et al. 2009**)

Model Used : PISCES model

Experimental Design: « Pipes » every 20°x10°, 200m deep, 20 years (2000-2020)

No change in T and S (solubility).

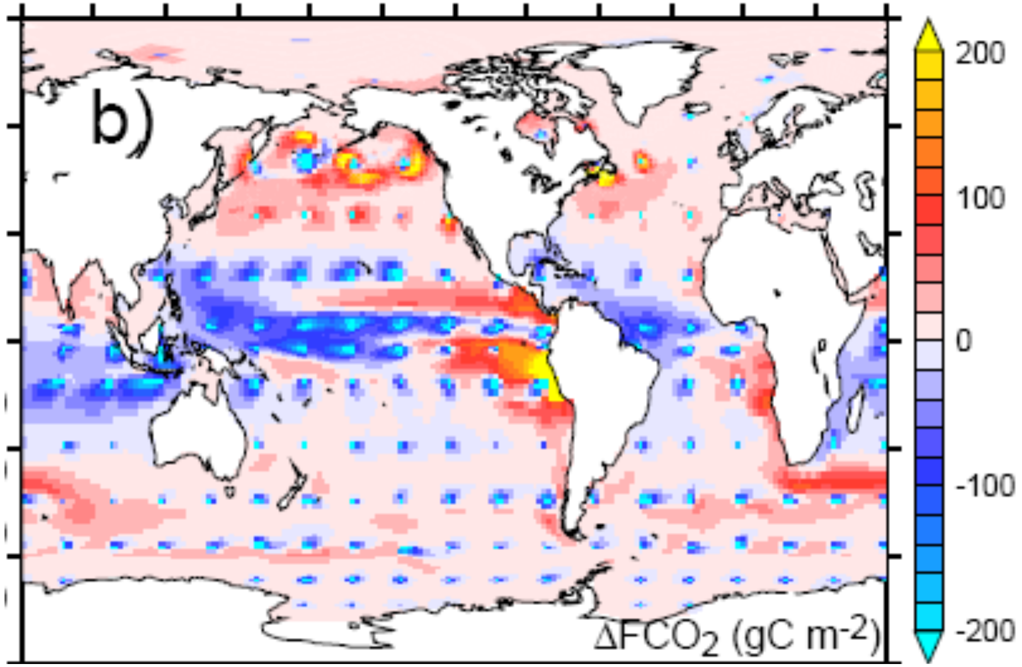
Impact on Export Production after 20y



- Carbon Export increases in response to the greater vertical supply of nutrients
- But a weak response in Fe limited regions (Southern Ocean, equatorial Pacific)

(increased Fe/C ratios)

Modelling Ocean Pipes: Impact on CO_2

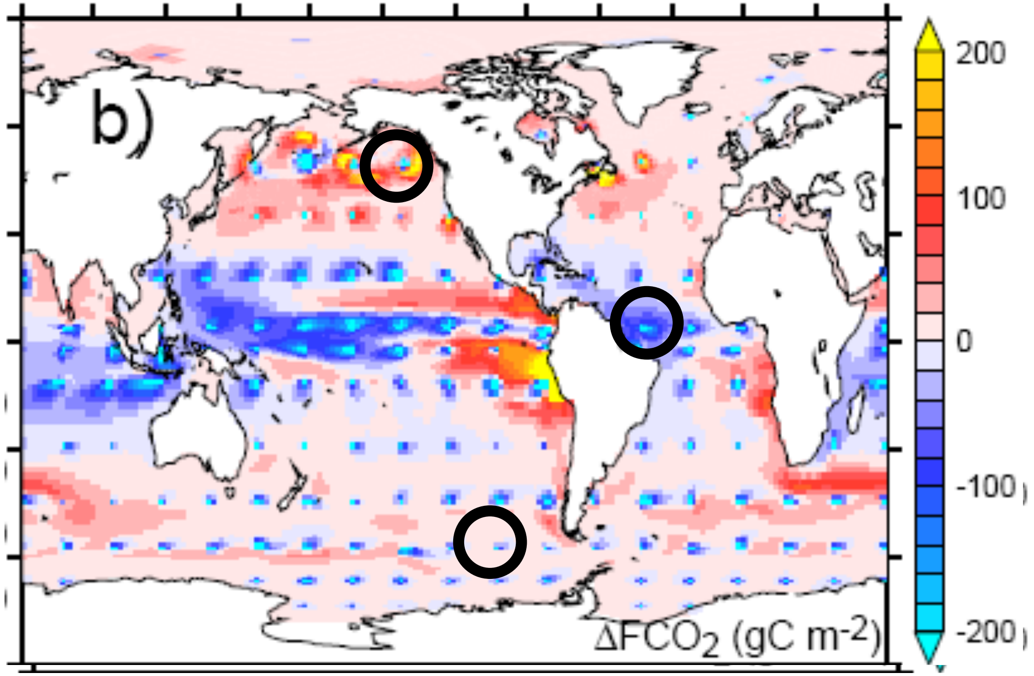


- Upwelling of DIC increases pCO_2 and decreases uptake of atmospheric CO_2
- But some regions are sinks around pipe location

- Response very diverse regionally:

Compare NE Pac (+) / Southern Ocean (-) / Tropical Atlantic (---)

Modelling Ocean Pipes: Impact on CO_2



- Upwelling of DIC increases pCO_2 and decreases uptake of atmospheric CO_2
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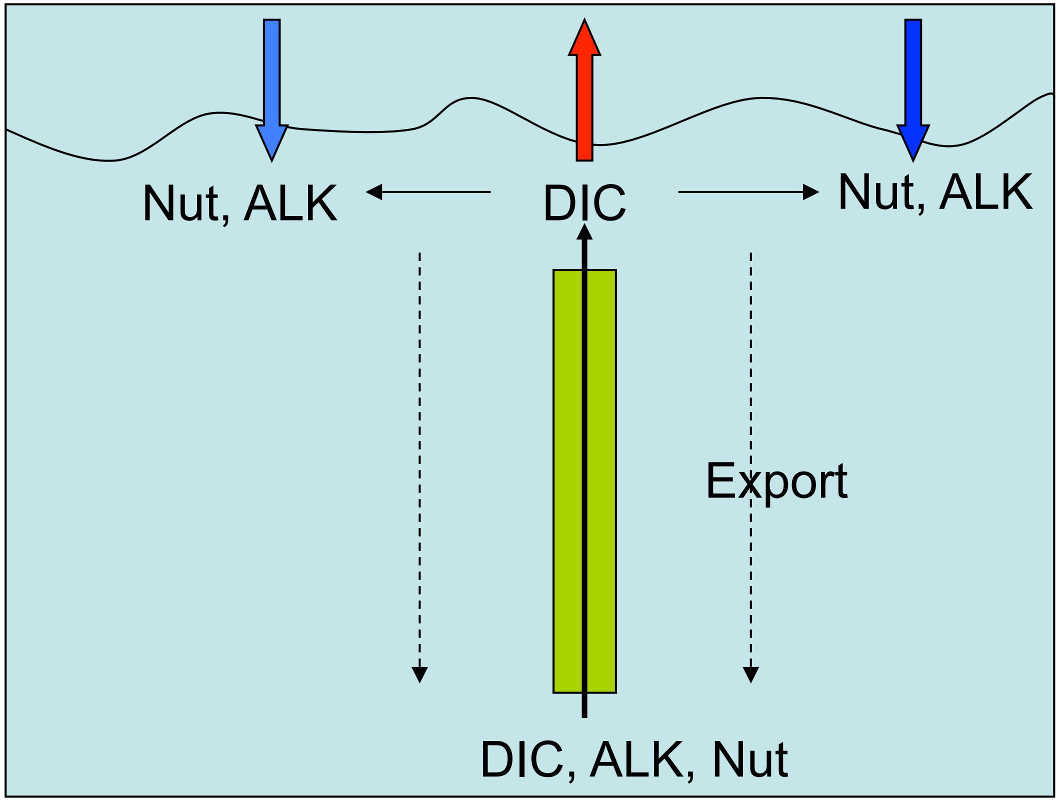
- 3 factors influence pCO_2 and thus air-sea CO_2 exchange:

  1. DIC 2. Alkalinity 3. Bio. Export (linked to changes in nutrient)

Modelling Ocean Pipes: Impact on CO_2



- 3 factors influence pCO_2 and thus air-sea CO_2 exchange:

  1. DIC 2. Alkalinity 3. Bio. Export (linked to changes in nutrient)

  (and also T and S would change…)

Modelling Ocean Pipes: Impact on CO_2

- Global impact on CO_2 is « negative » (+ 6 ppm) despite a 6% increase in export

- When taking only favorable regions (subartic Pacific here),

    only very moderate pCO2 response (less than a 1ppm reduction)

- Comparison to Yool et al. 2009 study:

    -Design not similar (variable depth, translocation instead of mixing,…)

    - large spatial variability in efficiency (from – to + in the tropics)
    - would require 100s of millions of pipes to be efficient

-Lots of caveats:

    -Simplistic representation ecosystem / export
    - C/Si and C/Fe variability but no C/N variations…