Climate sensitivity:

what observations tell us about model predictions

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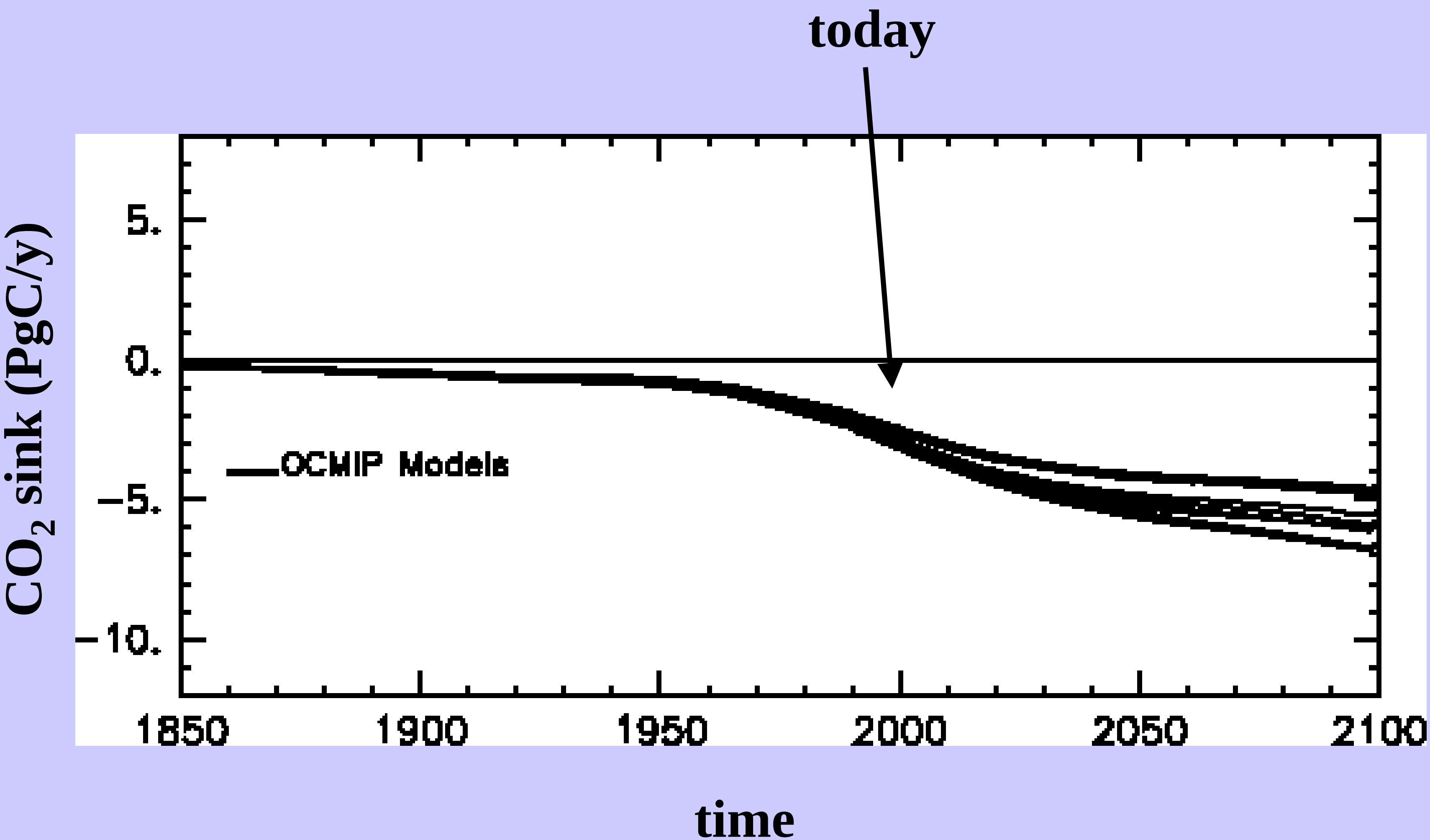
Acknowledgements:

Laurent Bopp, Karen Kohfeld, Erik Buitenhuis, Olivier Aumont

no biology, no climate change



(J. Orr and OCMIP-2 participants)

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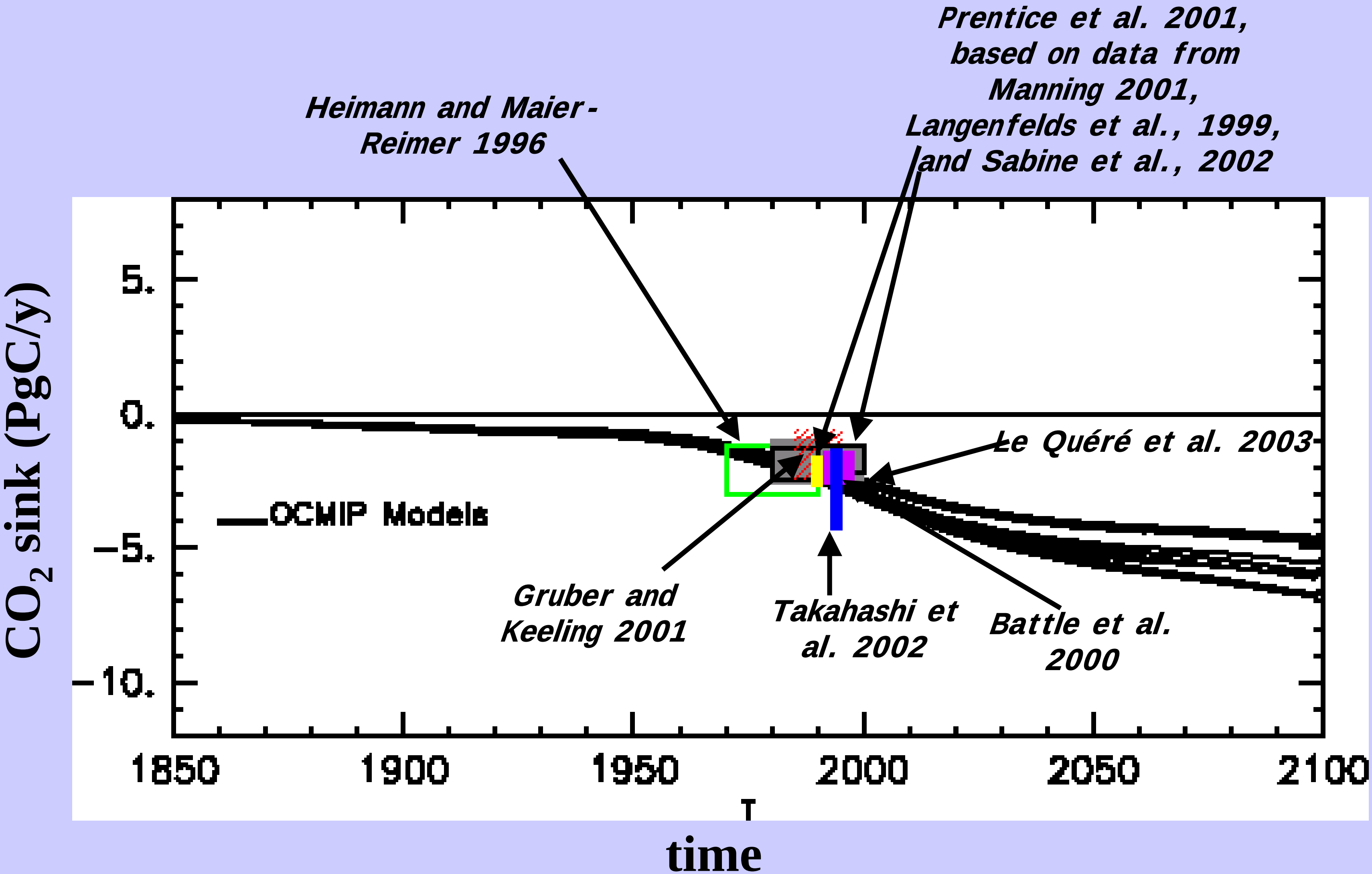
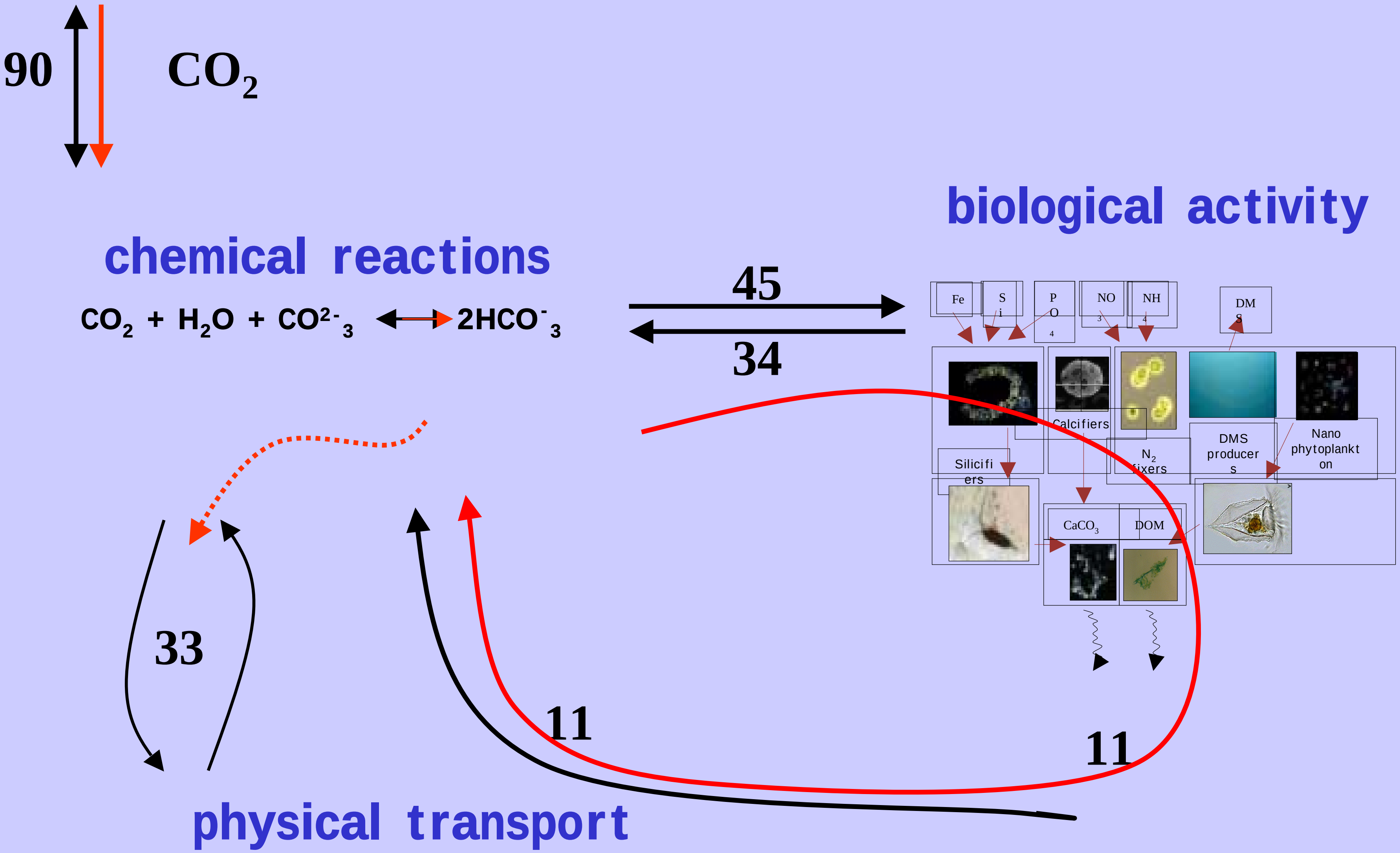


(J. Orr and OCMIP-2 participants)

outline

	CO_2	export production
100 yr predictions		
100,000 yrs variations		
interannual variations		

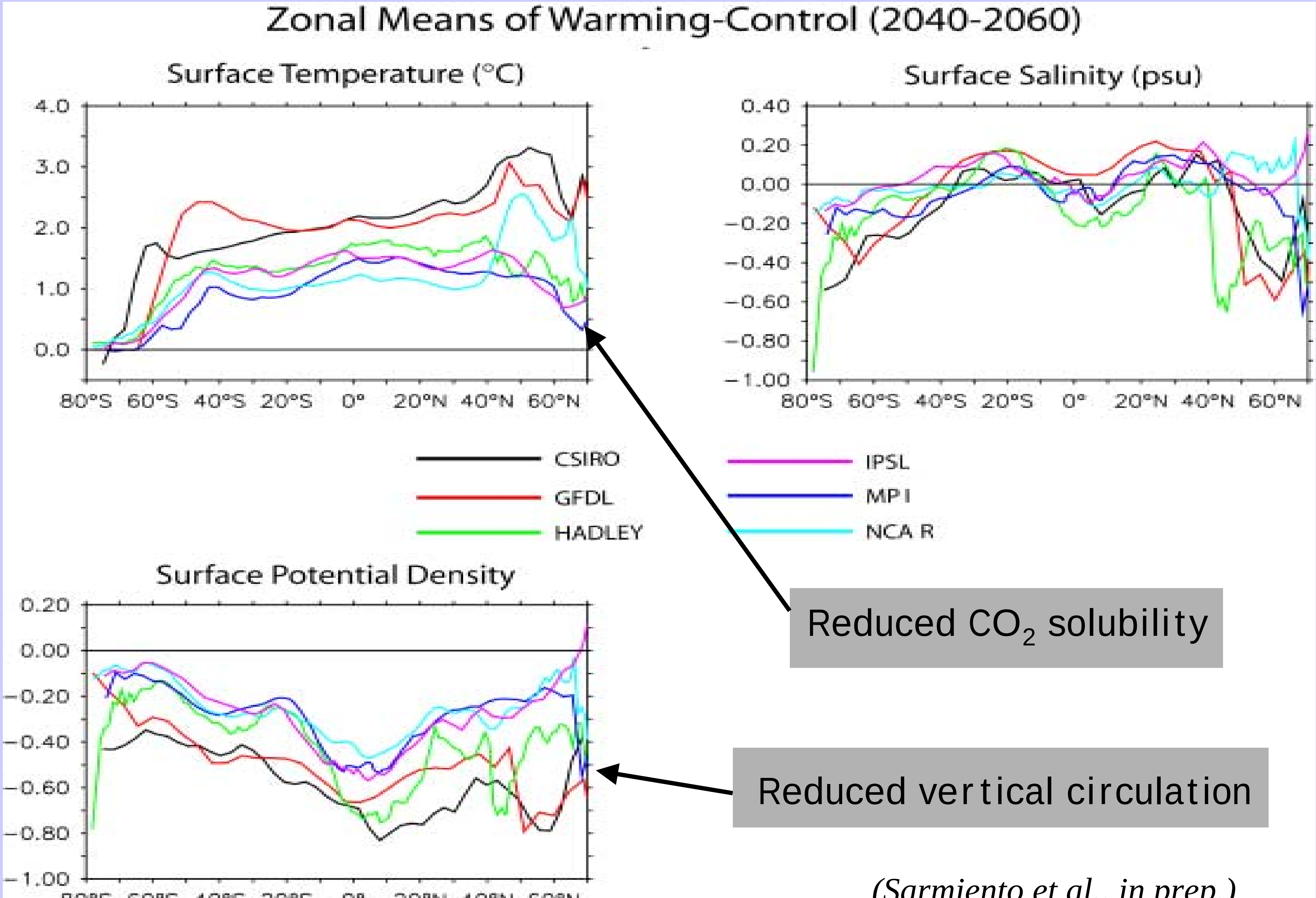
oceanic carbon cycle



how do marine ecosystems respond to:

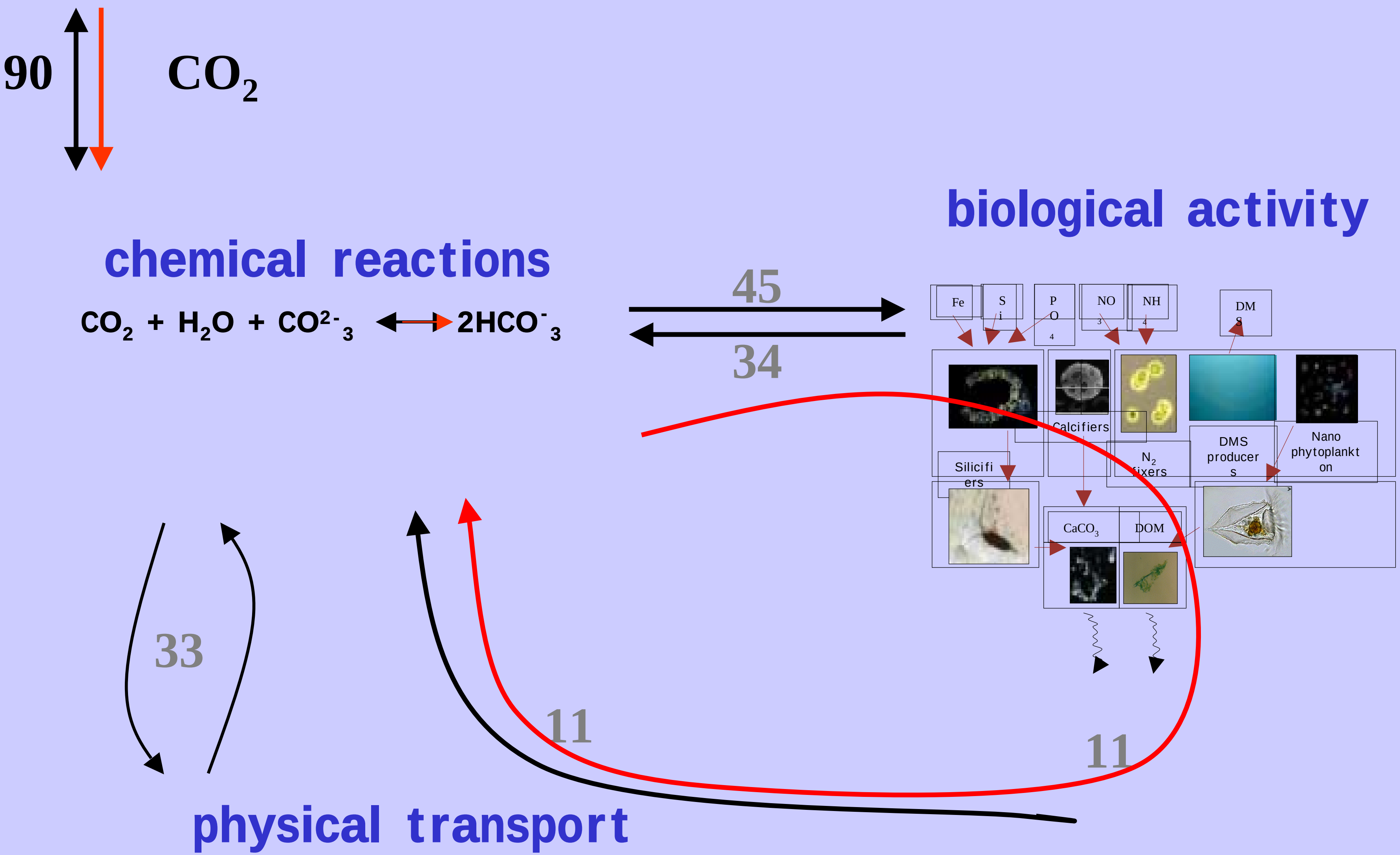
- elevated CO_2
- warming
- nutrient supply
- stratification

physical response to elevated CO_2

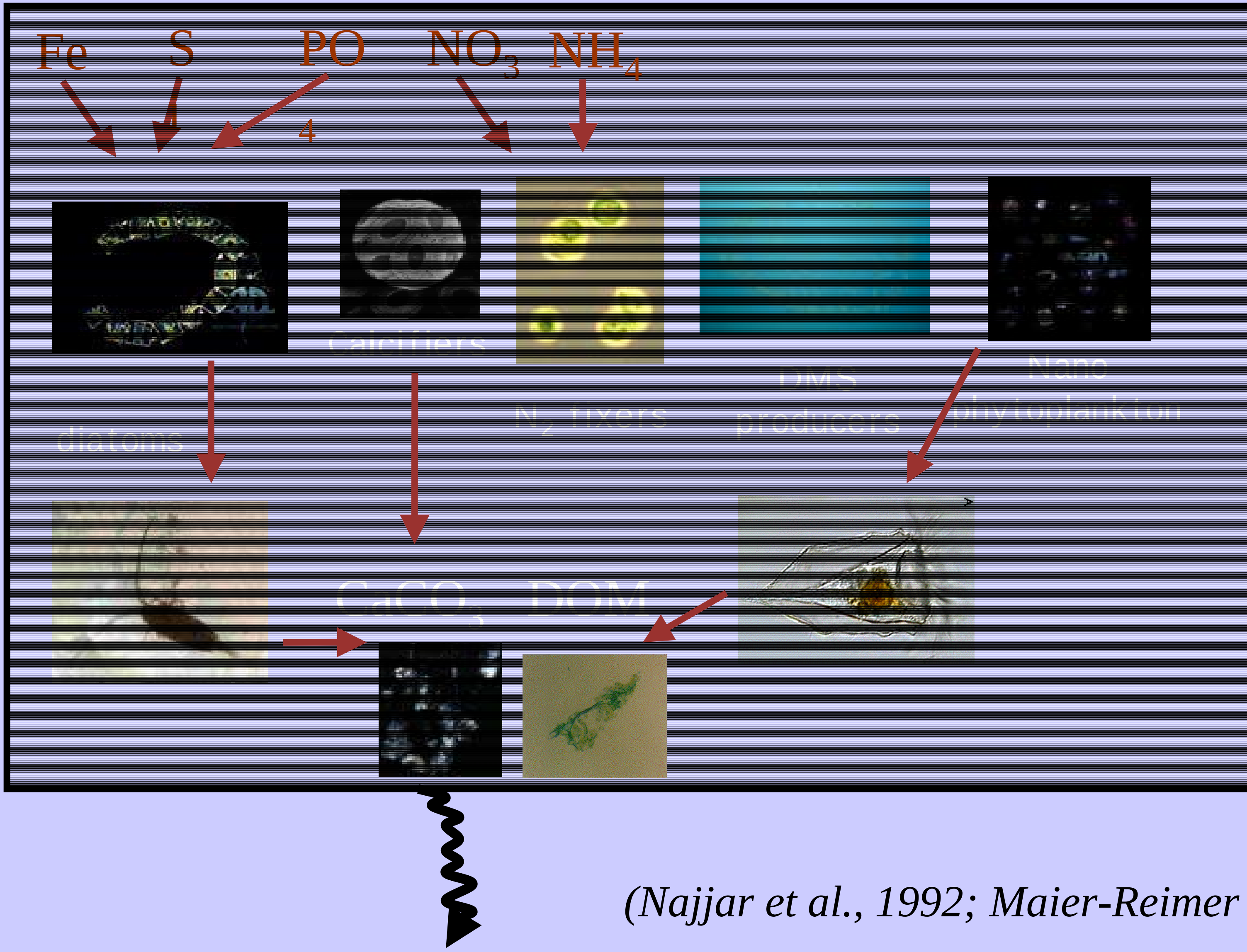


(Sarmiento et al., in prep.)

oceanic carbon cycle

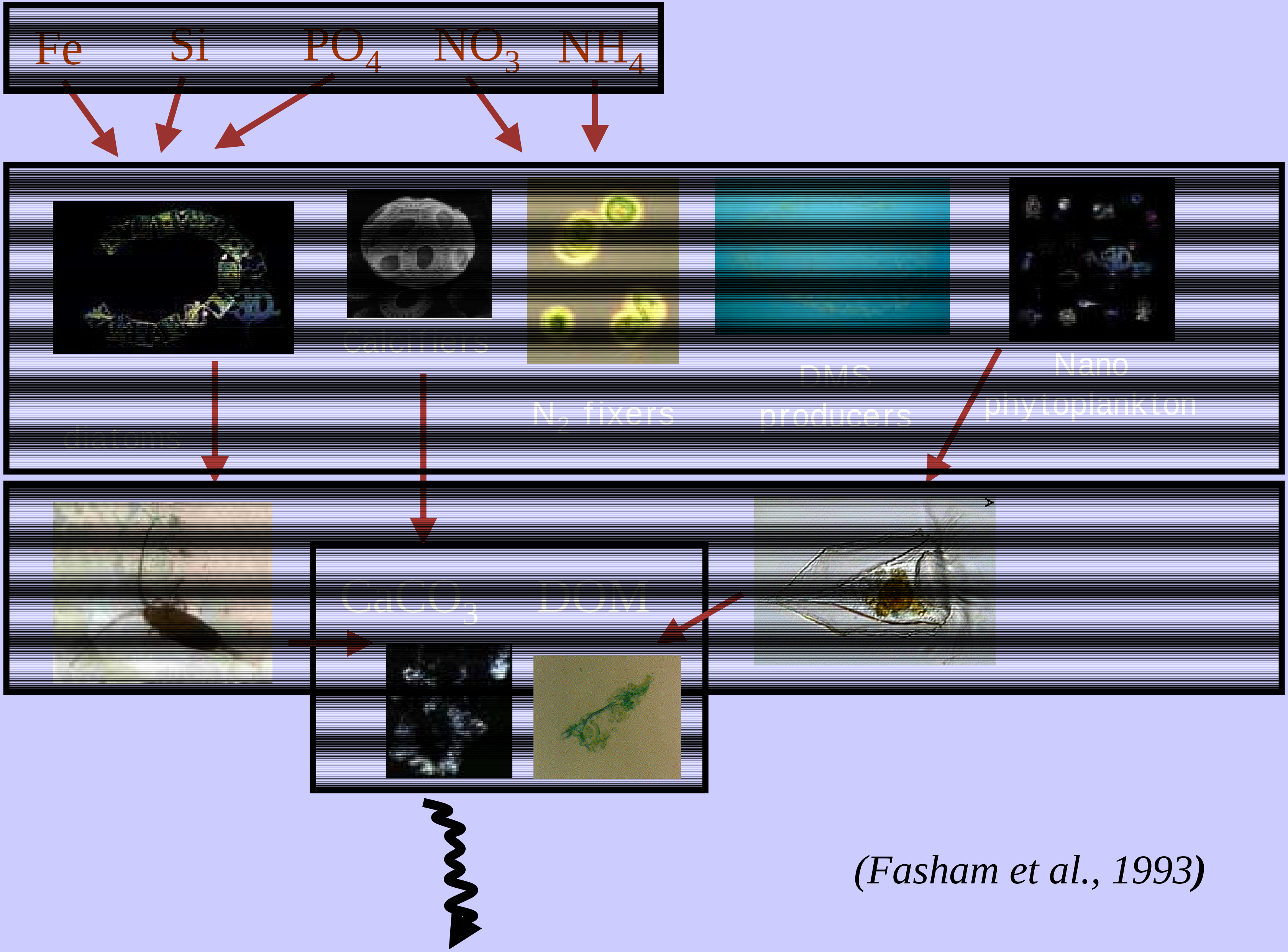


nutrient-based models



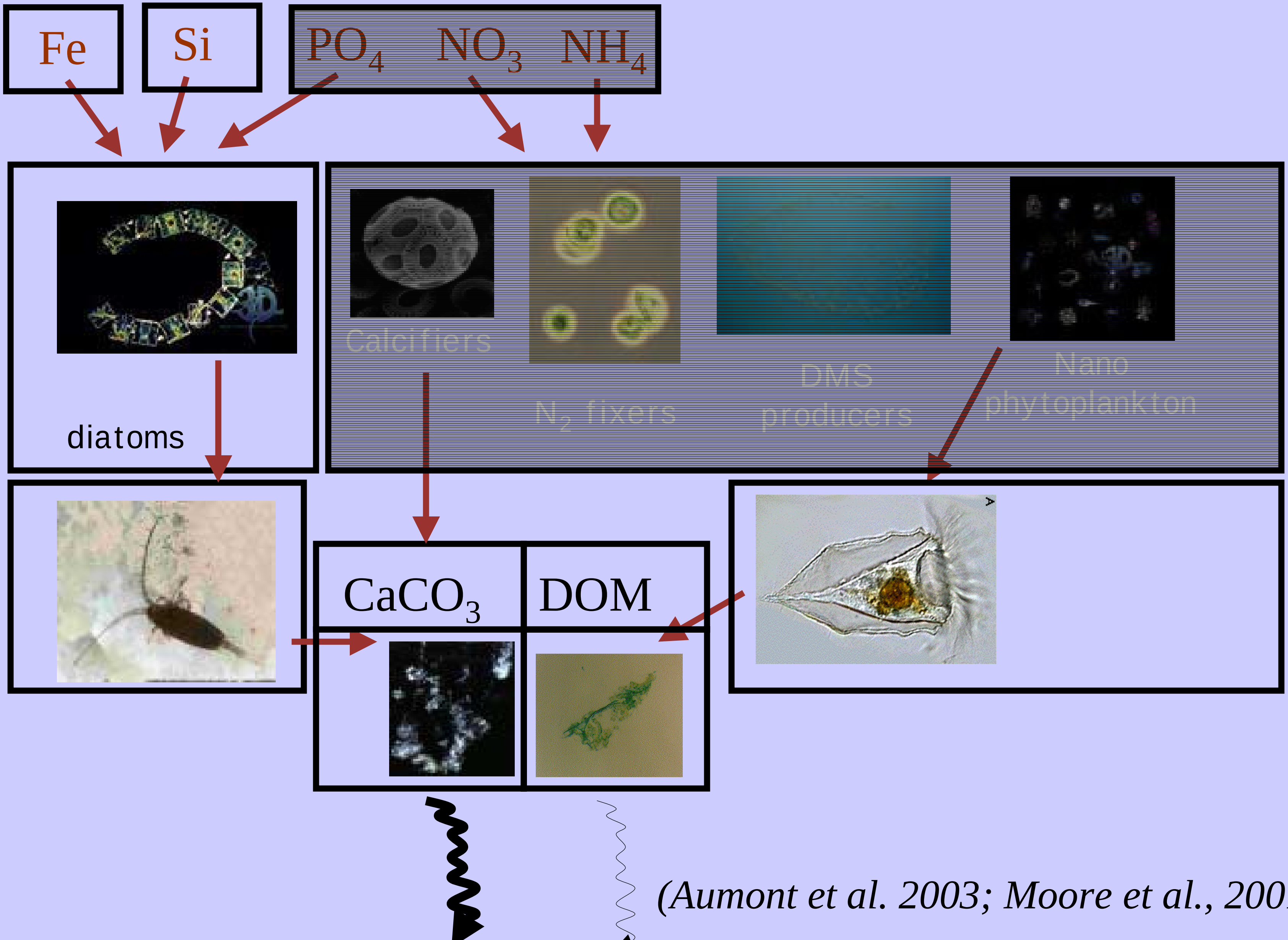
(Najjar et al., 1992; Maier-Reimer 1993)

NPZD



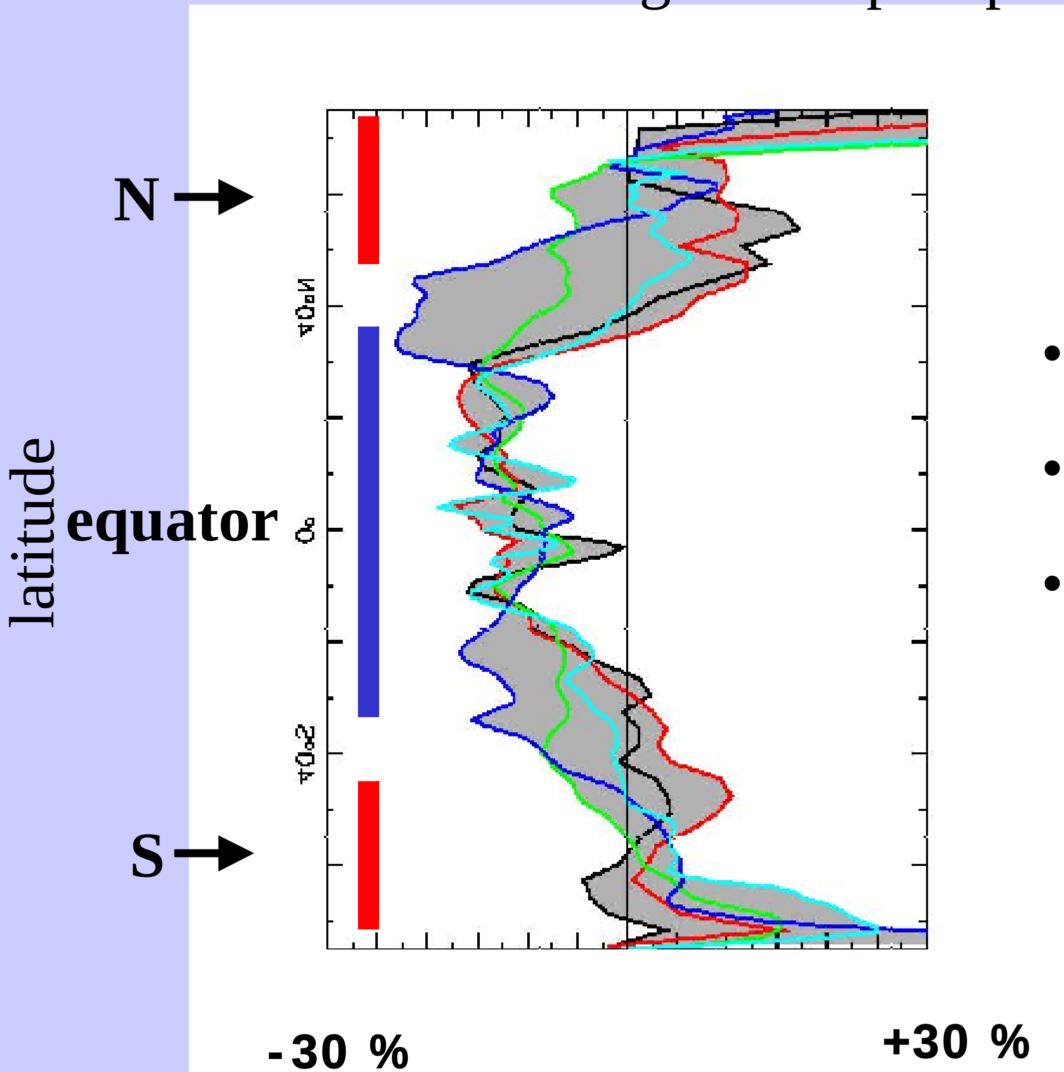
(Fasham et al., 1993)

ecosystem models



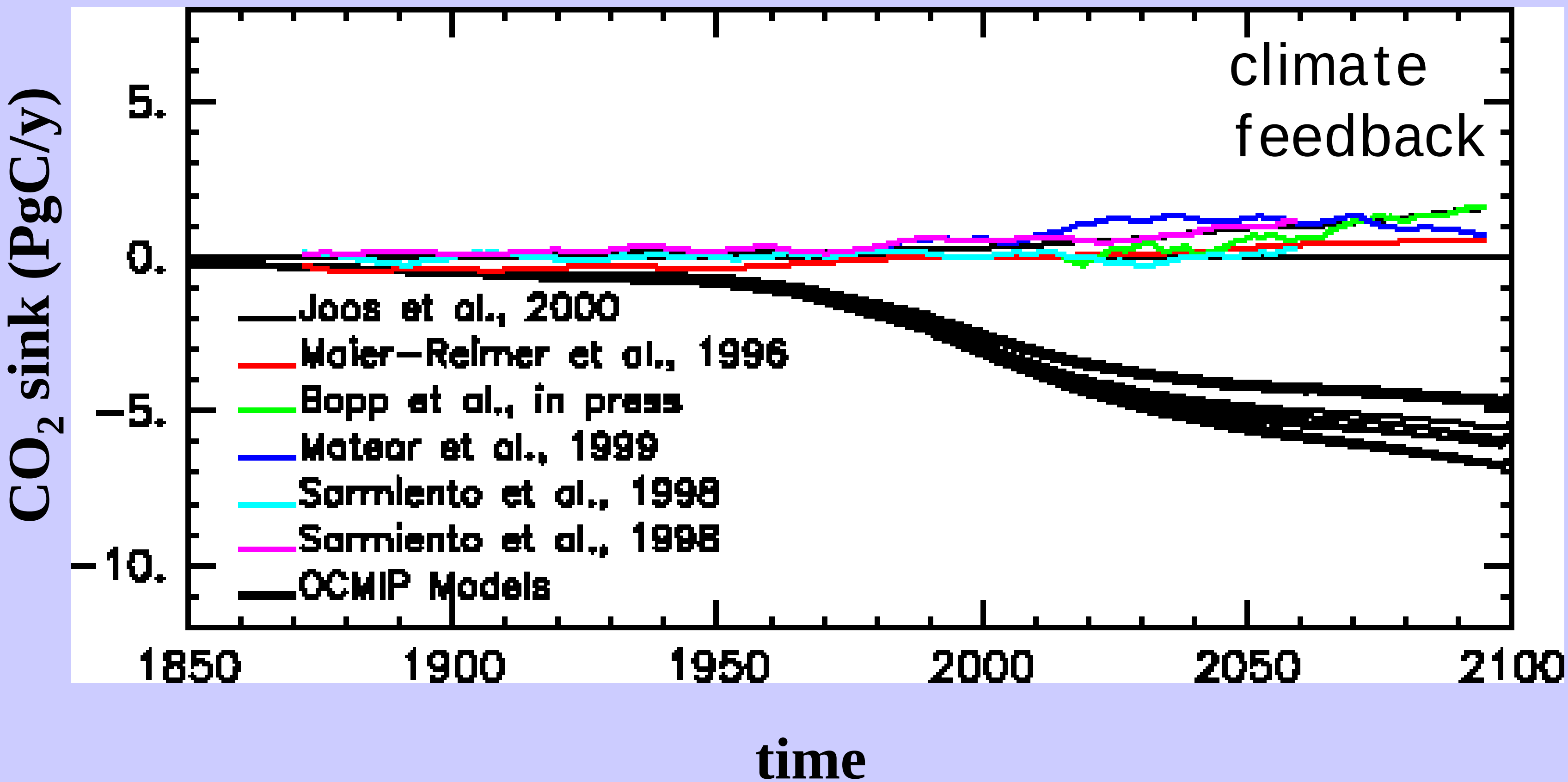
(Aumont et al. 2003; Moore et al., 2001)

Modelled changes in export production at $2xCO_2$

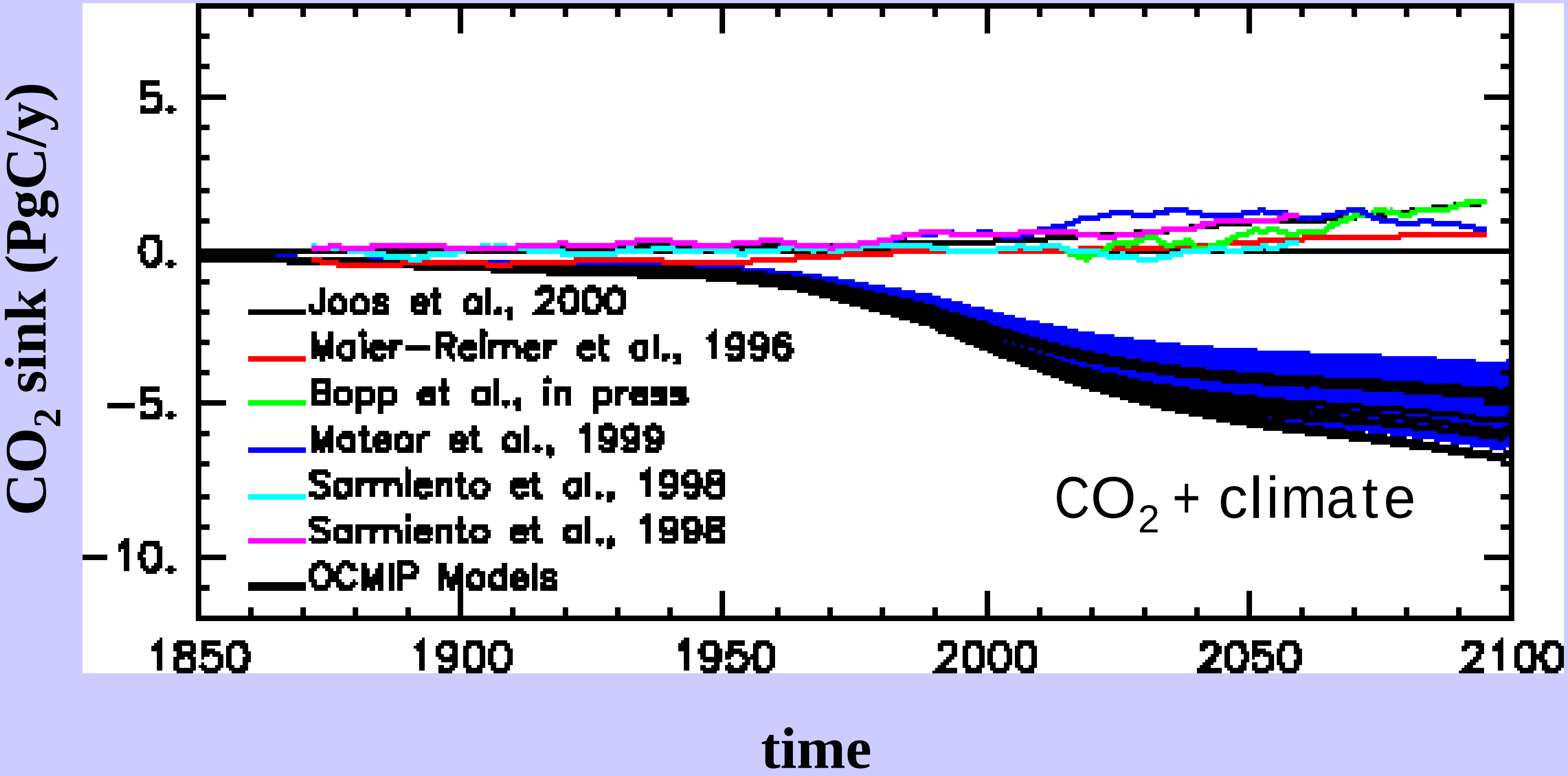


- reduction in nutrient supply
- increase of oligotrophic gyres
- longer growing season

(Bopp 2001)



(Prentice et al., 2001)



(Prentice et al., 2001)

CLIMATE RESPONSE OF OCEANIC UPTAKE

	Sarmiento et al. (1998)	Matear and Hirst (1999)	Joos et al. (1999)
Time Span	1990-2065	1850-2100	1765-2100
Warming Effect	-11%	-12%	-13%
Circulation Effect	-22%	-10%	-3%
Biological Effect	+24%	+8%	+6%
TOTAL	-9%	-14%	-10%

(slide from J. Sarmiento)

	CO_2	export production
100 yr predictions	-5 to -15% [warming]	0 to -6% [nutrient supply] - low lat + high lat
100,000 yrs variations		
interannual variations		

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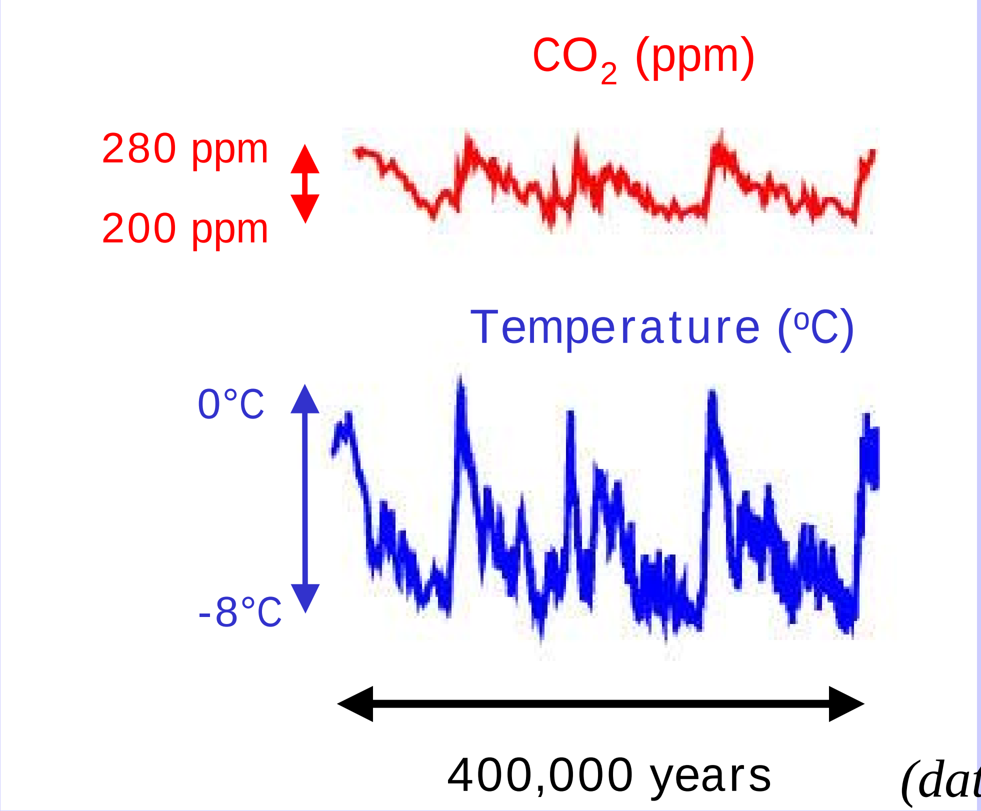
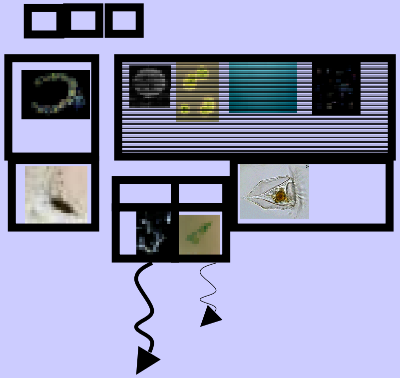
100,000 yrs variations

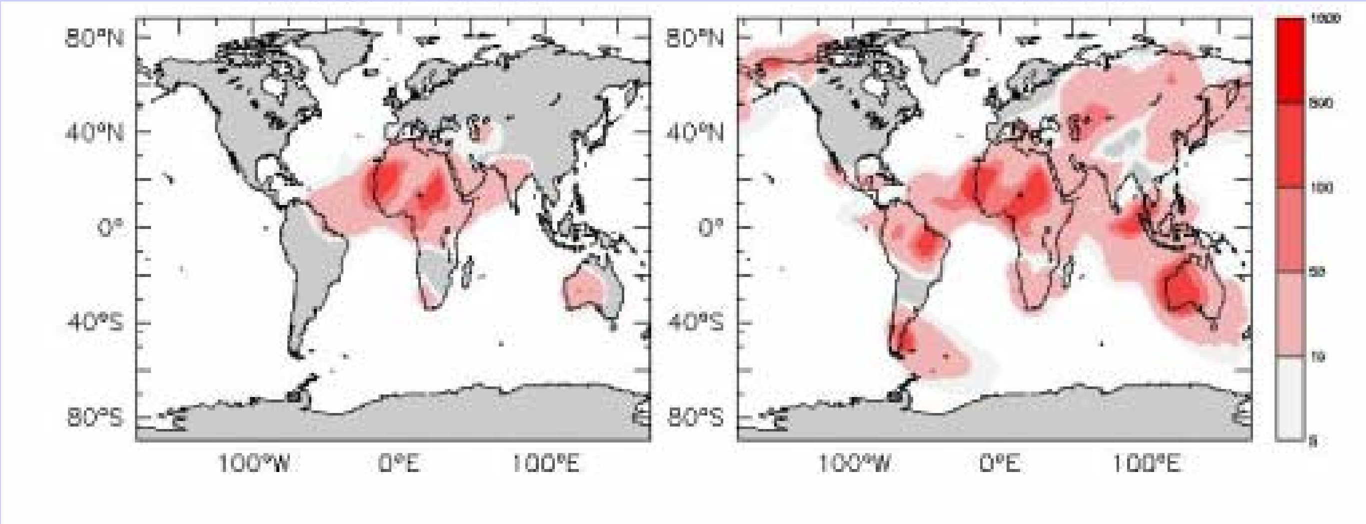


(data from Petit et al., 1999)

Model simulations of the last glacial maximum



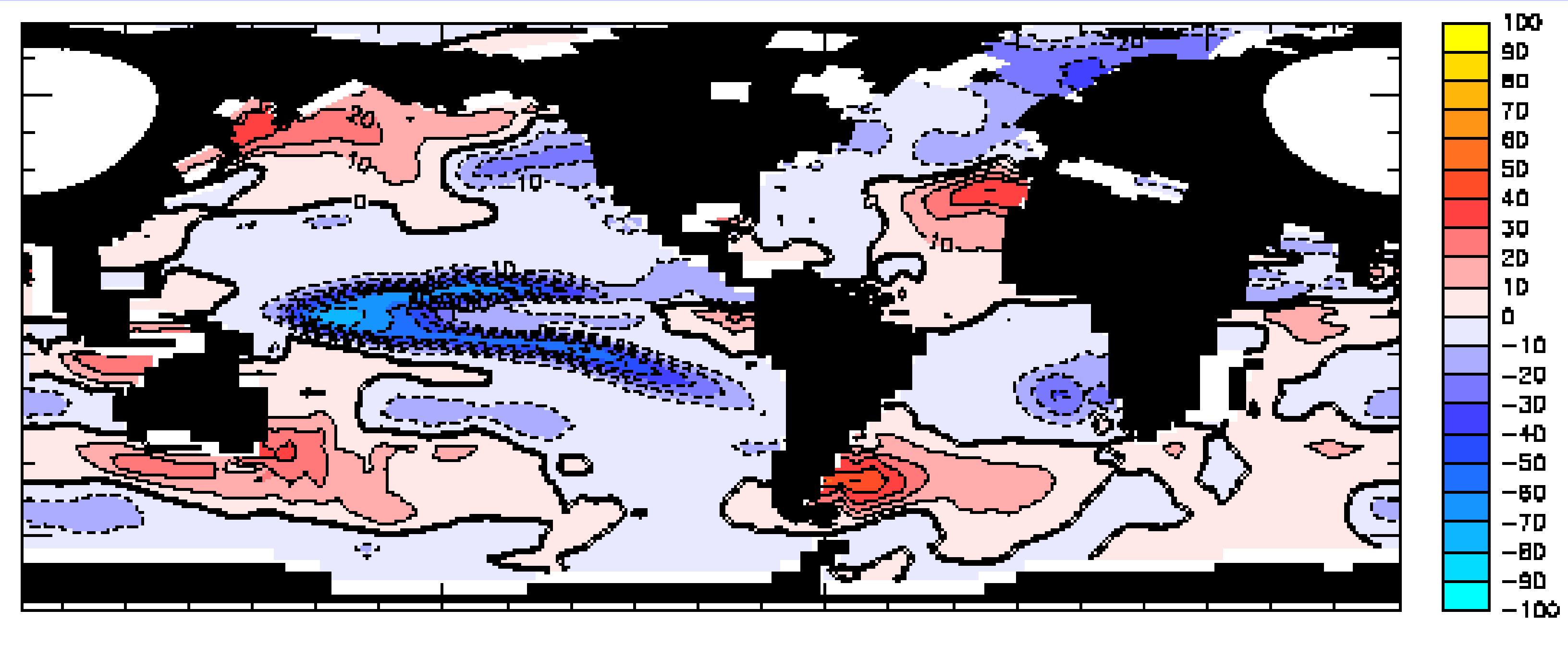
- Cooling of SST (CLIMAP 1981)
- Circulation Changes (Simulation OPA model, O. Marti)
- Increased Sea-Ice in Winter (Crosta et al. 1998)
- Increased dust deposition on the ocean (Mahowald et al. 1999)



➔ x2 over the ocean

(Bopp et al., 2003)

total LGM impact on export production

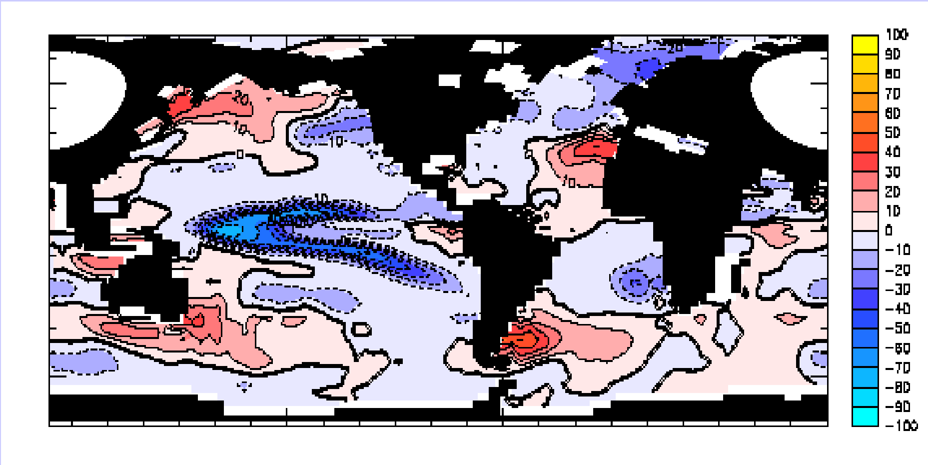


gC/m2/y

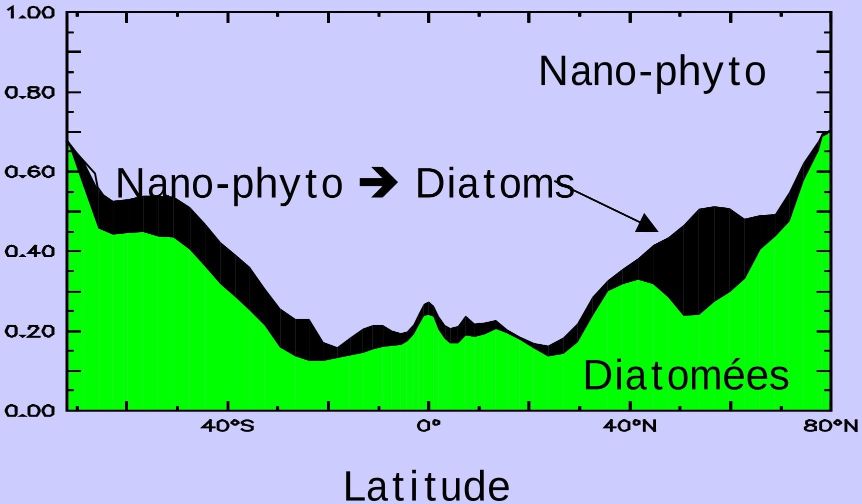
- decreased export production (-7 %)
- decreased atmospheric CO_2 (-30 ppm)

(Bopp et al., 2003)

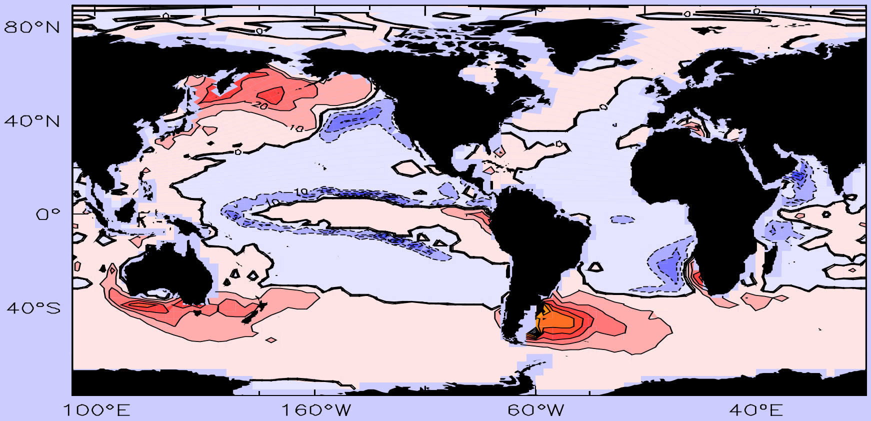
total LGM impact on export production



diatoms relative abundance



iron LGM impact on export production



- increased export production (+6 %)
- but increase of oligotrophic gyres
- shift from nano-phyto to diatoms

(Bopp et al., 2003)

Evaluation of Paleo-Data

Paleo-Export Proxies:

- Opal (SiO_2)
- Calcium Carbonate ($CaCO_3$)
- Organic Carbon
- Biomarker (C37 Alkenones)

- ^{10}Be
- ^{231}Pa
- Excess Barium

- Authigenic Uranium
- Authigenic Cadmium
- Benthic Foraminifera Fluxes

Ranking Criteria:

Age Models
- Radiocarbon dating (AMS)
- Oxygen Isotope Stratigraphy
- Lithogenic Correlation

Flux measurement
- Constant Flux Normalization (^{230}Th)
- Mass Accumulation Rates
- Sediment Concentration

Proxy Agreement
- How many?
- Percentage agreement

Ranked Classes:

Data Confidence

○ high
○ medium
○ low

(Kohfeld et al., in prep.)

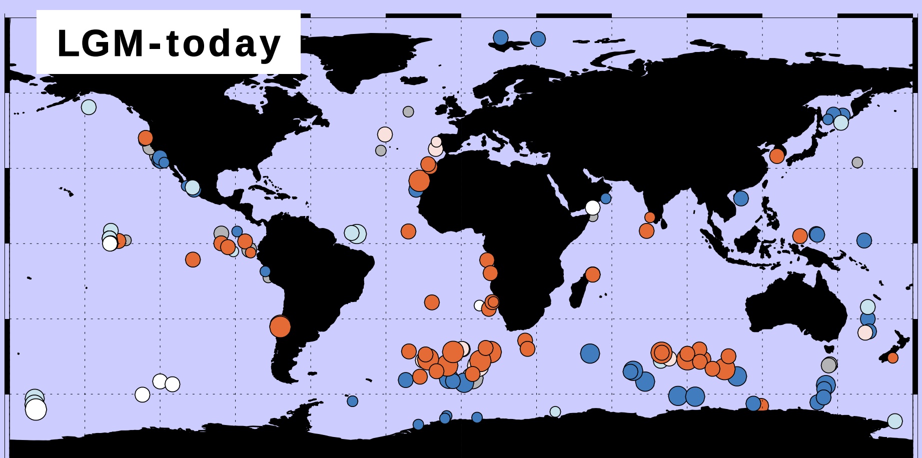
Stage 5ad-today

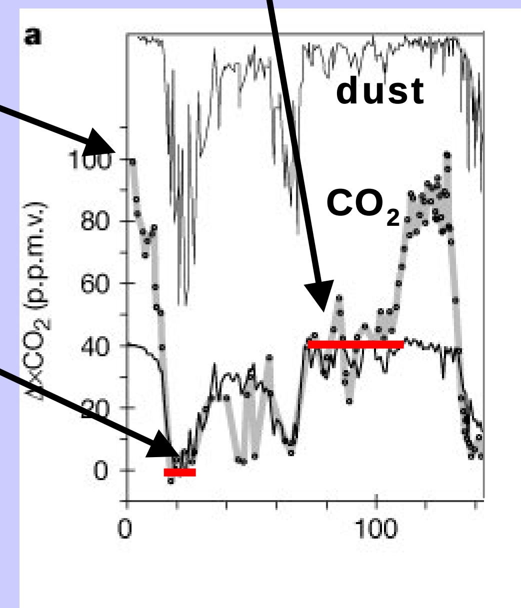
Unpublished map not available

change in export production

LGM-Stage 5ad

Unpublished map not available

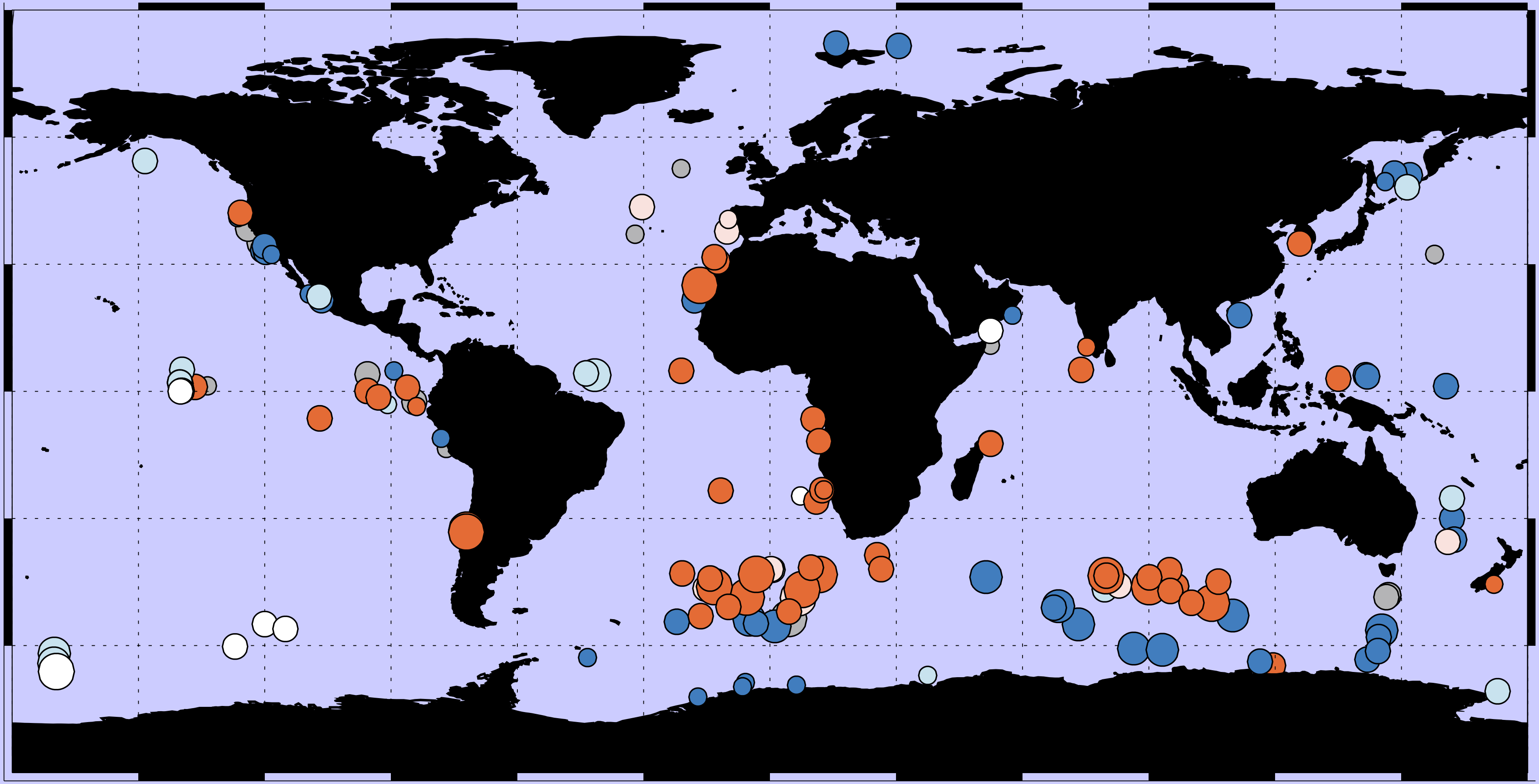




time

(Kohfeld et al., in prep.)

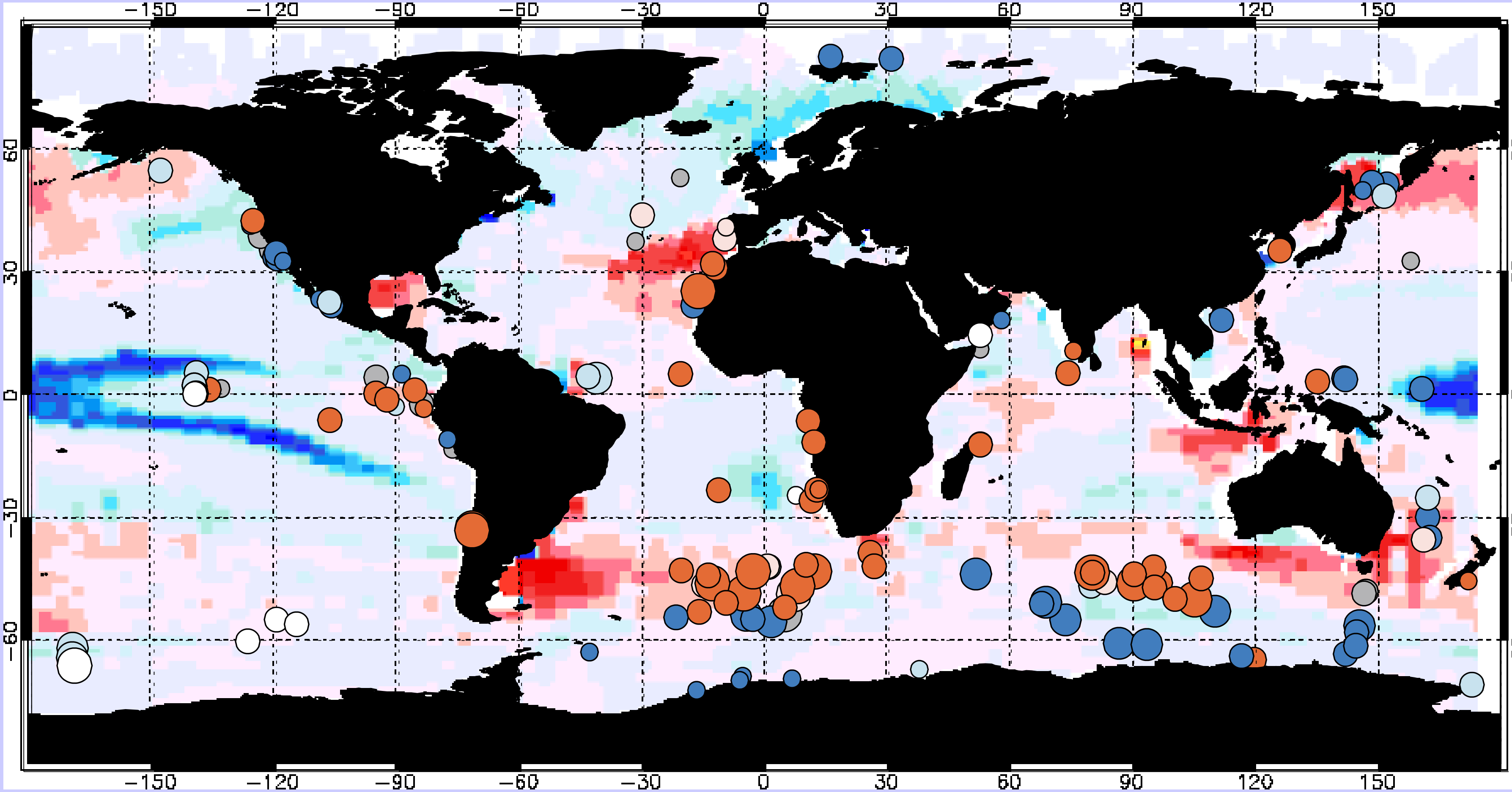
change in export production



Data-base (Kohfeld et al., in prep.)/ OPA-PISCES model (Bopp et al. 2003)

(gC m^{-2} yr^{-1})

change in export production



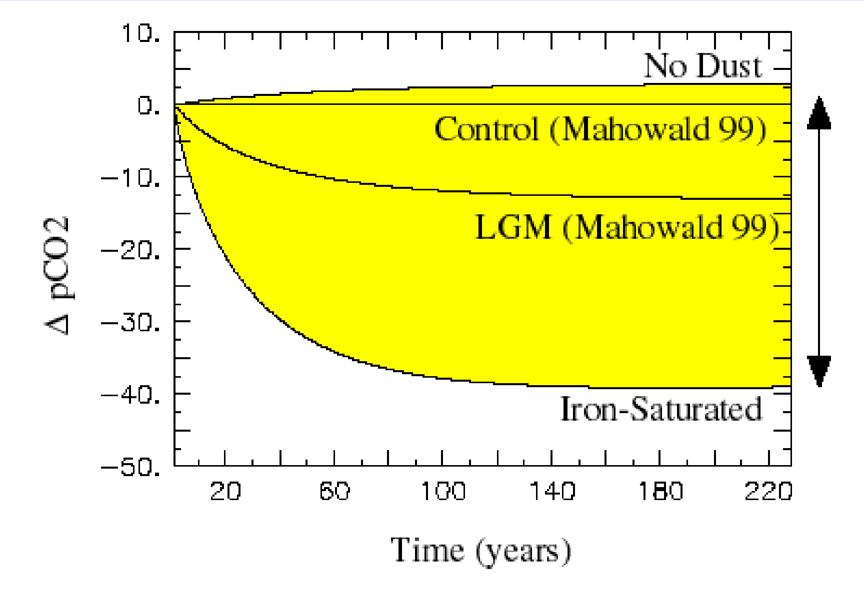
Data-base (Kohfeld et al., in prep.)/ OPA-PISCES model (Bopp et al. 2003)

(gC m^{-2} yr^{-1})

CO_2 drawdown with this model 30 ppm

SST + SSS (+ sea ice + circ.) = –15 ppm

Dust increase –15 ppm

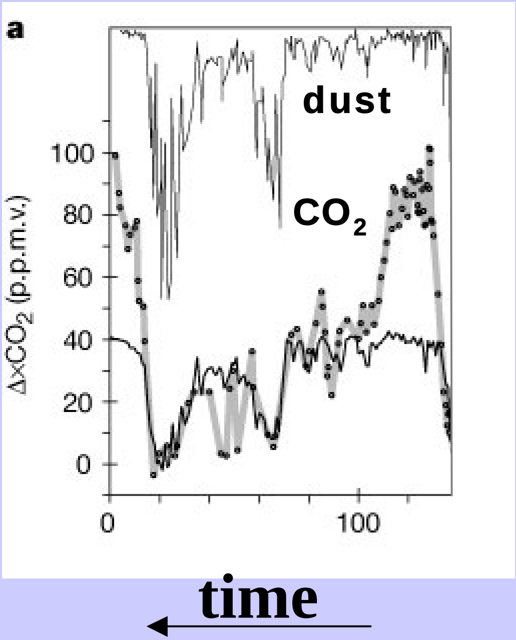


Maximum effect with this model

41 ppm

(Bopp et al., 2003)

CO_2 reduction due to dust at the LGM	Reference
15 ppm	Bopp et al. in press
8 ppm	Archer et al. 2000
40 ppm	Watson et al., 2000



reasonable agreement considering the phasing of dust/CO_2 changes

(Watson et al., 2000)

	CO_2	export production
100 yr predictions	-5 to -15% [warming]	0 to -6% [nutrient supply] - low lat + high lat
100,000 yrs variations	-8 to -40 ppm [iron] -15 ppm [solub.] -25 to -75 ppm left	~0 [iron + circ] + mid-low lat [iron] - high lat [circ + bio]
interannual variations		

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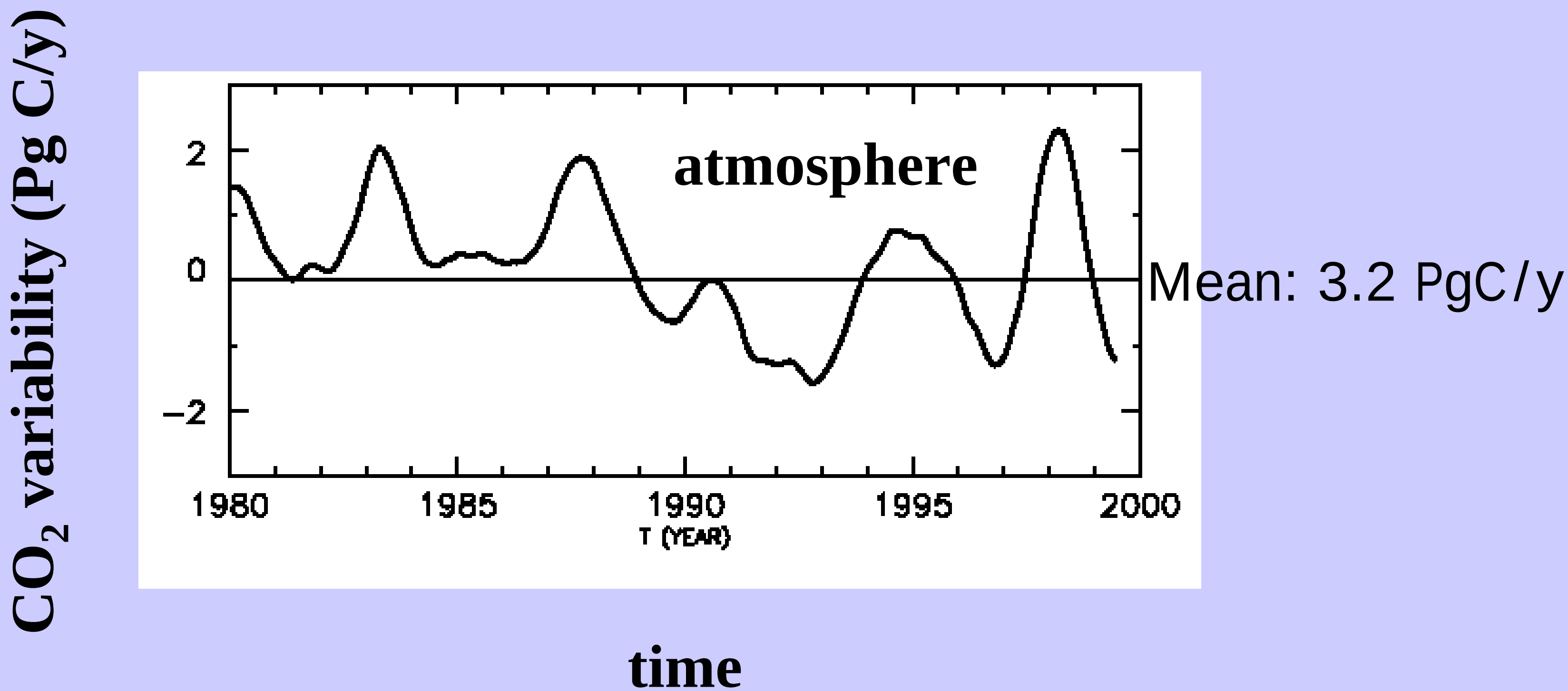
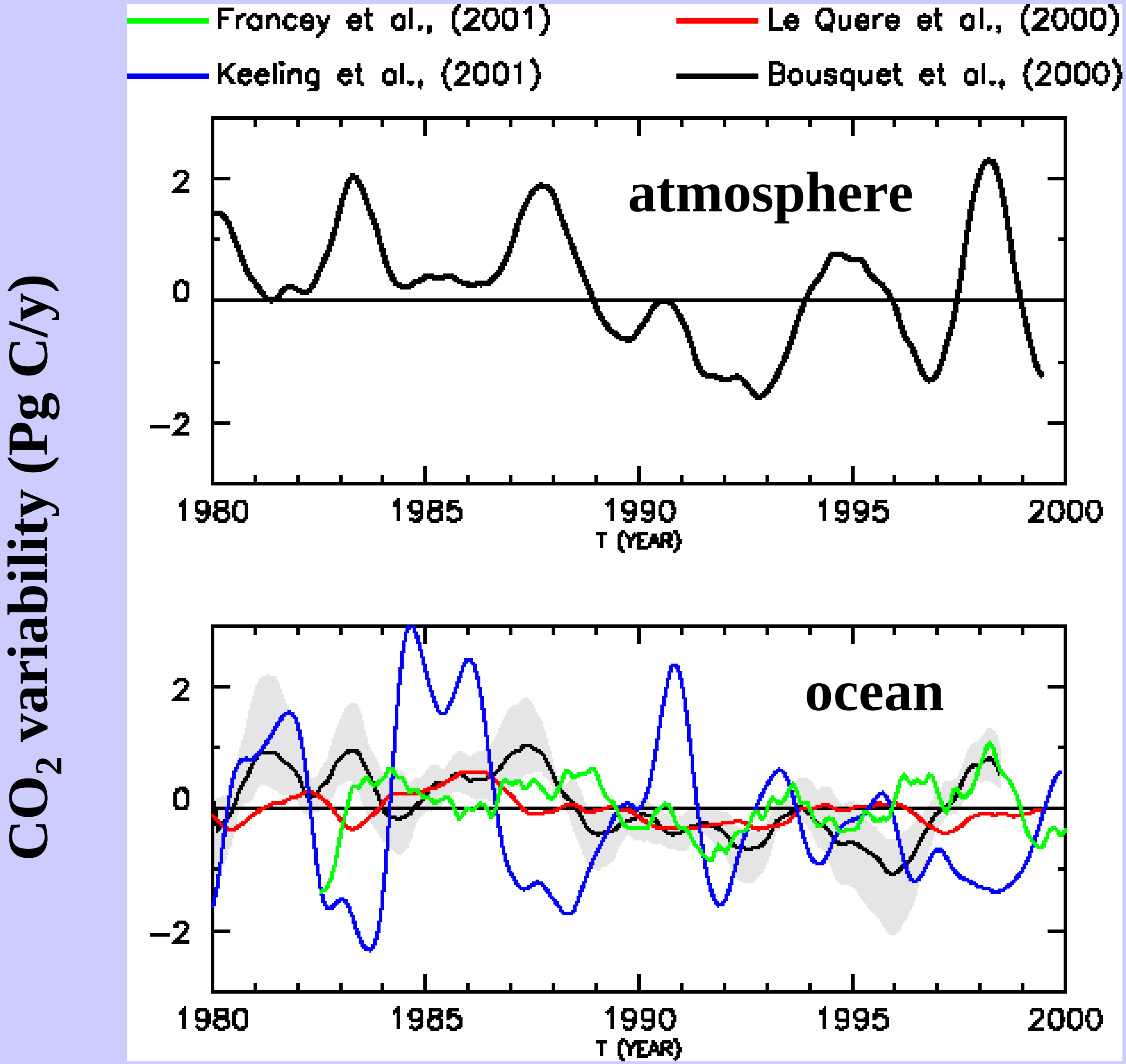
interannual CO_2 variability

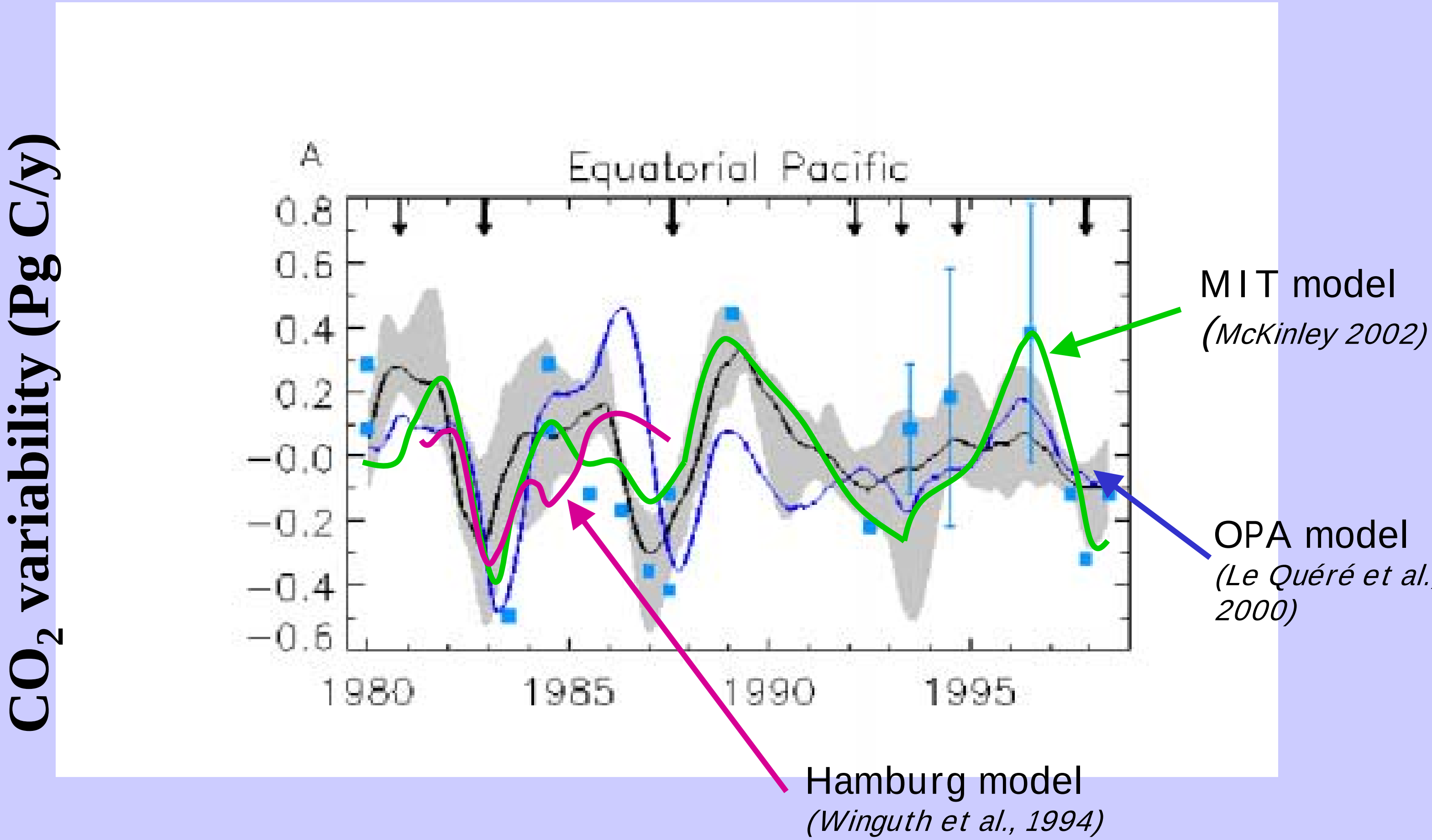


20 years



(Le Quéré et al., 2003)

equatorial Pacific

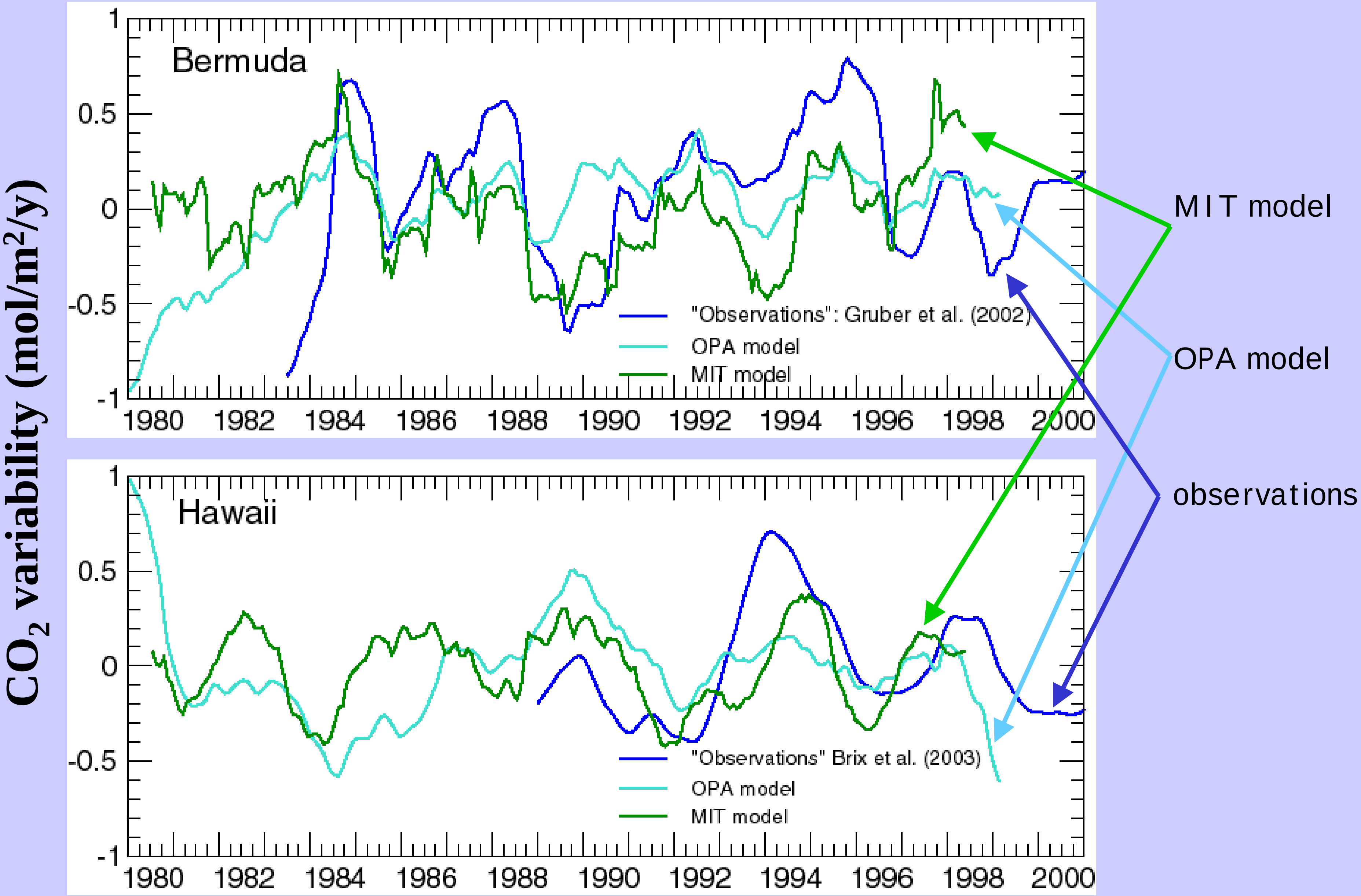


During El Nino events: CO_2

- warming ↗
- decreased upwelling ↙
- decreased export production ↗

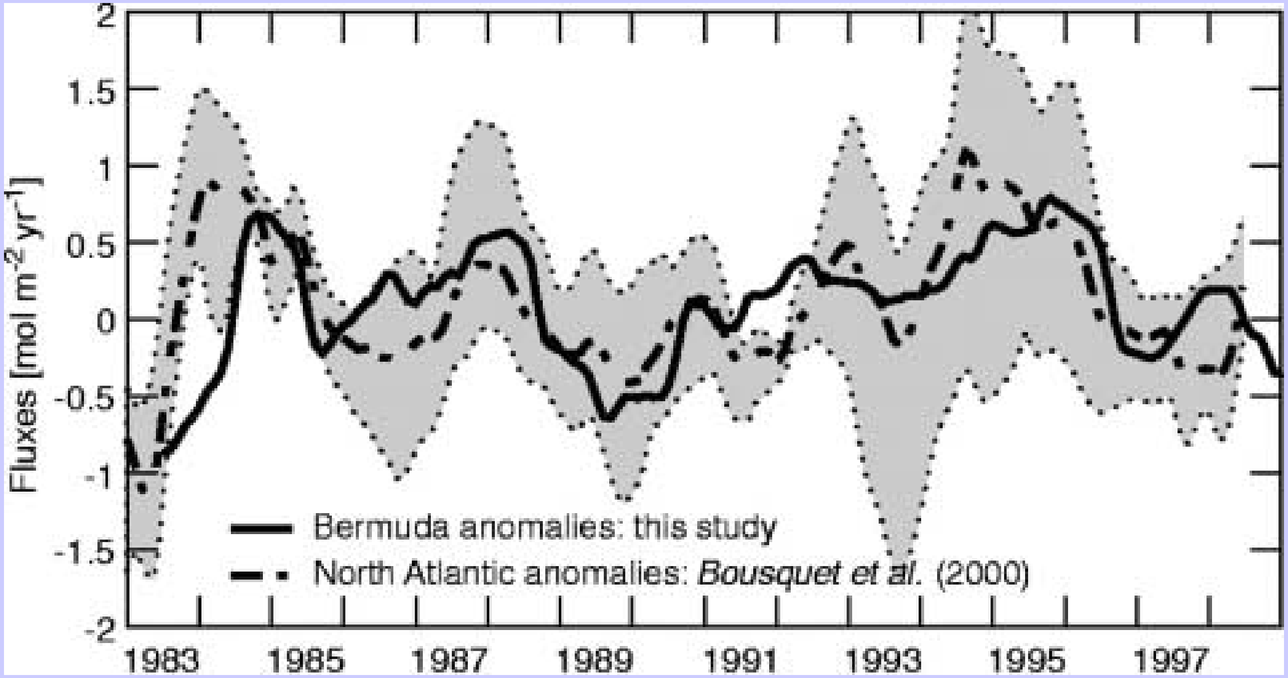
(Bousquet et al., 2000;
data from Feely et al., 1999)

northern sub-tropics



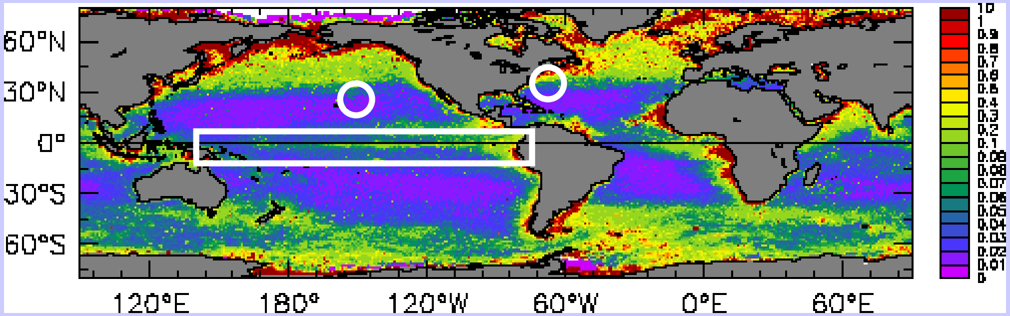
(Peylin et al., in prep)

North Atlantic

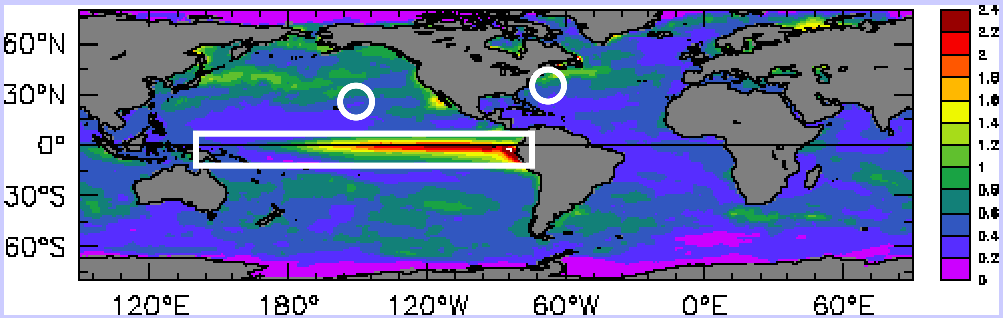


(Gruber et al., 2002)

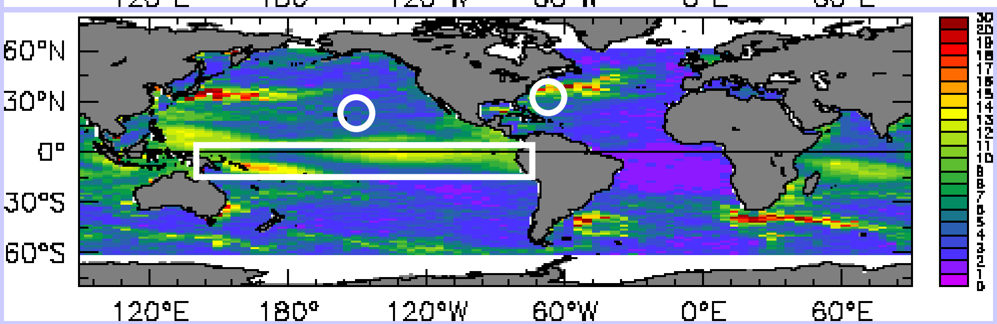
Standard deviation of interannual signal



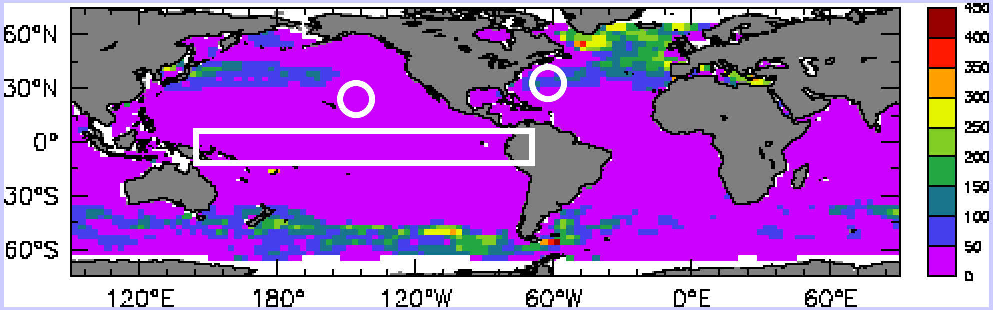
Chla (SeaWiFS)



SST (Reynolds and Smith 1994)



SSH (TOPEX/Poseidon)



MLD (indirect estimate using SSH)

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100,000 yrs variations	-8 to -40 ppm [iron] -15 ppm [solub.] -25 to -75 ppm left	~0 [iron + circ] + mid-low lat [iron] - high lat [circ + bio]
interannual variations	+/- 0.3 ppm +/- 0.3 ppm tropics [circ] +/- 0.05 ppm mid lat [solub.] +/- 0.05 ppm high lat [circ + bio]	

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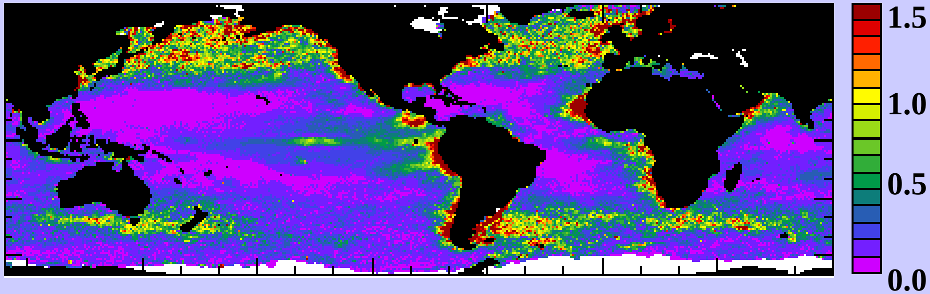
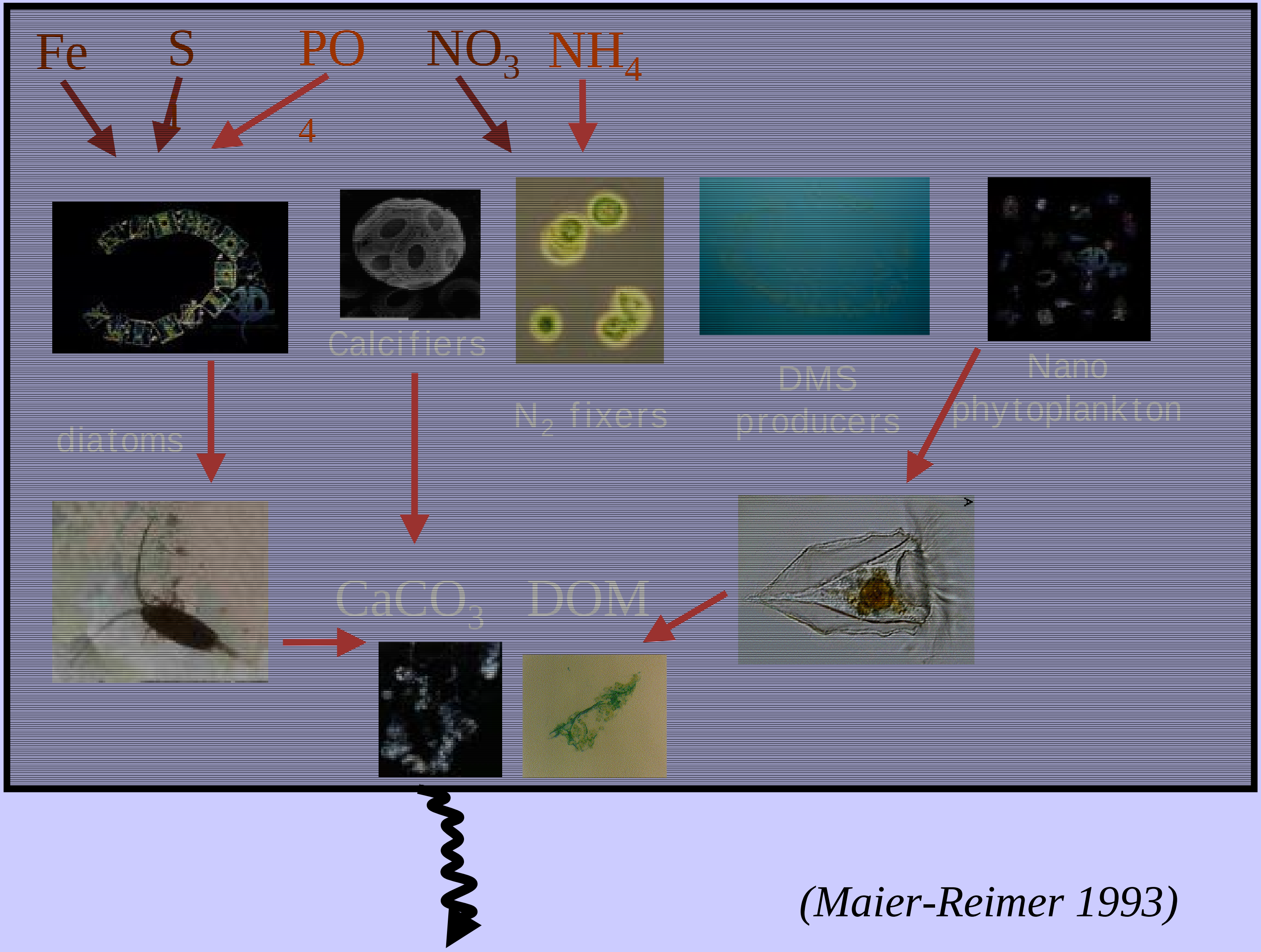
Standard deviation of export production variability 1997-2002 (mol C/m^2/yr)

SeaWiFS chl*a*, PP from Behrenfeld and Falkowski (1997), ef-ratio from Laws et al. (2000)



nutrient-based models (HAMOCC3)



(Maier-Reimer 1993)

Standard deviation of export production variability (mol C/m^2/yr)

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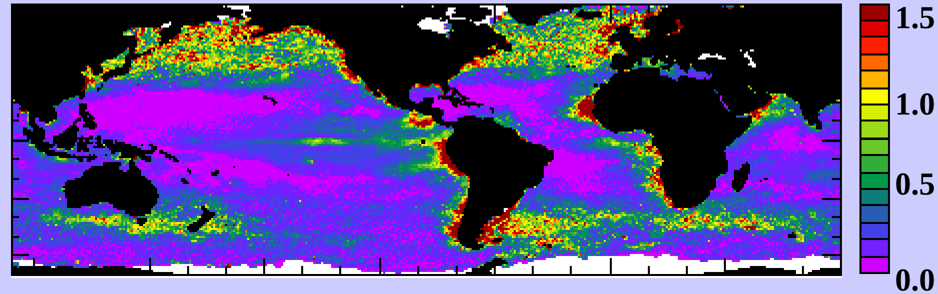
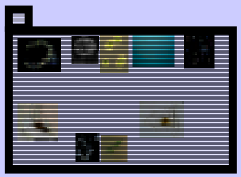
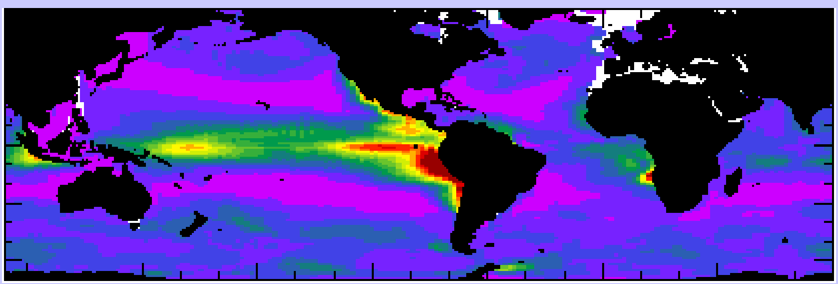
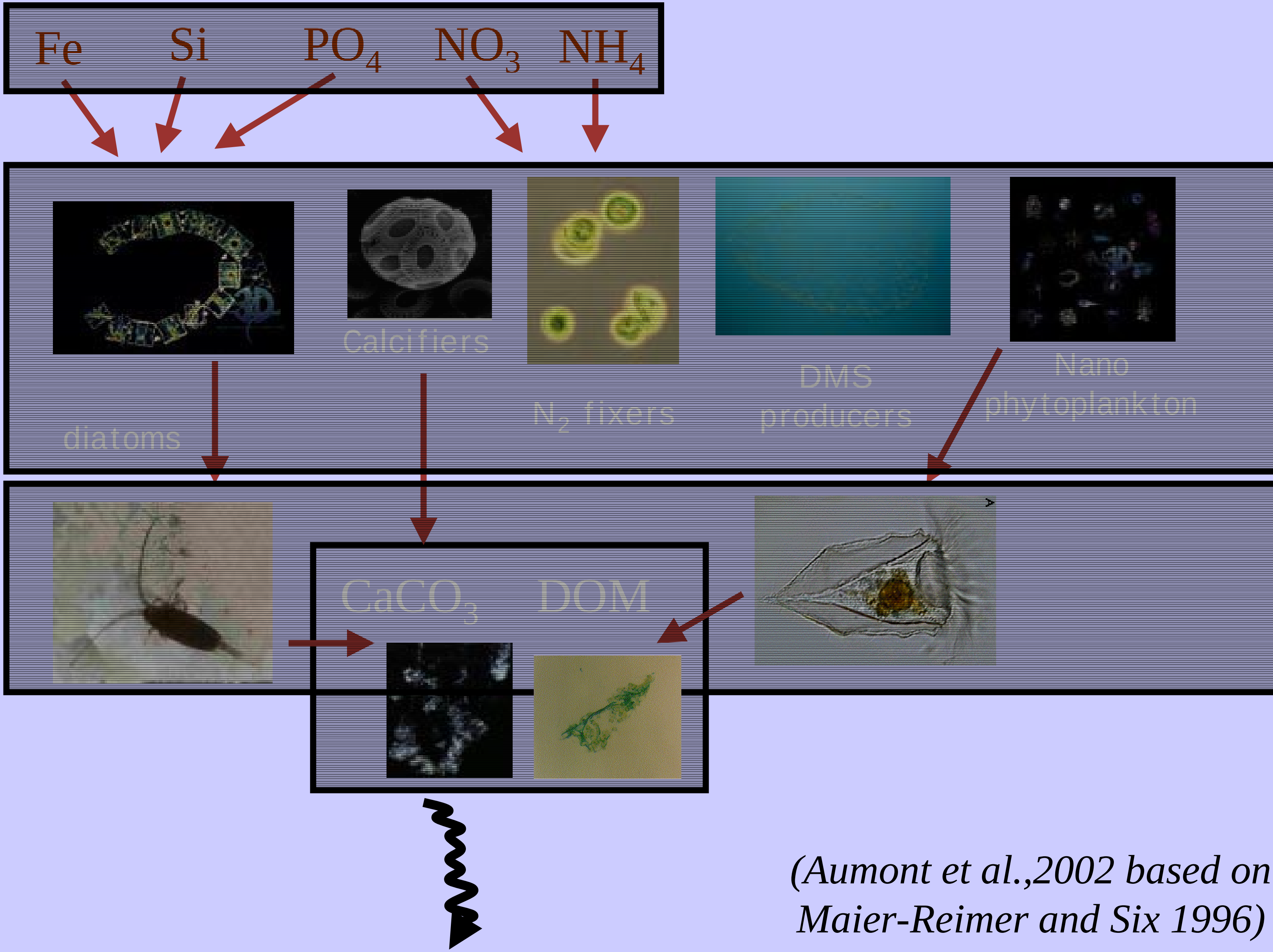


HAMOCC3





NPZD



(Aumont et al.,2002 based on Maier-Reimer and Six 1996)

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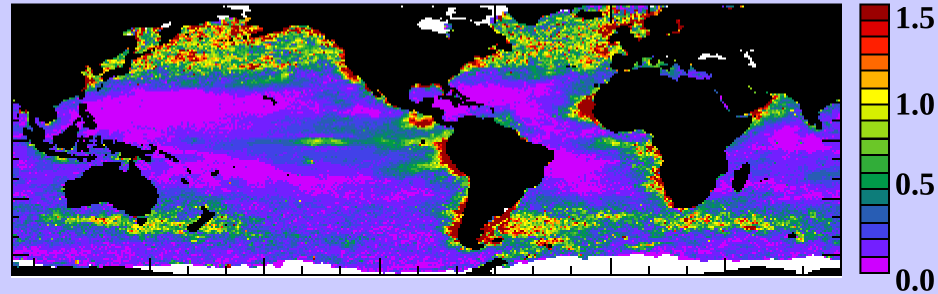

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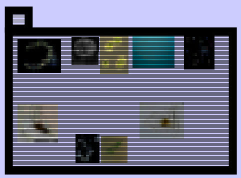

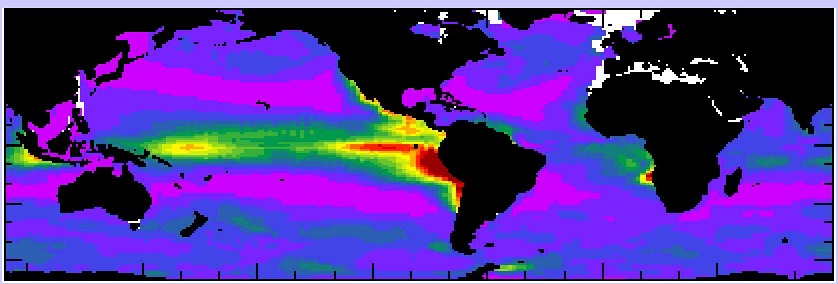

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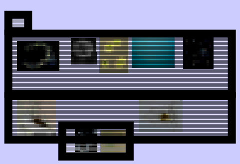
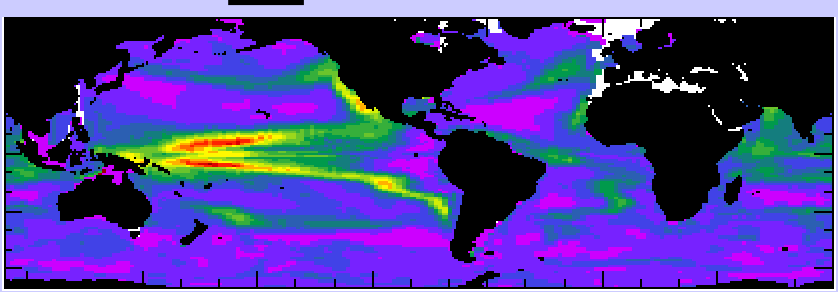
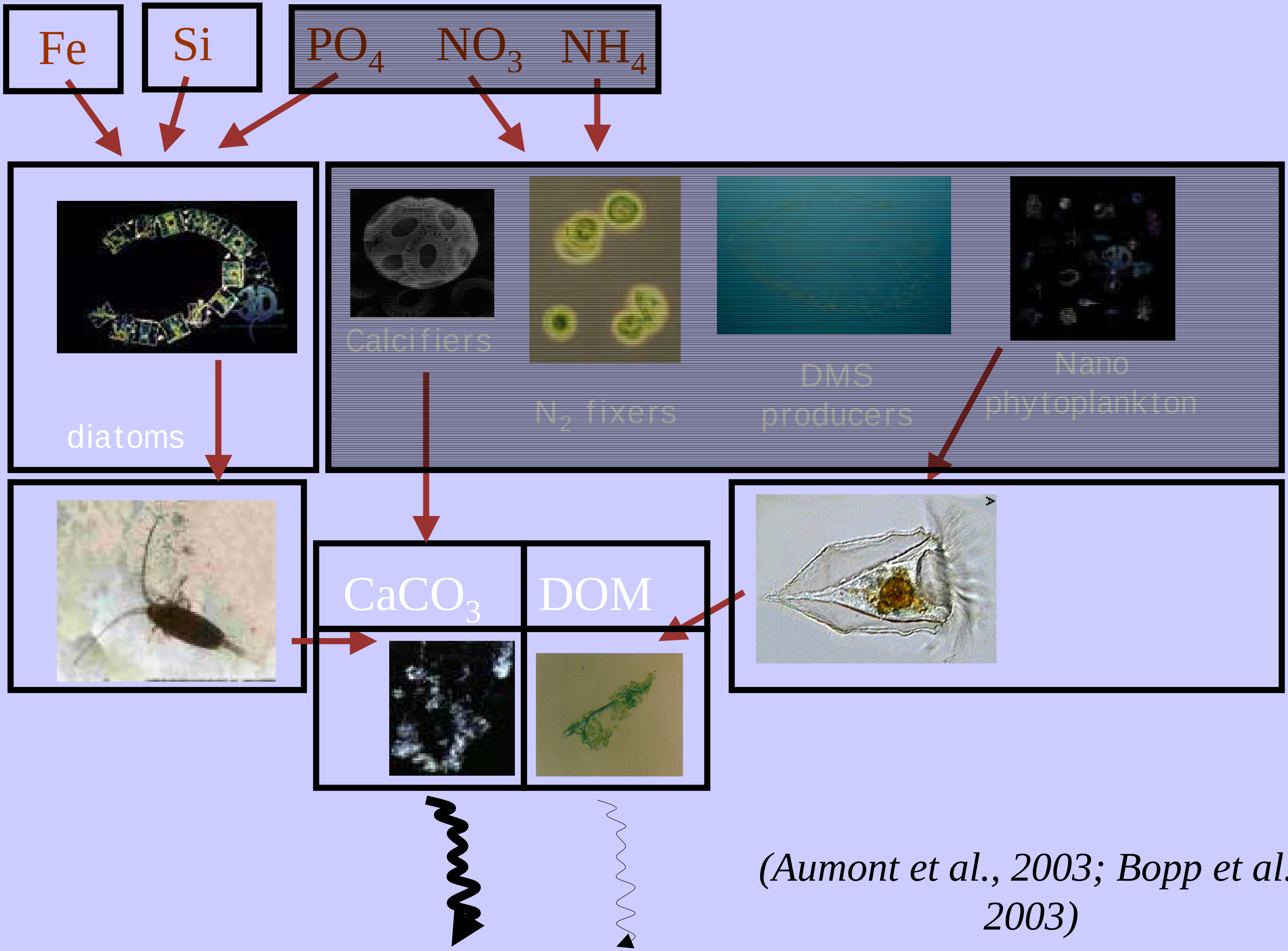




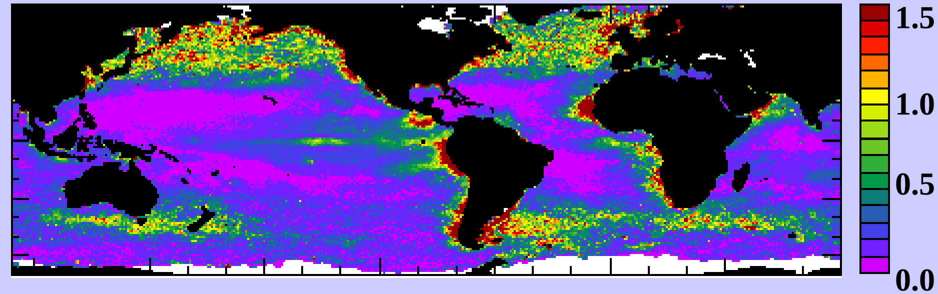
PISCES model based on plankton functional types



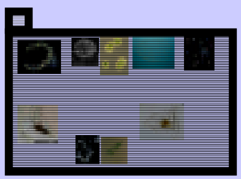
(Aumont et al., 2003; Bopp et al., 2003)

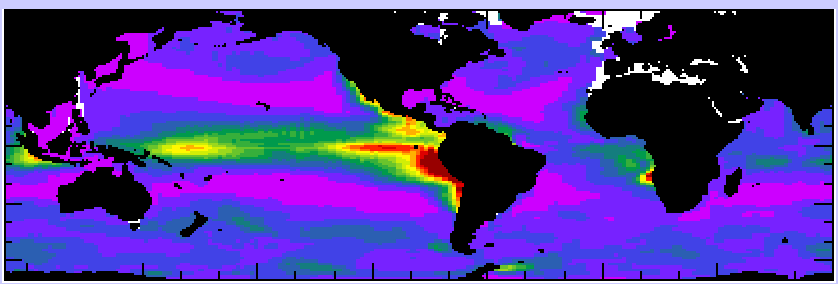
Standard deviation of export production variability (mol C/m^2/yr)

SeaWiFS chl*a*, PP from Behrenfeld and Falkowski (1997), ef-ratio from Laws et al. (2000)

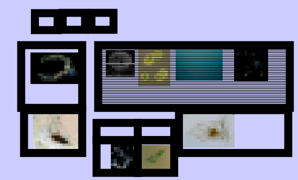


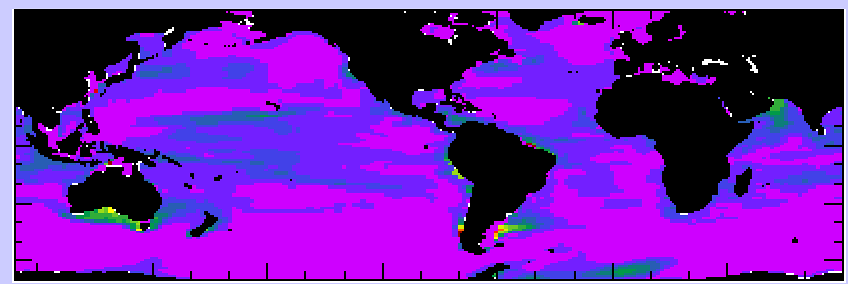
HAMOCC3





PISCES





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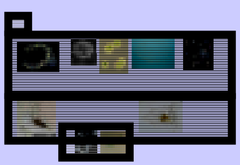
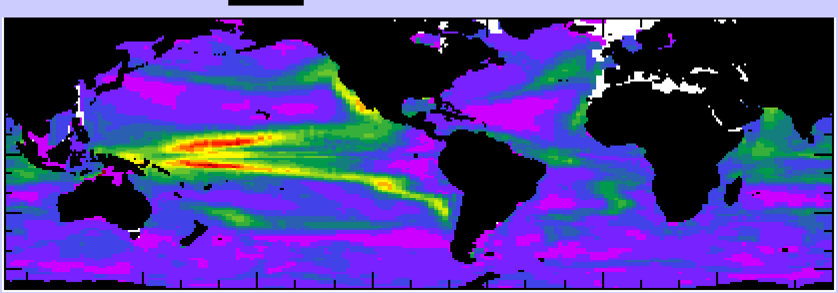
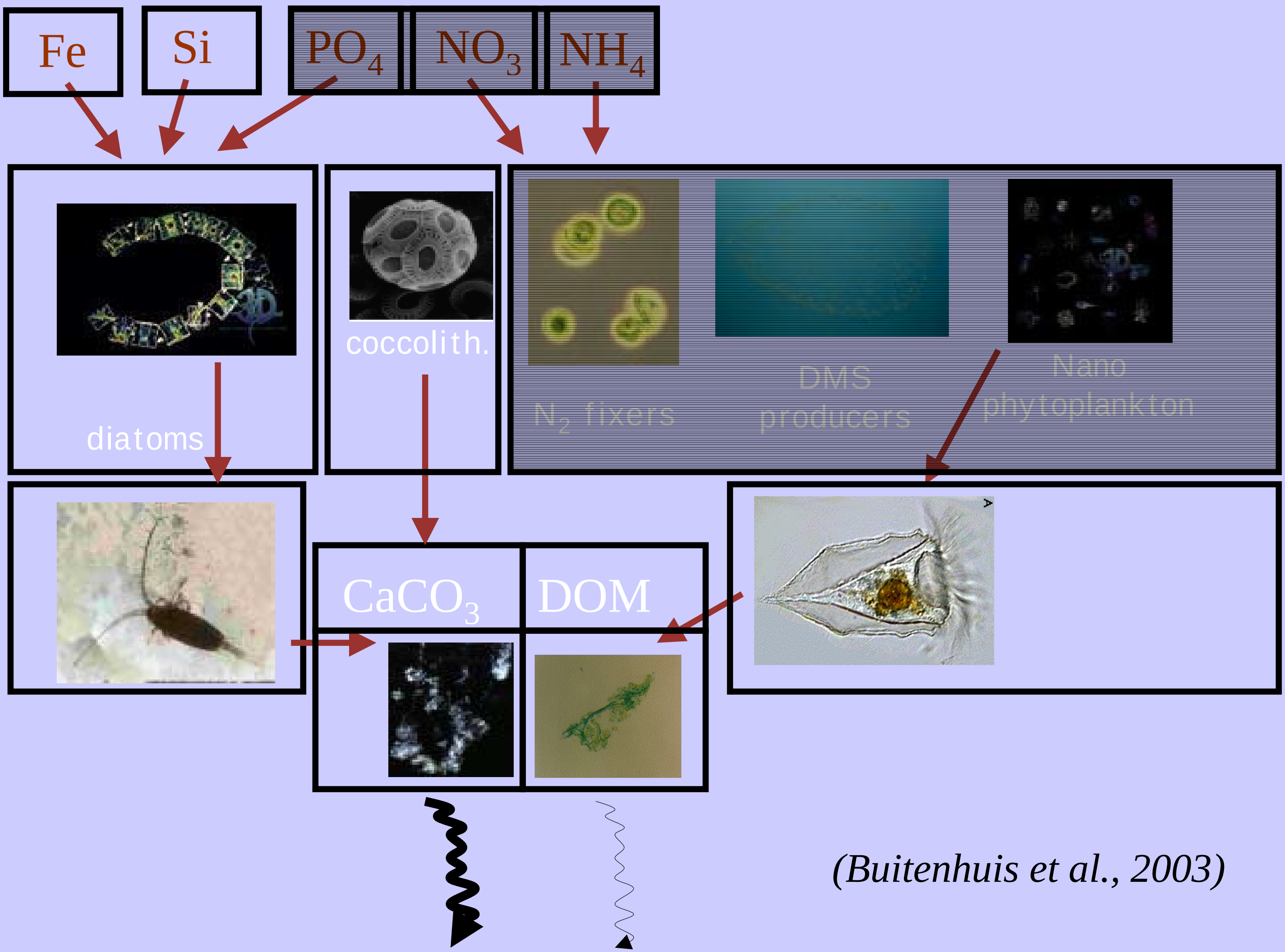




Dynamic Green Ocean Model



(Buitenhuis et al., 2003)

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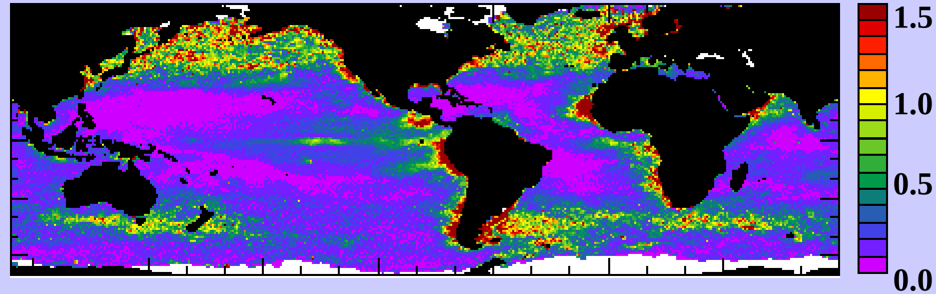
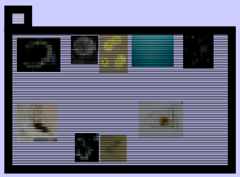
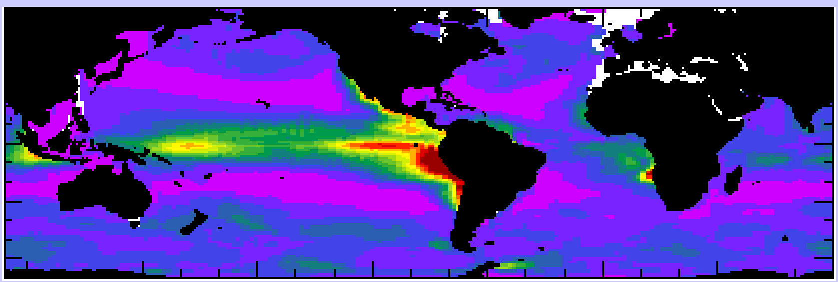
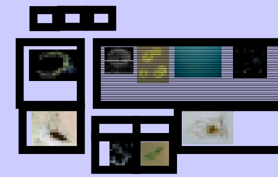


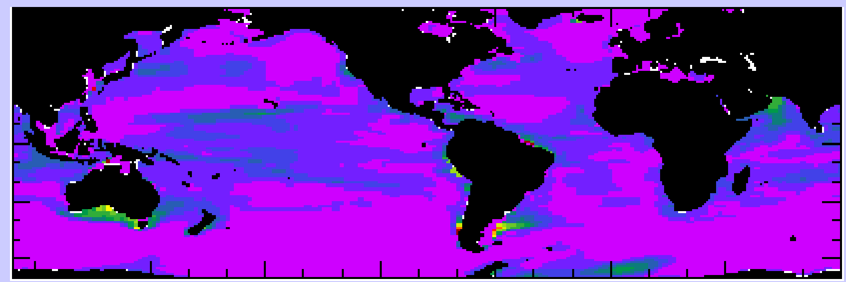
HAMOCC3





PISCES





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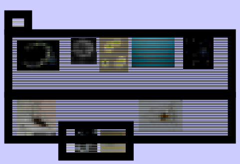
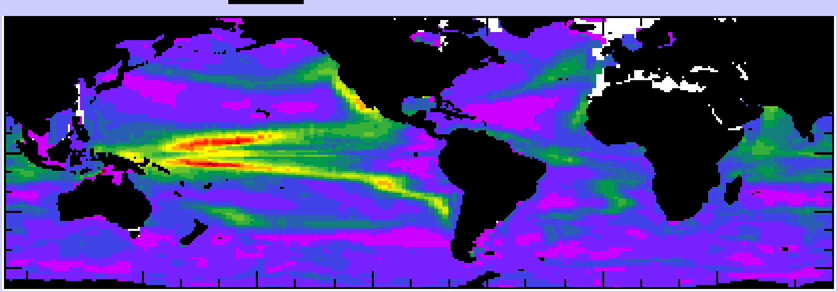
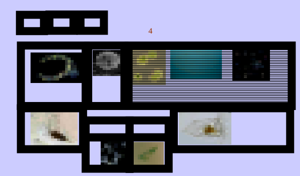
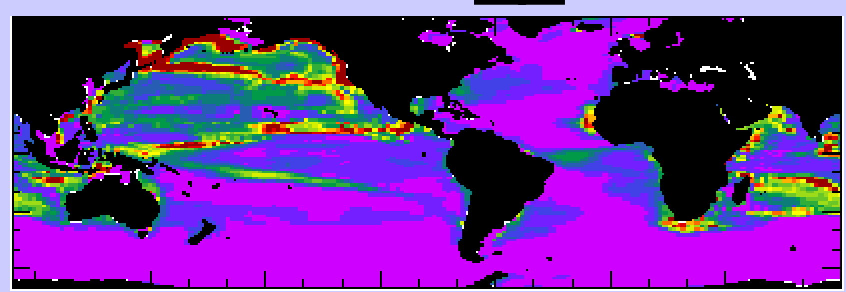




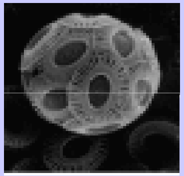
DGOM





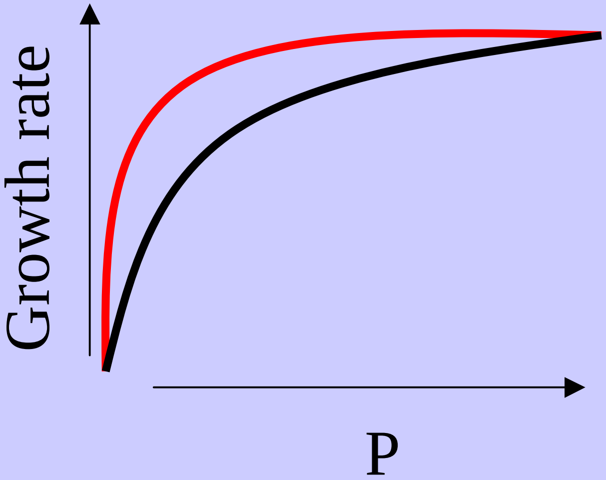
(Le Quéré et al., in prep.)

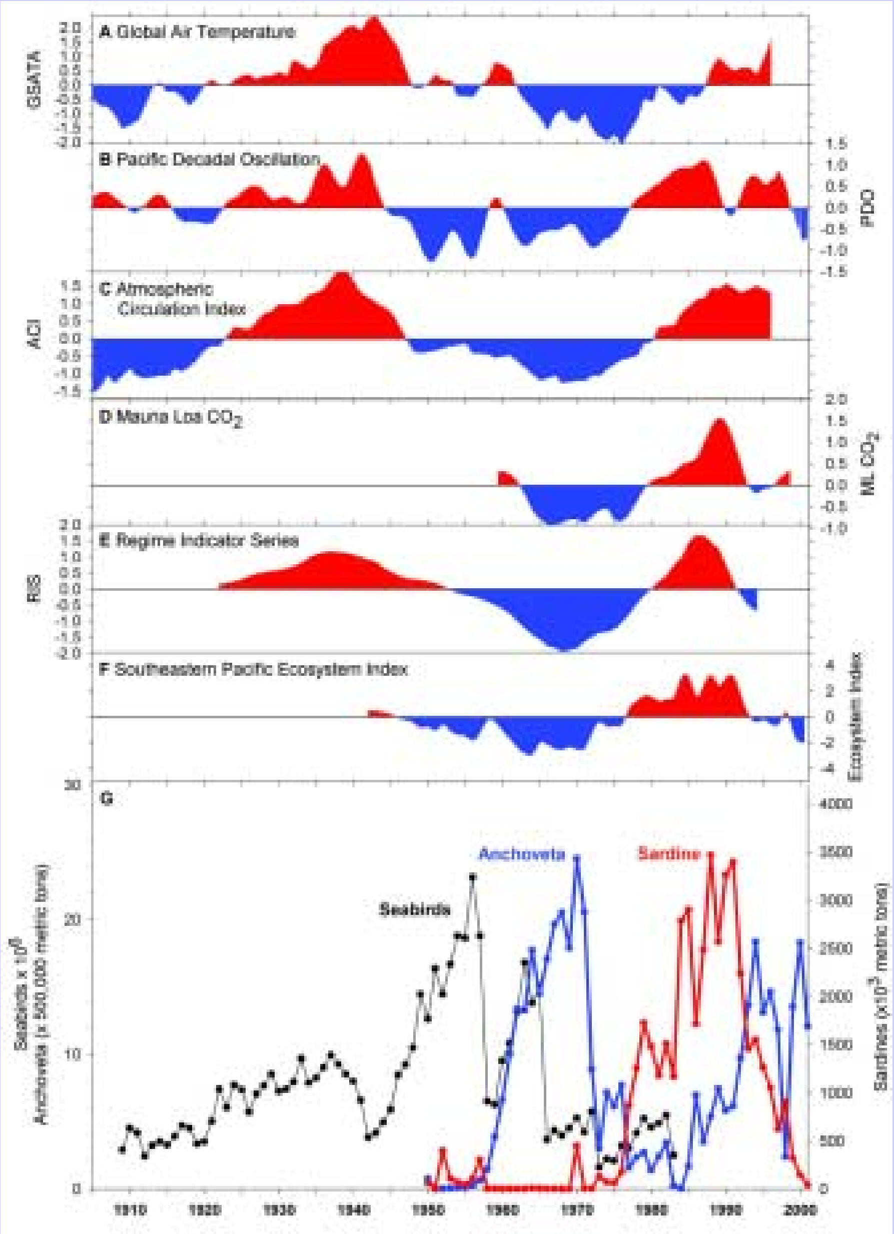
diatoms



coccolithophorids

nano-
phytoplankton





(Chavez et al 2003)

	CO_2	export production
100 yr predictions	-5 to -15% [warming]	0 to -6% [nutrient supply] - low lat + high lat
100,000 yrs variations	-8 to -40 ppm [iron] -15 ppm [solub.] -25 to -75 ppm left	~0 [iron + circ] + mid-low lat [iron] - high lat [circ + bio]
interannual variations	+/- 0.3 ppm +/- 0.3 ppm tropics [circ] +/- 0.05 ppm mid lat [solub.] +/- 0.05 ppm high lat [circ + bio]	+/- 1%

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plankton functional types

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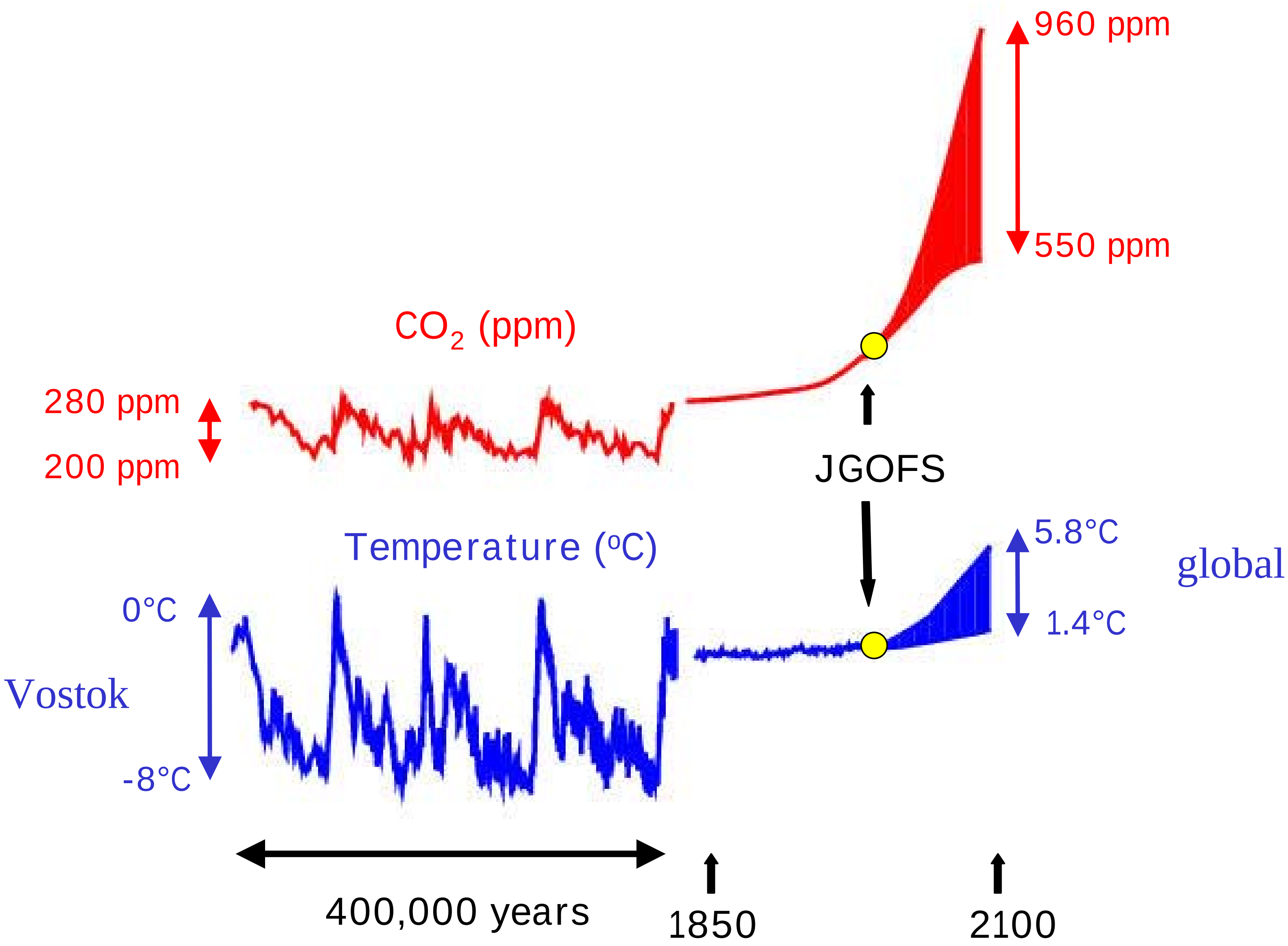
plankton functional types

linkages between biogeochemistry and physics (including the coastal ocean)


960 ppm
550 ppm
CO2 (ppm)
280 ppm
200 ppm
JGOFS
Temperature (oC)
5.8°C
global
1.4°C
0°C
Vostok
-8°C
400,000 years
1850
2100

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