Modeling Low-Oxygen Regions

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1. How well can global models simulate low-oxygen regions?
2. Long-term projections
3. Variability
4. Coastal ocean oxygen modeling
5. Paleo prespective

Ocean Carbon and Biogeochemistry (OCB) summer workshop 2010
Scripps Institution of Oceanography

1. How well can global models simulate low-oxygen regions?

UVic Model

(Weaver et al. 2001)

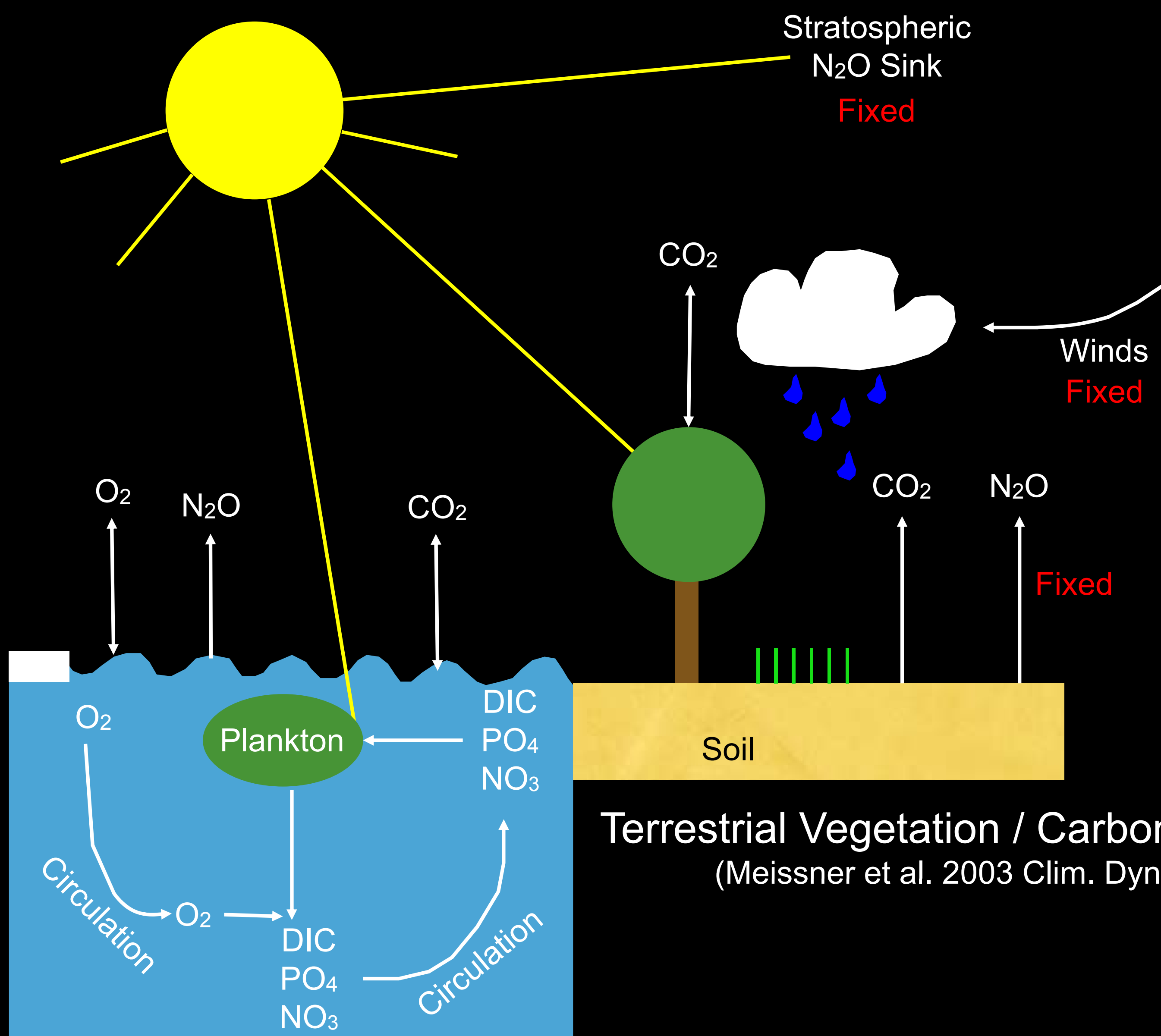
2D Energy-Moisture Balance Atmosphere (fixed winds)

Dyn. Thermod. Sea Ice

3D Ocean (1.8x3.6 deg, 19 levels)

2N2PZD Ocean Ecosystem / Biogeochemistry Model

(Schmittner et al. 2008 GBC)



Terrestrial Vegetation / Carbon Cycle

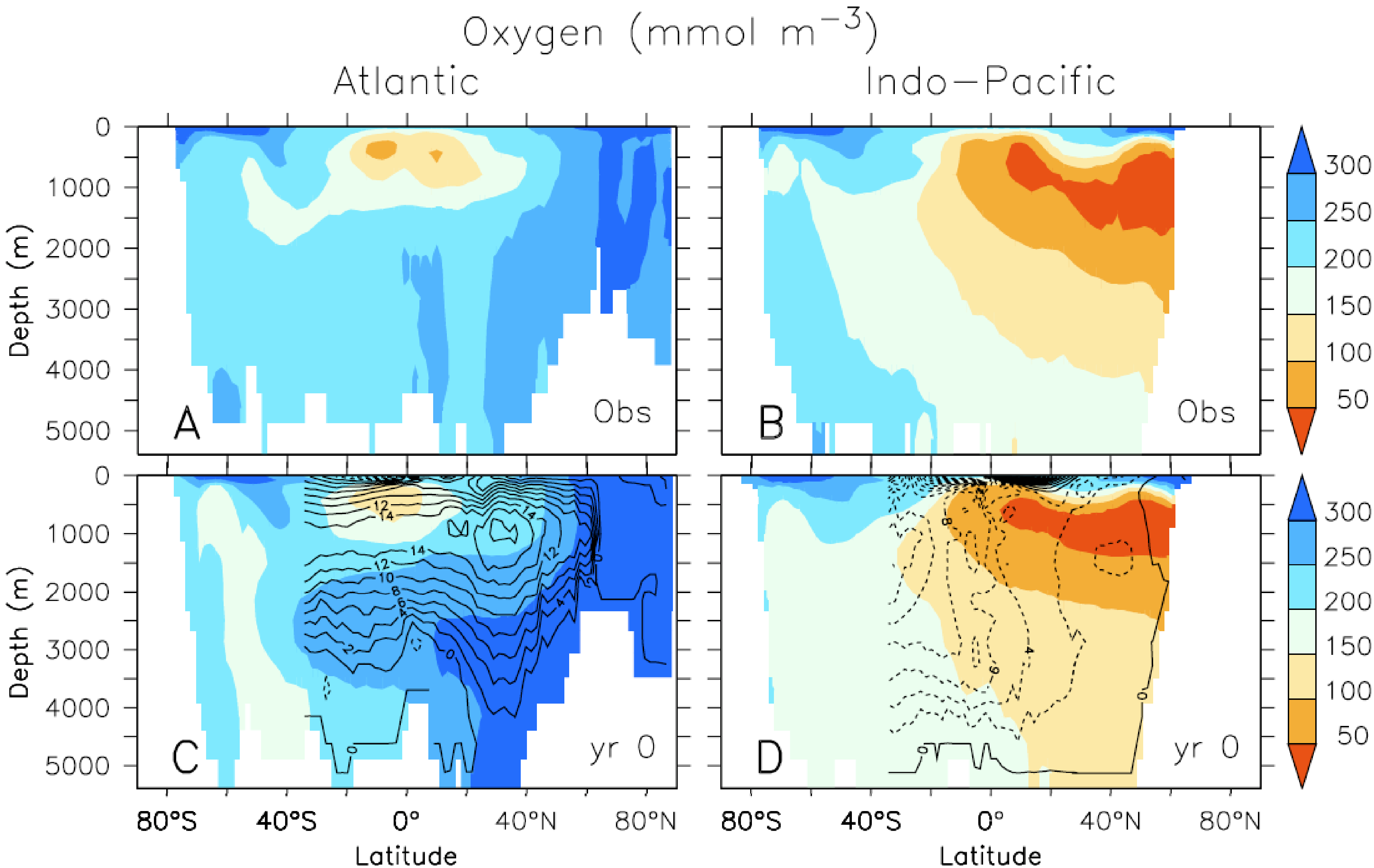
(Meissner et al. 2003 Clim. Dyn.)

$$dN_2O/-dO_2 = R_{N:O2}(a_1/O_2 + a_2)\exp(-Z/Z_{scale})$$
$$O_2 > O_{2,crit},\ Z > Z_{euph},$$

Nevison et al. 2003 GBC

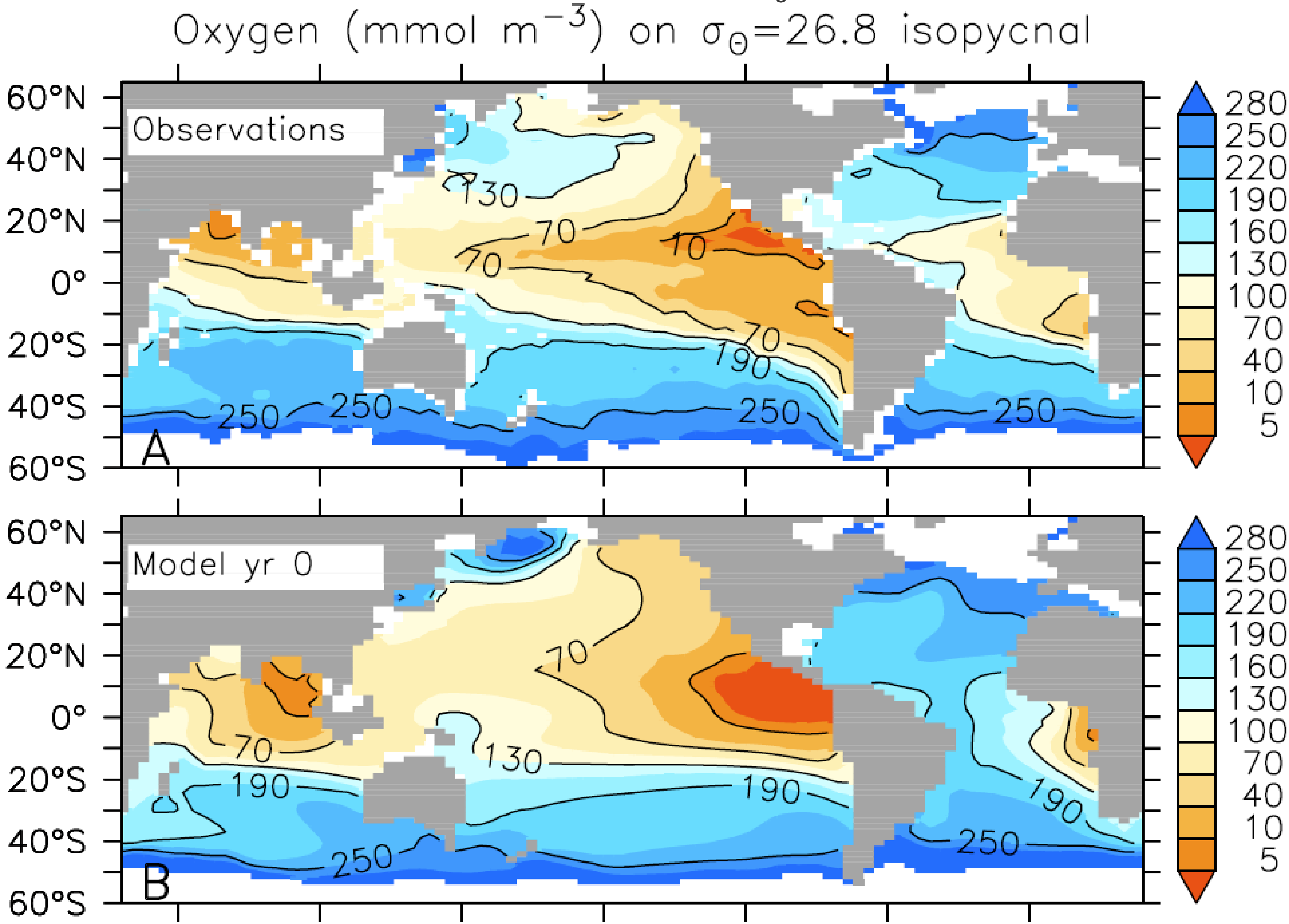
$O_{2,crit}$=4±3μM

1. How well can global models simulate low-oxygen regions?



Schmittner et al. (2007) Paleoceanography

1. How well can global models simulate low-oxygen regions?



Schmittner et al. (2007) Paleoceanography

How well can global models simulate low-oxygen regions?

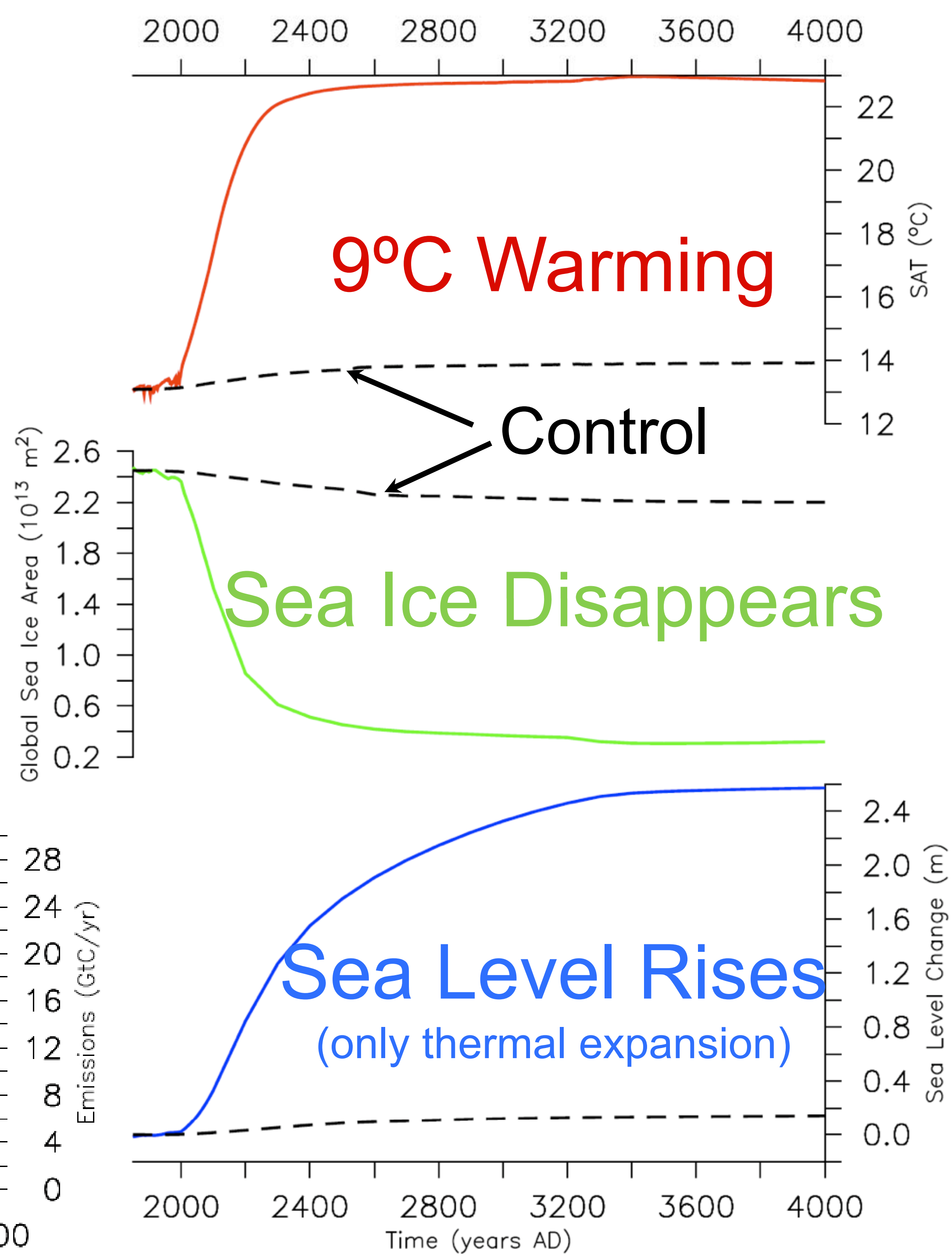
- Large scale oxygen distribution can be modeled well
- Low-oxygen regions not so well. Typically suboxic volume overestimated. Issues: physics (resolution, mixing parameterizations), biology (zooplankton vertical migration, ...)

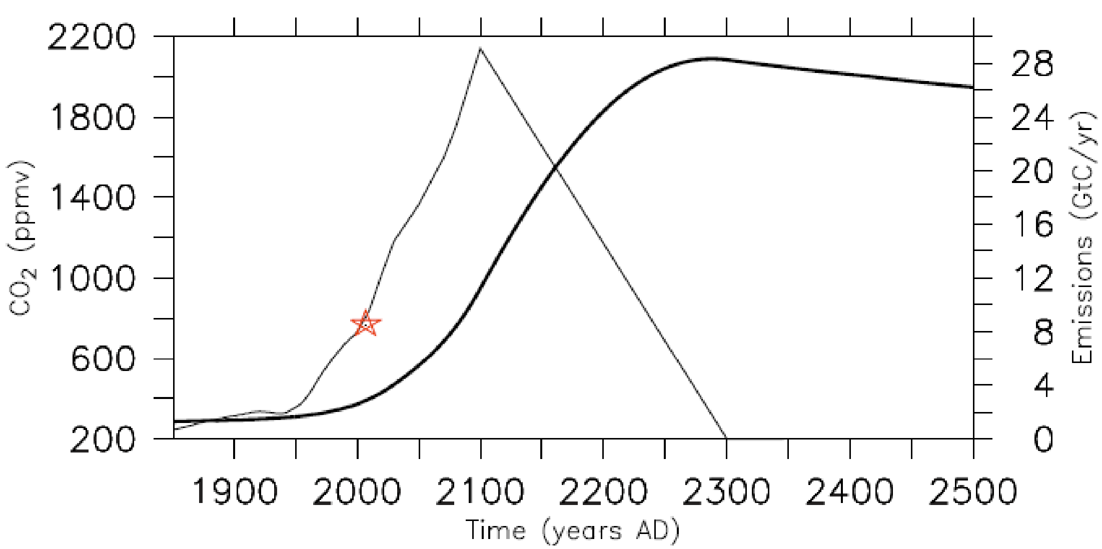
2. Long-Term Projections

Global Warming until year 4000

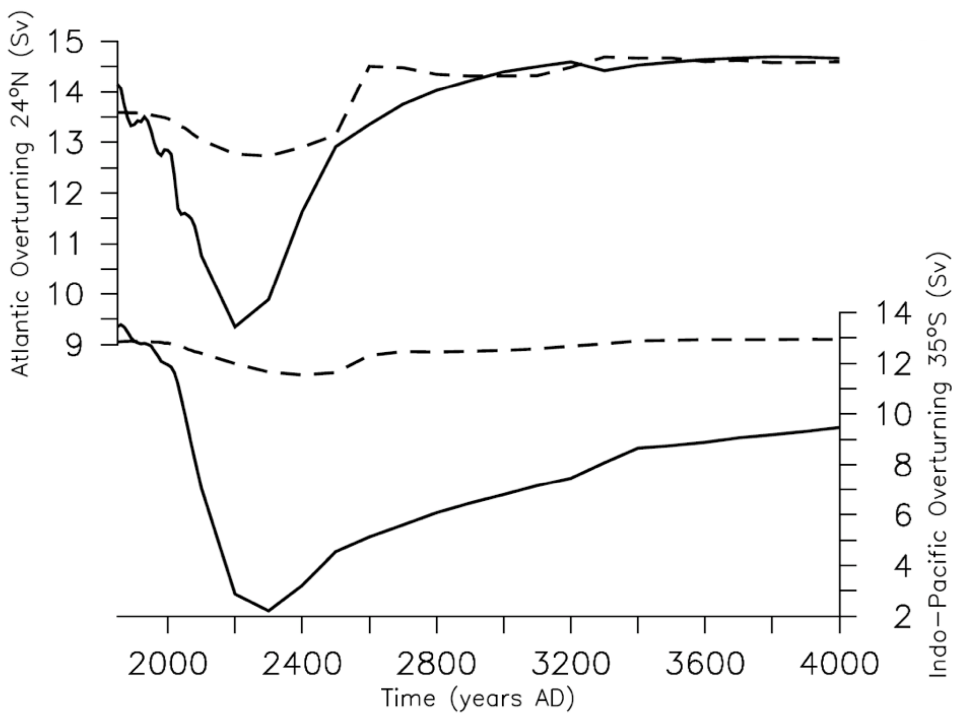
- Business-as-usual based on burning of all readily available fossil fuel reserves (SRES A2, linear decrease from 2100-2300)

Schmittner et al. (2008) GBC

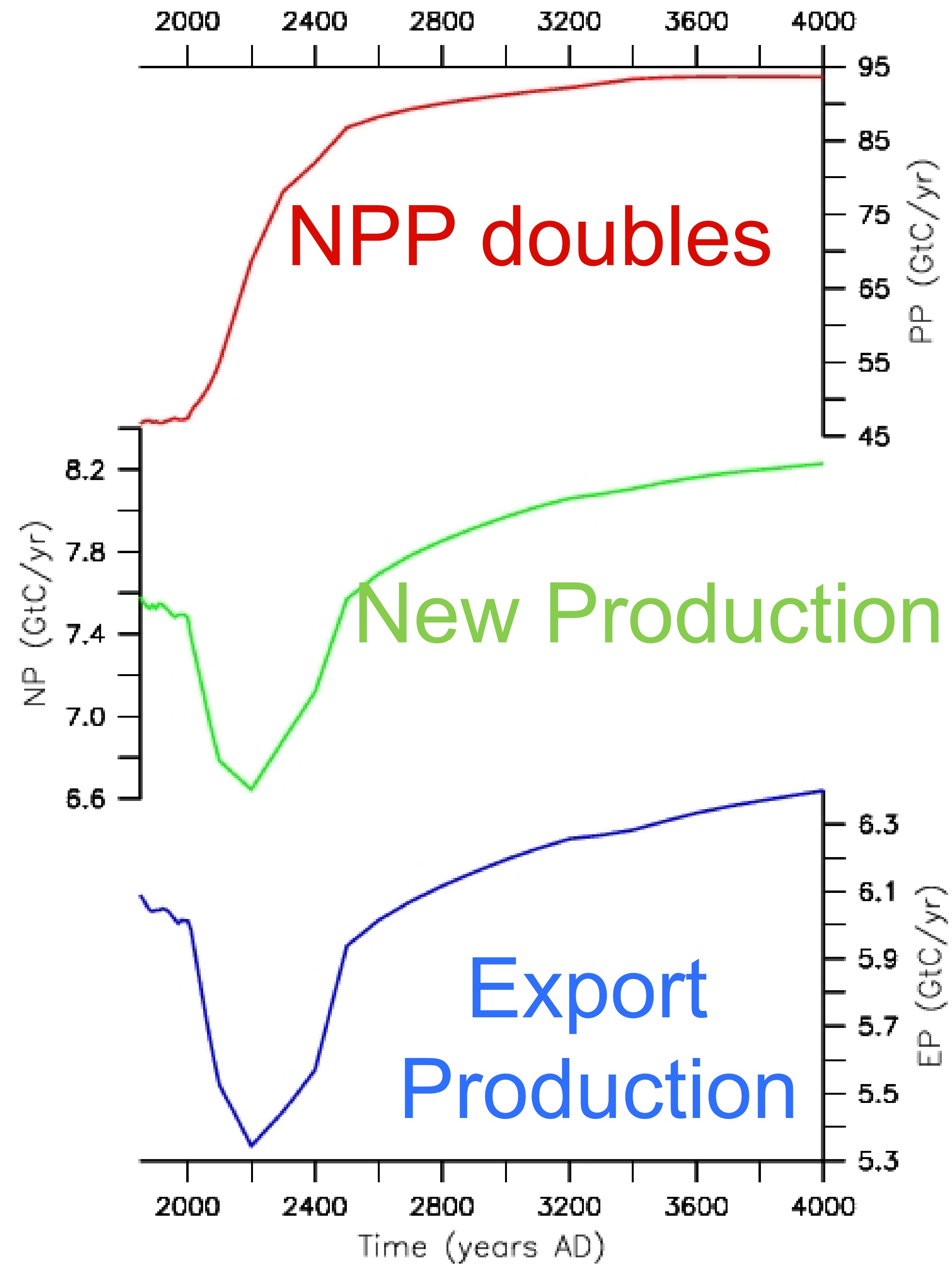




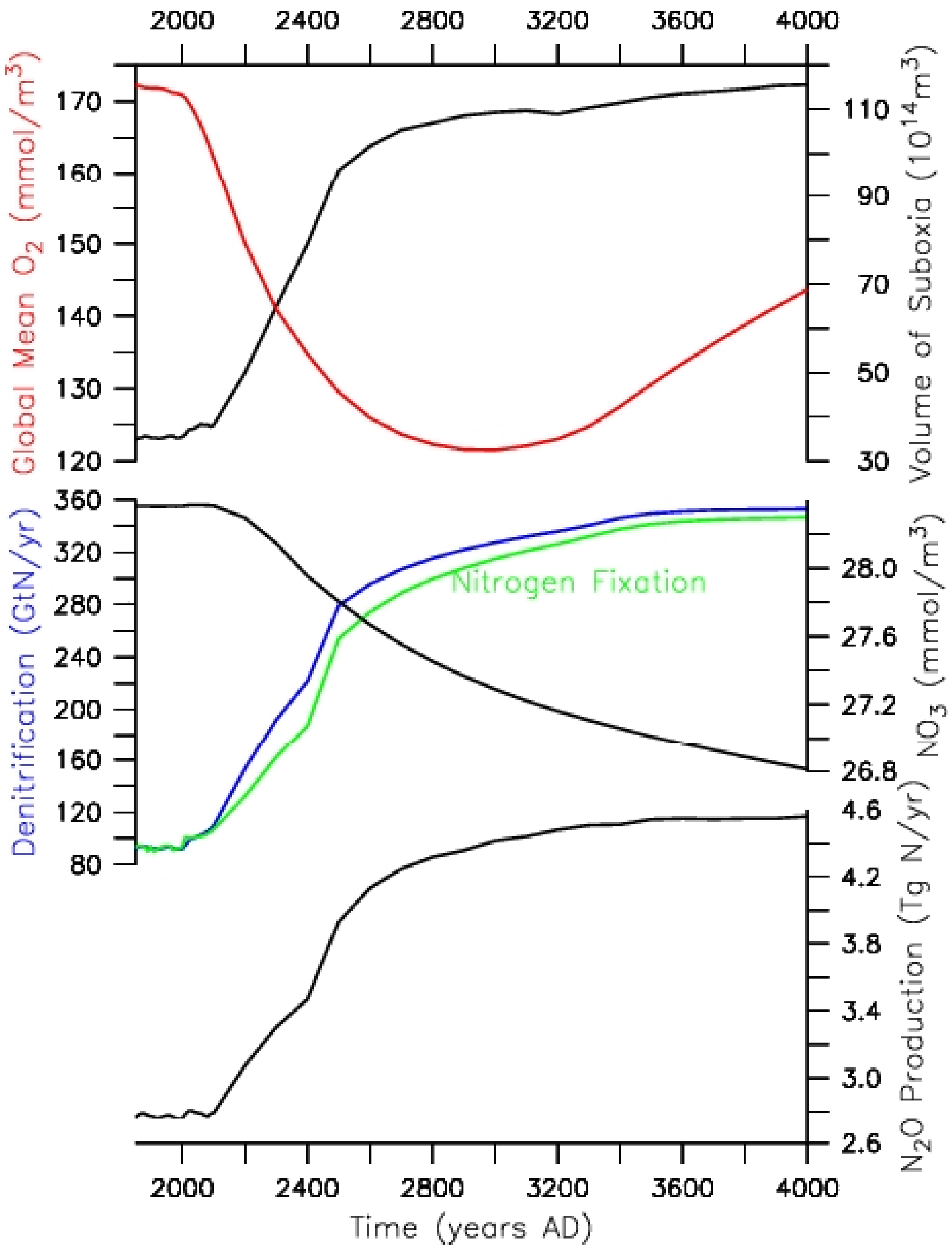
Impacts on Ocean Circulation and Productivity



Schmittner et al. (2008)
GBC



Impact on O and N Cycles

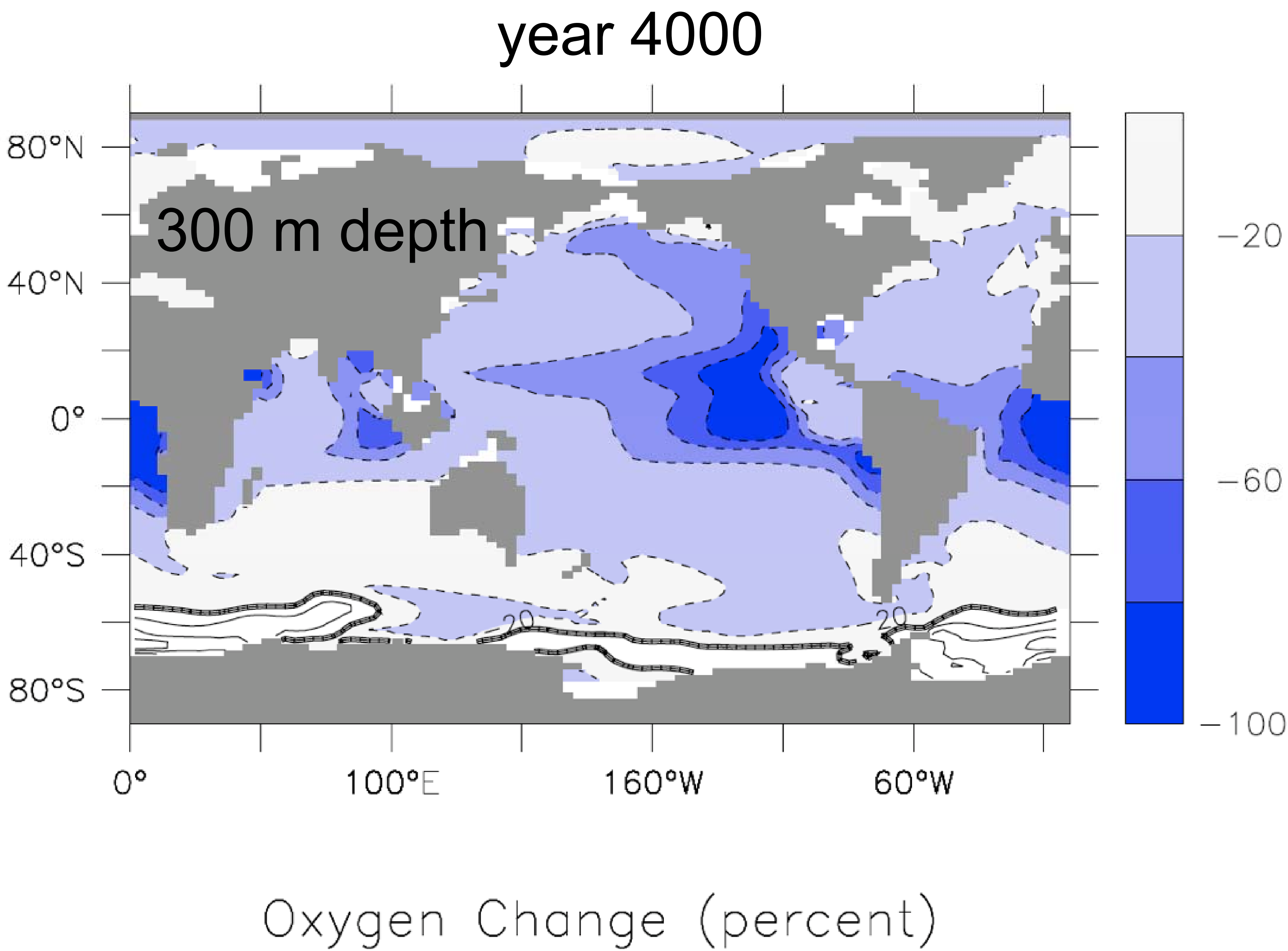


- Oxygen decreases
- Suboxic water volume increases
- Denitrification increases by 350%
- Nitrogen fixation increases
- Decrease in NO_3 inventory small
- N_2O production increases by 64% (estimated from empirical relation by Nevison et al., 2003)
- => atmospheric N_2O increases by 60 ppb (21%)
- => additional warming by 0.2ºC

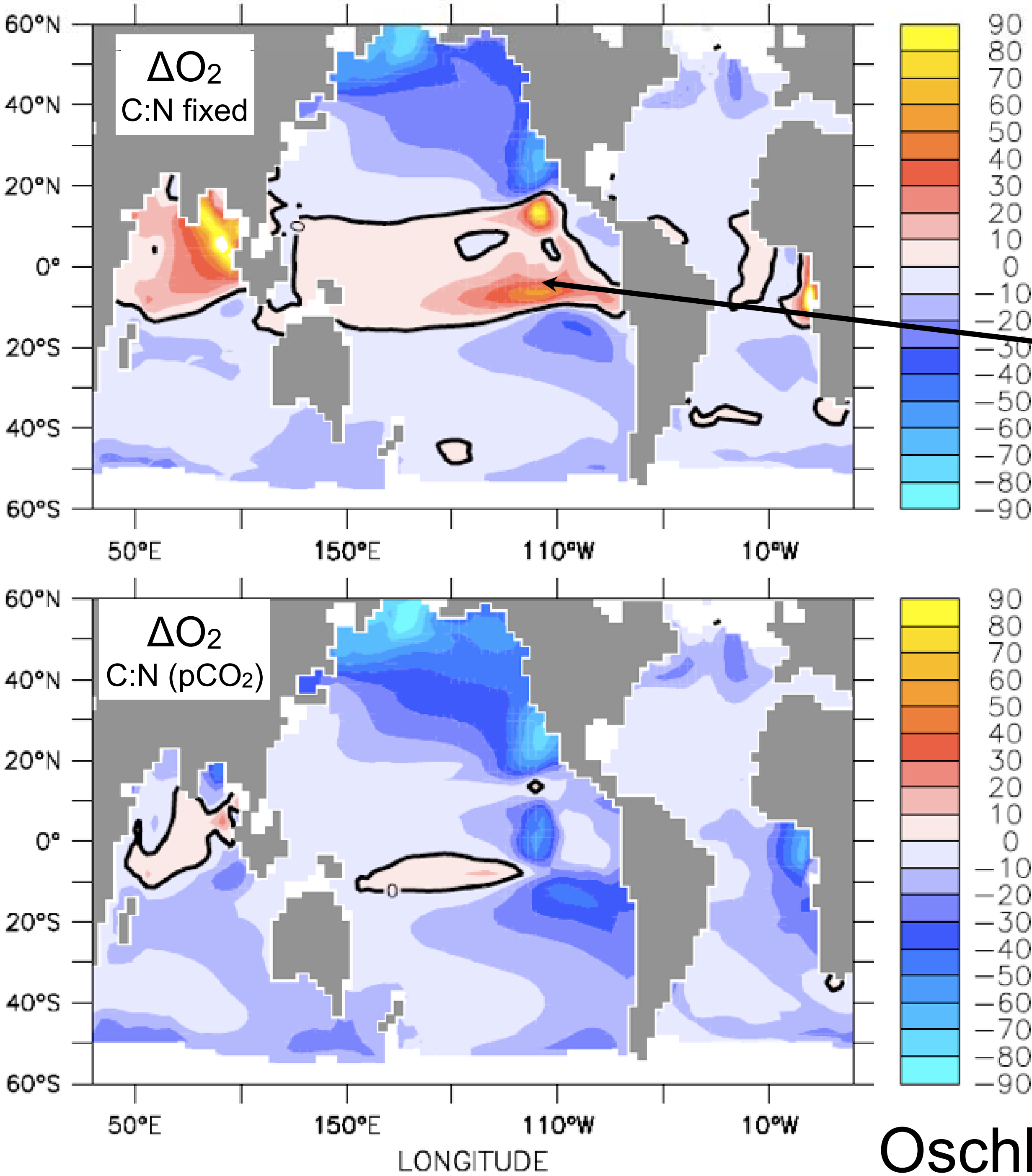
Schmittner et al. (2008)
GBC

Dissolved Oxygen Change (%)

Time (years)


year 4000
300 m depth
80°N
40°N
0°
40°S
80°S
0°
100°E
160°W
60°W
-20
-60
-100
20
20
Oxygen Change (percent)

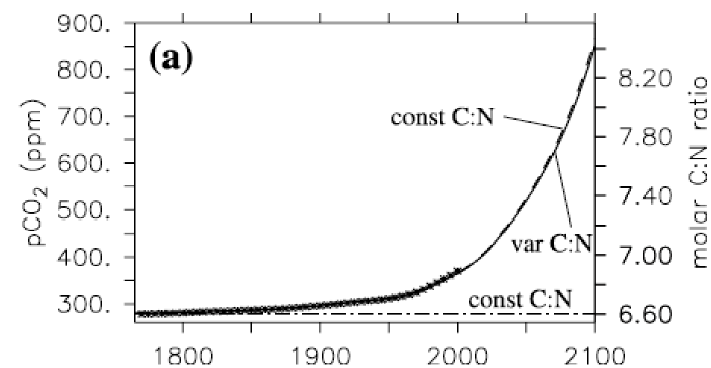
Oxygen on σ_Θ=27.0 kg/m^3 year 2100



Effects of C:N changes

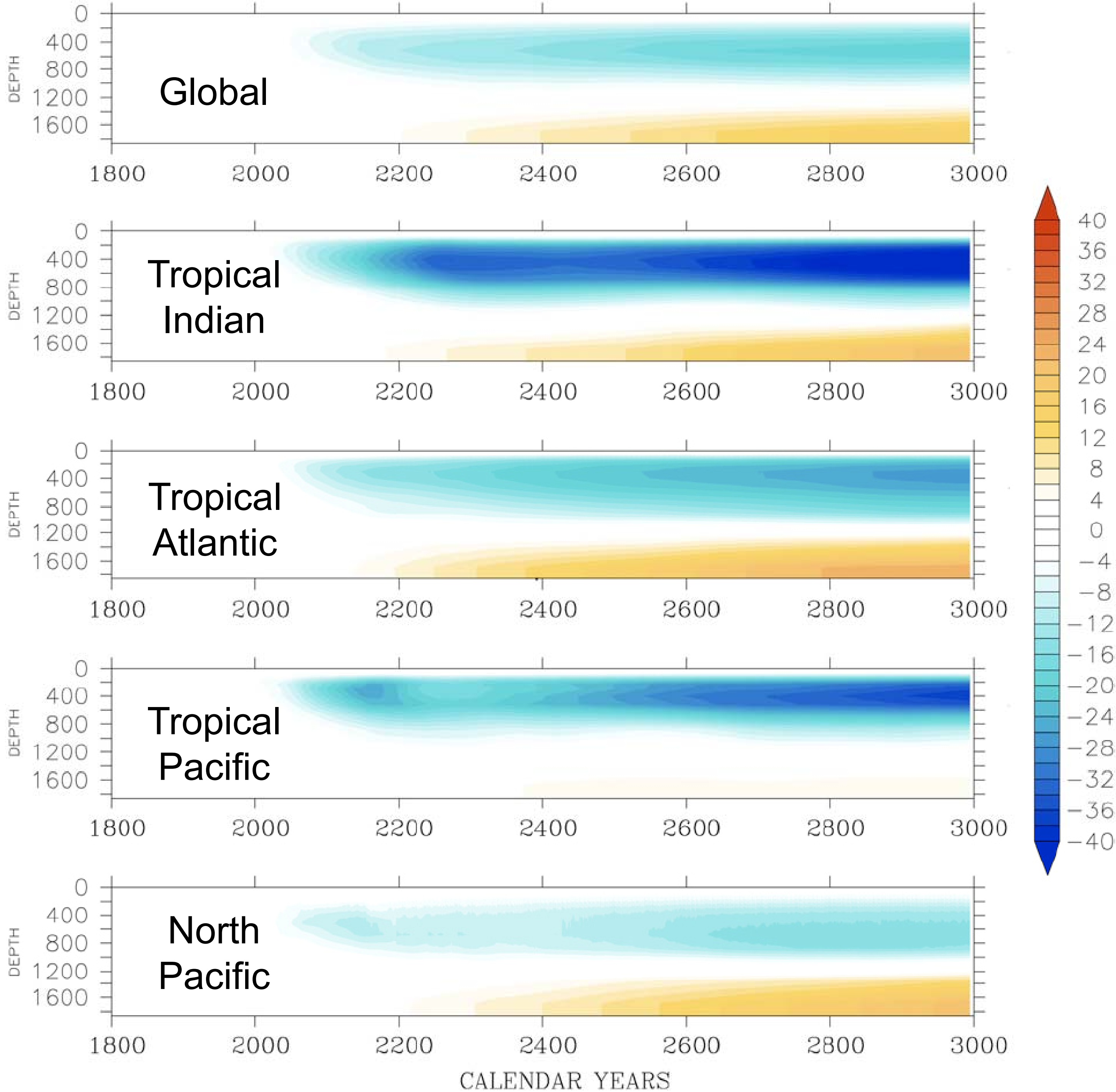
"Gnanadesikan et al. (2007) Ocean Sci. effect"

reduced upwelling



Oschlies et al. (2008) GBC

Acidification effects (decreased ballasting)



Hofmann & Schellnhuber 2009 PNAS

Table 2 Model predictions of average ocean O_2 decrease by year 2100

Study	Model	Forcing	O_2 decrease (μmol kg^{-1})[a]	Solubility contribution (%)	O_2/Heat ratio nmol J^{-1}
Sarmiento et al. (1998)	GFDL		7[b]		
Matear et al. (2000)	CSIRO	IS92A	7	18	
Plattner et al. (2001, 2002)	Bern 2D	SRES A1	12	35	5.9[c]
Bopp et al. (2002)	OPAICE-LMD5	SRES A2 CO_2 only	4	25	6.1
	HAMOCC-3				6.6
Matear & Hirst (2003)	CSIRO		9	26	
Schmittner et al. (2008)	UVic	SRES A2	9		6.7[d]
Oschlies et al. (2008)	UVic	SRES A2	9		6.7[d]
	UVic-variable C/N	SRES A2	12		
Frölicher et al. (2009)	NCAR CSM1.4-CCCM	SRES A2	4	50	
		SRES B1	3		

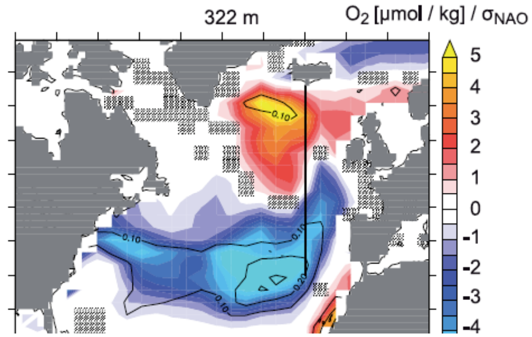
Keeling et al. 2010 Annu. Rev. Mar. Sci

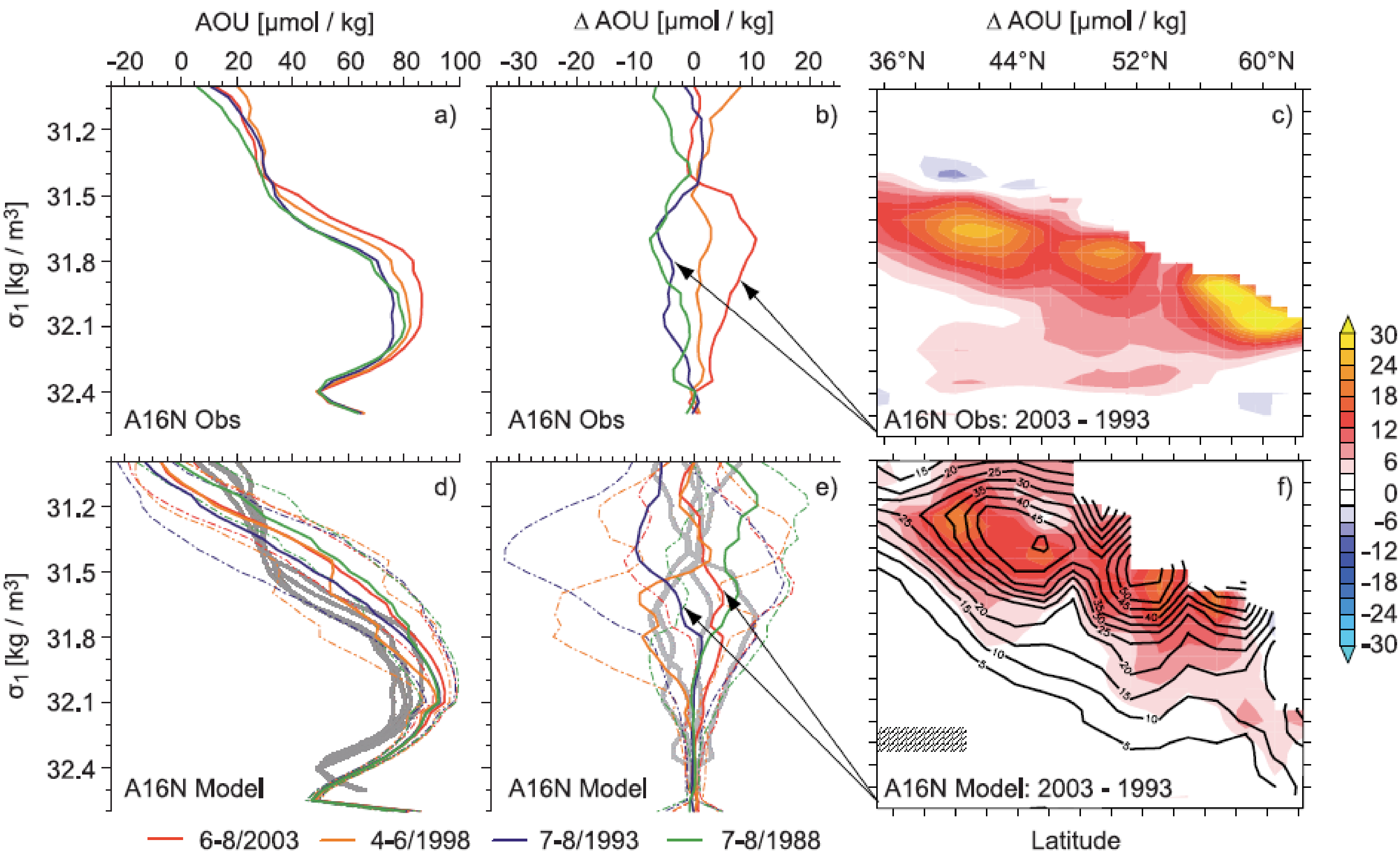
3. Long-Term Projections

- Dissolved Oxygen is projected to decrease world-wide due to
  - decreased solubility
  - increased stratification / slower circulation
- Low-oxygen regions will expand, perhaps dramatically
  - increased denitrification
  - increased N_2O production (very small positive climate feedback)
- Biological effects of acidification may

Variability: Atlantic

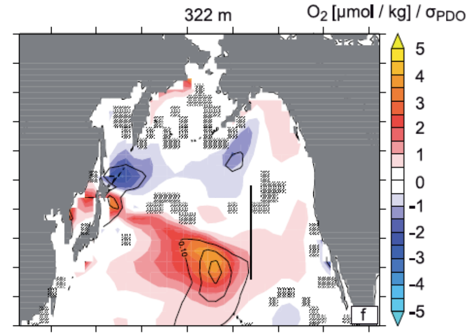
Fröhlicher et al., 2009, GBC

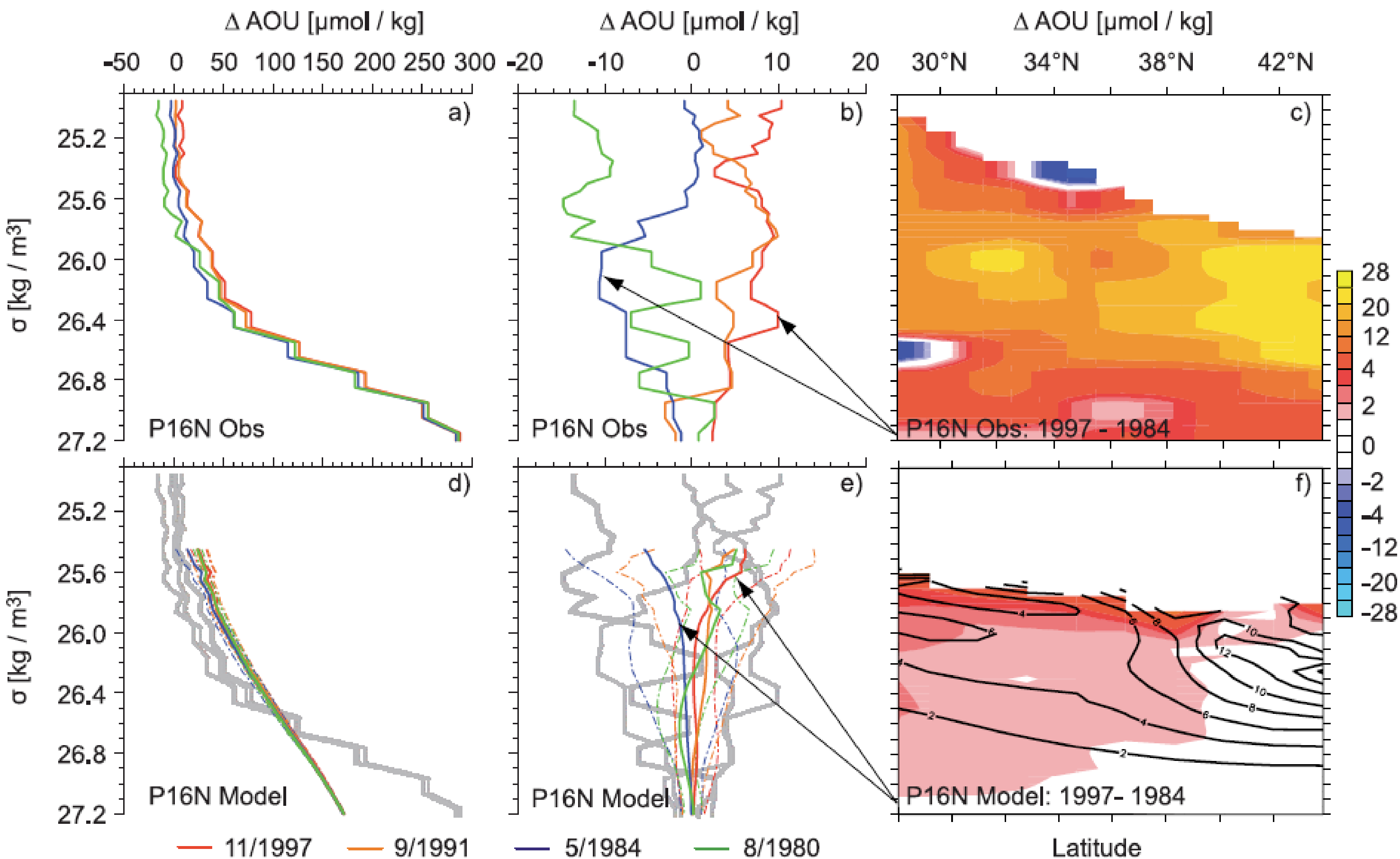




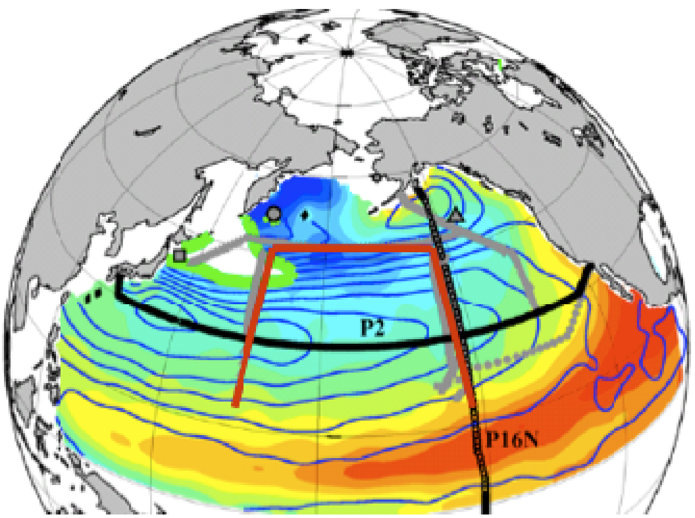
Variability: Pacific

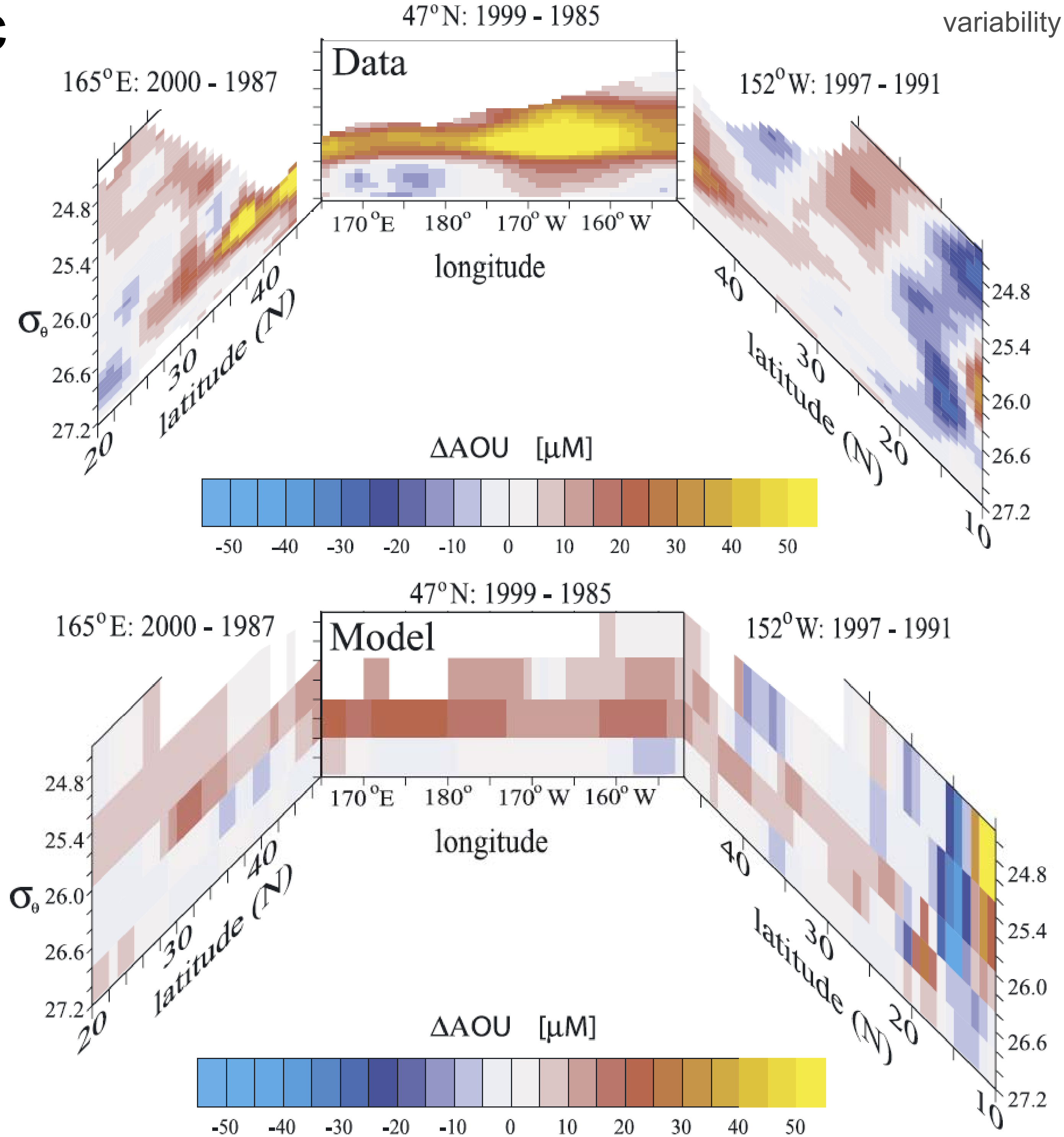
Fröhlicher et al., 2009, GBC





Variability: Pacific





Deutsch et al. (2006) GBC

Variability

- Much of the observed changes due to internal variability
- Models capture variability in North Atlantic
- Models underestimate variability in North Pacific

Biological-physical model configuration

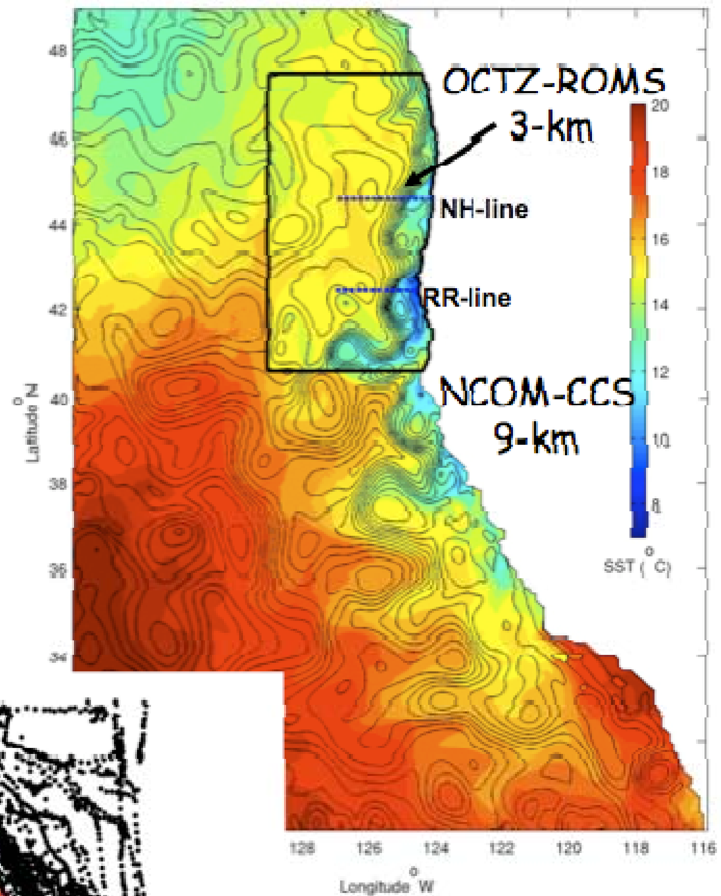
ROMS:
3 km horizontal & 40 s-layers vertical resolution

Model runs:
Apr-Aug 2002, 2006, 2008

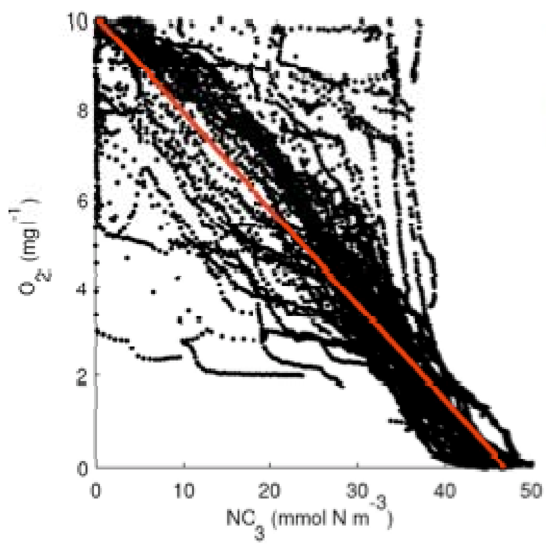
Atmospheric forcing:
2002: COAMPS winds & NCEP heat flux
2006, 2008: NAM winds & heat flux

Oceanic forcing:
NCOM-CCS (I. Shulman, S. DeRada)

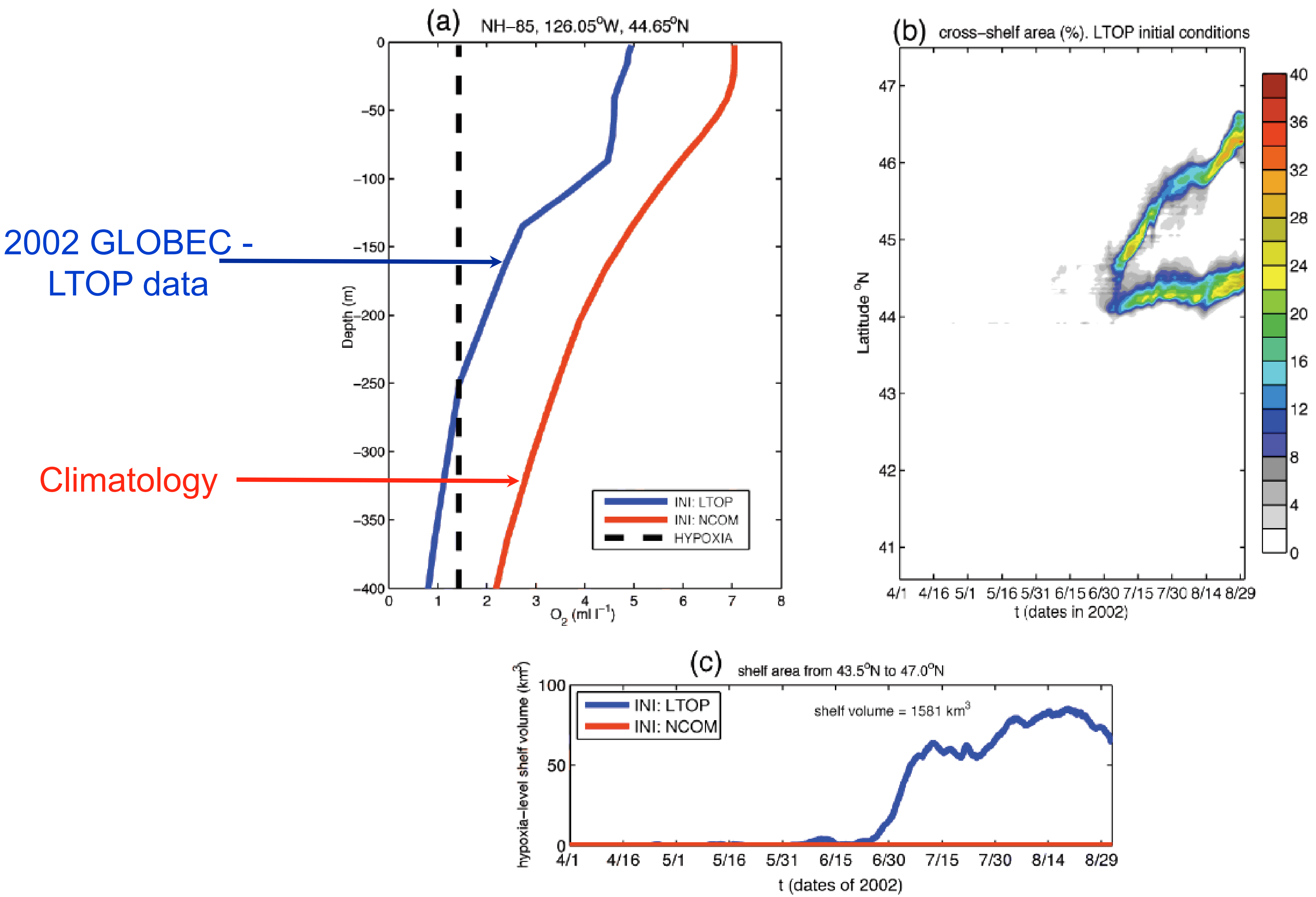
Biological forcing:
NCOM-CCS 2006, 2008



Oxygen OBC & IC: empirical NO_3:O_2 ratio derived from GLOBEC-LTOP observations in the Oregon CTZ



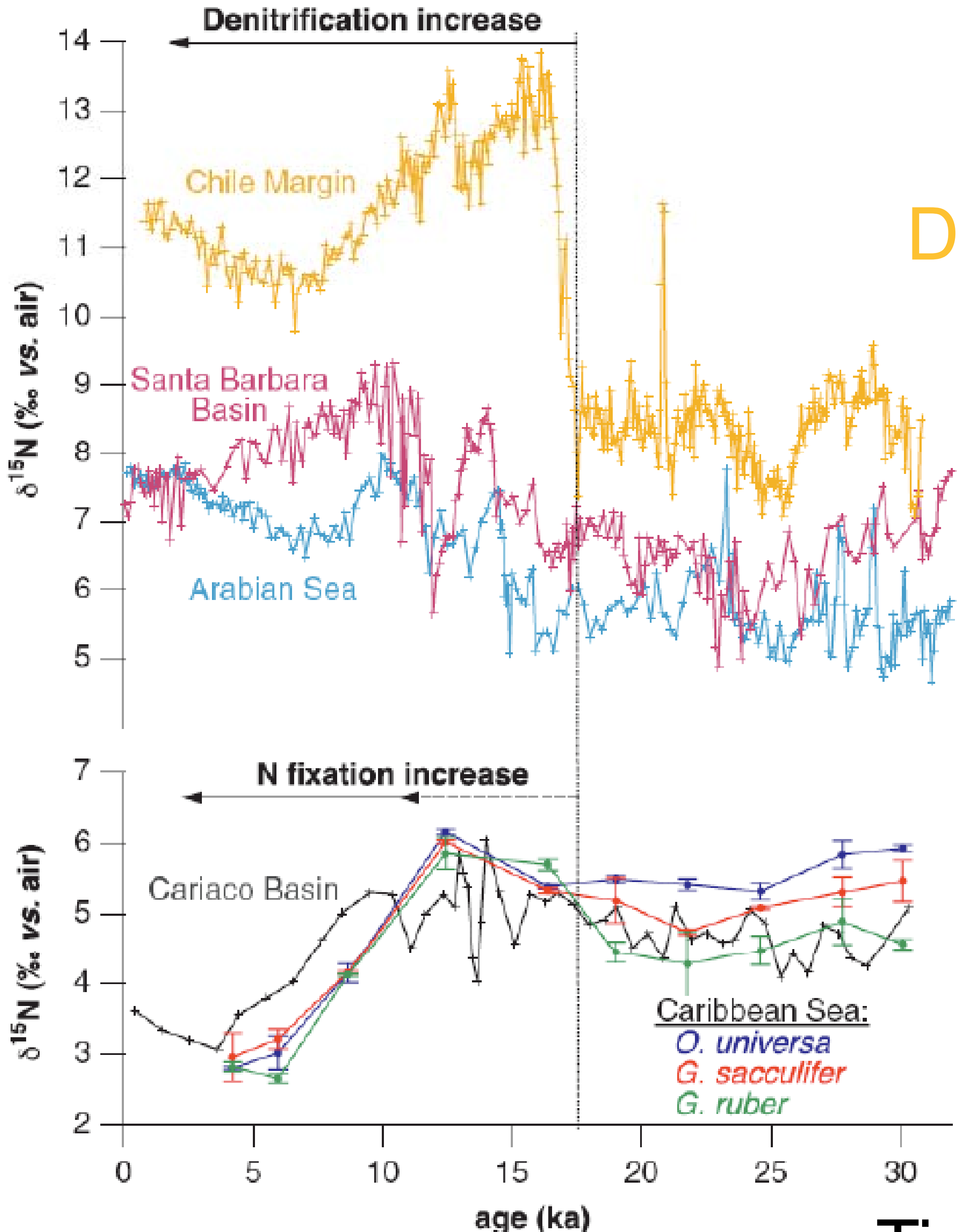
Spitz, Batchelder, Koch CIOSS Project



Spitz, Batchelder, Koch CIOSS Project

Coastal Models

- Important to predict local occurrence of hypoxia
- Boundary conditions crucial



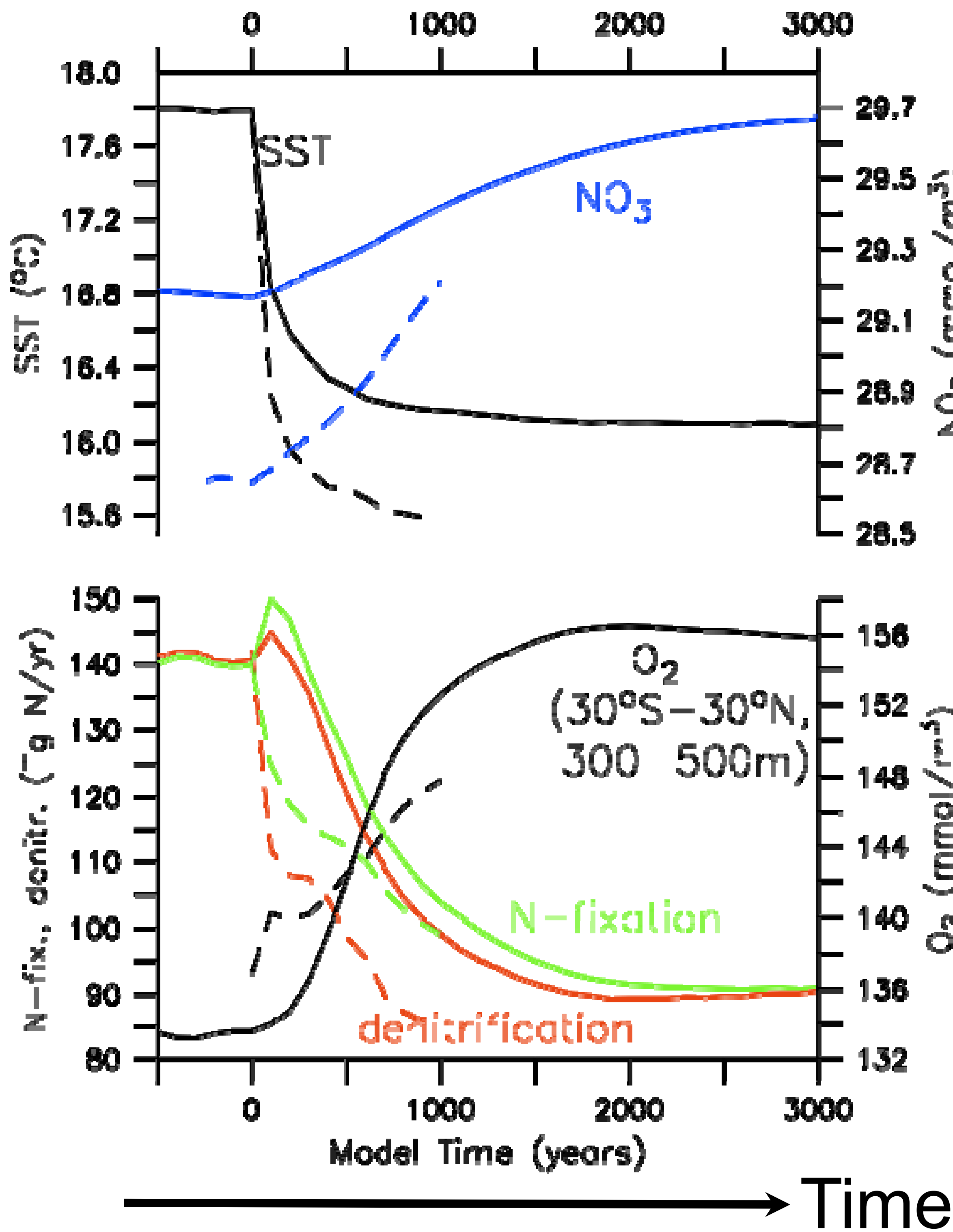
De Pol-Holz et al. (2006)

Emmer and Thrunell (2000)

Altabet et al. (2002)

Ren et al. (2009)

Time



LGM

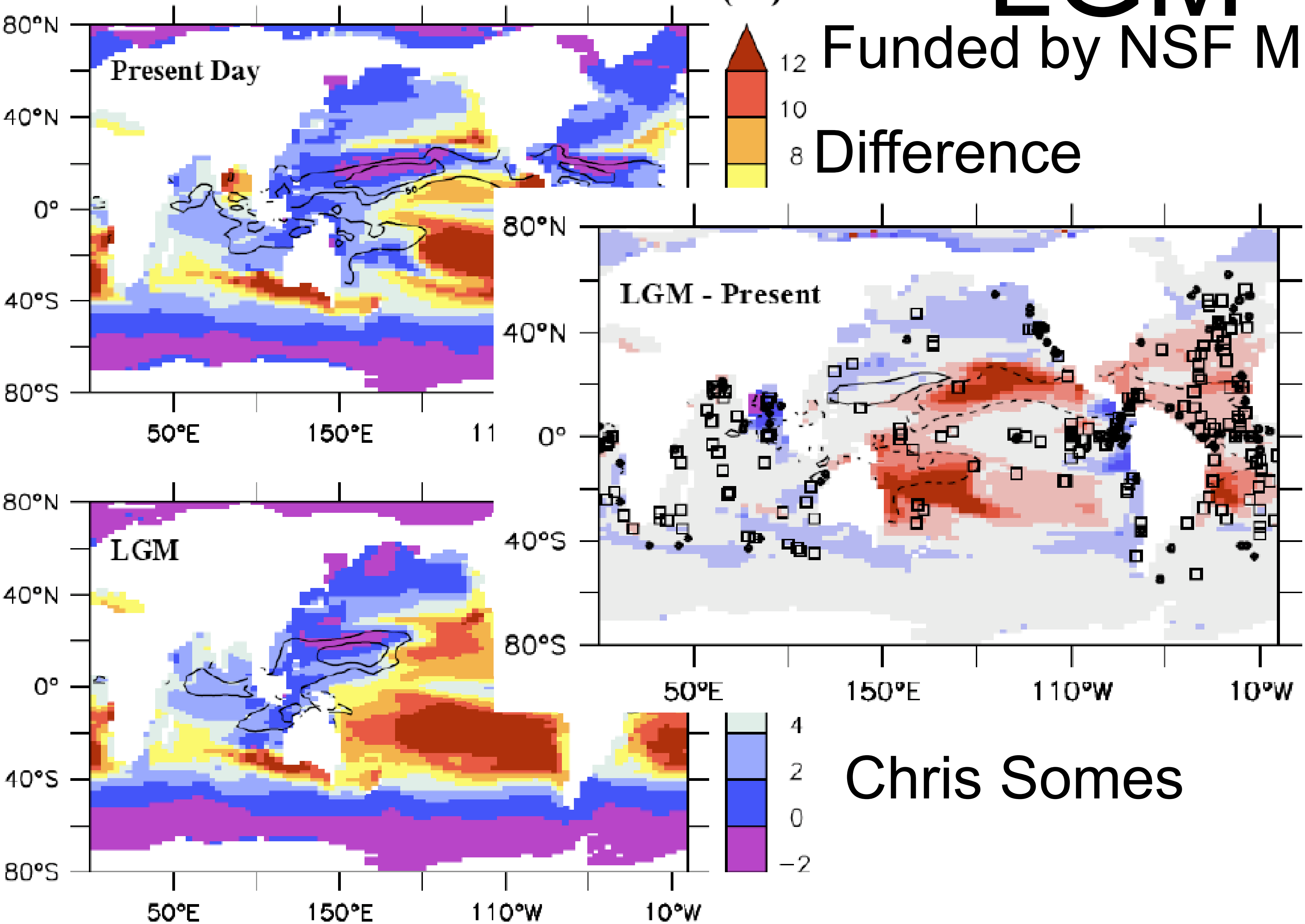
preliminary model results

	Solid Lines	Dashed Lines
Fe Limitation	No	Yes
Sedim. Denitrification	No	Yes
AMOC	collapsed	not collapsed

LGM

Funded by NSF MG&G

δ15N of Sinking Organic Matter (200 m)



Difference

Chris Somes

Paleo Perspective

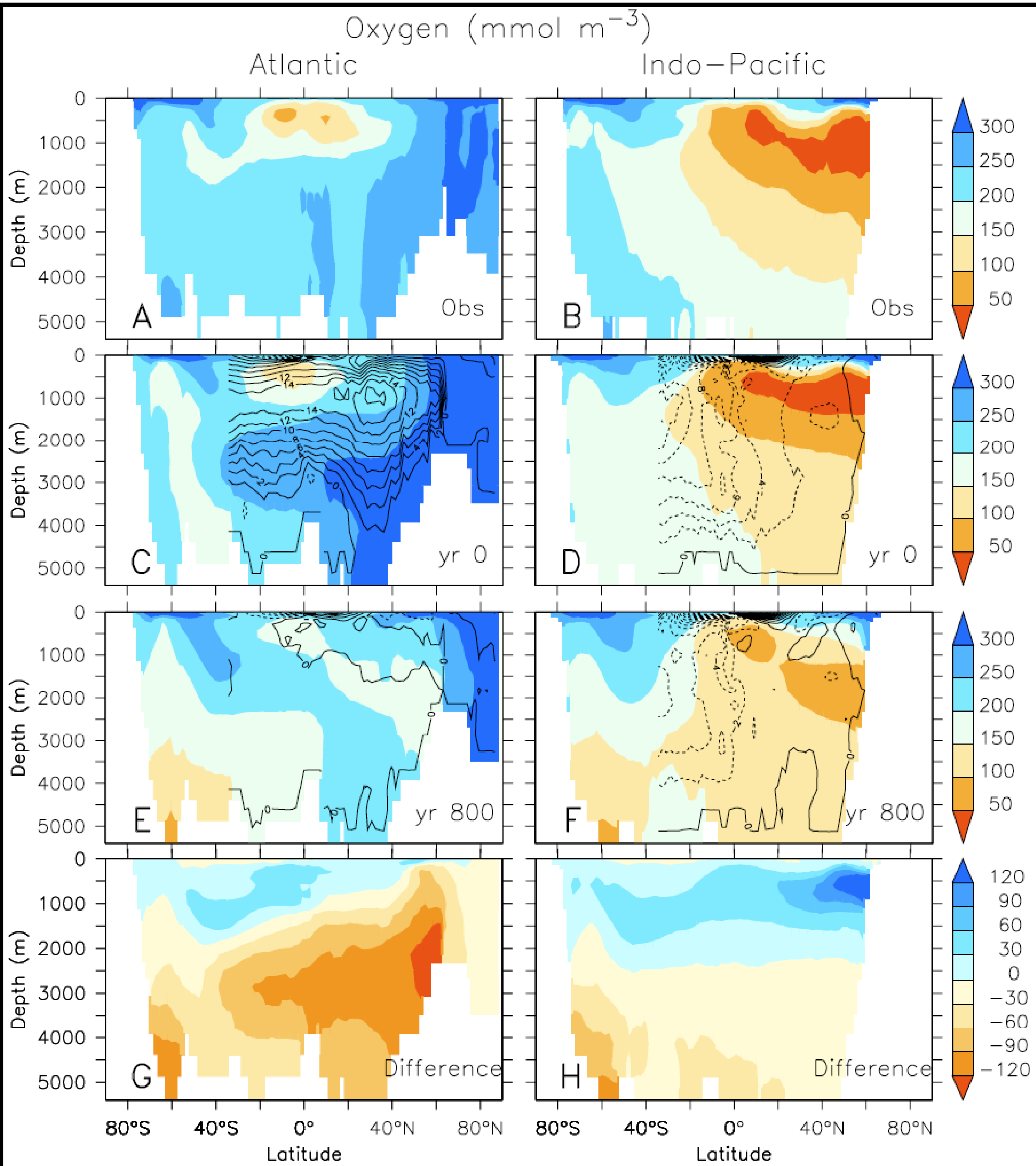
- Provides information on past episodes of ocean deoxygenation and effects on biogeochemical cycles (e.g. N-cycle)
- Models including N-isotopes are now available and can provide quantitative constraints in combination with observations

Thanks

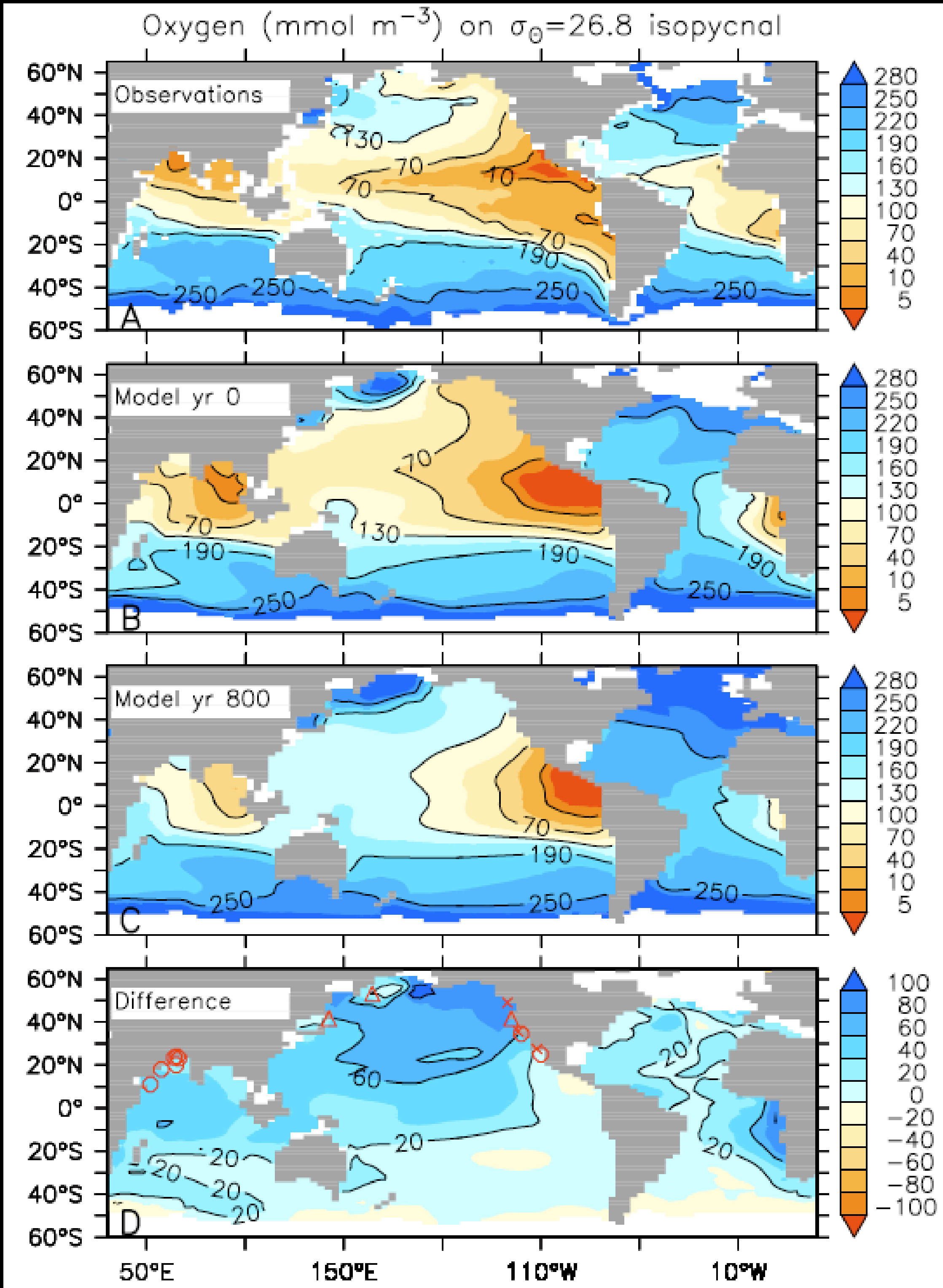
Paleo:

Effects of Ocean Circulation Changes

Shutdown of Atlantic Meridional Overturning Circulation

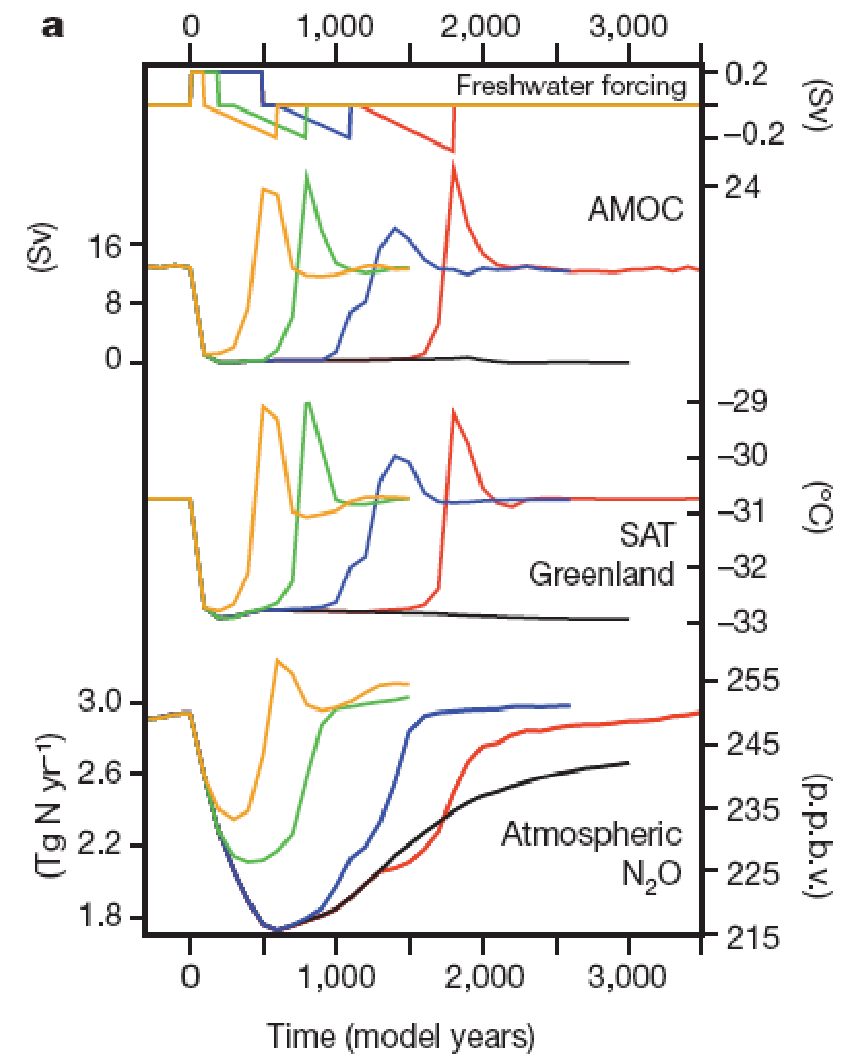


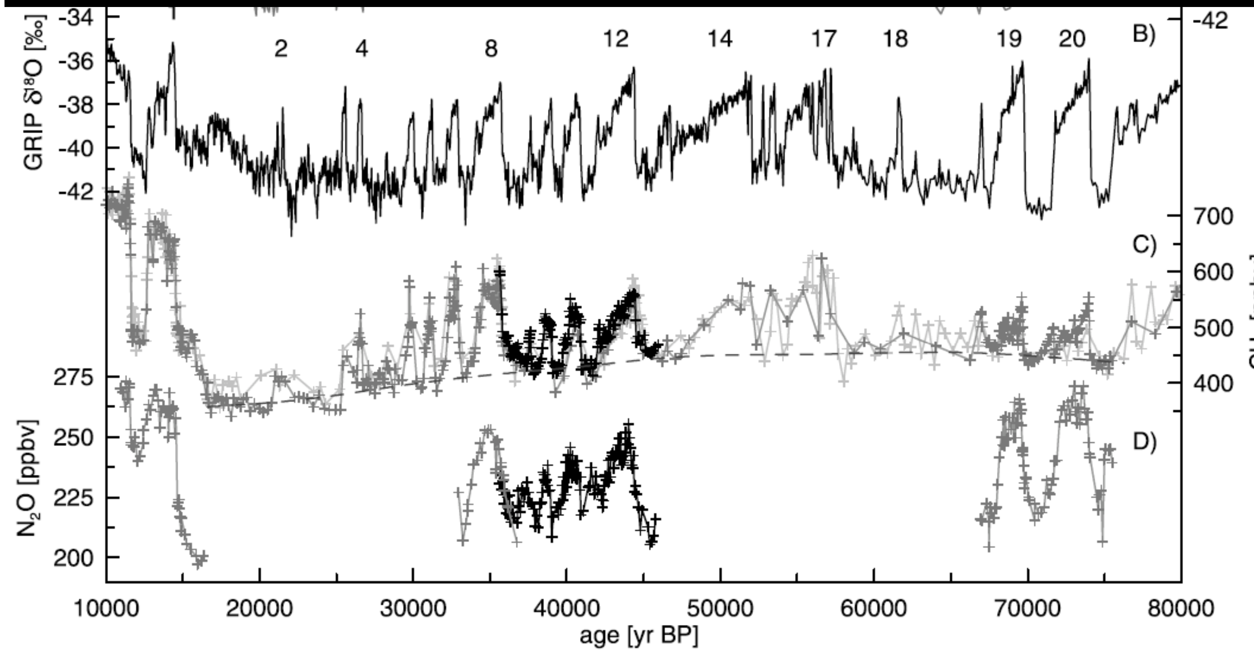
Schmittner et al. (2007) Paleoceanography



Schmittner et al. (2007) Paleoceanograph

Comparison with Ice Core Record

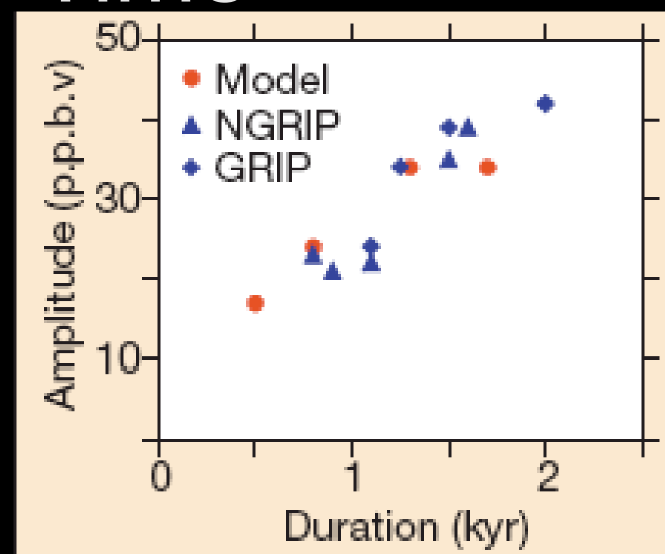


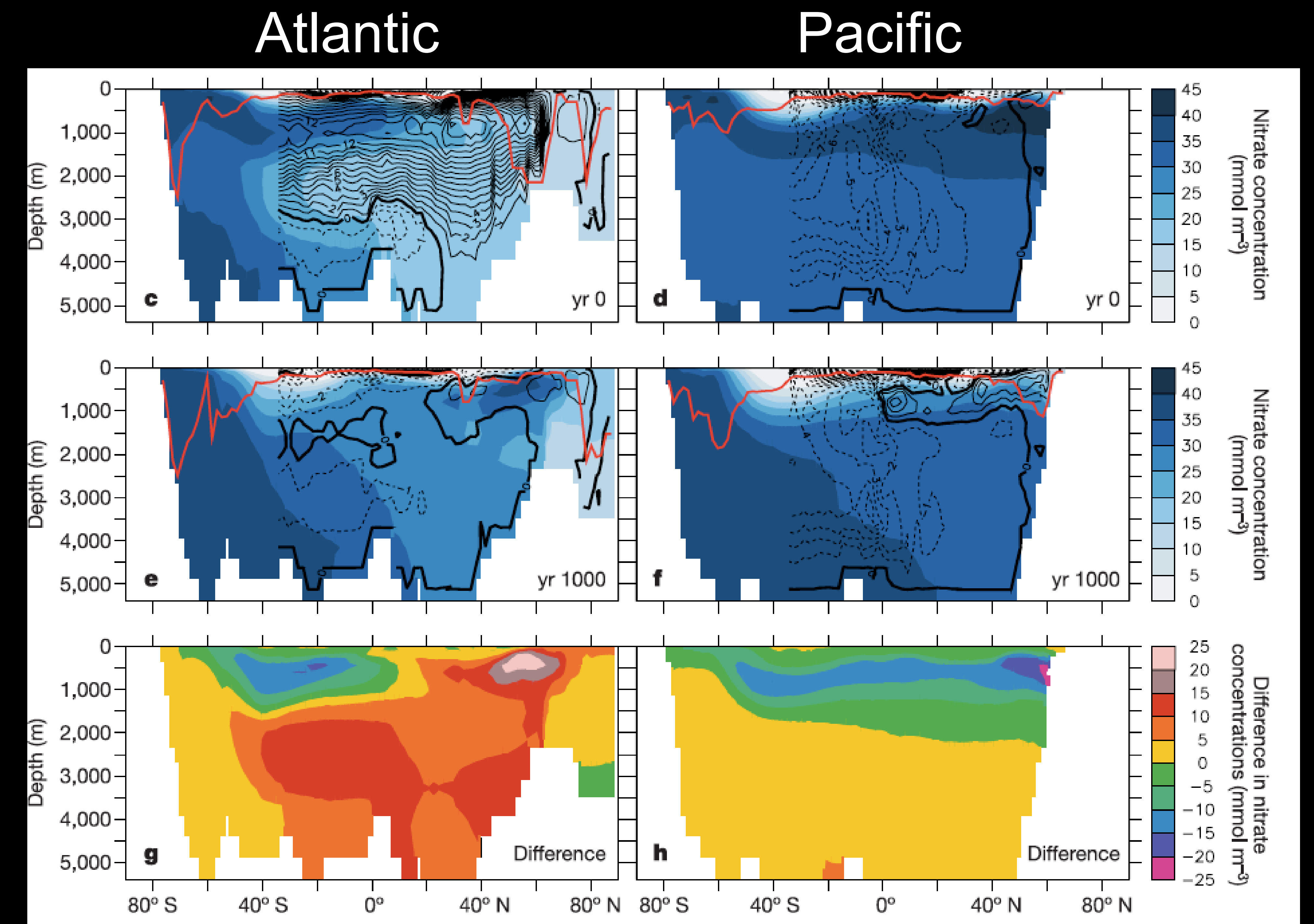


Time

Time

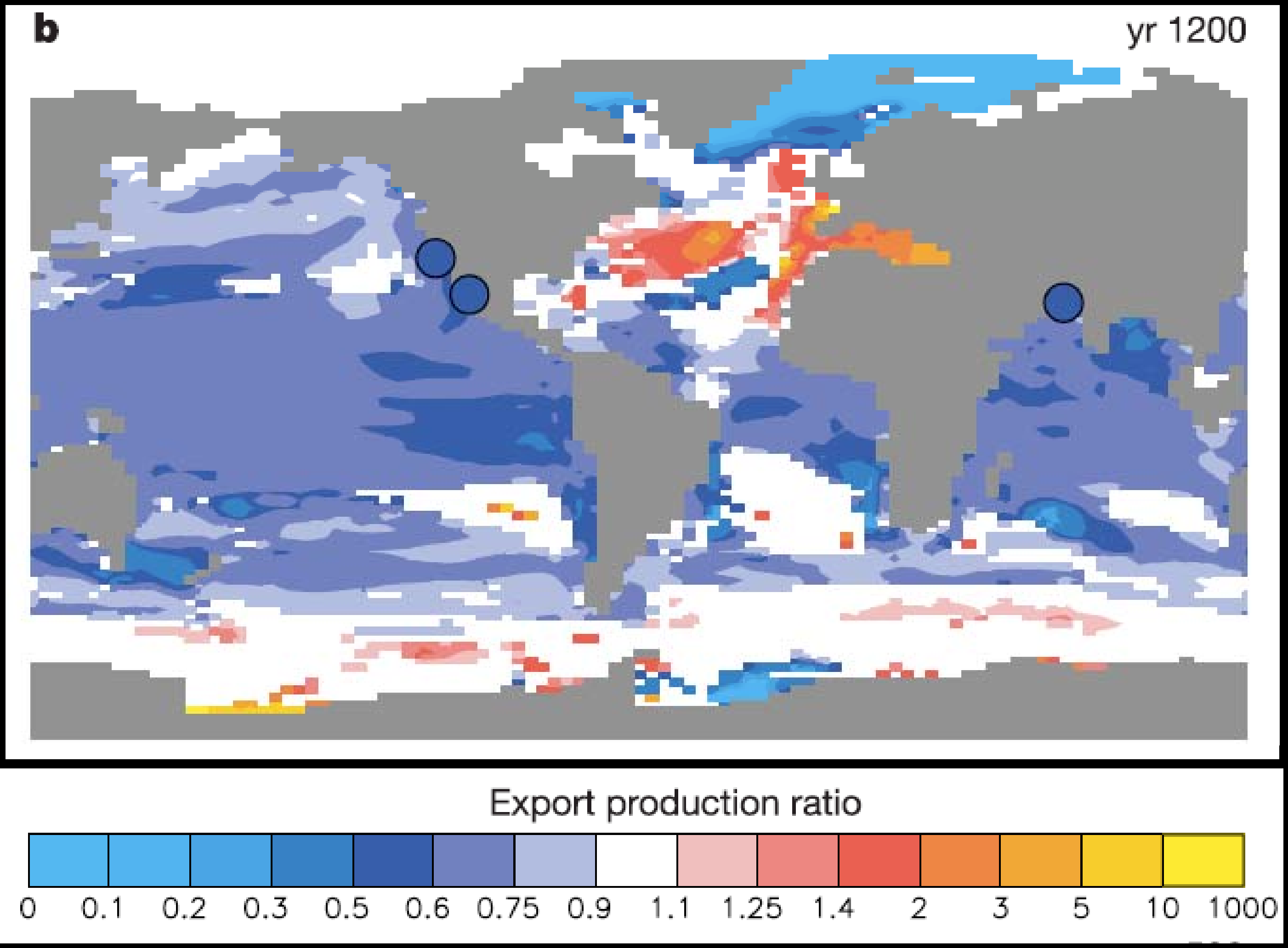
• Model reproduces N_2O amplitude and timescale



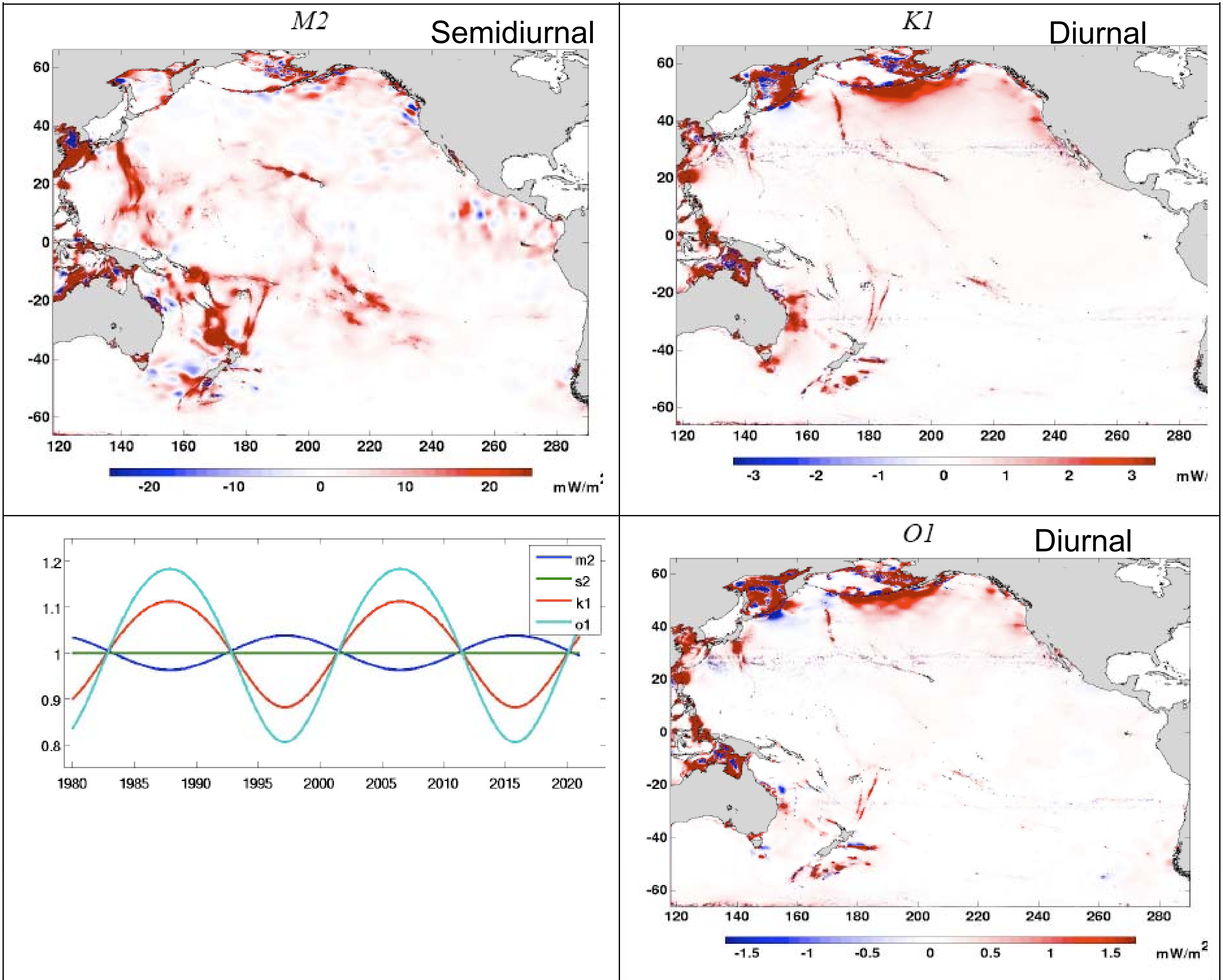


Schmittner (2005) Nature

Productivity Decreases

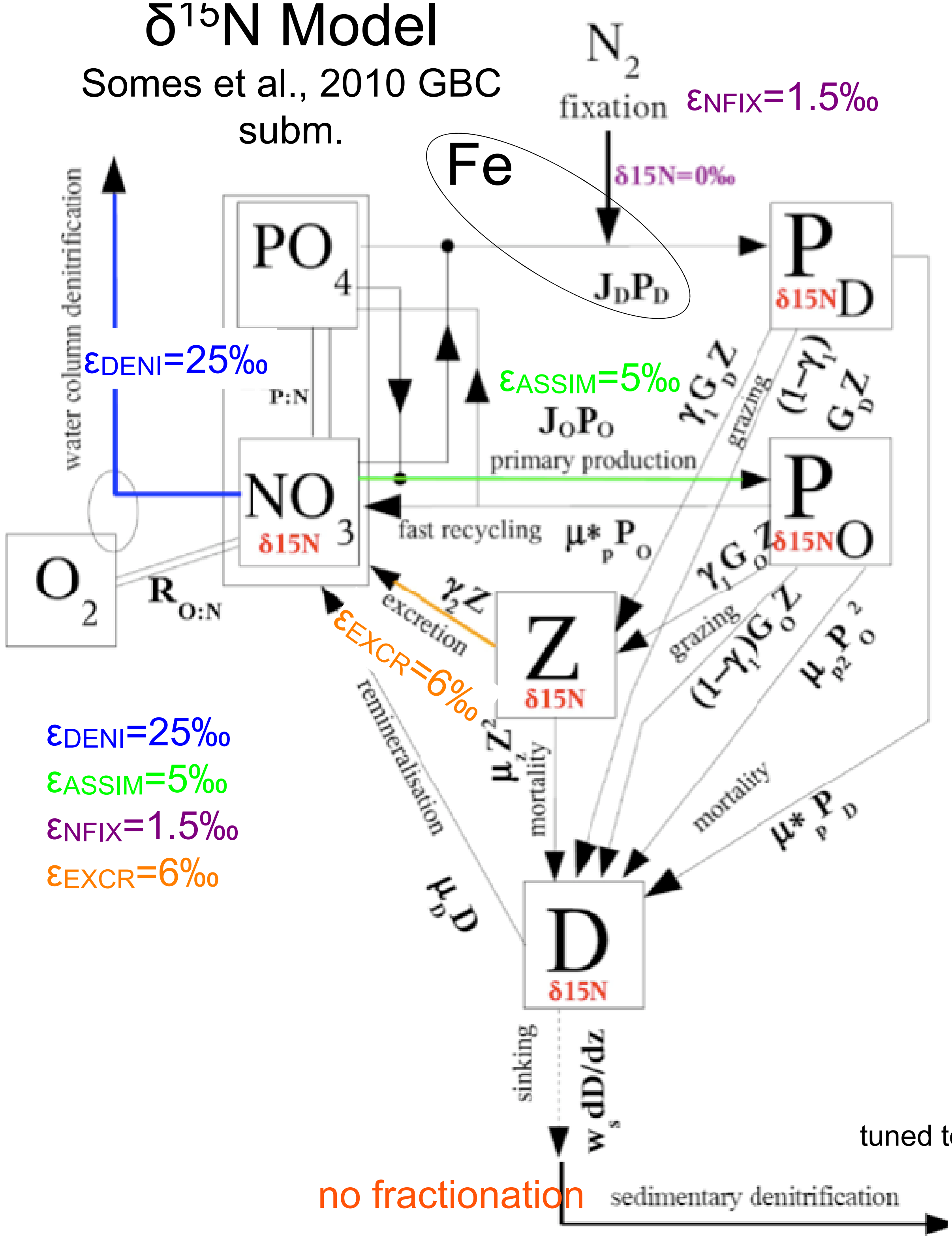


Schmittner 2005 Nature


M2
Semidiurnal
mW/m2
K1
Diurnal
mW/
O1
Diurnal
mW/m2
m2
s2
k1
o1

δ¹⁵N Model

Somes et al., 2010 GBC subm.



tuned to reproduce global mean ™15N

Middleburg et al. [1996]

$$SedDeni = \alpha_{SD} \cdot 10 \wedge \left[-0.9543 + 0.7662 \cdot \log(F_c) - 0.2350 \cdot \log(F_c)^2\right]$$

UVic Model

(Weaver et al. 2001)

2D Energy-Moisture Balance Atmosphere (fixed winds)

Dyn. Thermod. Sea Ice

3D Ocean Circulation (MOM) (1-1.8)x3.6, 19 levels

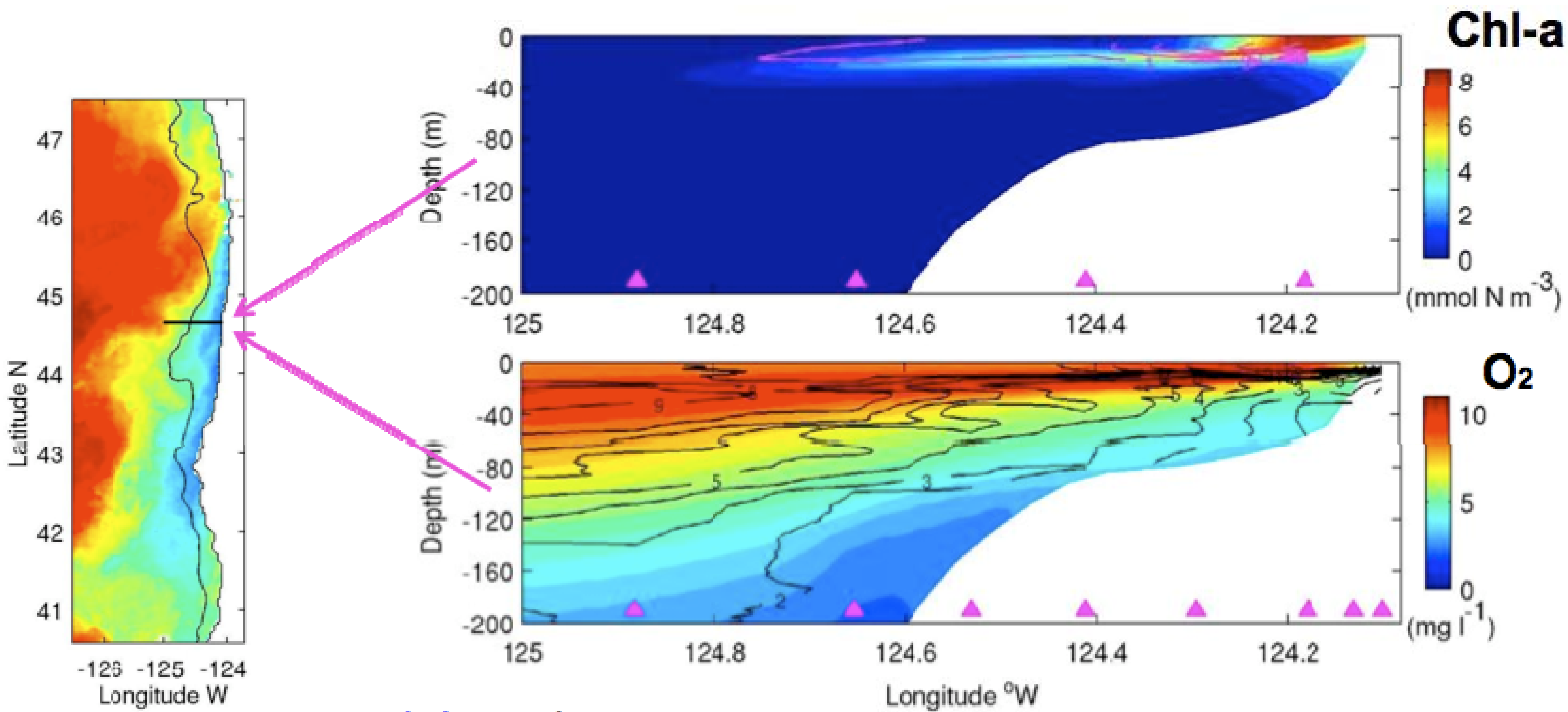
2N2PZD Ocean Ecosystem / Biogeochemistry Model

(Schmittner et al. 2008 GBC)

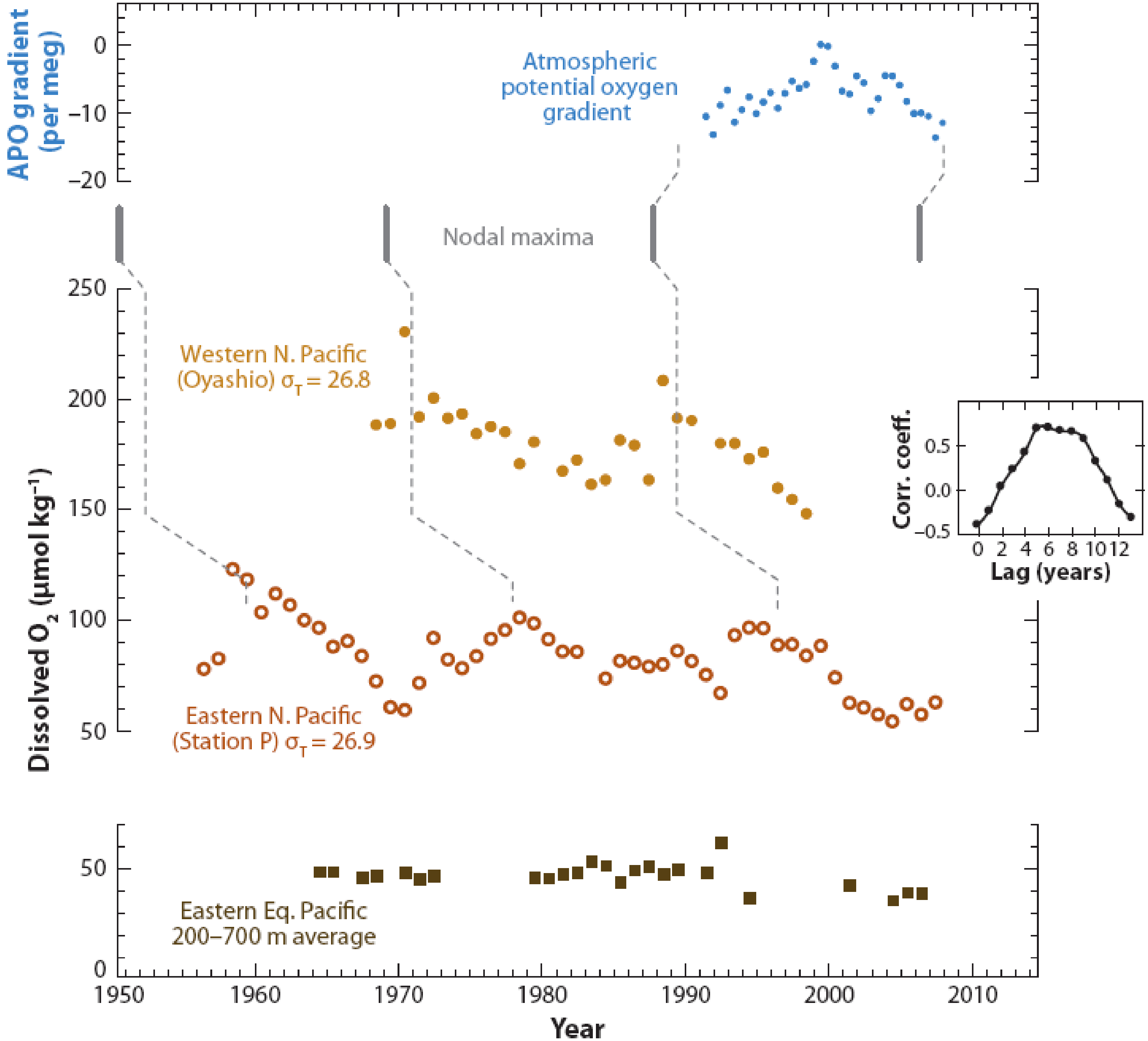
Assumptions:

- Constant Elemental Ratios
- No DOM
- No N-Deposition
- No River Input of N

Model/data comparisons: cross-sections of Chl-a, O_2 at 44.65N on 10 July 2002



model – color
data – contours



APO gradient (per meg)
0
−10
−20
Atmospheric potential oxygen gradient
Nodal maxima
Dissolved O_2 (µmol kg^{-1})
250
200
150
100
50
Western N. Pacific (Oyashio) $\sigma_T = 26.8$
Eastern N. Pacific (Station P) $\sigma_T = 26.9$
Corr. coeff.
0.5
0.0
−0.5
0 2 4 6 8 10 12
Lag (years)
50
0
Eastern Eq. Pacific 200–700 m average
1950
1960
1970
1980
1990
2000
2010
Year