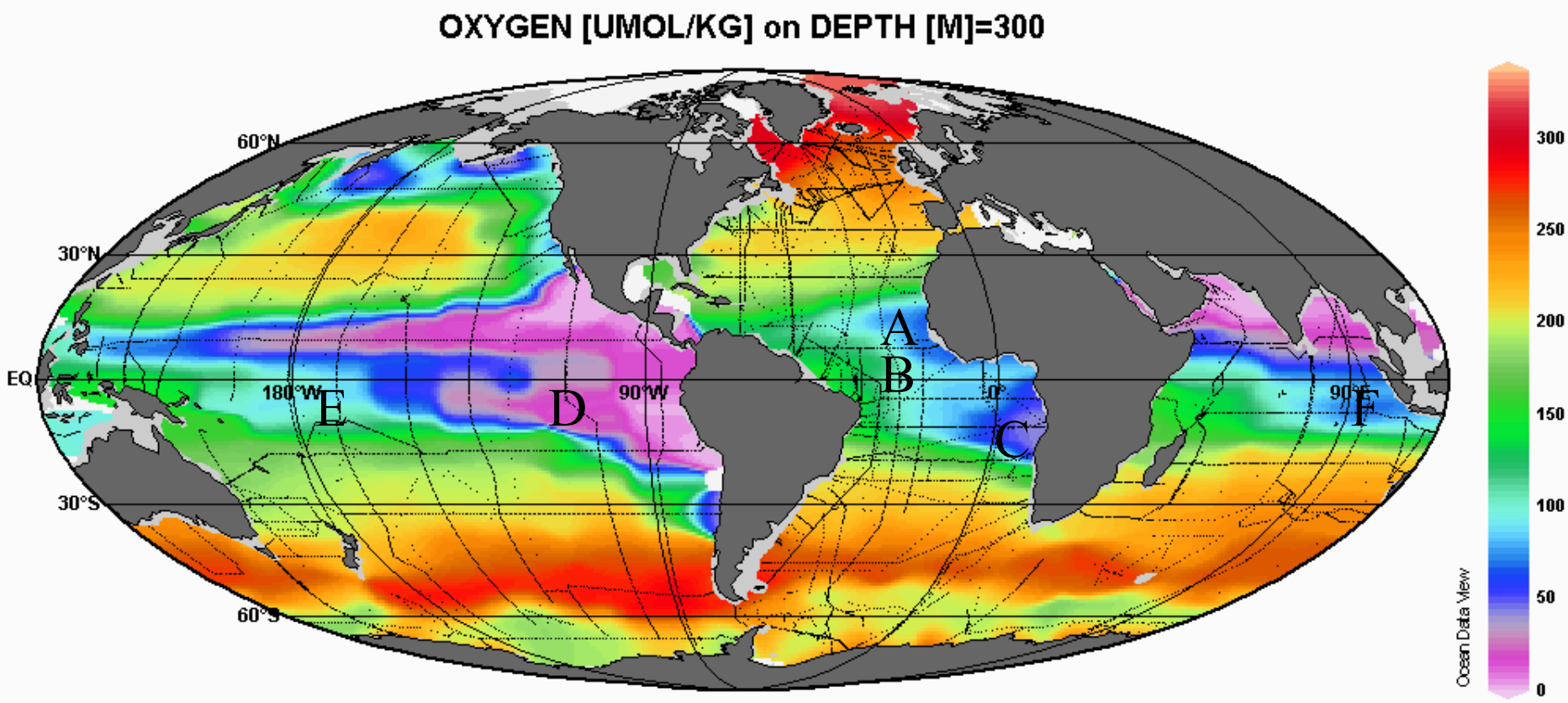
Climate Change Forcing of Intense Oceanic O_2 Minimum Zones

- Existence dependent on interplay of ocean physics and biogeochemistry - focus on ETP
- Paleo-evidence for climate forcing on Ma to decadal scales
- Prospects for model simulation and experimentation

Modern Open Ocean Suboxic zones



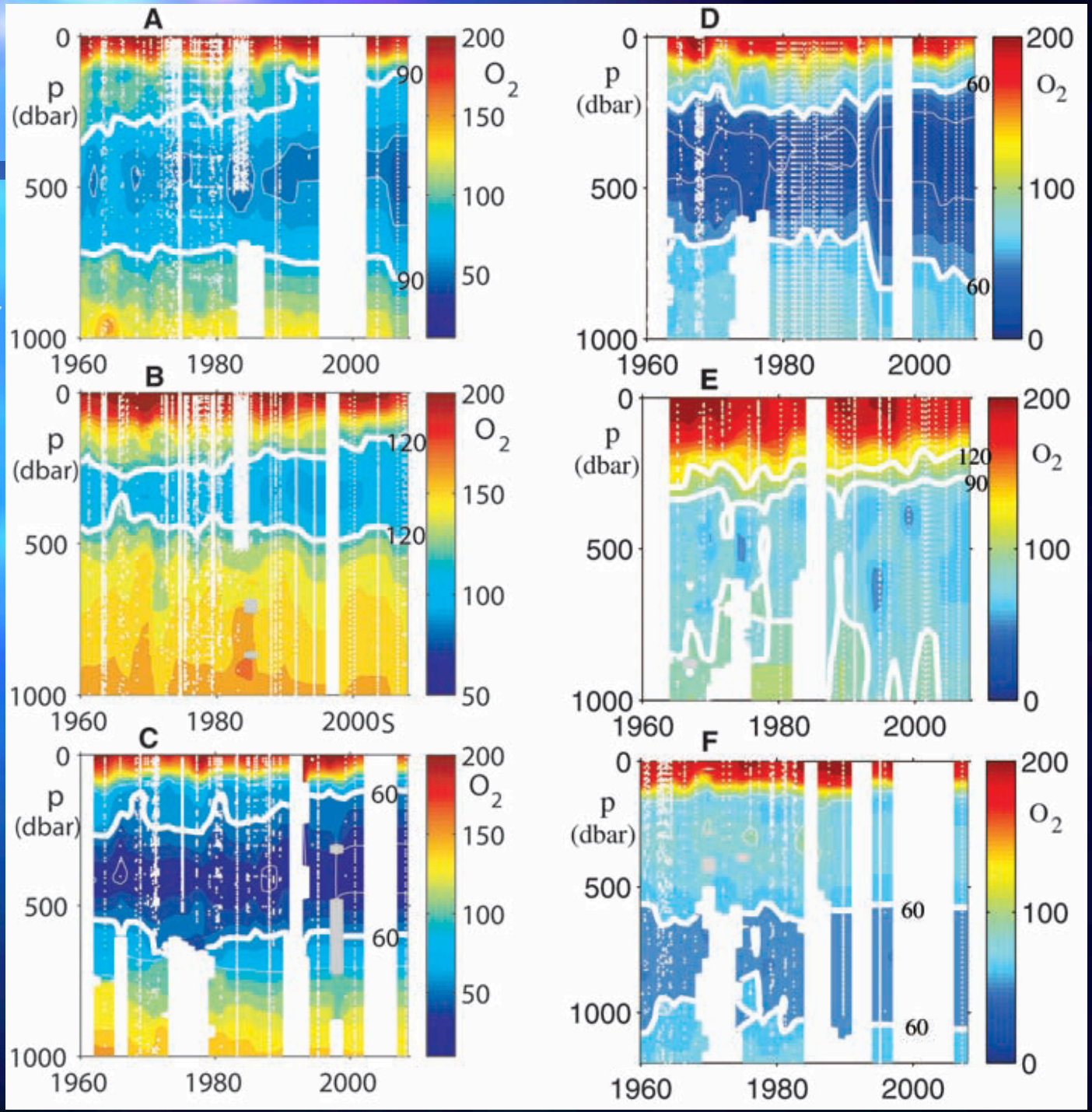
- High surface productivity and downward OM flux
- Poor subsurface water mass ventilation

-closed regional circulation (shadow zone)

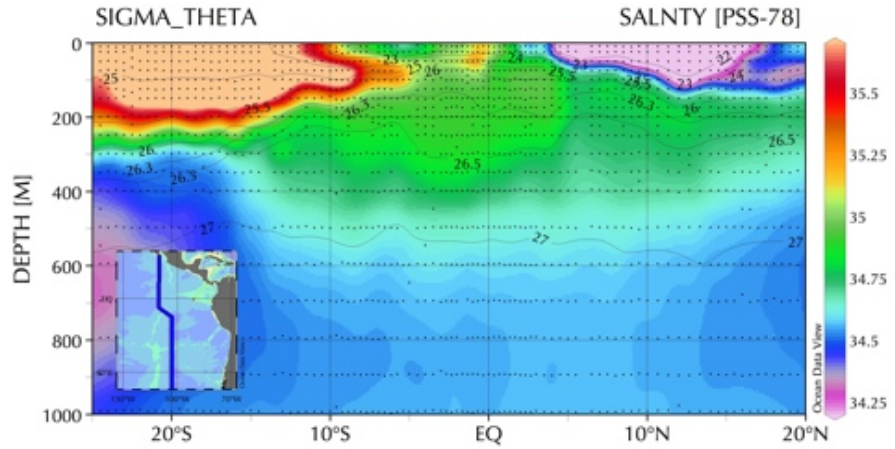
-remote surface (outcrop) ventilation zone

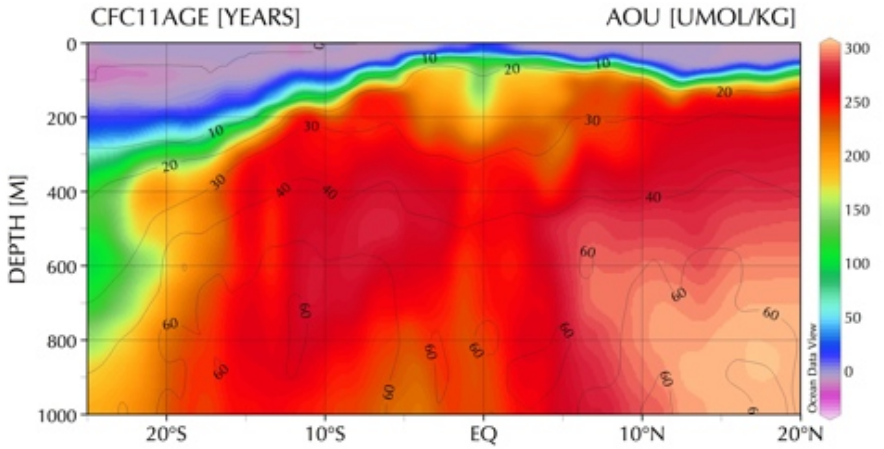


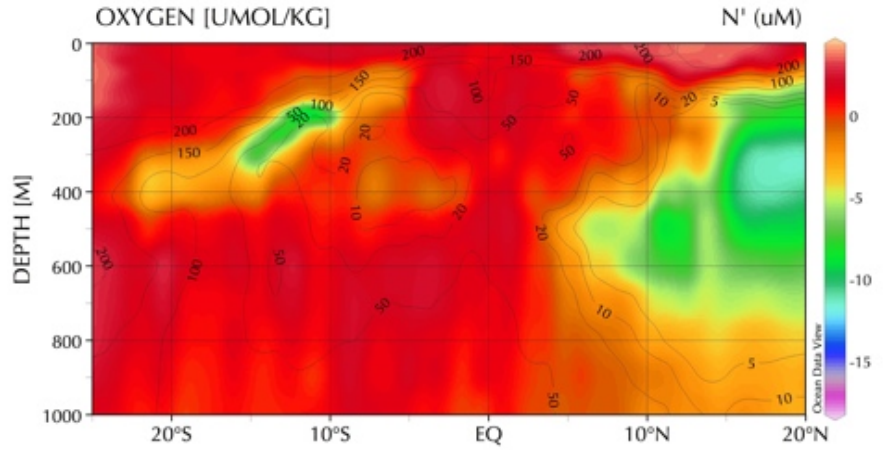
Lothar Stramma, *et al.*
Science **320**, 655 (2008);
DOI: 10.1126/science.1153847

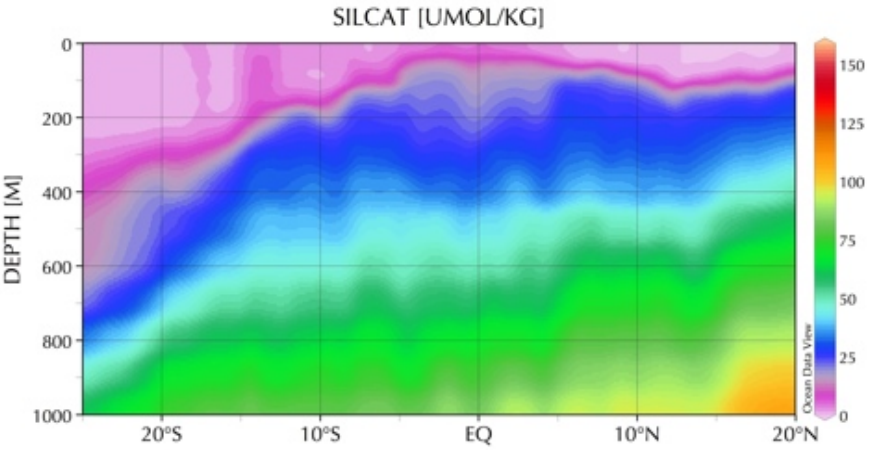


Hydrography Along P18

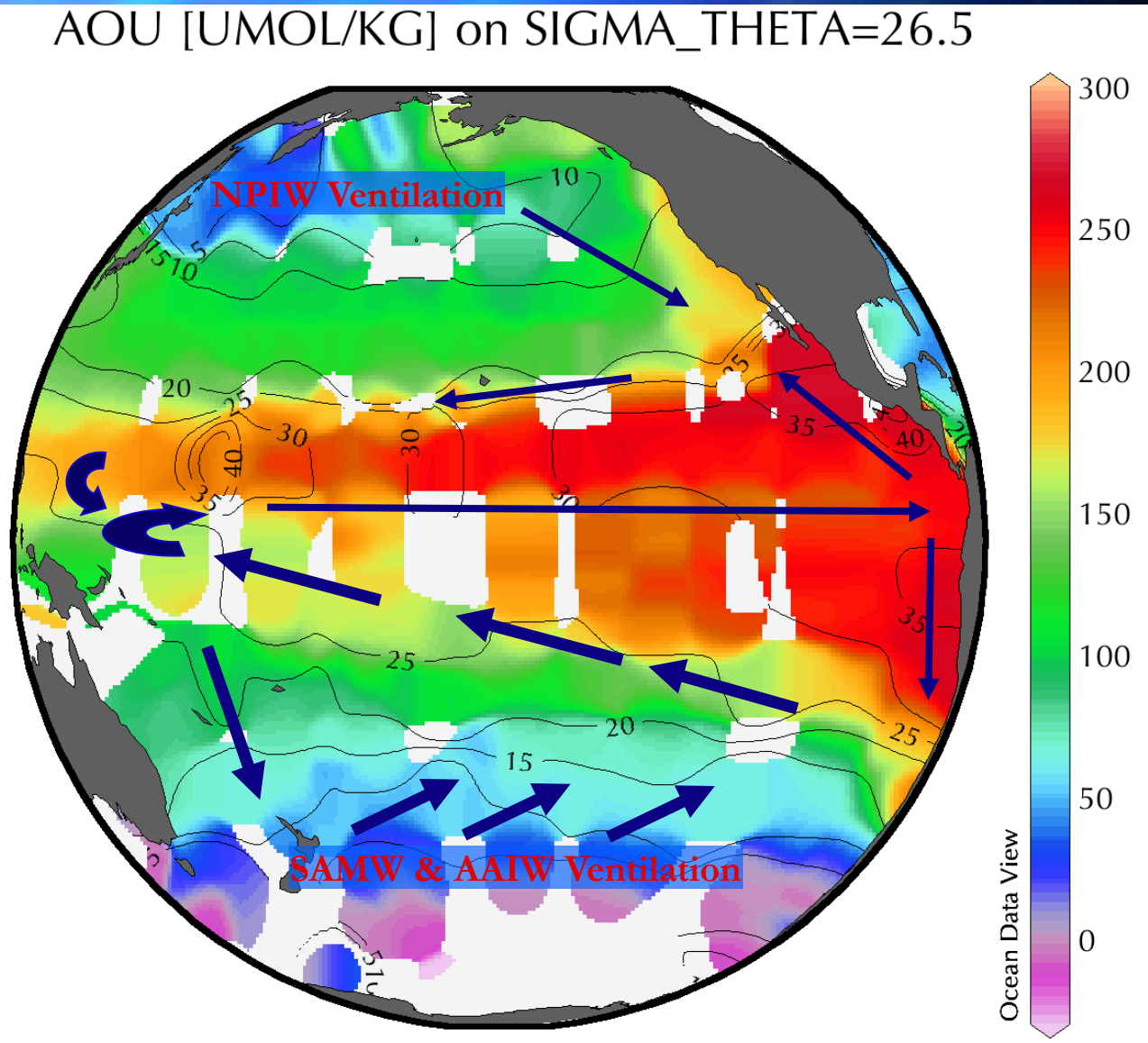






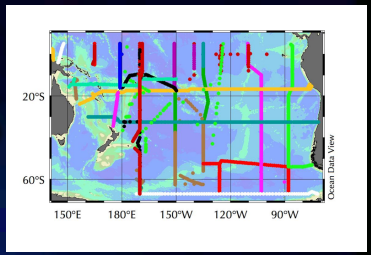


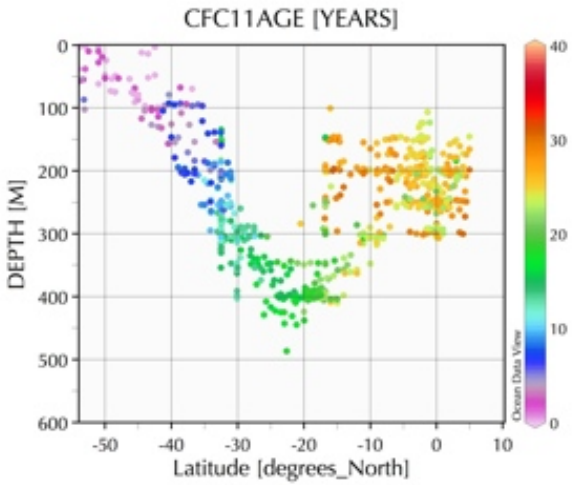
Remote Subpolar Ventilation

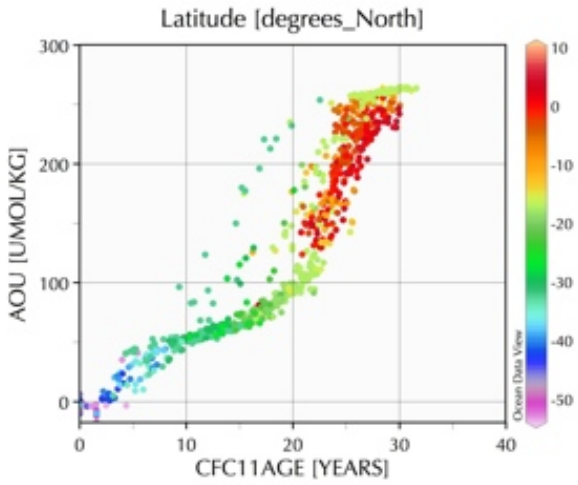


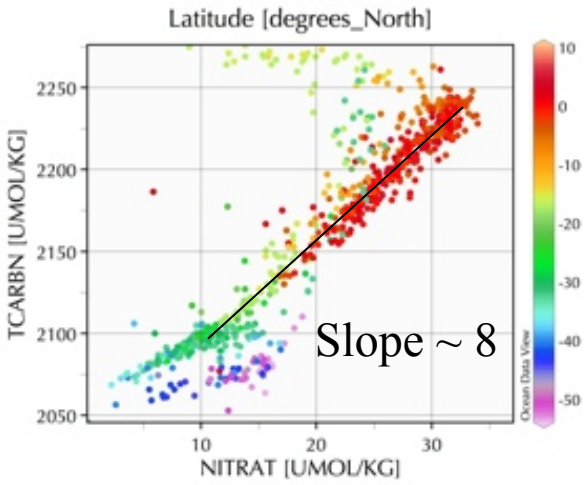
Contours are CFC-12 ages

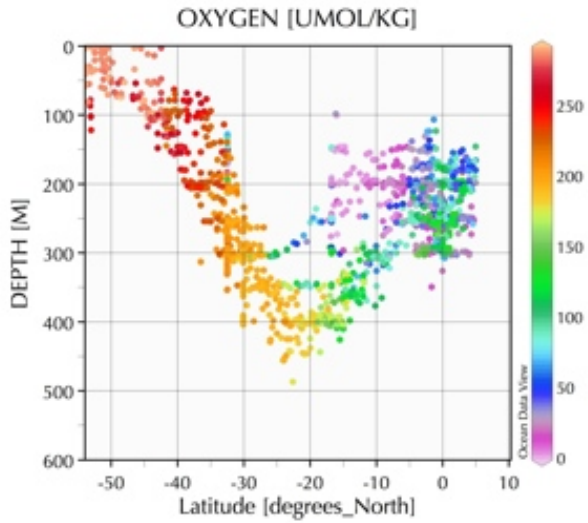
Property Relationships along σ_θ 26.3 to 26.5

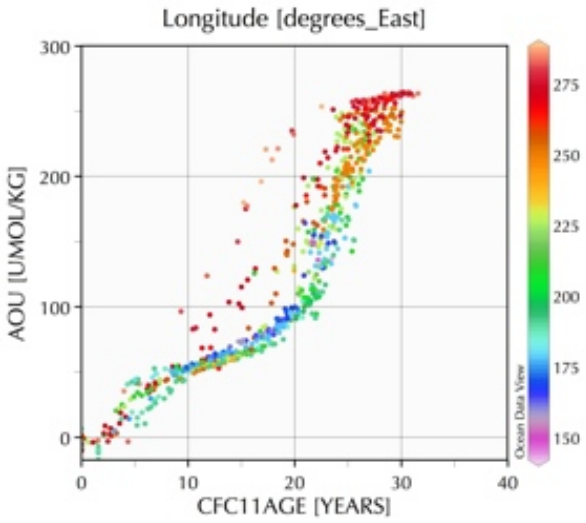


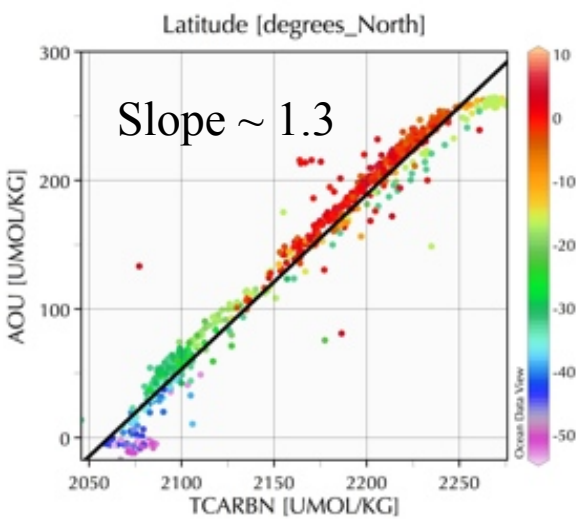




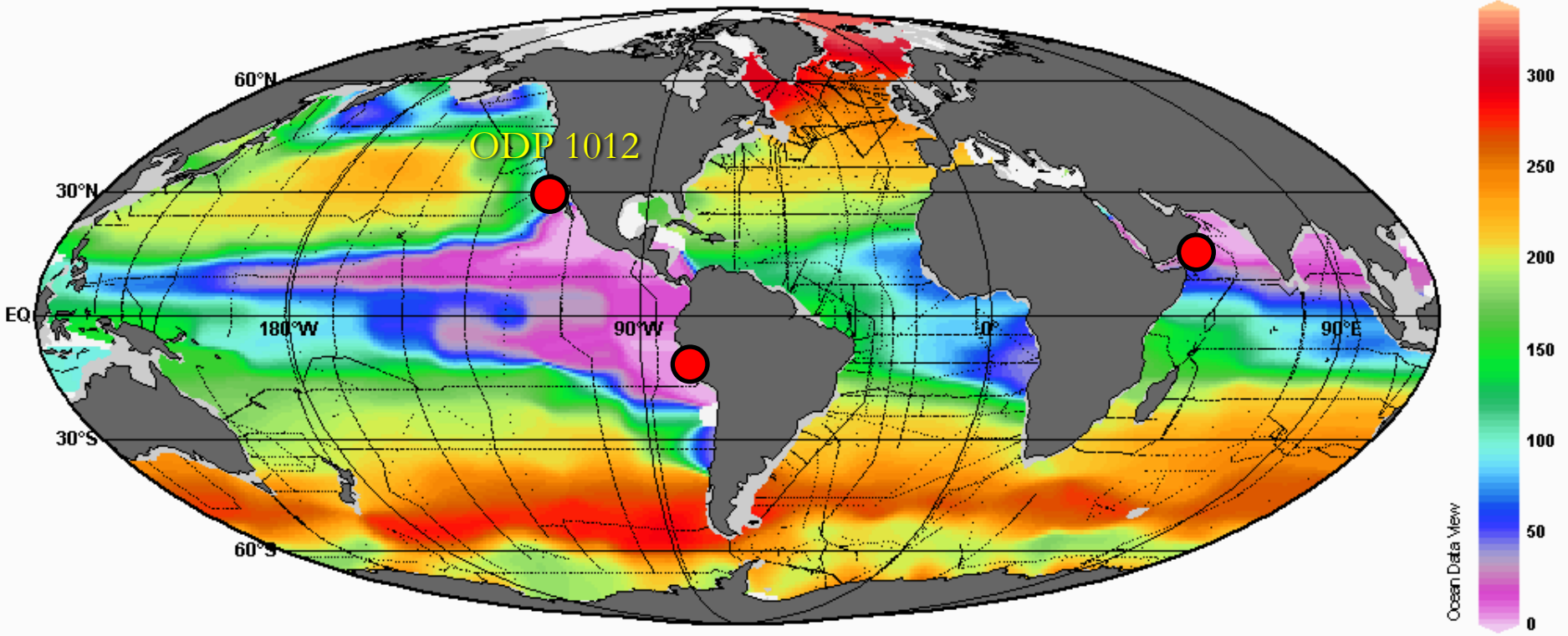




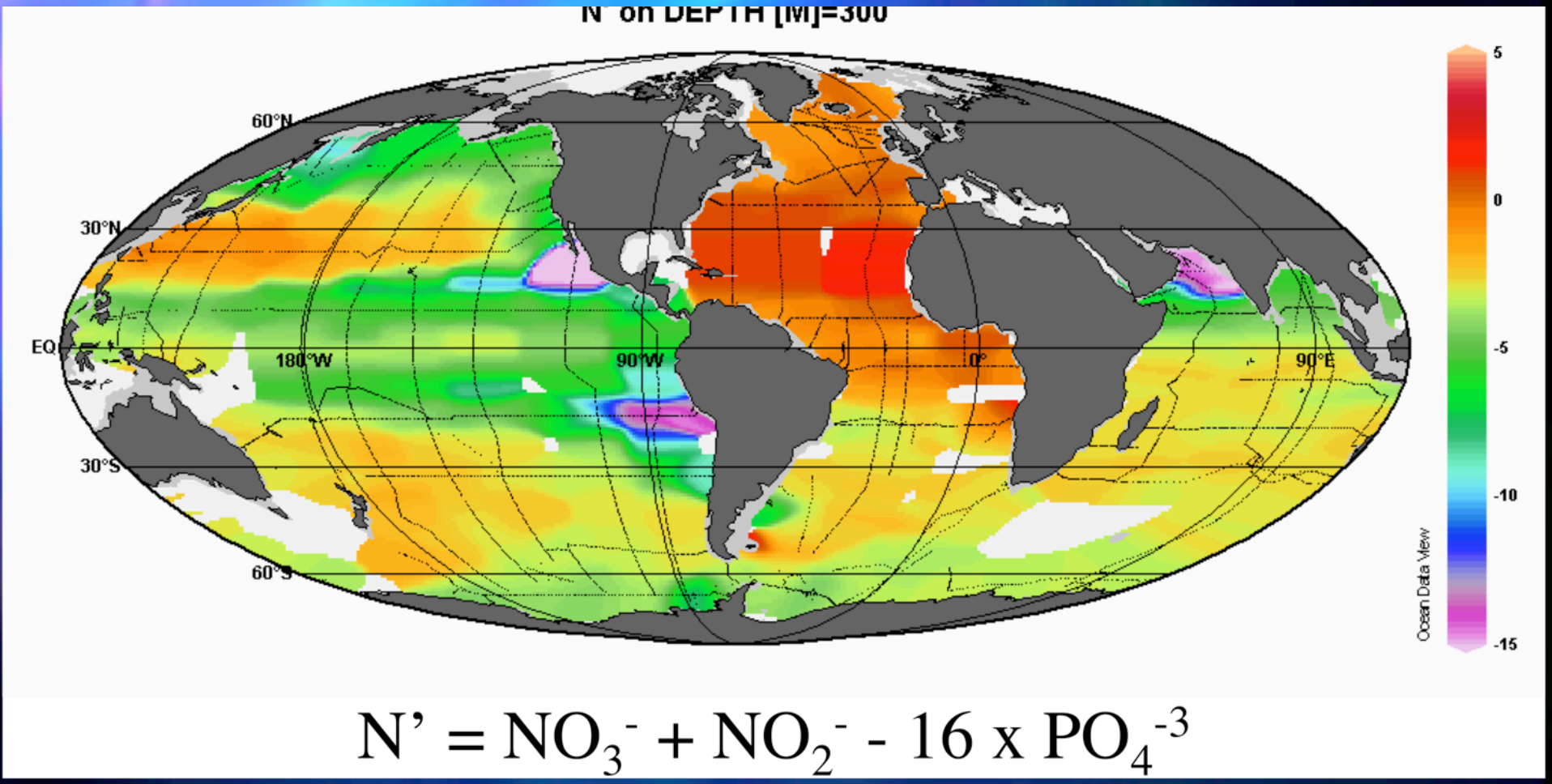




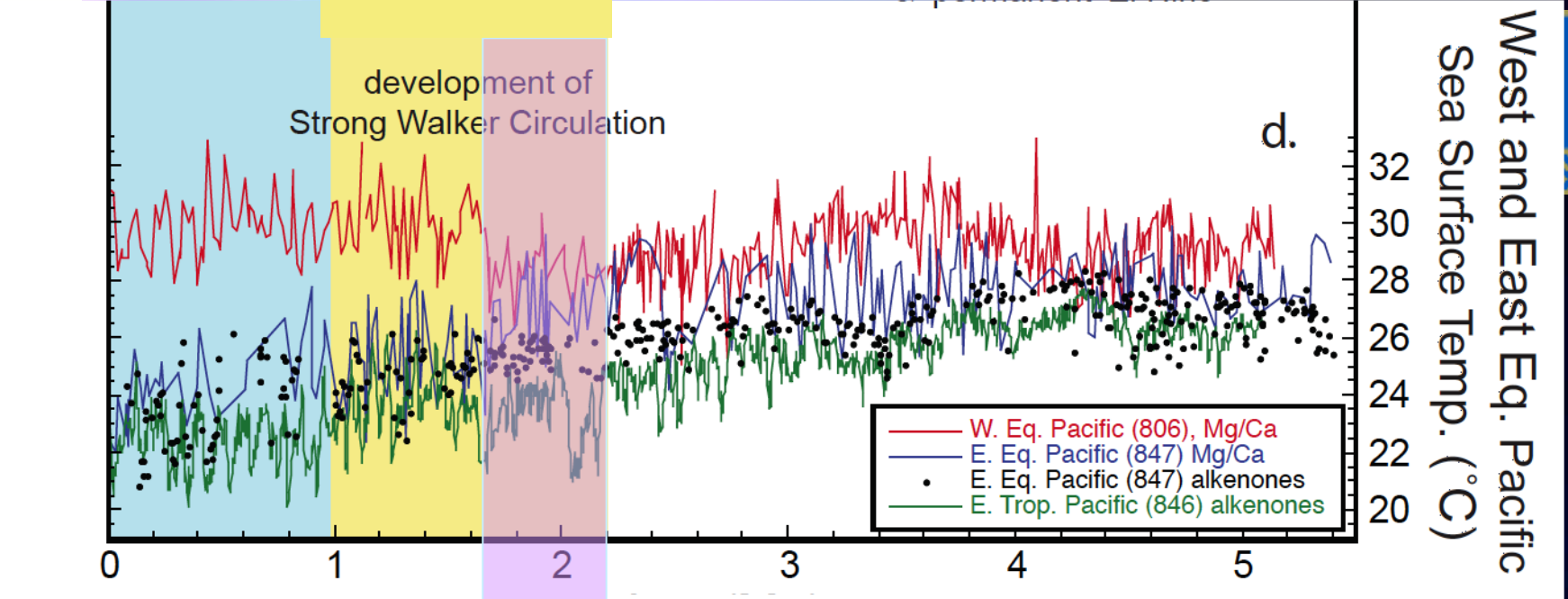
Locations of Paleo-records

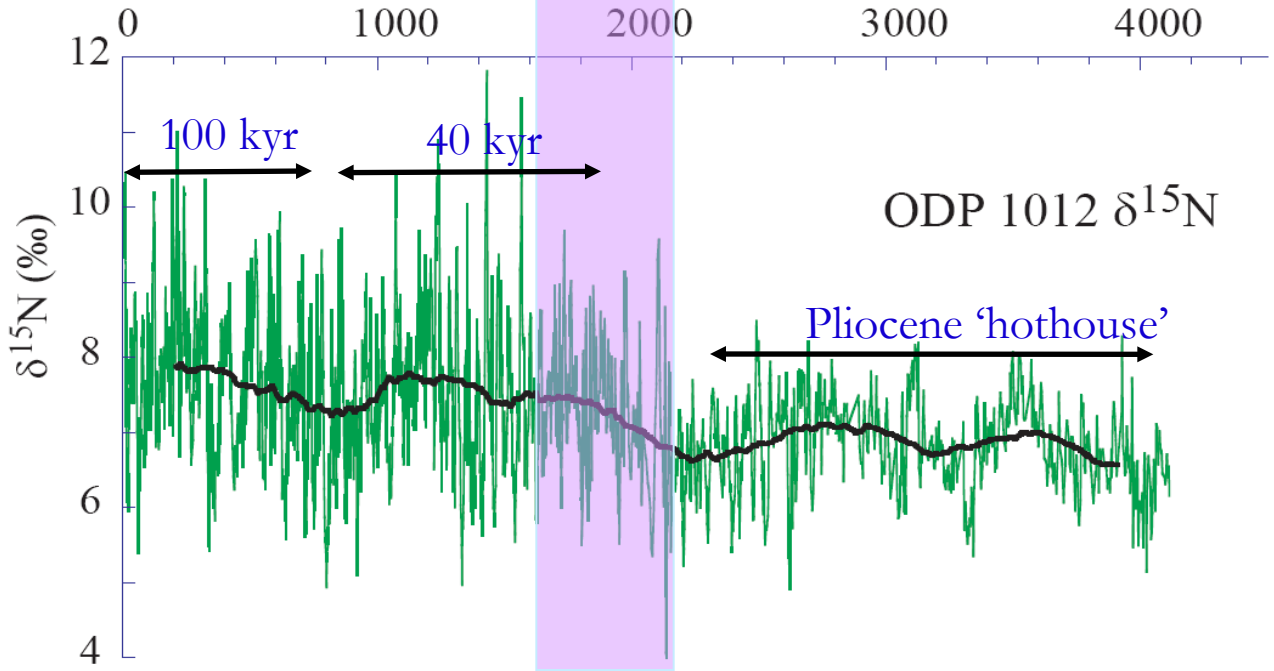


Important Locations for Denitrification

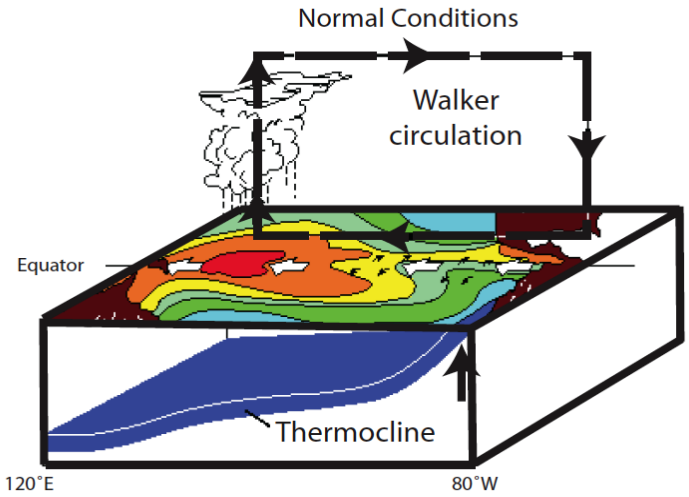


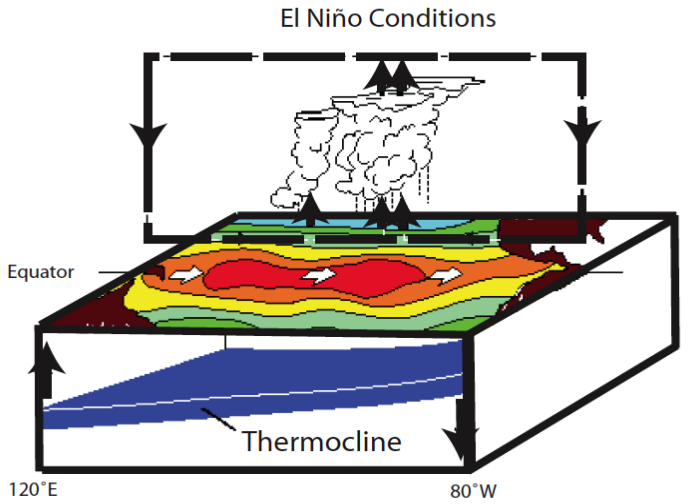
$$N' = NO_3^- + NO_2^- - 16 \times PO_4^{-3}$$

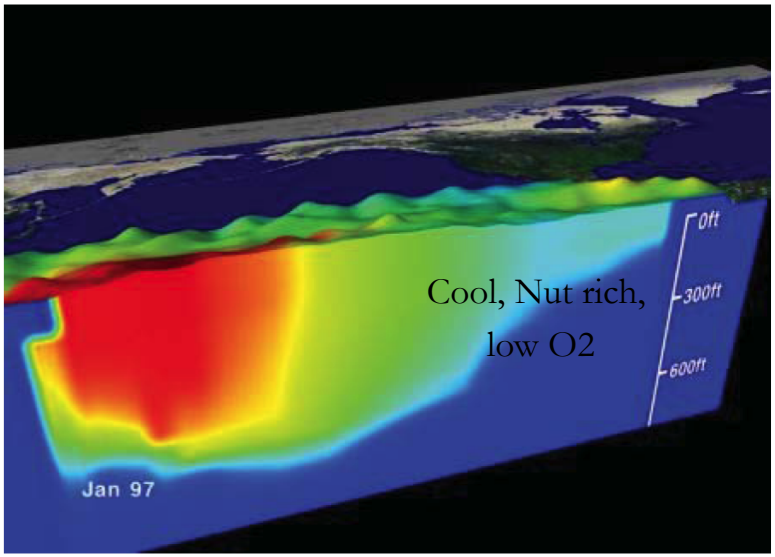

development of
Strong Walker Circulation
d.
W. Eq. Pacific (806), Mg/Ca
E. Eq. Pacific (847) Mg/Ca
E. Eq. Pacific (847) alkenones
E. Trop. Pacific (846) alkenones
West and East Eq. Pacific
Sea Surface Temp. (°C)
32
30
28
26
24
22
20
0
1
2
3
4
5


0
1000
2000
3000
4000
12
10
8
6
4
δ15N (‰)
100 kyr
40 kyr
ODP 1012 δ15N
Pliocene 'hothouse'

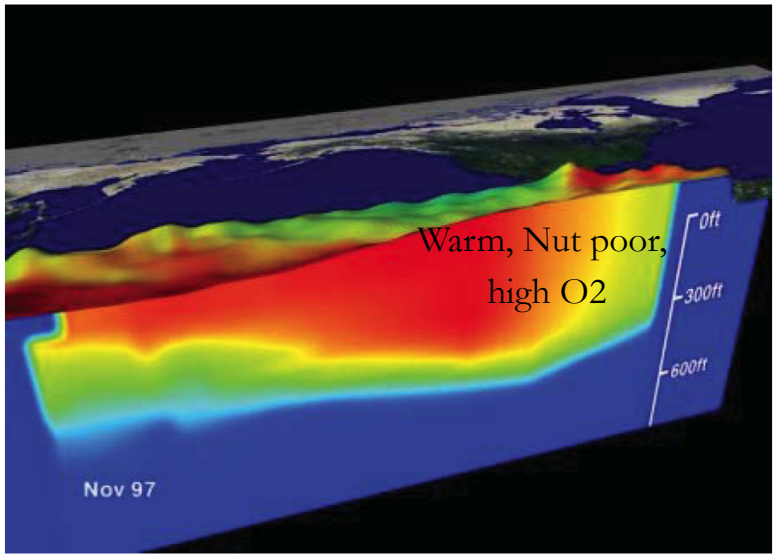
ENSO, Walker Circulation, and Eq. Pacific Thermocline Structure





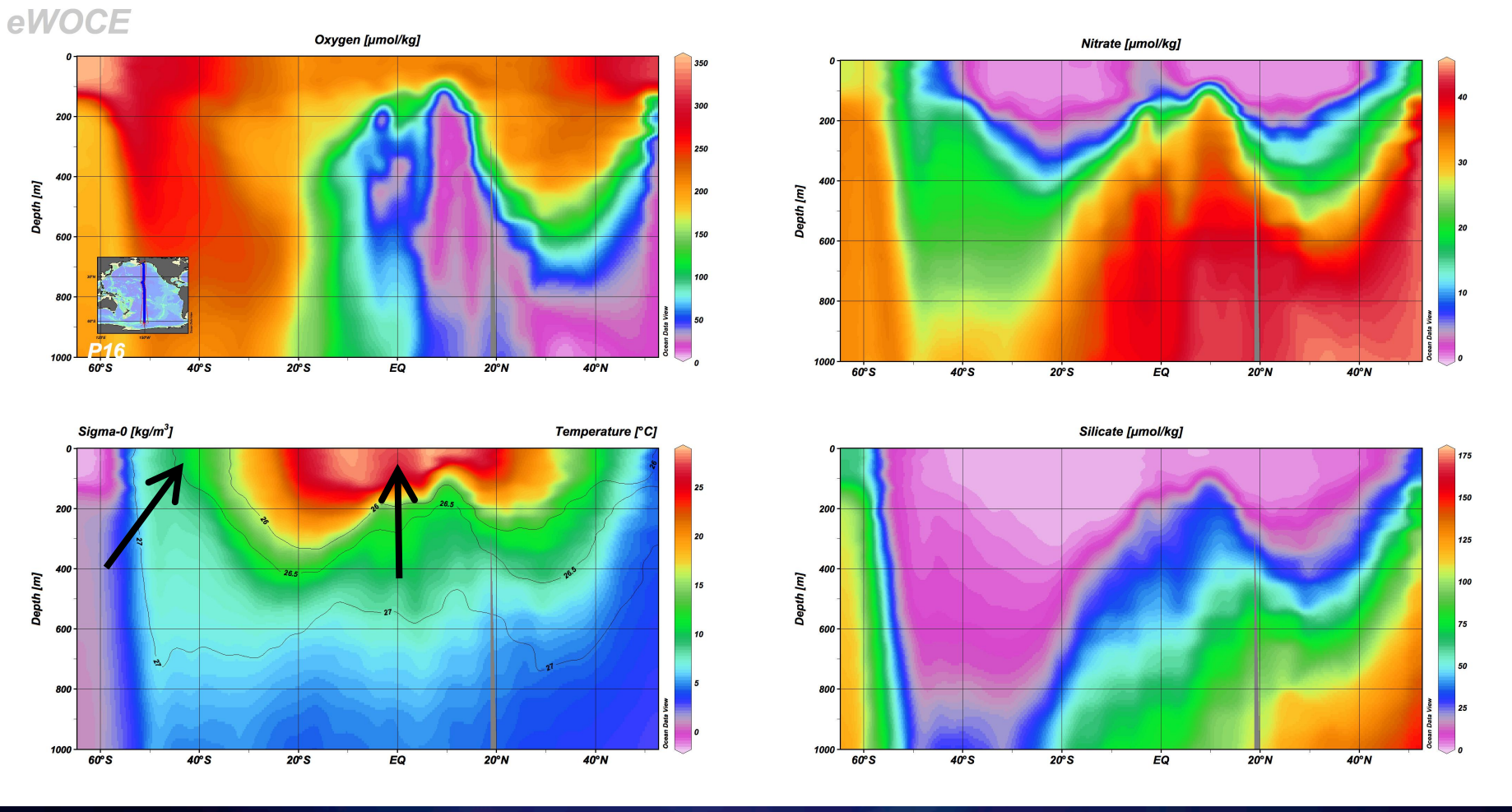


January 1997 Normal

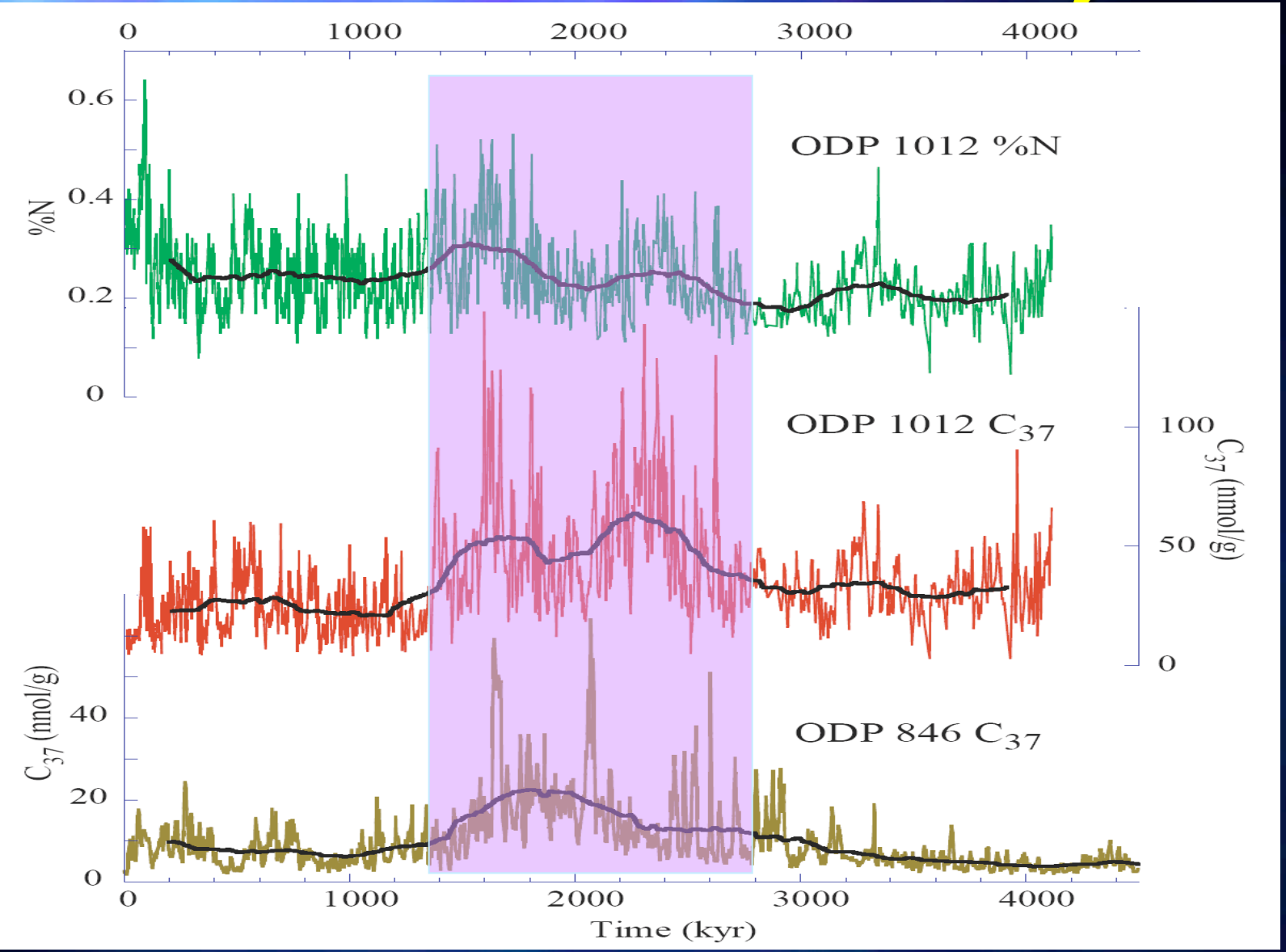


November 1997 El Niño

Consistent with shoaling thermocline theory?

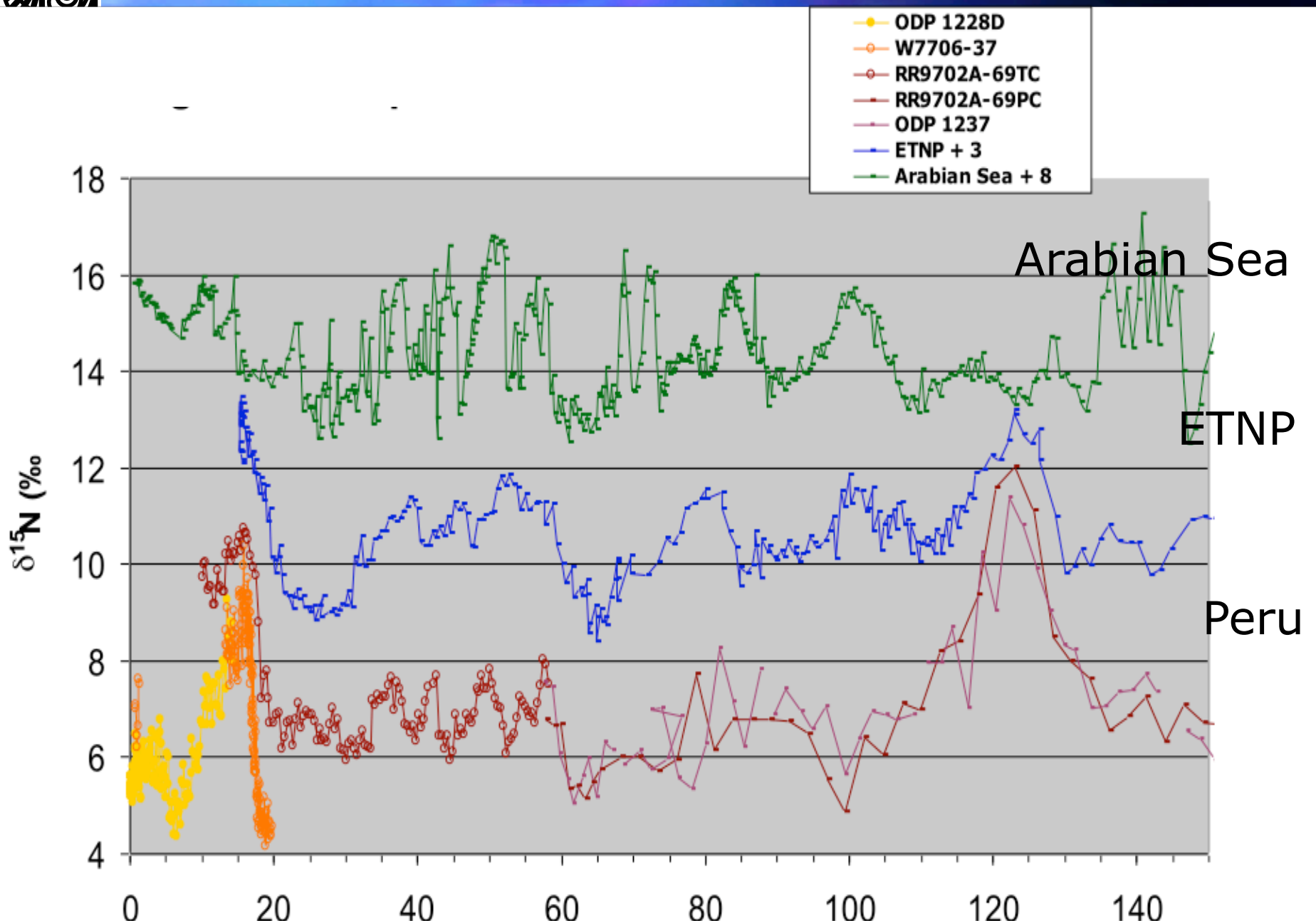


Eastern Pacific Productivity

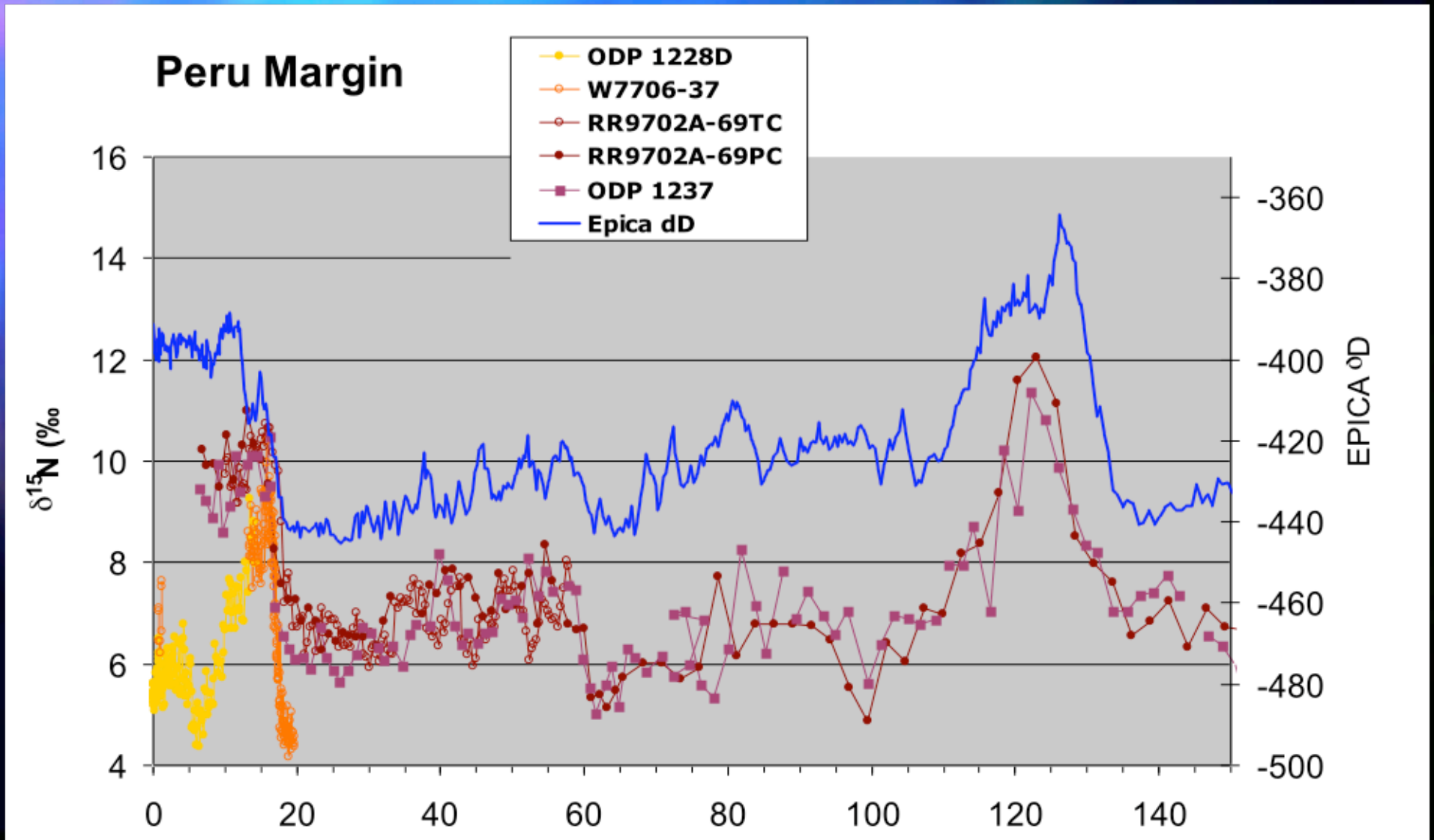


Productivity max ~3-1.5 Ma (Cortese et al., 2004);

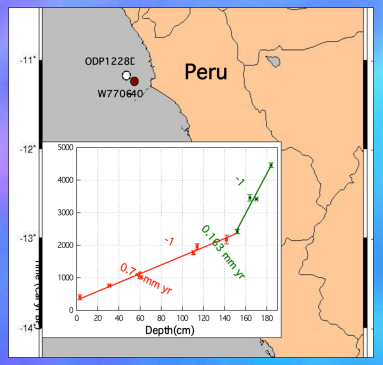
Regional comparison last glacial cycle

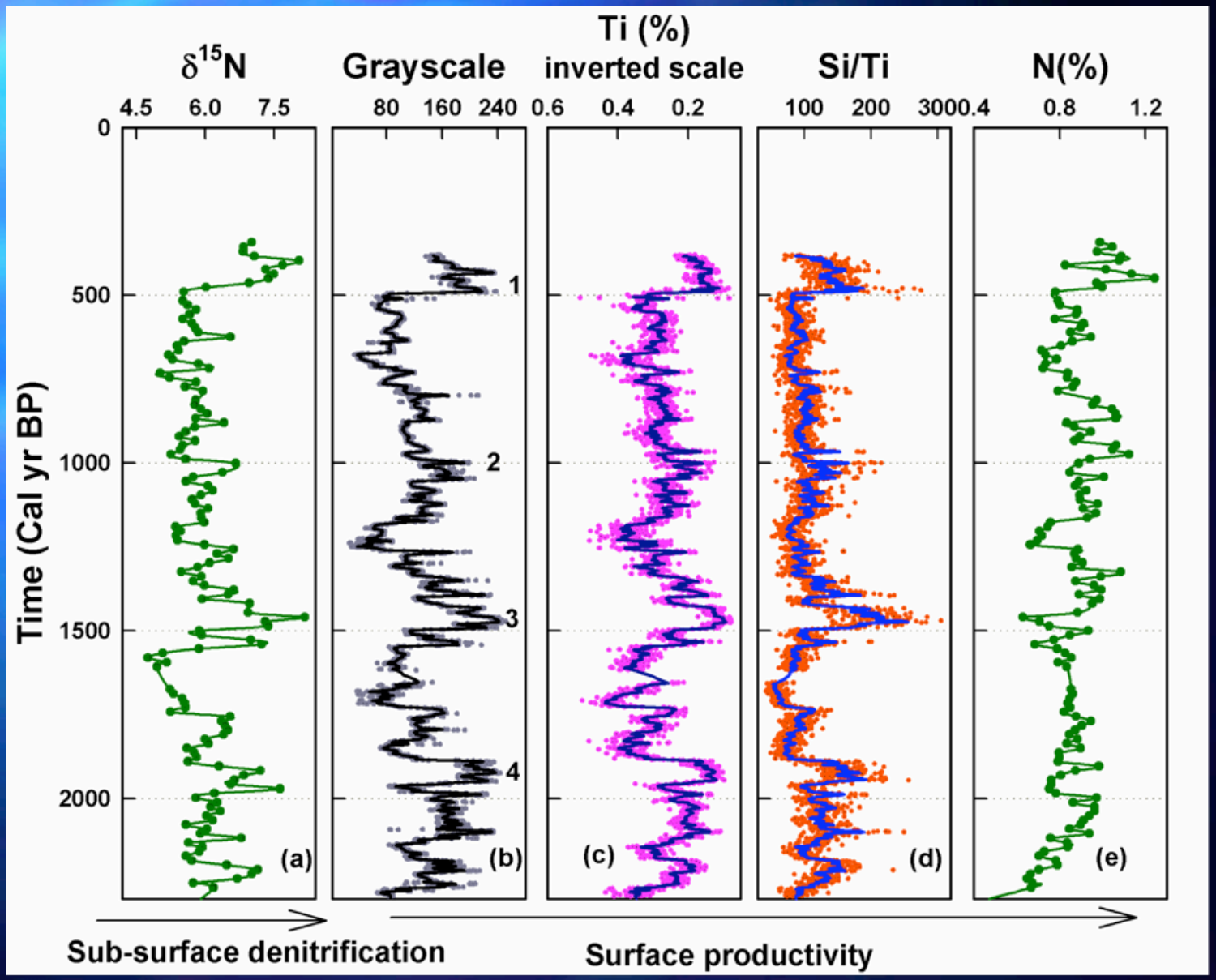


Relationship to southern polar climate



Late Holocene Variations Linked to Productivity?





GCM's can simulate the major low O_2 zones, but are too coarse for getting the detailed circulation right!

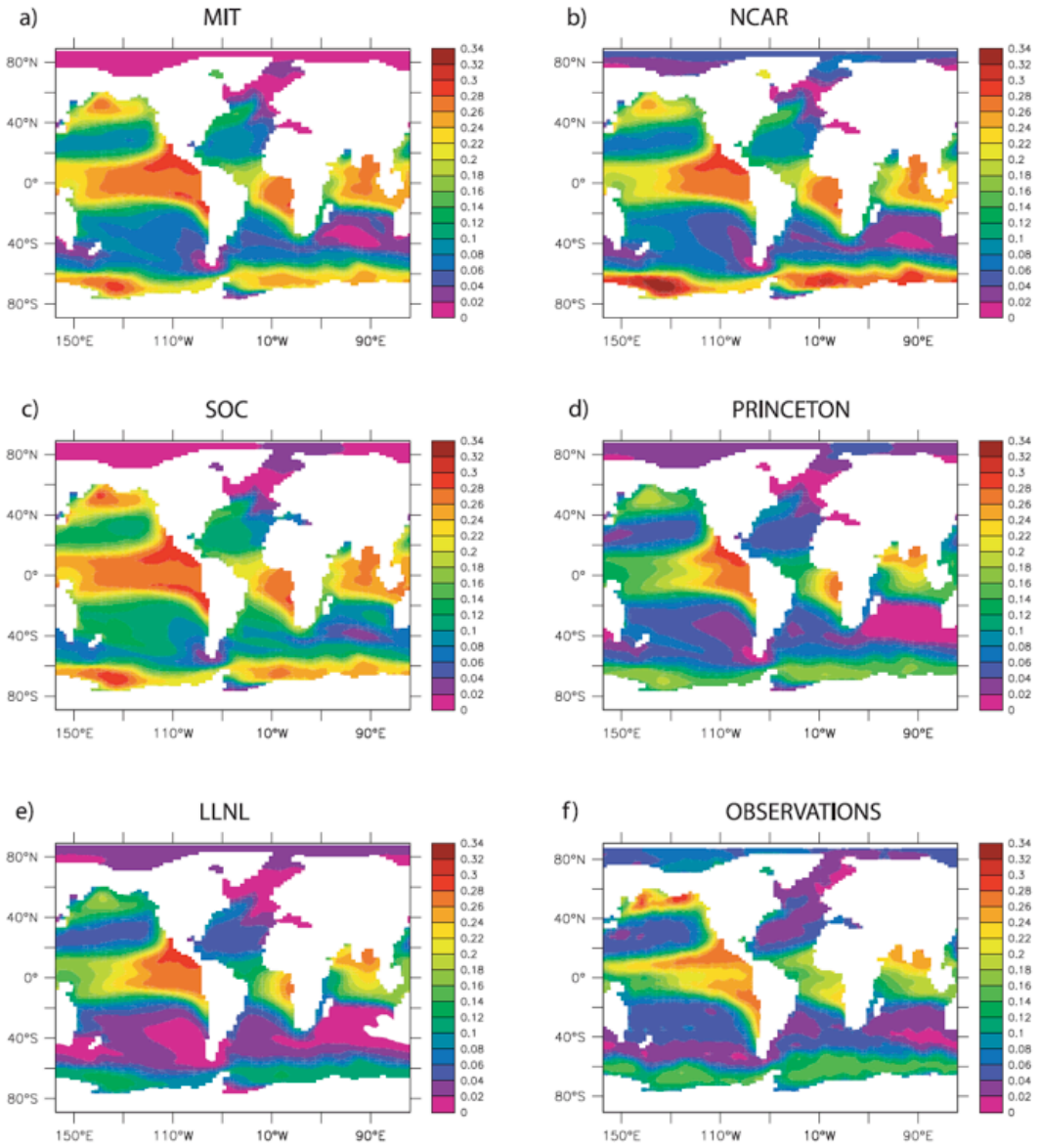
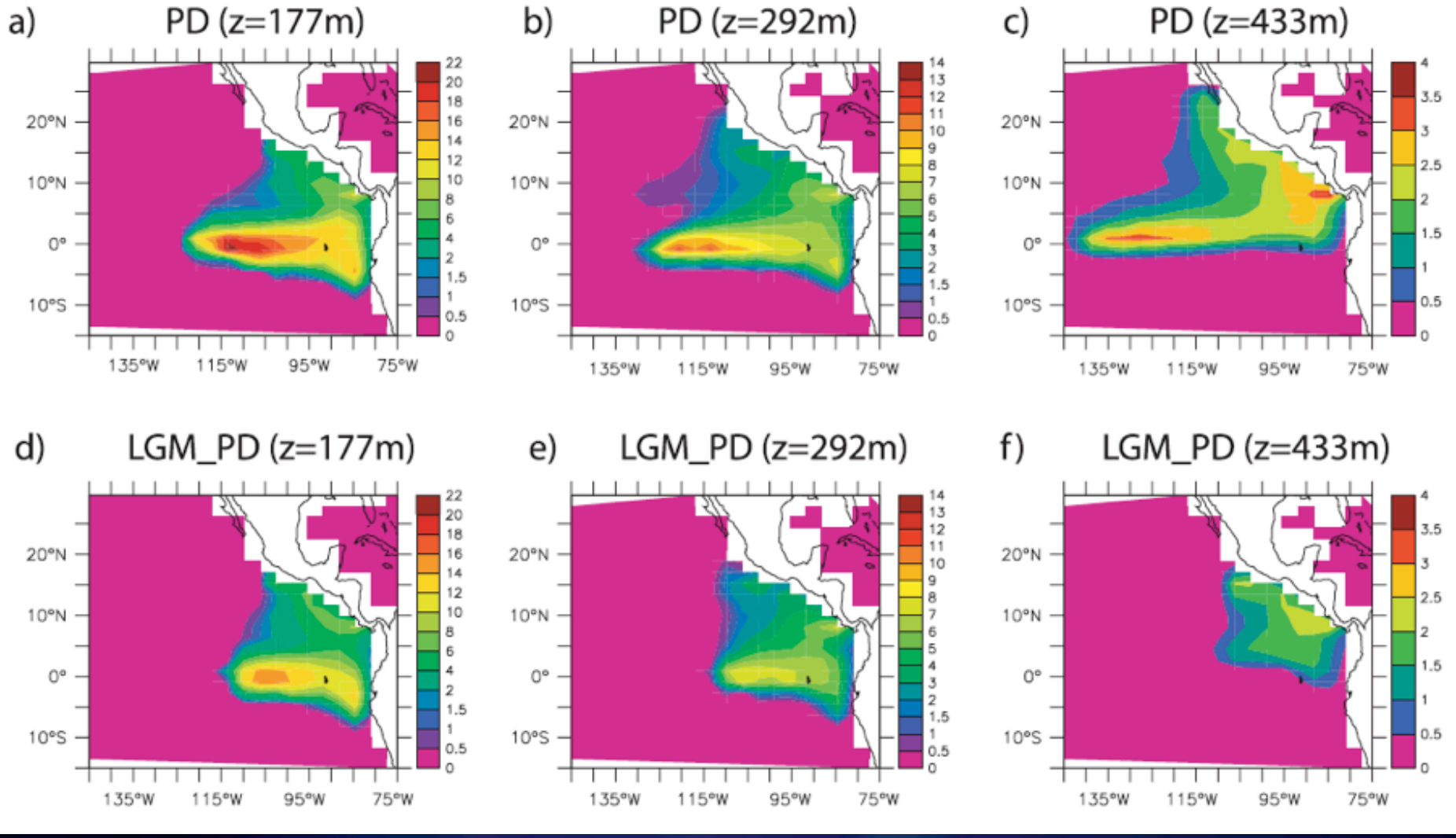
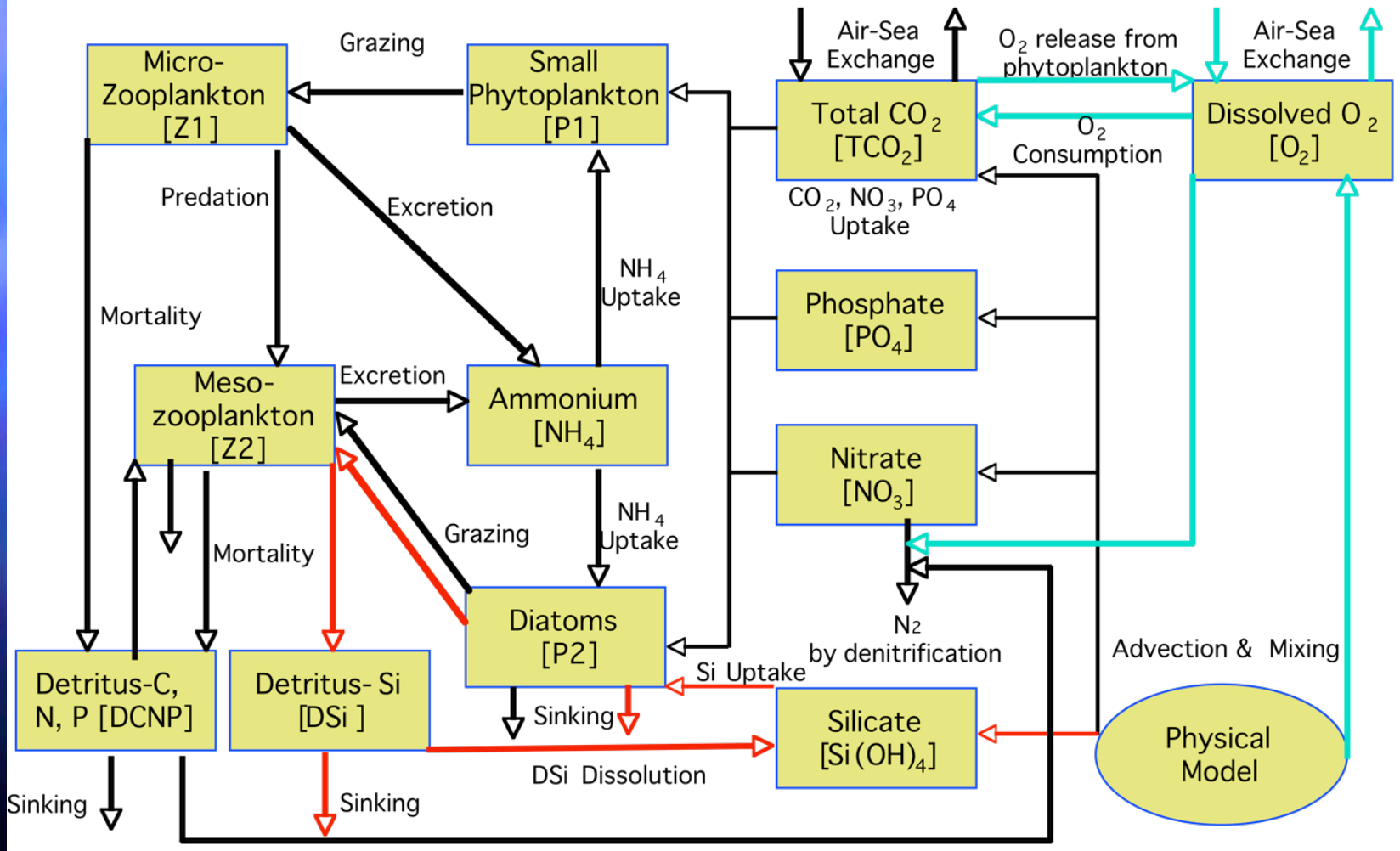


Figure 1. Annually averaged apparent oxygen utilization (AOU) at 300 m depth under present-day conditions for experiments run with data from (a) MIT, (b) NCAR, (c) SOC, (d) PRINCETON, (e) LLNL, and (f) observations [*Conkright et al.*, 2002]. Units are in mol m^{-3}.

Citation: Meissner, K. J., E. D. Galbraith, and C. Völker (2005), Denitrification under glacial and interglacial conditions: A physical approach, *Paleoceanography*, *20*, PA3001, doi:10.1029/2004PA001083.

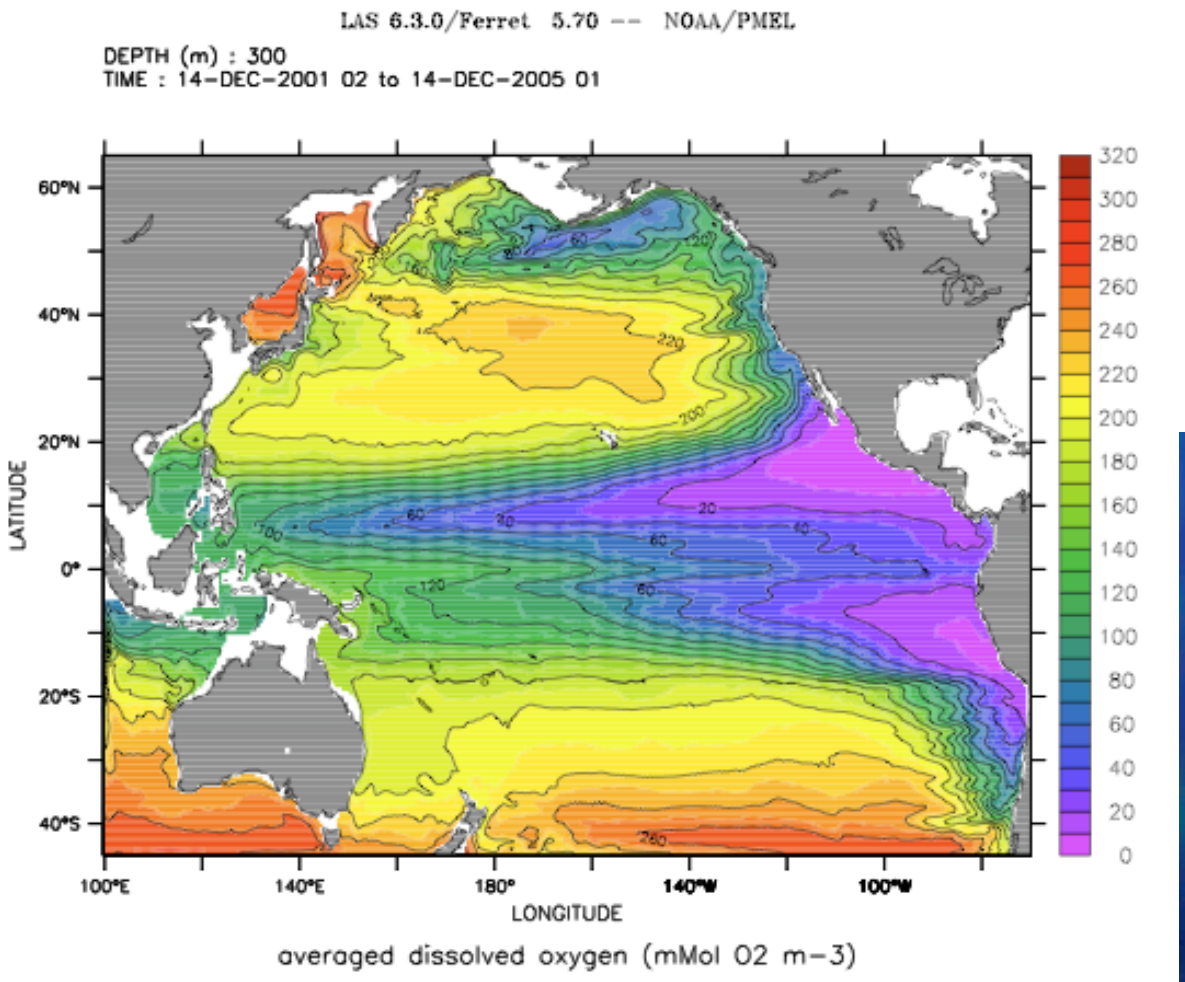


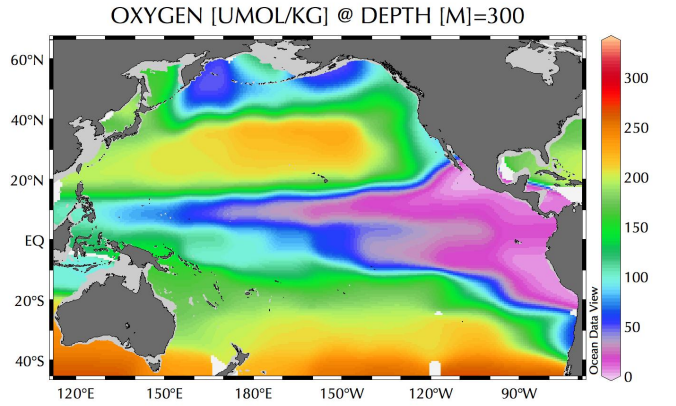
Modified CoSINE Model with Denitrification



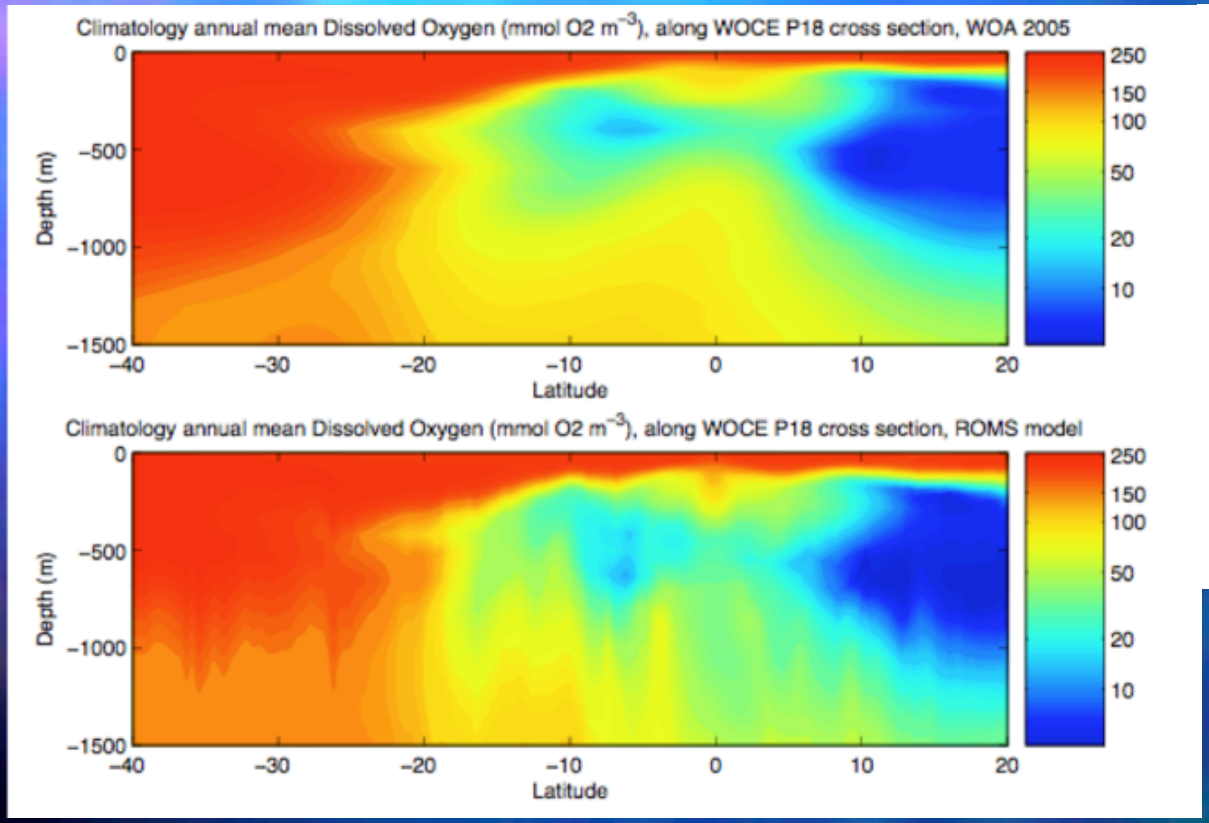
Chai et al. (2002, 2003), Dugdale et al. (2002), Jiang et al. (2003), Chai et al. (2007).

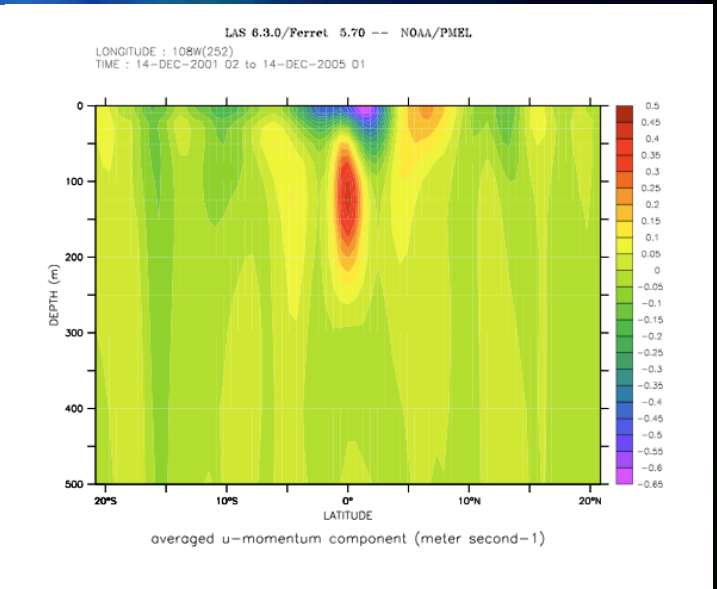
A 50-year modern simulation using the Pacific ROMS-CoSine



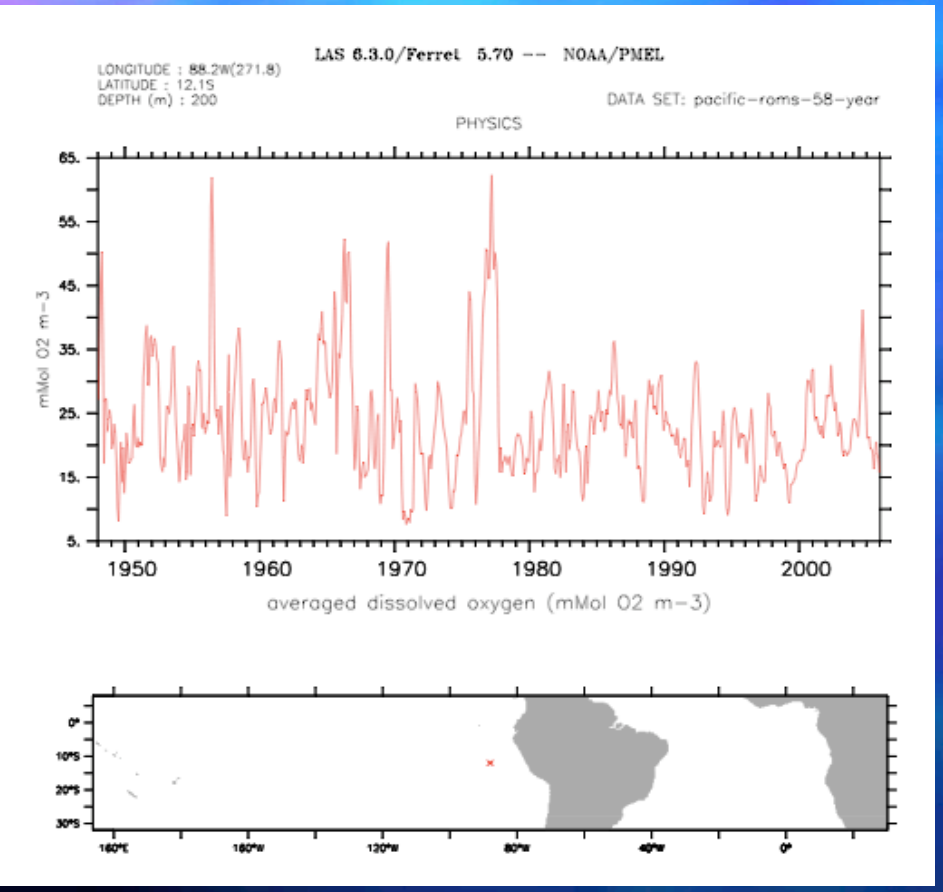


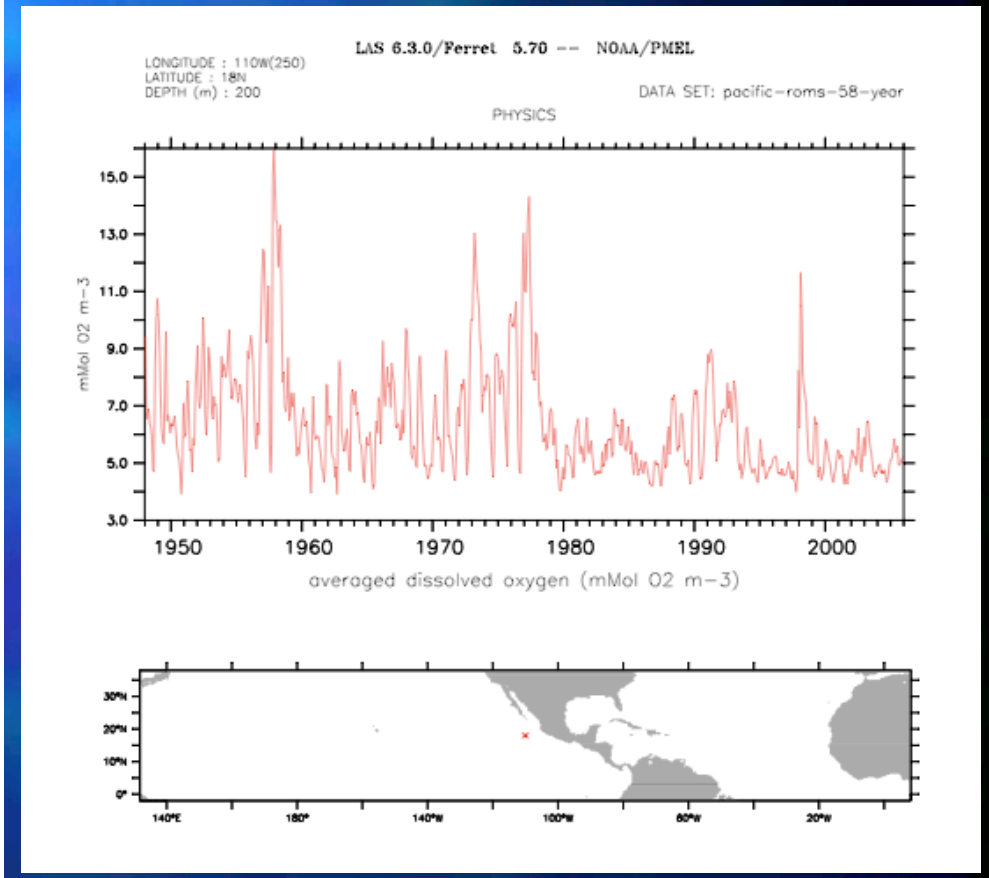
Comparison at the P18 Section





Simulated variability over the last 60 years





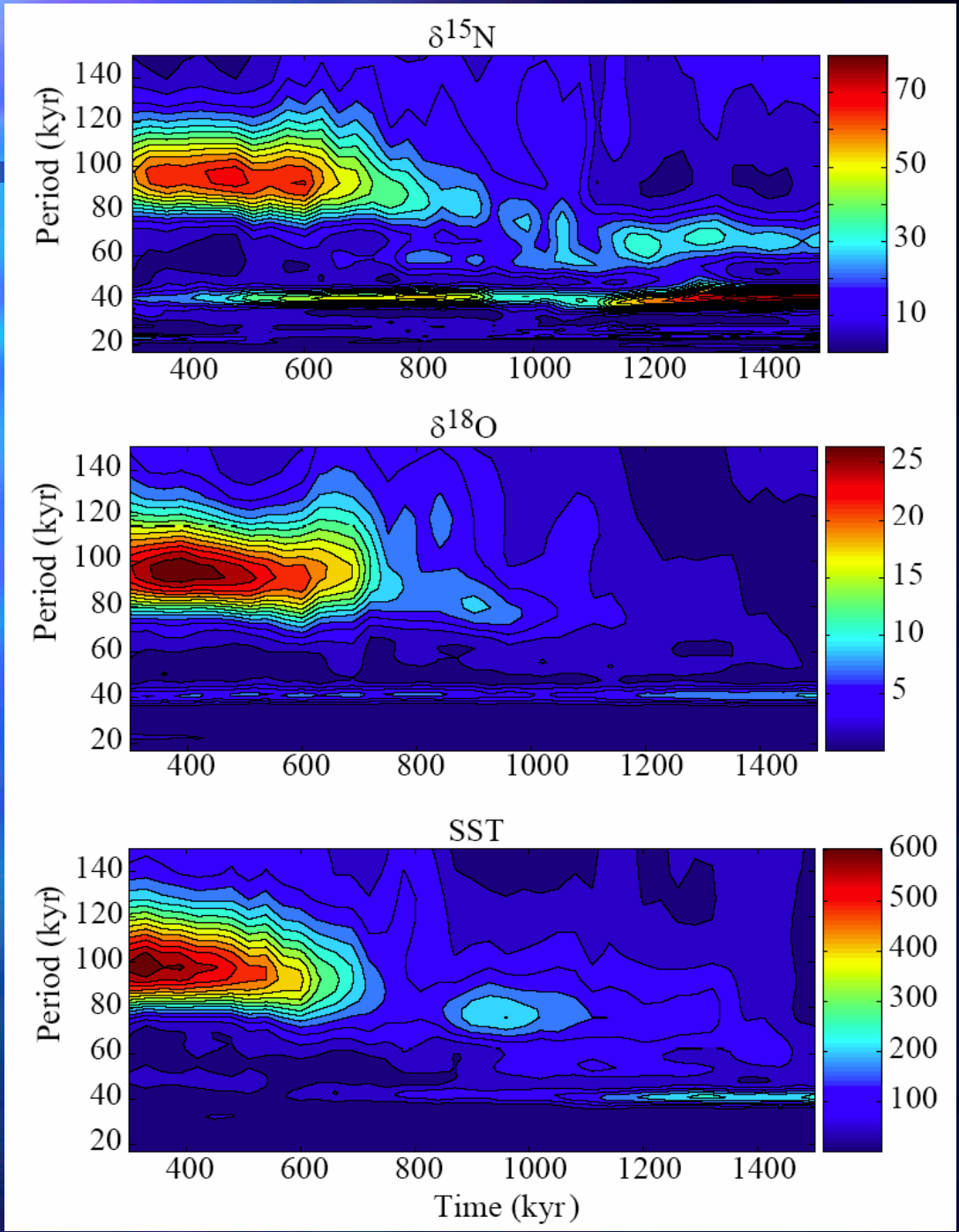
Summary

- Oceanic low O_2 zones are sensitive to climate forcing on a large range on time scales including those relevant to future global warming
- Forcing may be through either remote subpolar ventilation and/or regional productivity depending on time scale and nature of forcing
- Feedbacks through ocean biogeochemistry likely as well as impacts on regional living marine resources
- Advances are needed in understanding the interplay of hydrography, ventilation, and productivity
- Numerical models will be an important experimental approach given resolution of key circulation features

Wavelet Analysis

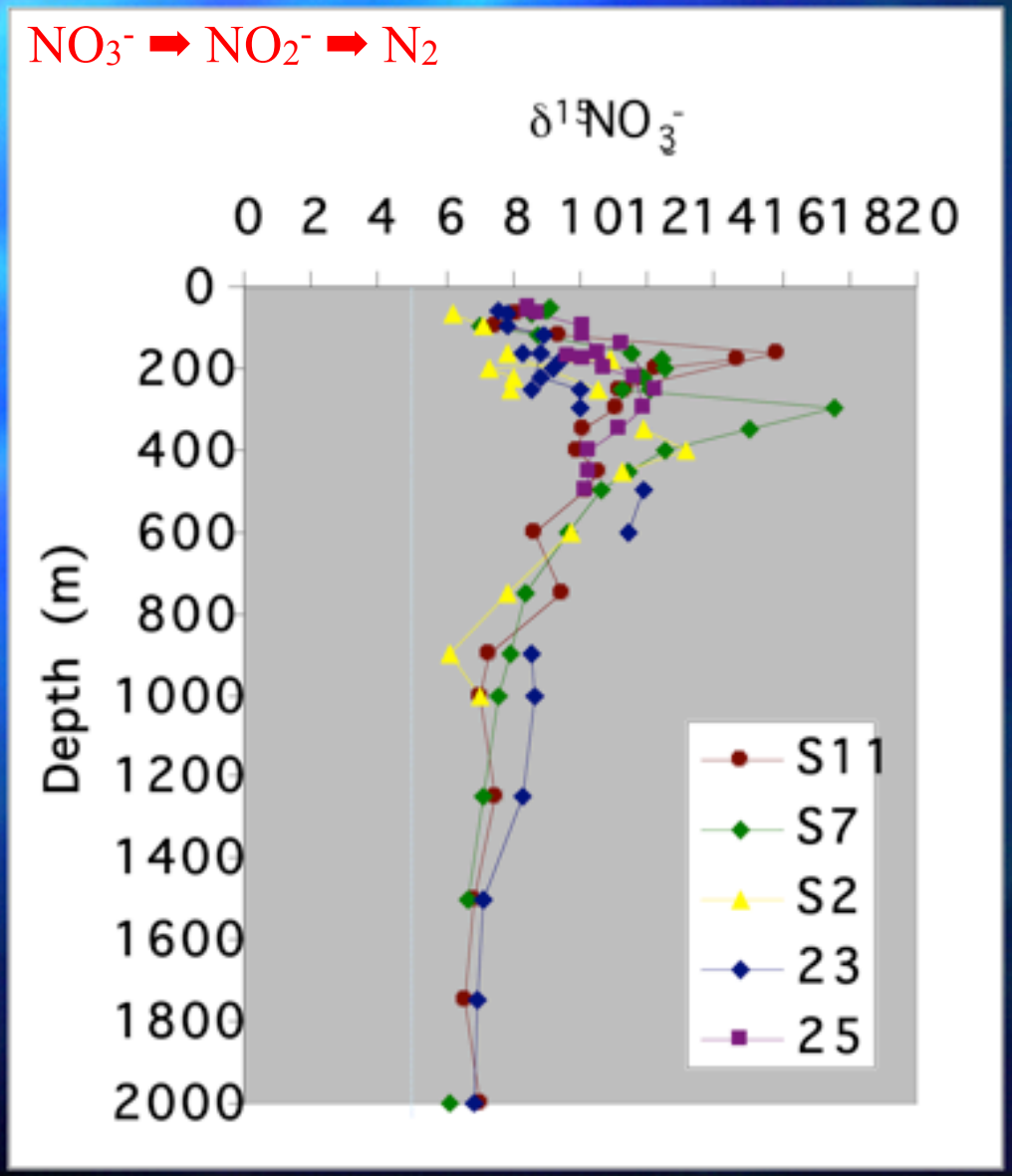
Last 1.5 Myr; denitrification (suboxia) variability strongly correlated with orbital-scale climate oscillation and transition from 40 kyr to 100 kyr dominance.

Obliquity signal (40 kyr) also consistent with polar forcing.

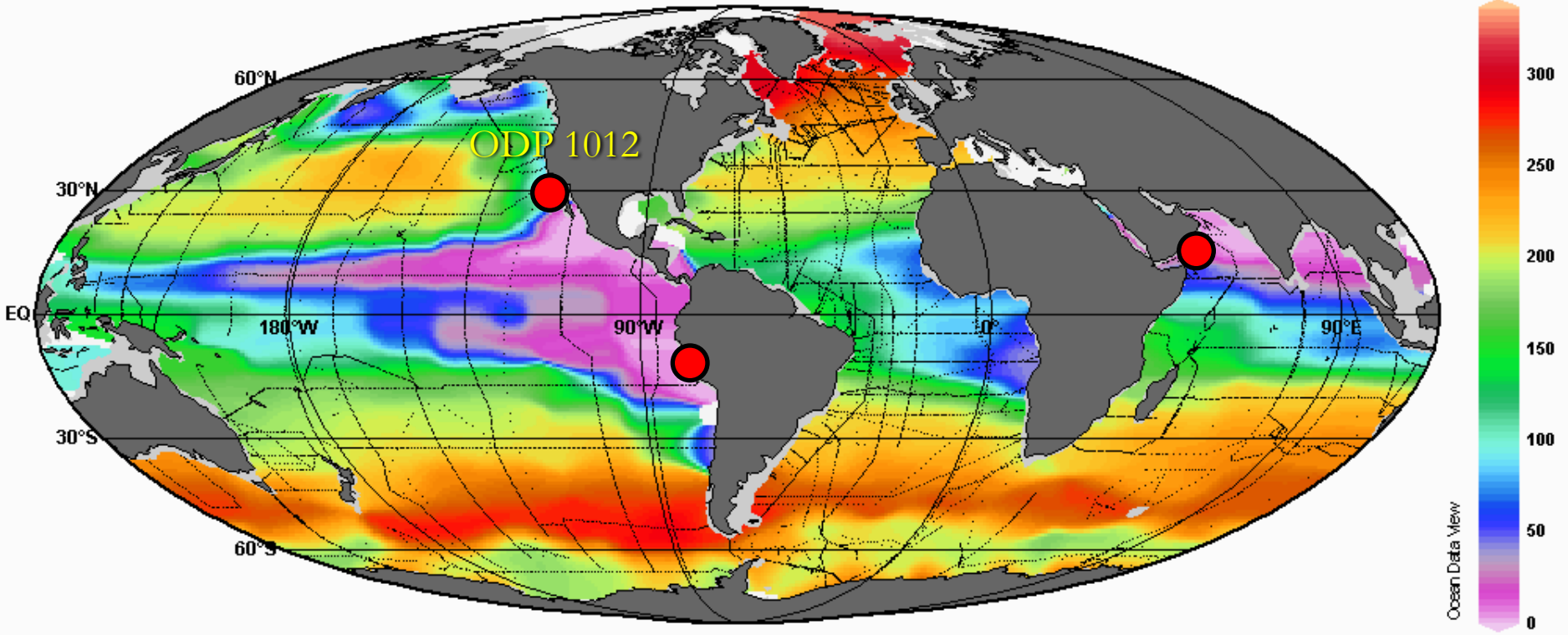


Denitrification N isotope fractionation

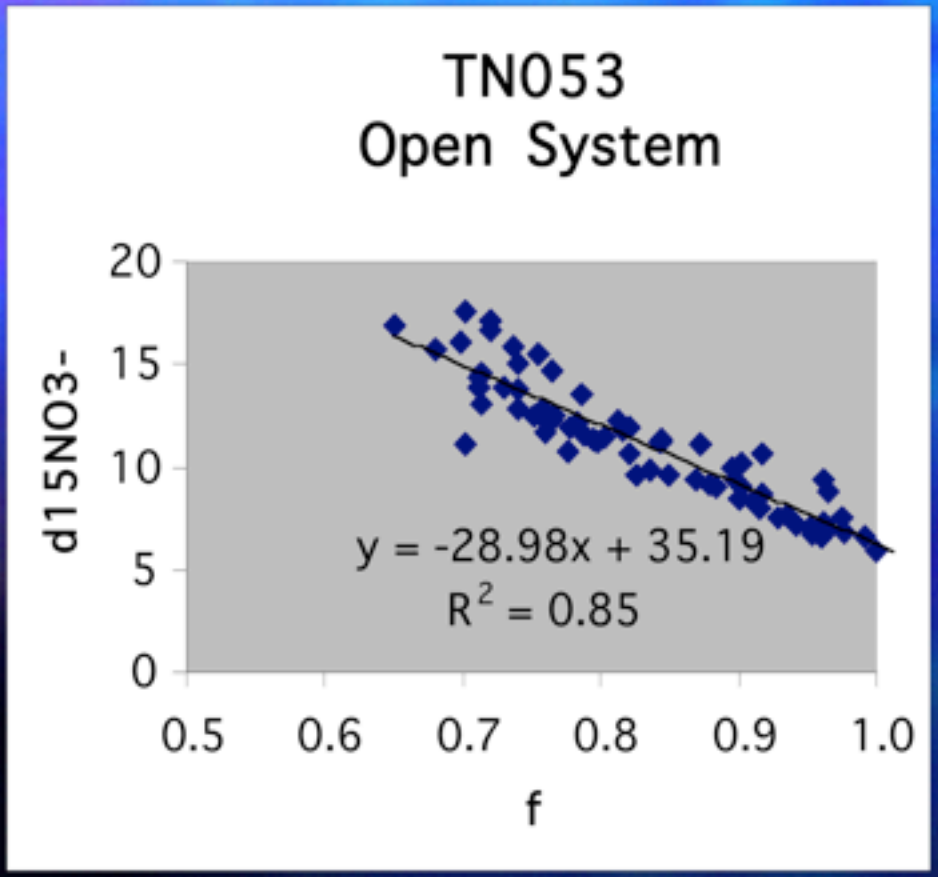
$NO_3^- \rightarrow NO_2^- \rightarrow N_2$

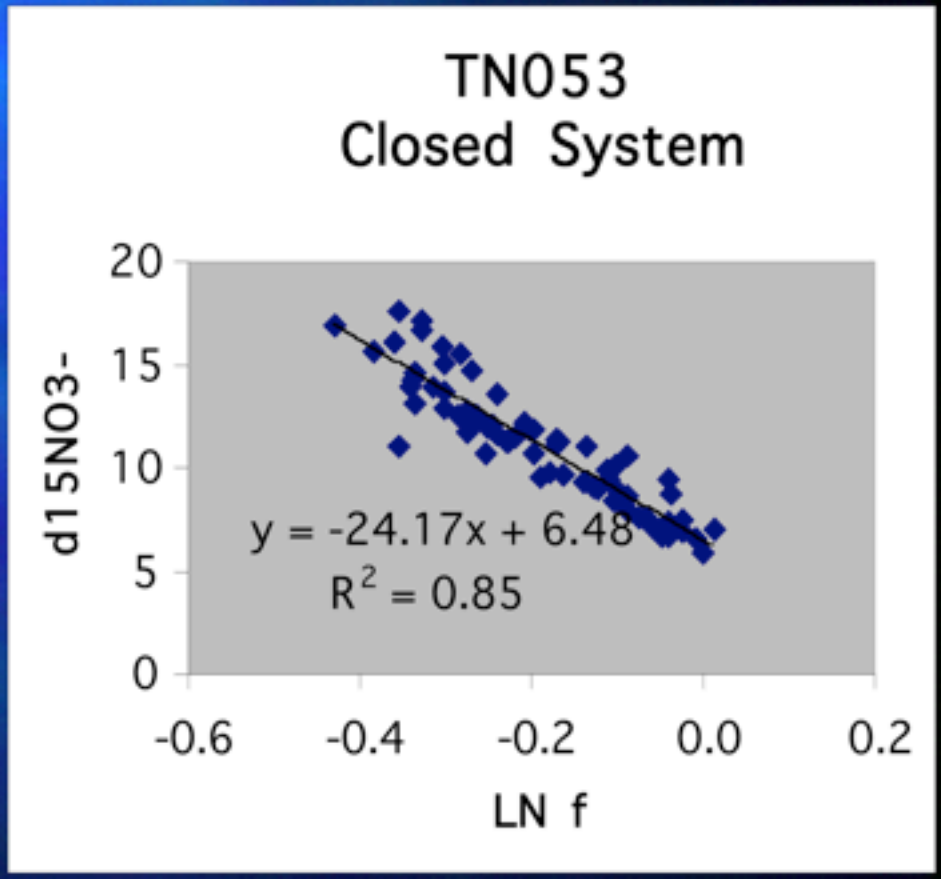


Locations of denitrification records



Consistent with Rayleigh Fractionation

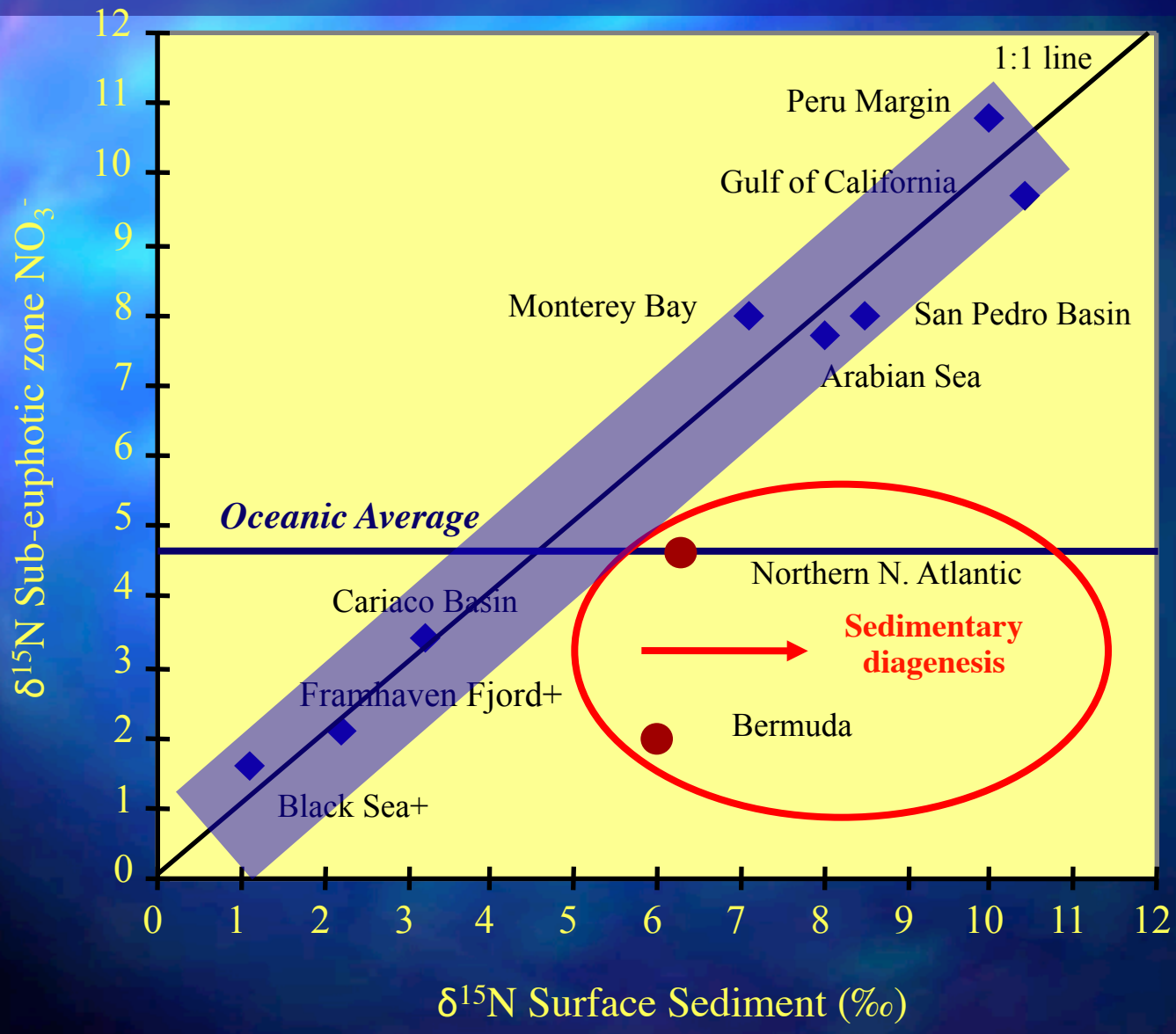




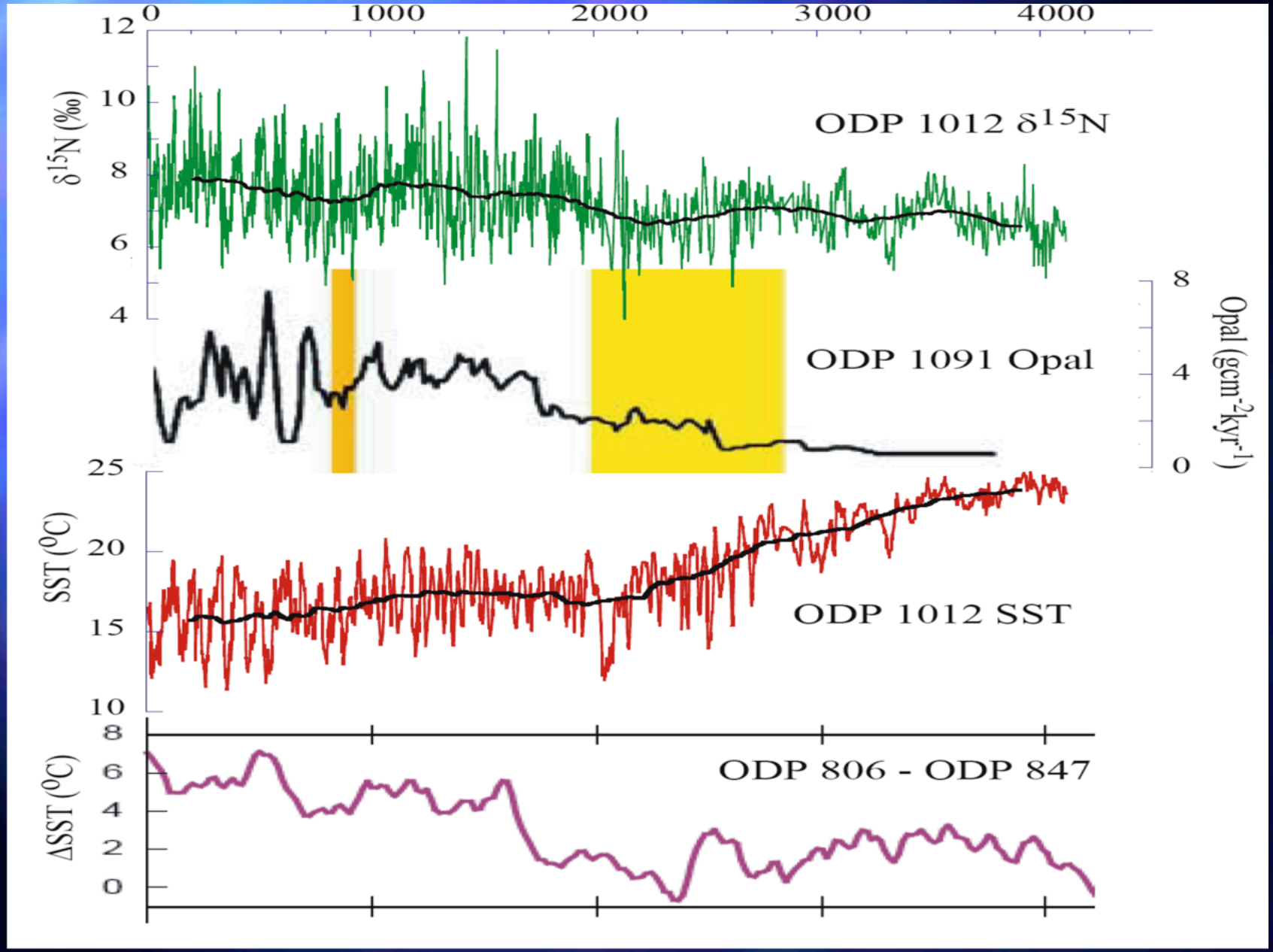
$\Delta\delta^{15}N = \varepsilon - \varepsilon \times f$

$\Delta\delta^{15}N = -\varepsilon \times \ln f$

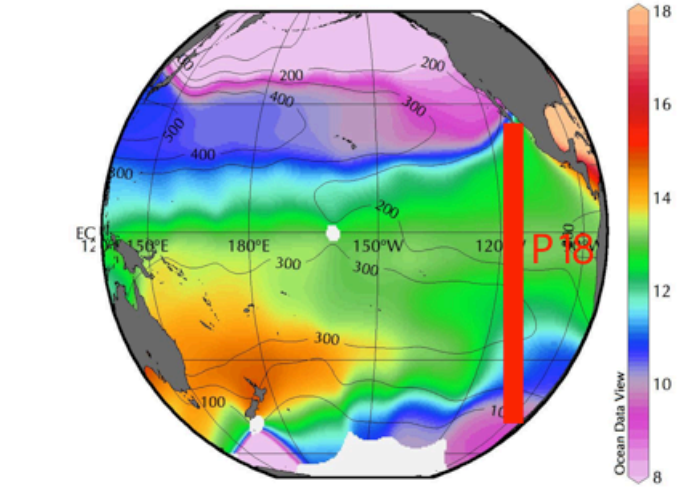
Preservation of $\delta^{15}N$ Signal in Marine Sediments

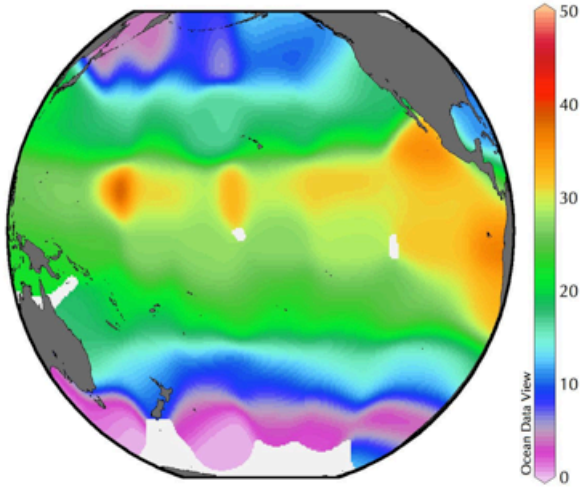


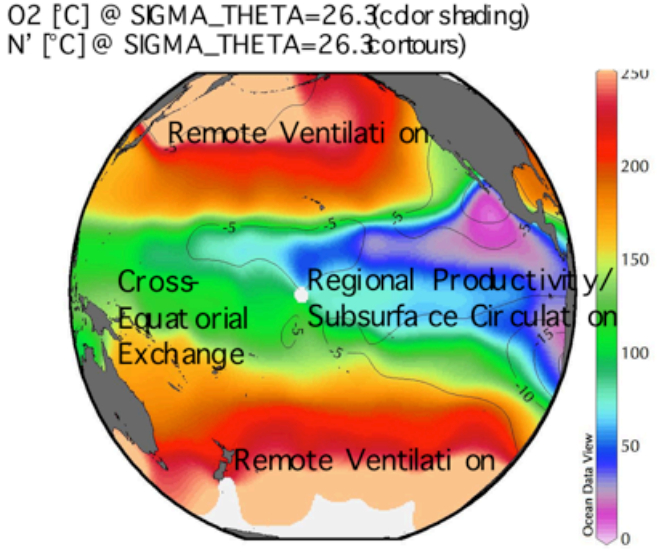
Connection between Antarctic opal be

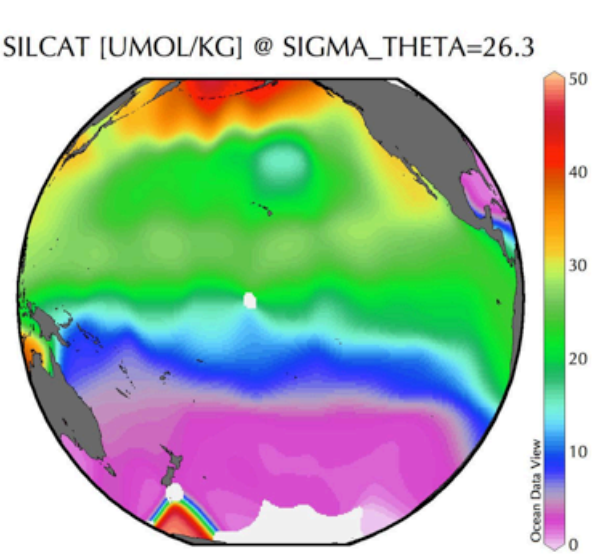


Hydrography of σ_θ = 26.5









Composite Denitrification Record

