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Workshop and Conference on Biogeochemical Impacts of Climate and Land-Use Changes on Marine Ecosystems

2 - 10 November 2009

Testing the P* Hypothesis (aka the "Deutsch Conjecture") in the Eastern Tropical South Pacific

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Testing the P Hypothesis (aka the "Deutsch Conjecture") in the Eastern Tropical South Pacific*

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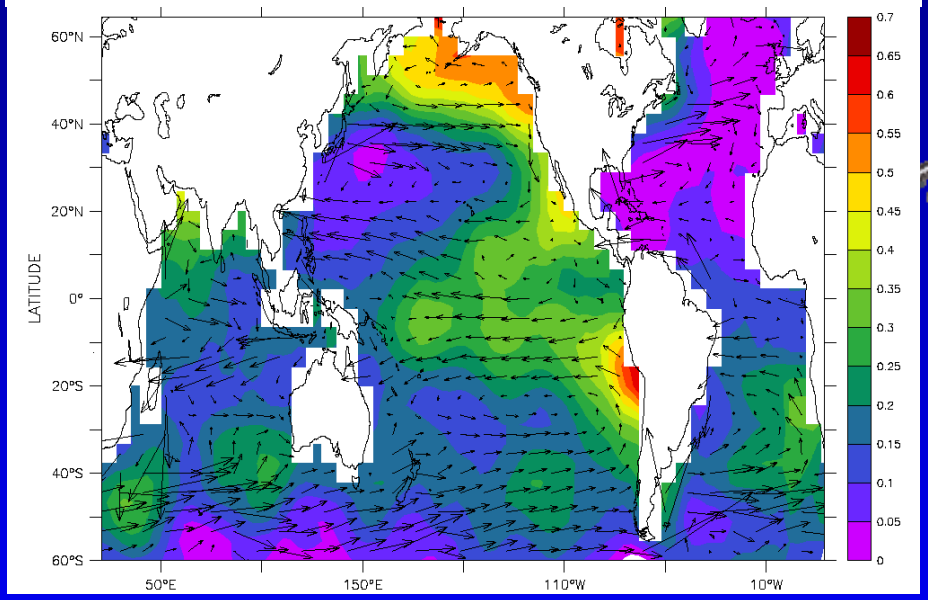
Vol 445|11 January 2007|doi:10.1038/nature05392 nature

ARTICLES

Spatial coupling of nitrogen inputs and losses in the ocean

Curtis Deutsch[1], Jorge L. Sarmiento[2], Daniel M. Sigman[3], Nicolas Gruber[4]† & John P. Dunne[5]



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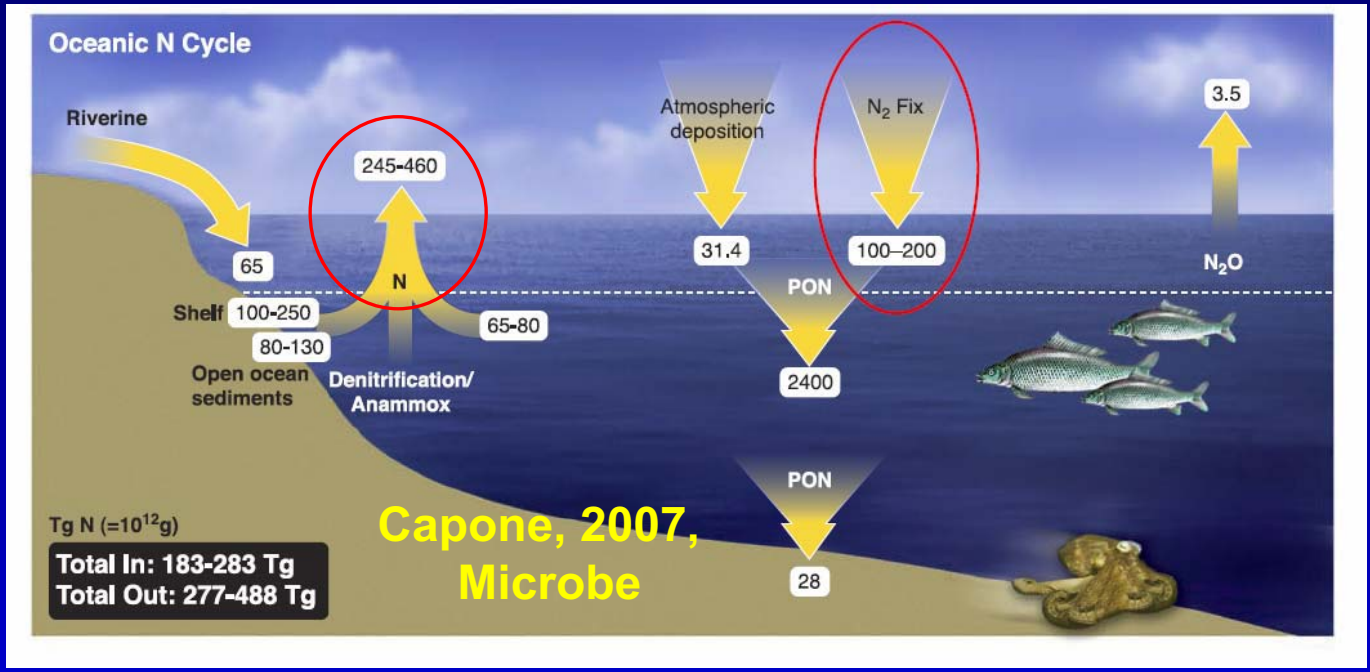
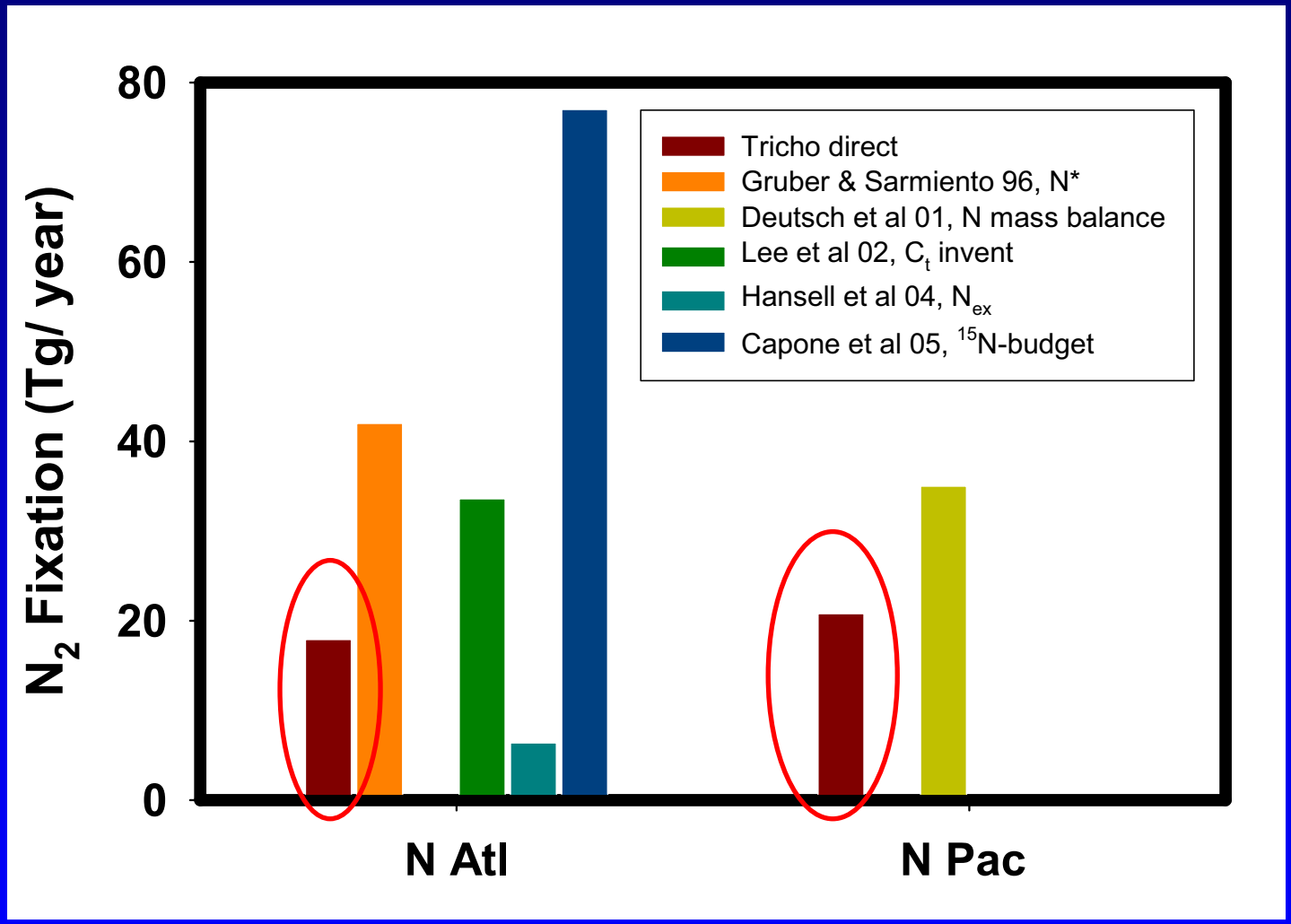
Several Current Conundrums in the Marine N Cycle



- *Is the cycle unbalanced? Denitrification is reported to exceed N_2 Fixation*
- *Sites of N_2 fixation and denitrification appear to be spatially uncoupled*

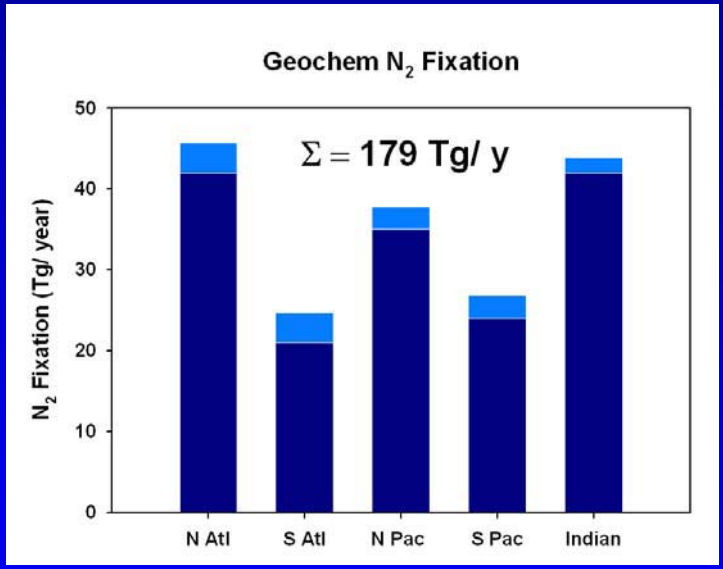
Trichodesmium scaled to waters ≥ 25° C, seasonally averaged – Galloway et al. 2004



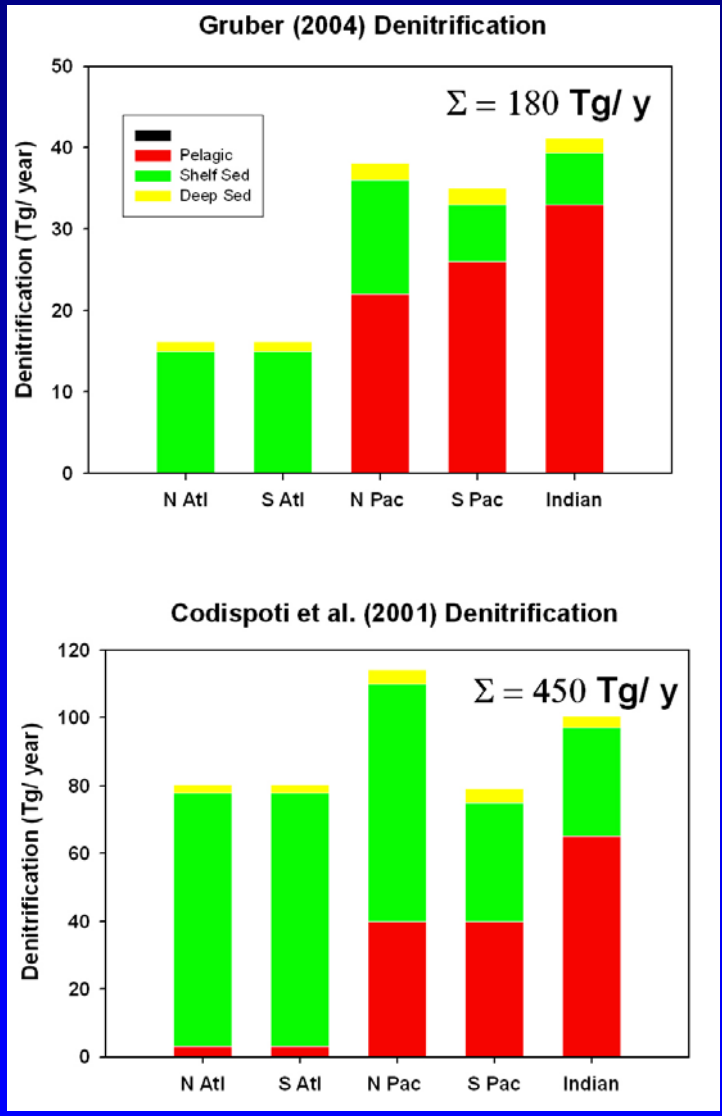
Trichodesmium **N_2 fixation can account for about ¼ to ½ the geochemically inferred flux - so not the whole story**

Does Denitrification exceed N_2 Fixation?

Balanced



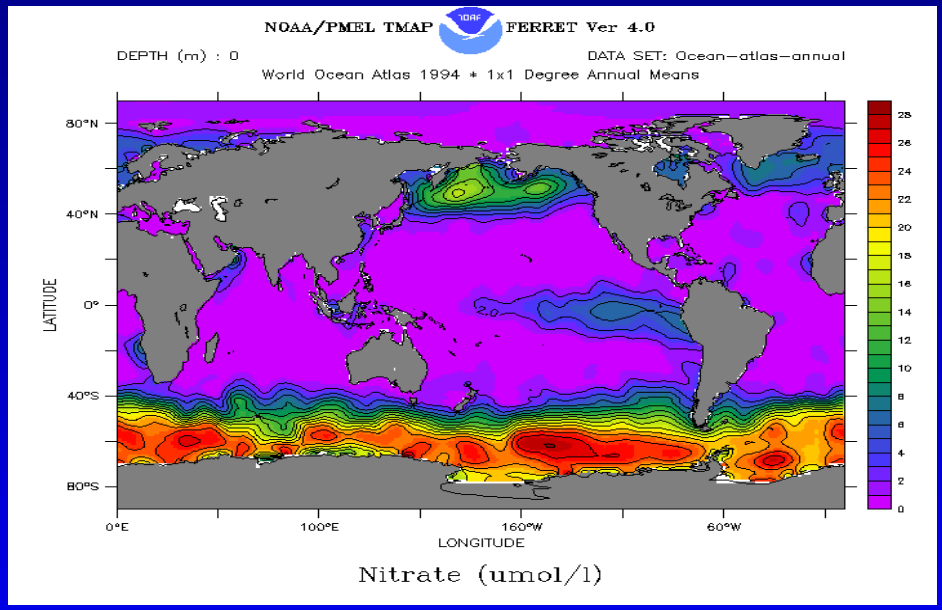
Out of Whack



Sites of N_2 fixation and Denitrification appear to be spatially uncoupled

Conventional View:

N_2 fixation largely occurs in oligotrophic upper ocean

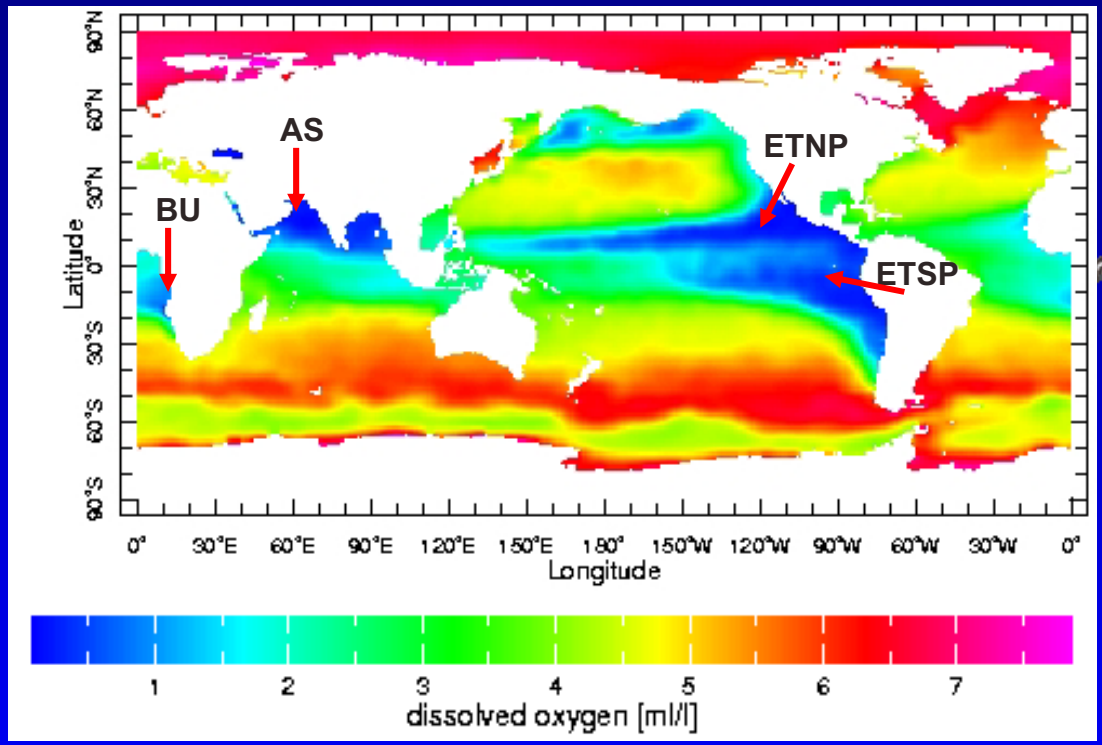


- warm, euphotic zone waters above nitracline
- typically < 60m depth assoc w/ cyanobacteria
- (spatial bias- tropical N. Atlantic, N Pacific gyre)

Denitrification and/ or Anammox

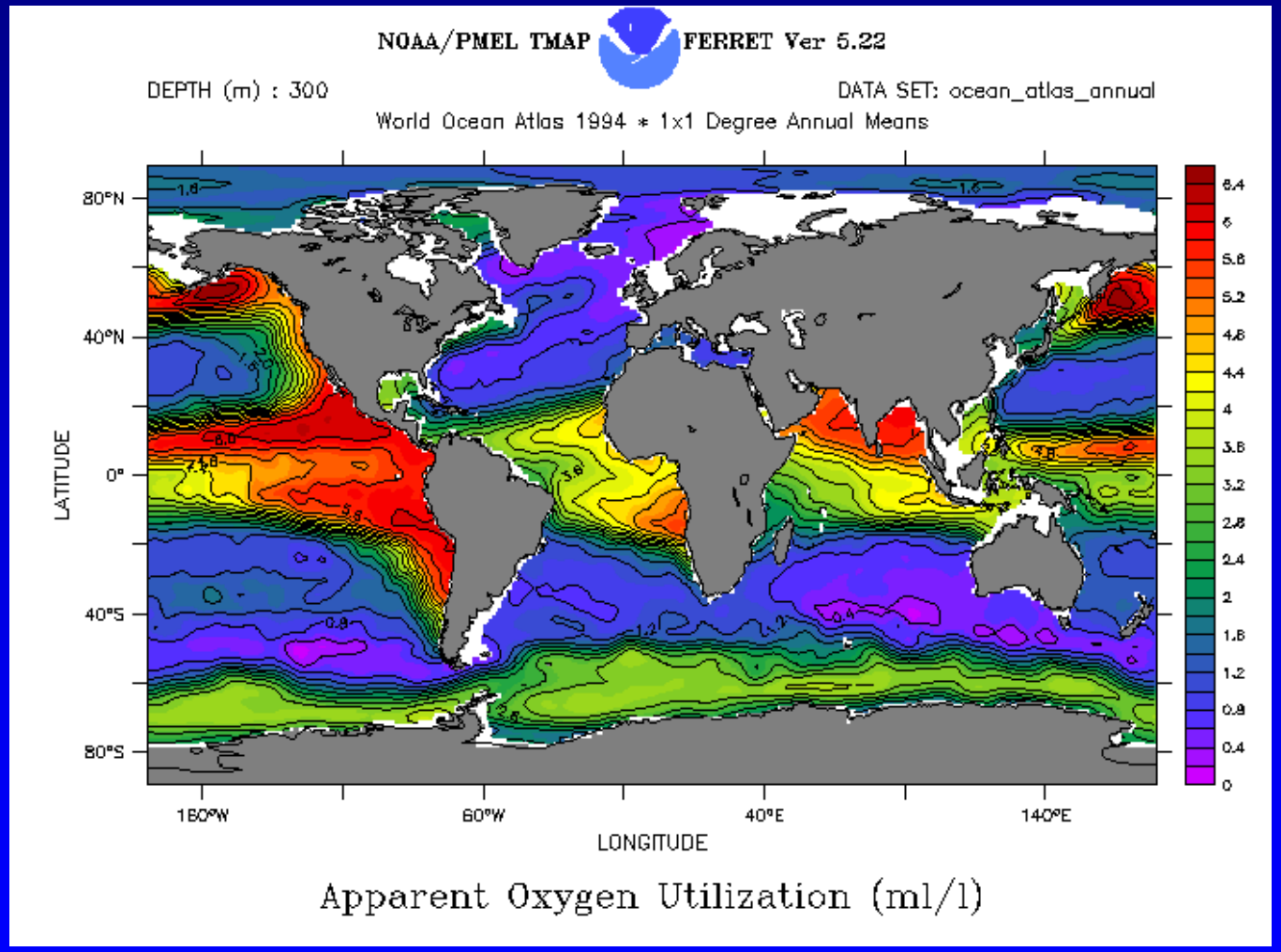
Largely occur in oxygen minimium zones (OMZs) typically 200-500m depth & in shelf sediment

Dissolved O_2



Footnote: Anammox (NO_2 + NH_4 -> N_2) predominant in OMZs (Kuypers et al. 2005)

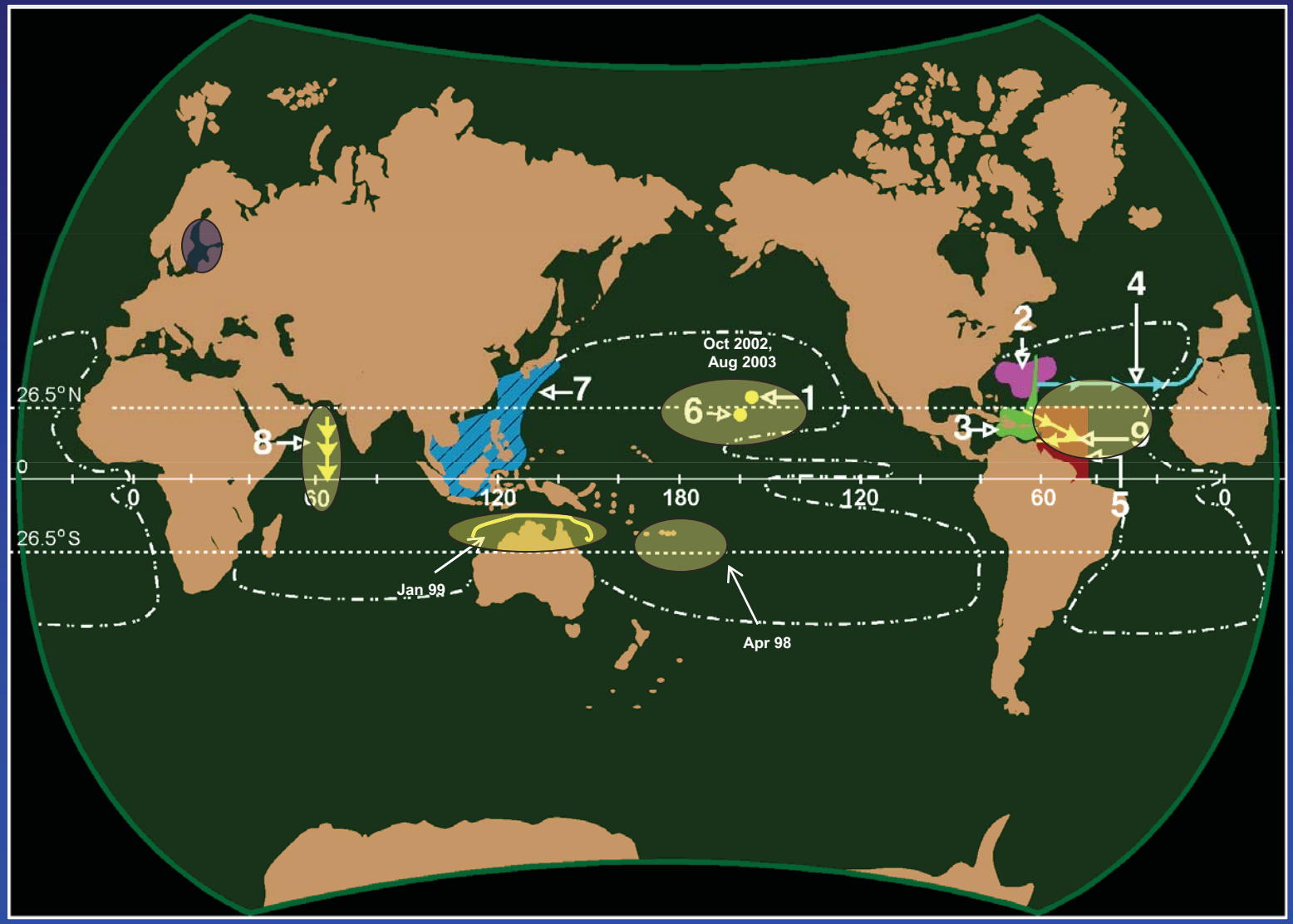
AOU Distributions



Possibilities

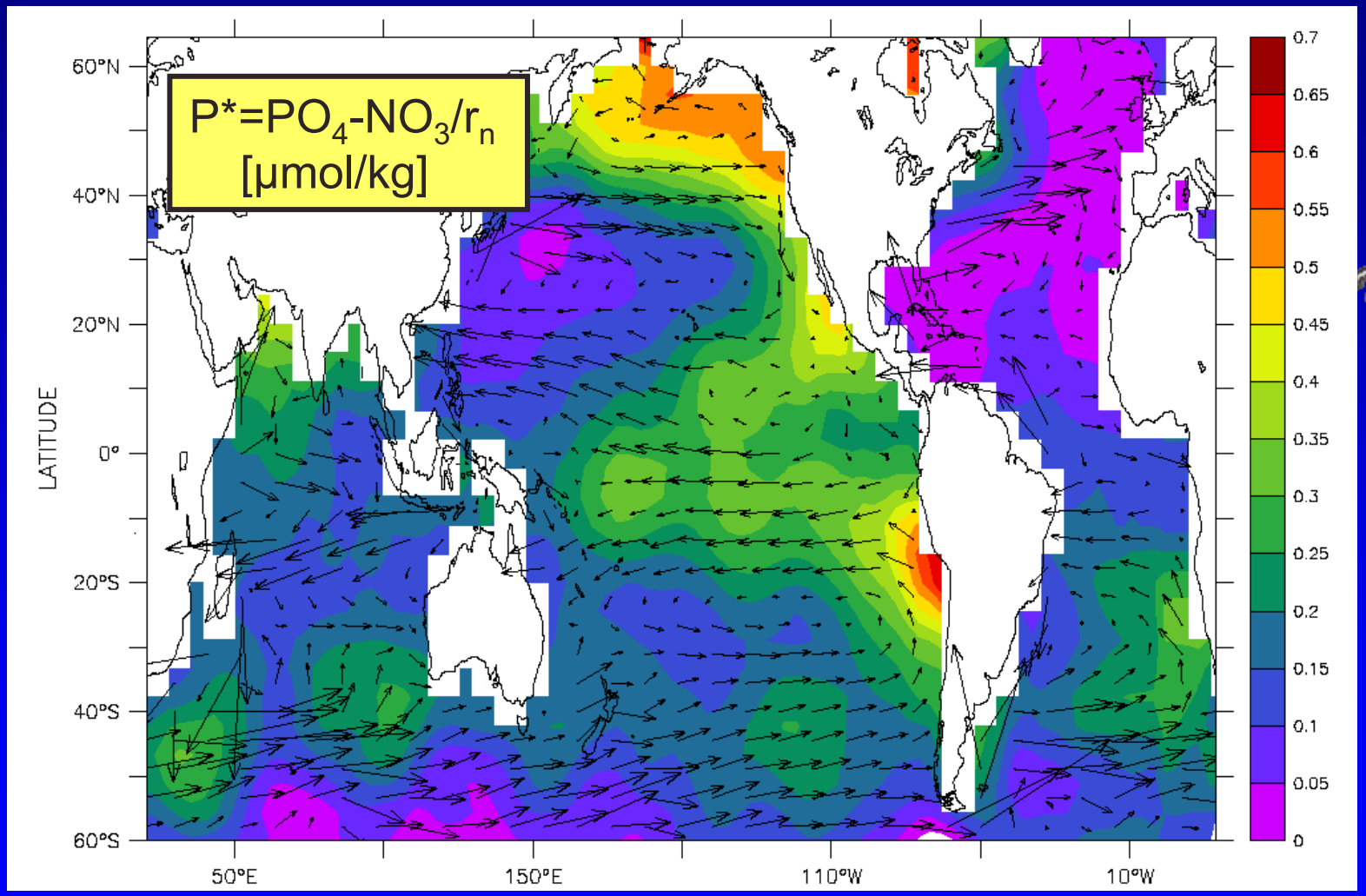
- ***Overestimation of removal:***
  - ***i.e. Denitrification (broadly defined)***
  - ***Anammox consumes "recycled" N- NO_3 consump in OMZs 50% of prior estimates- Lam et al. submitted***
- ***Underestimation of inputs***
  - ***Other sources in the upper euphotic zone***
    - ***e.g. pico/ nanoplankton***
  - ***In the deep sea below the euphotic zone?***
    - ***Holl & Montoya 2006- NO_3 effects***
  - ***Low levels at higher latitudes-***
    - ***Needoba et al. 2007, Holl et al. 2007***
- ***Coupling: The "Deutsch" solution***
  - ***Inputs proximal to removal (OMZs)?***
    - ***N fix can respond over shorter time scales to N:P variability***

What is the spatial distribution of N_2 fixation?
Field efforts- largely N. Atlantic



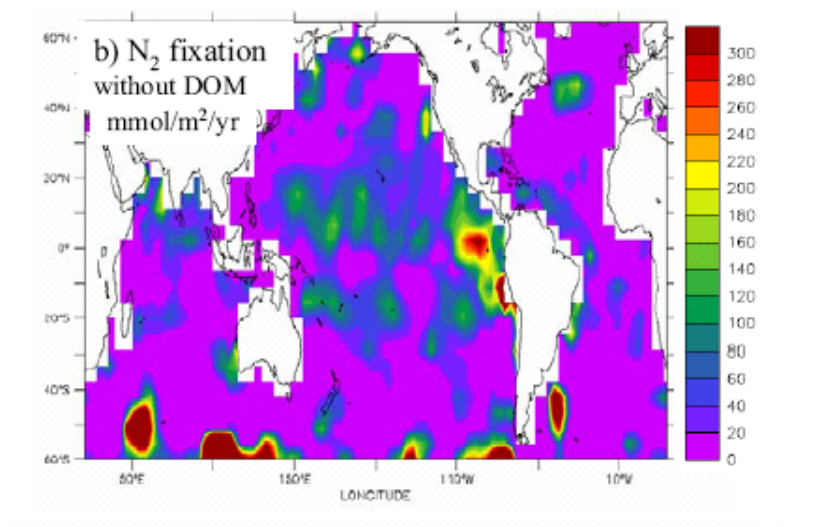
Climatological P* (0-100 m)

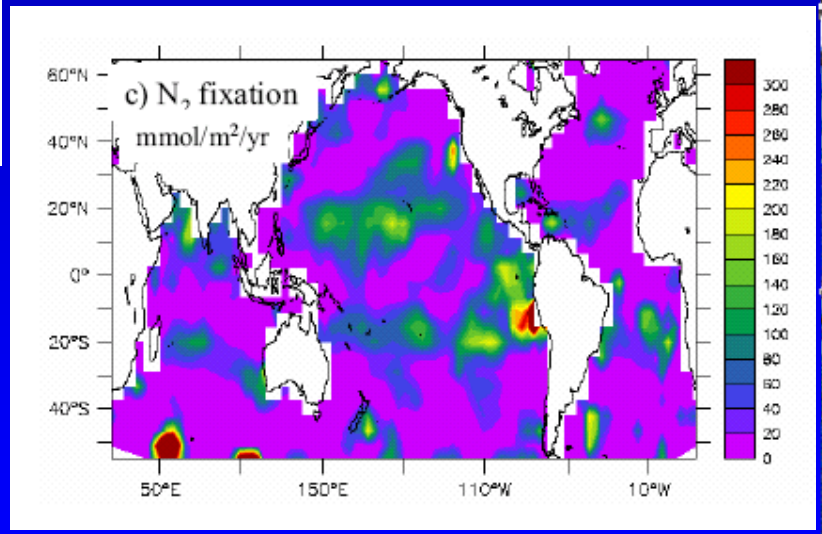
Deutsch et al., 2007, Nature World Ocean Atlas [2001] + GCM



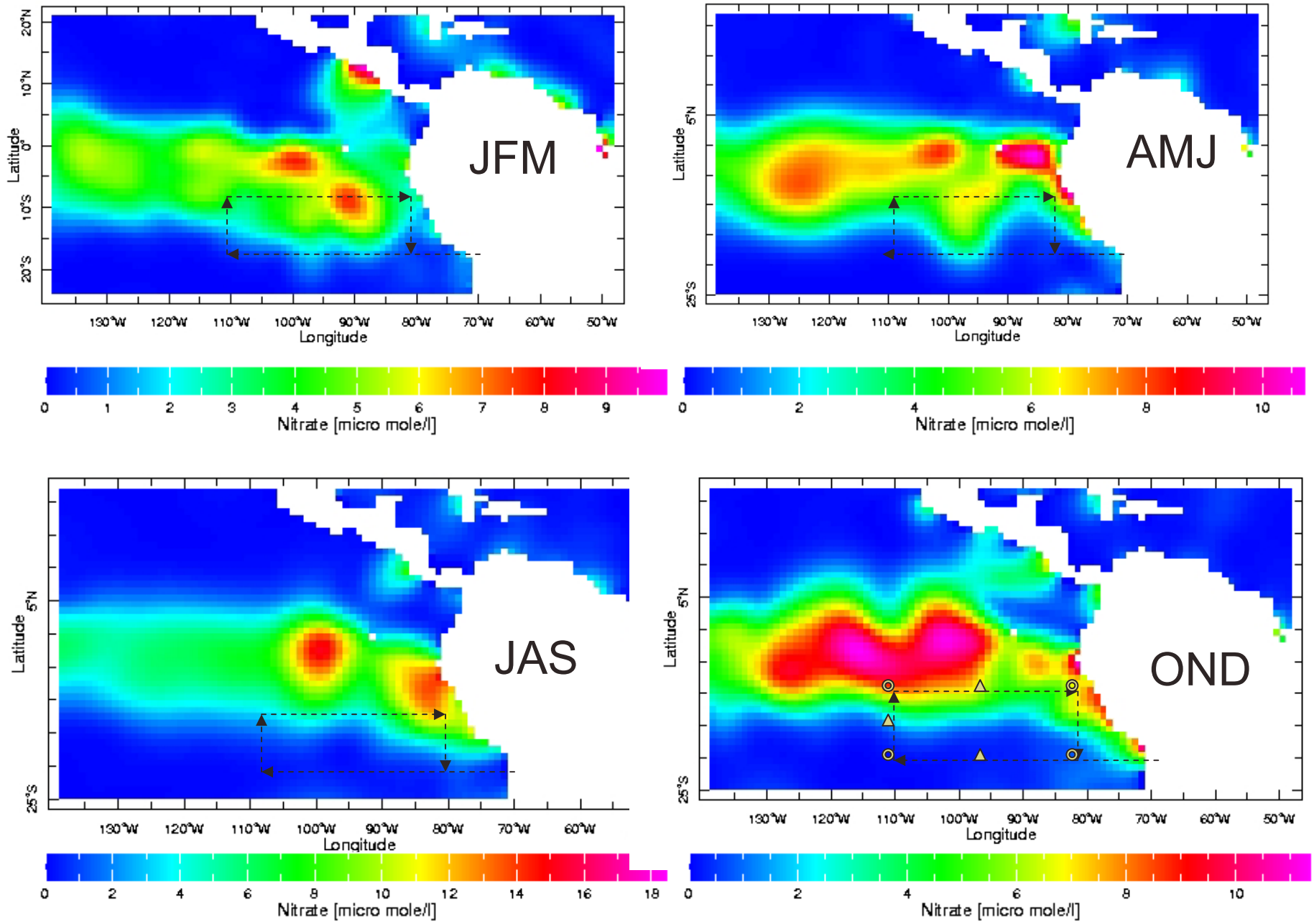
N_2 Fixation- 140 Tg y^{-1}, Pacific & sub-tropics

Deutsch et al., 2007, 140 Tg y^{-1}, Pacific & sub-tropics

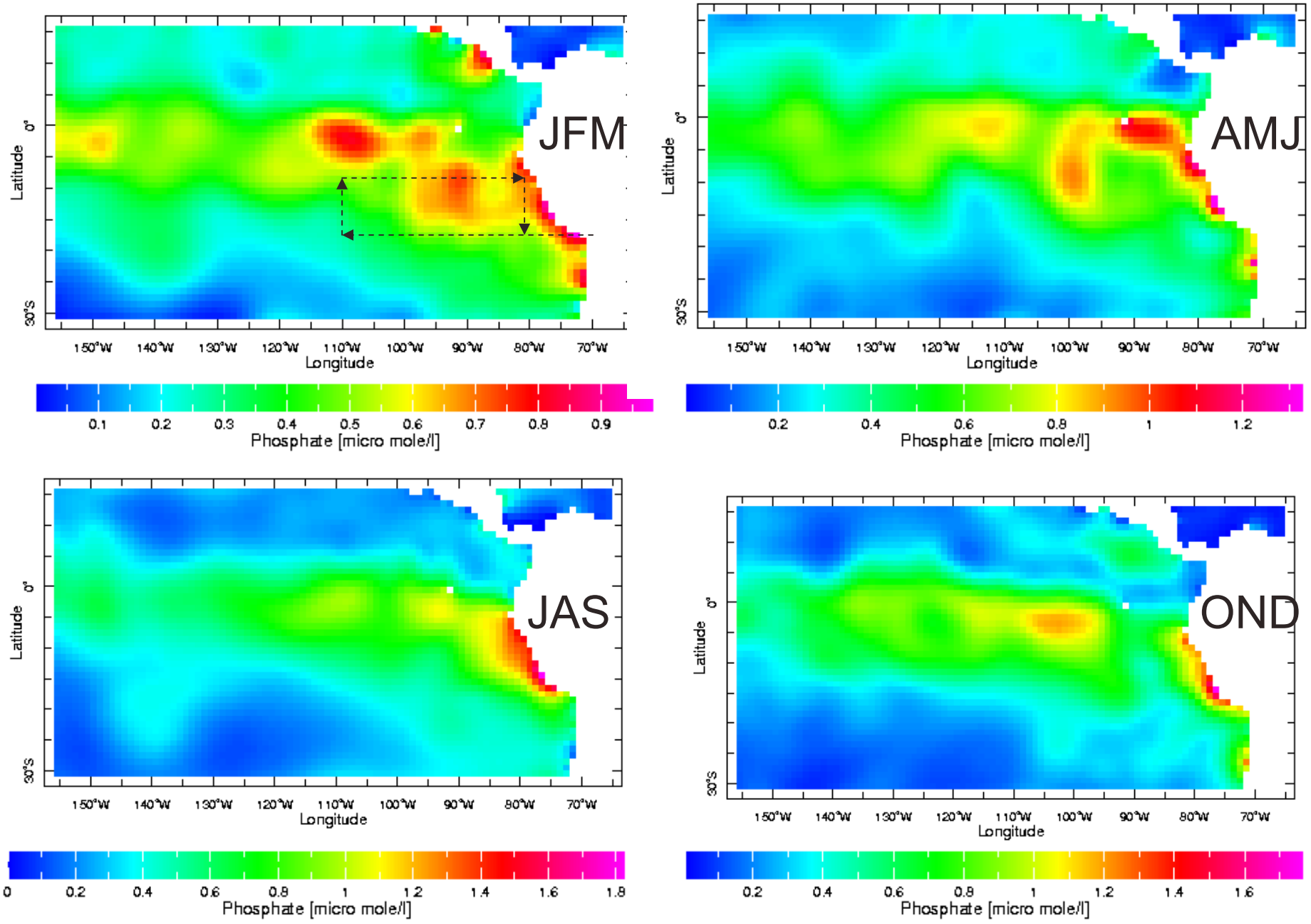


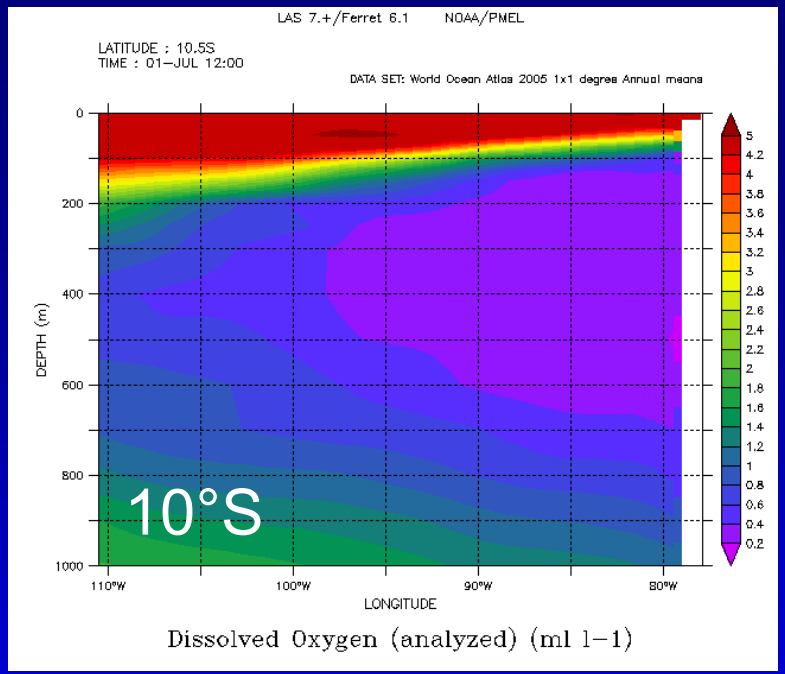


Surface nitrates

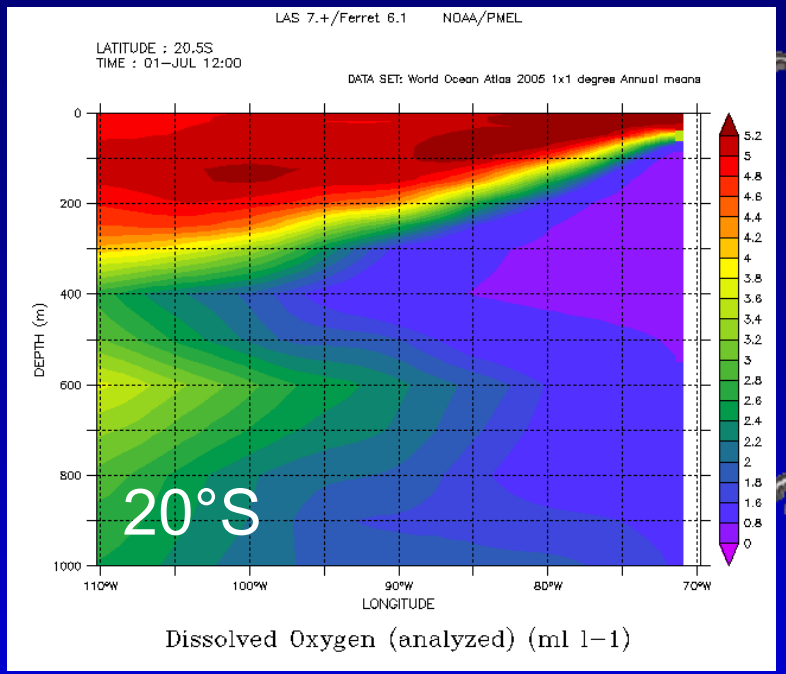


Surface phosphates

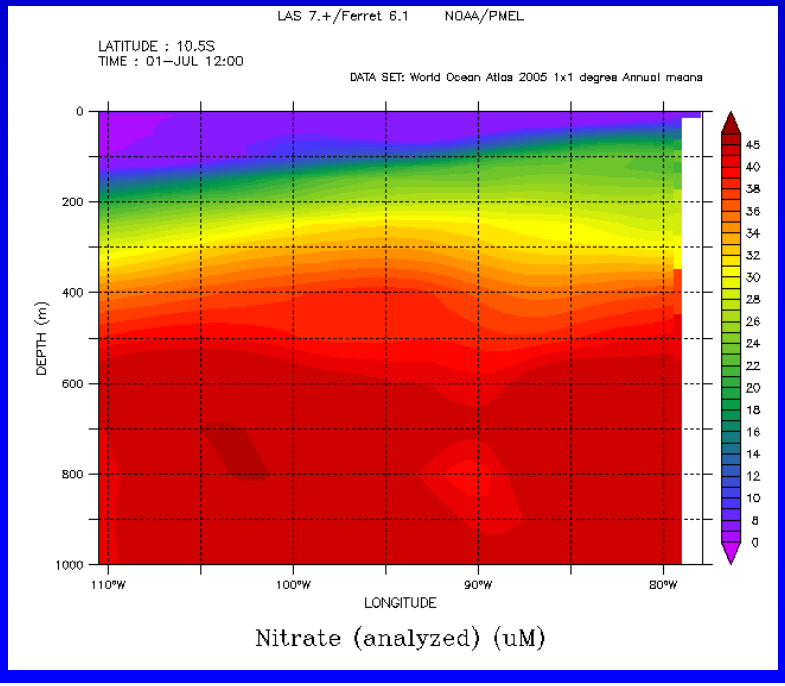




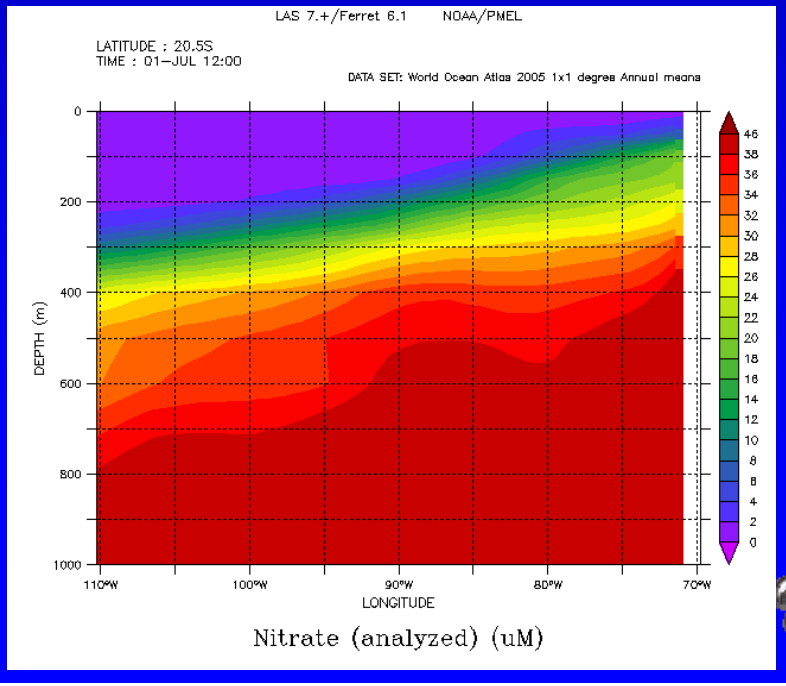
Dissolved Oxygen (analyzed) (ml l-1)



Dissolved Oxygen (analyzed) (ml l-1)



Nitrate (analyzed) (uM)



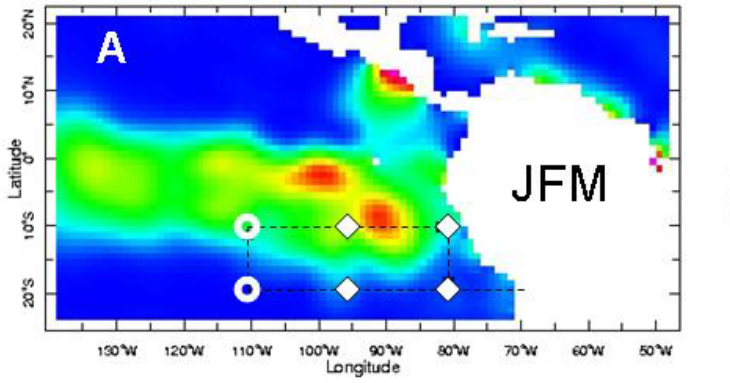
Nitrate (analyzed) (uM)

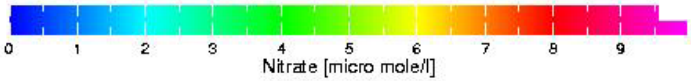
Planned Efforts

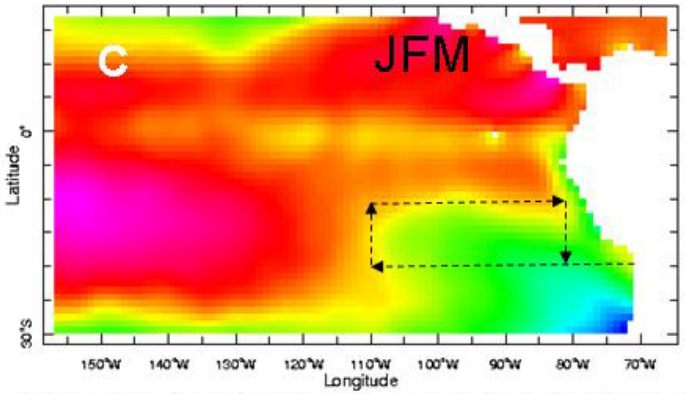
- *Capone (USC)- Assays/ quantification of N_2 Fixation*
- *Berelson (USC)- Sed flux and traps, Th, MIMS O_2/ Ar*
- *Moffett (USC)- trace metals/ redox chem*
- *Webb/ Sohm (USC) – cyanobacterial pop dynamics*
- *Sanudo-Wilhelmy (USC)- metal redox chem, B vitamins*
- *Knapp (U Miami)- N isotope mass balance*
- *Bonnet (IRD)- N fix limitation, mesocosm*
- *Casciotti (WHOI)- nitrification (AOB, AOA), N_2O*
- *Zehr (UCSC)/ Hewson (Cornell)- Molecular ecol of N Fix*
- *Kuypers (MPIMM)/ Hamersley (Soka U)- Anammox & denitrification*
- *Behrenfeld (OSU)- FRRF, Optics*

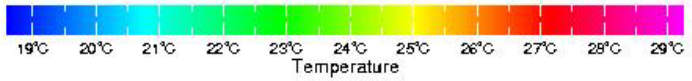
"… many Chiefs, no Indians".
A Subramaniam
circa mid 1990s

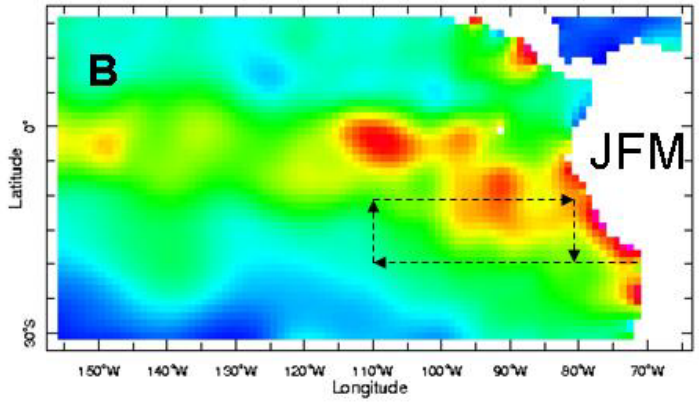
Testing the Hypothesis

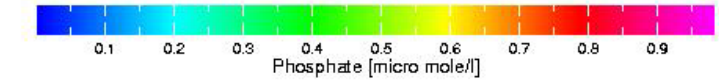


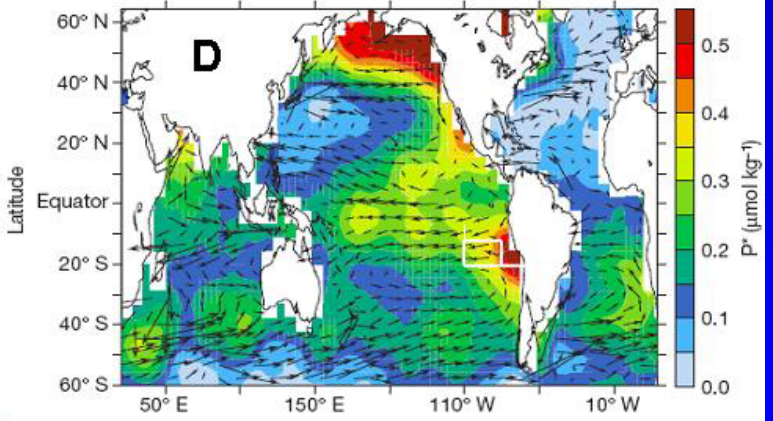








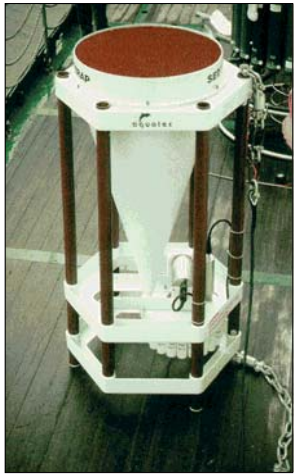


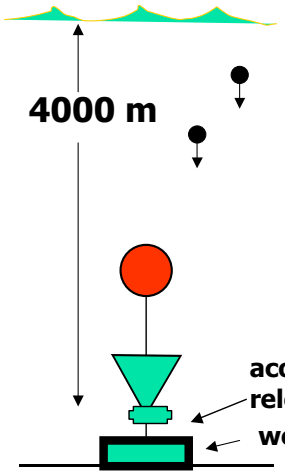


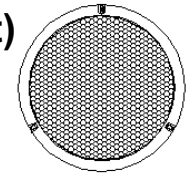
Iquique to Iquique, 28 Jan - 3 Mar 2010

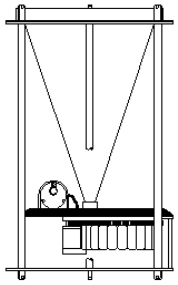
Sediment traps:
Big fancy funnels!

catch falling particles (export)

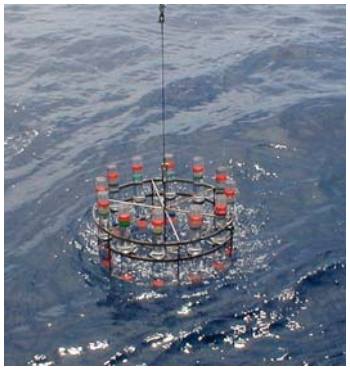


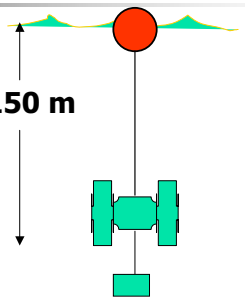






Free-floating traps





Just below zone of primary production (euphotic zone)

Recap

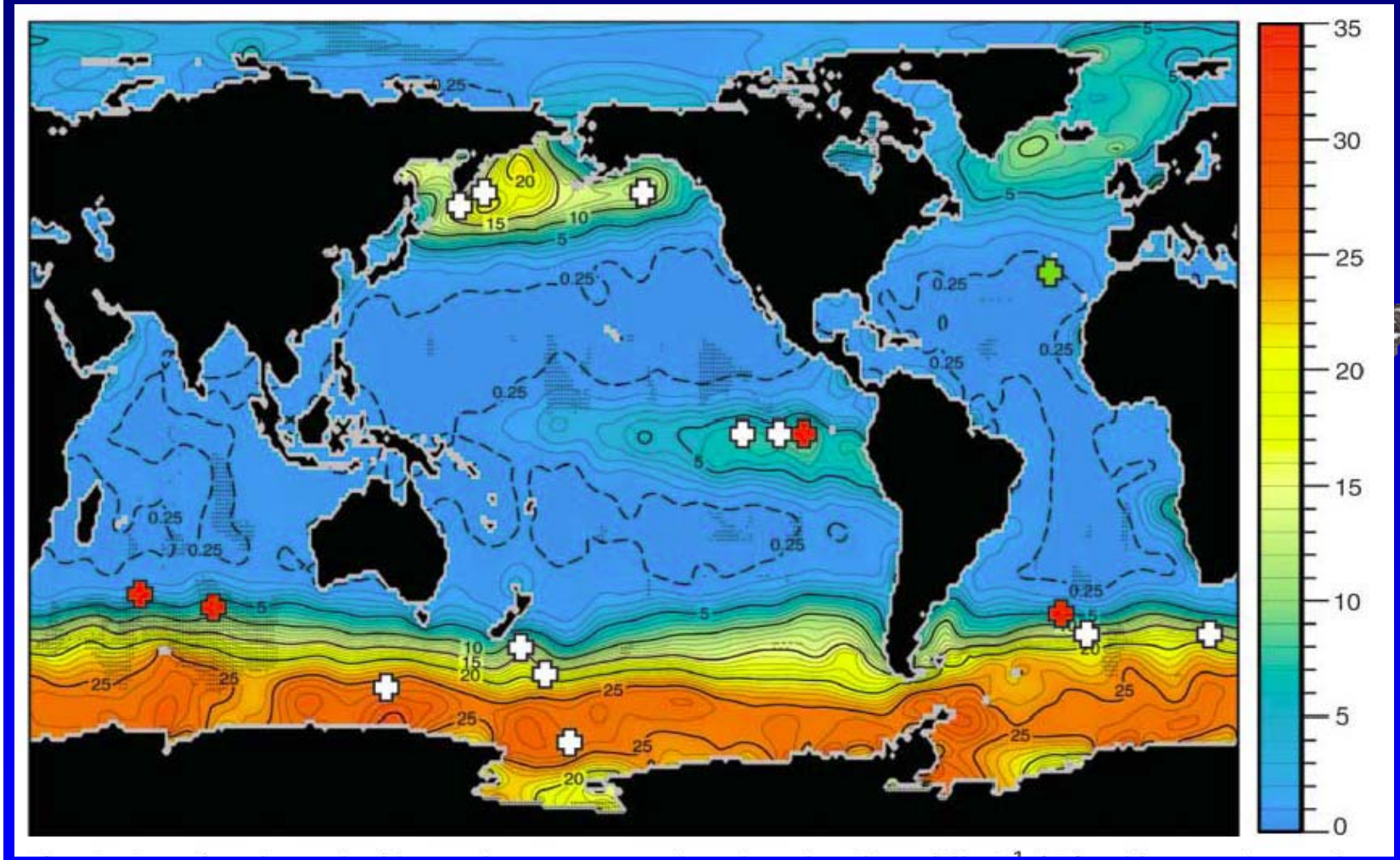
- ***Is the Marine N Cycle balanced?***
  - ***Open question***
- ***How closely coupled are denitrification and N_2 fixation?***
  - ***Perhaps much more closely coupled than previously thought***


The End
(for now…..)

Conundrum Status

- *Several Independent lines of evidence suggest N_2 fixation is occurring at significant rates in waters affected by N loss processes*
  - several independent geochem estimates
  - biological assays
  - nif genes
  - remote sensing
- *Solution to coupling of N Fix and NO_3 consumption w/ OMZs*
  - *More field data needed to verify*
- *Potential areas for Fe fertilization/ C sequestration*
- *New conundrum- what N* and P* tell us about the distribution of N_2 Fixation in the Ocean*

Footnote 1: LNLC Fertilization for C Sequestration?



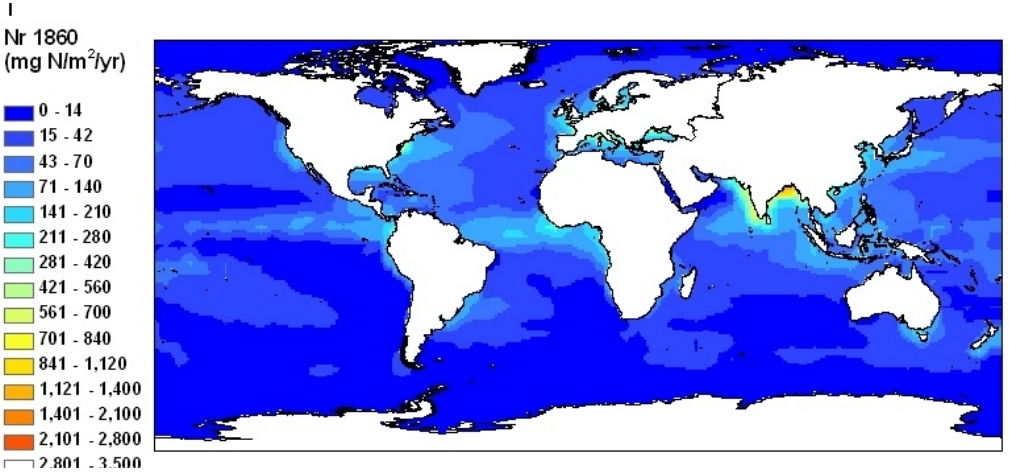
Boyd et al. Science 2007

Footnote 2

Year	Total	AAN
	Tg N yr^{-1}	
1860	20	5.7
2000	67	54
2030	77	62

Duce et al. Science 2008

i



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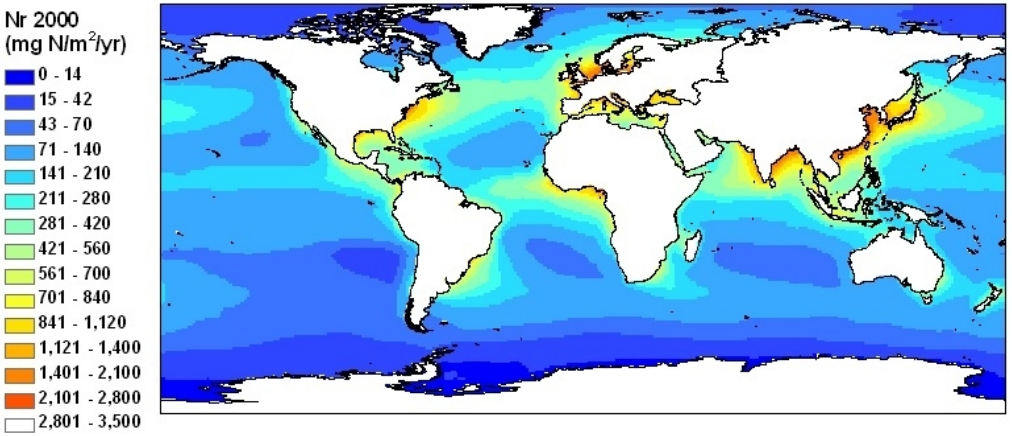
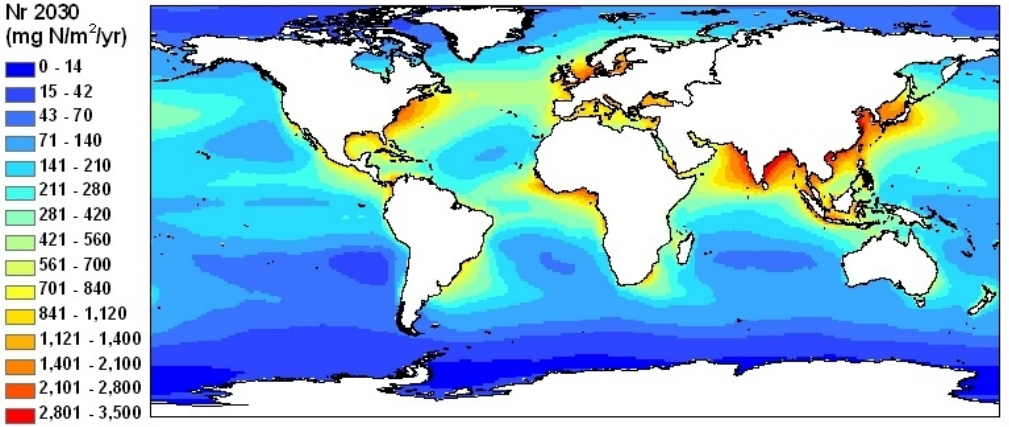




Acknowledgements


Ed Carpenter


Ajit Subramaniam


Joe Montoya


Raleigh Hood

Ron Siefert


Tony Michaels

Students, postdocs and assistants: the folks that make things happen!

My colleagues


Jed Fuhrman

Victoria Coles

Sergio Sanudo-Wilhelmy


Claire Mahaffey


Juliette Finzi

Robert Hamersley

Angie Knapp


Rebecca Shipe


Jay Burns

Jill Sohm


Ian Hewson


Sophie Bonnet


Troy Gunderson

N* Anomalies:

Redfield C:N:P: 106:16:1

N* = [N] –16[P]

+N* = N regen in excess of Redfield

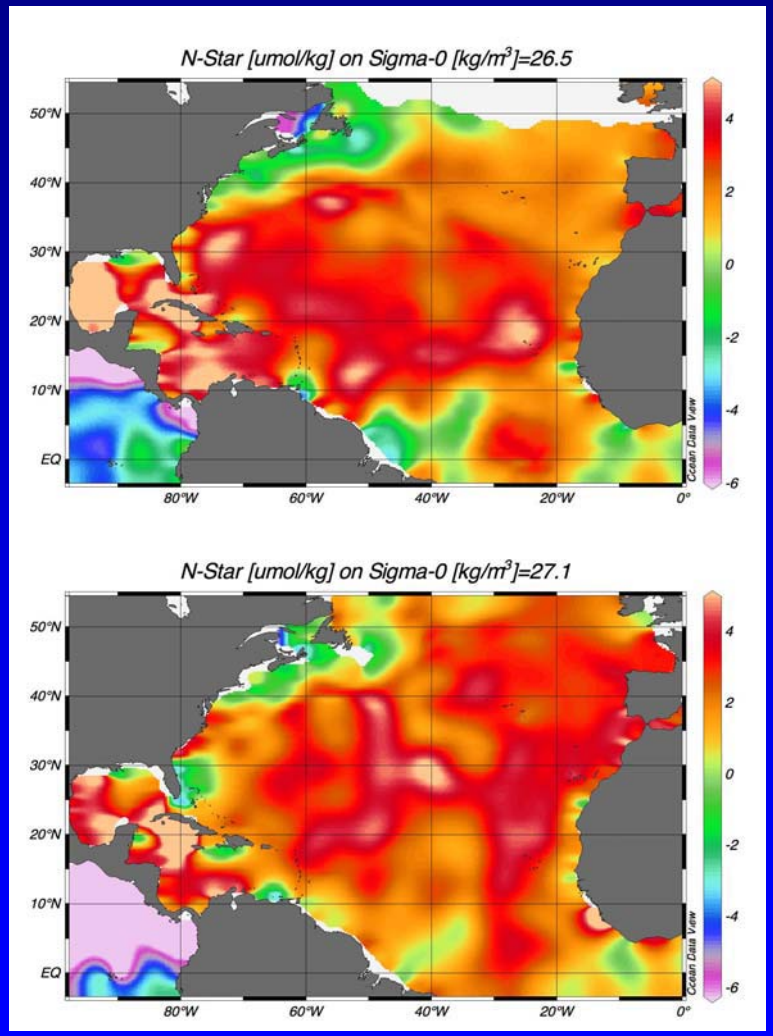
(Diazotroph biomass N:P > 16)

-N* = preferential N loss

(e.g. due to denitrification)

Gruber et al. 1997

•c.f. Hansell et al.



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