Nitrogen Fixation and Carbon Sequestration

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Outline

- Carbon Storage in the Sea - Mechanisms
- Nitrogen Fixation
- Verification Issues
- Academic Conflicts of Interest

Disclosure of Relevant Commercial Associations

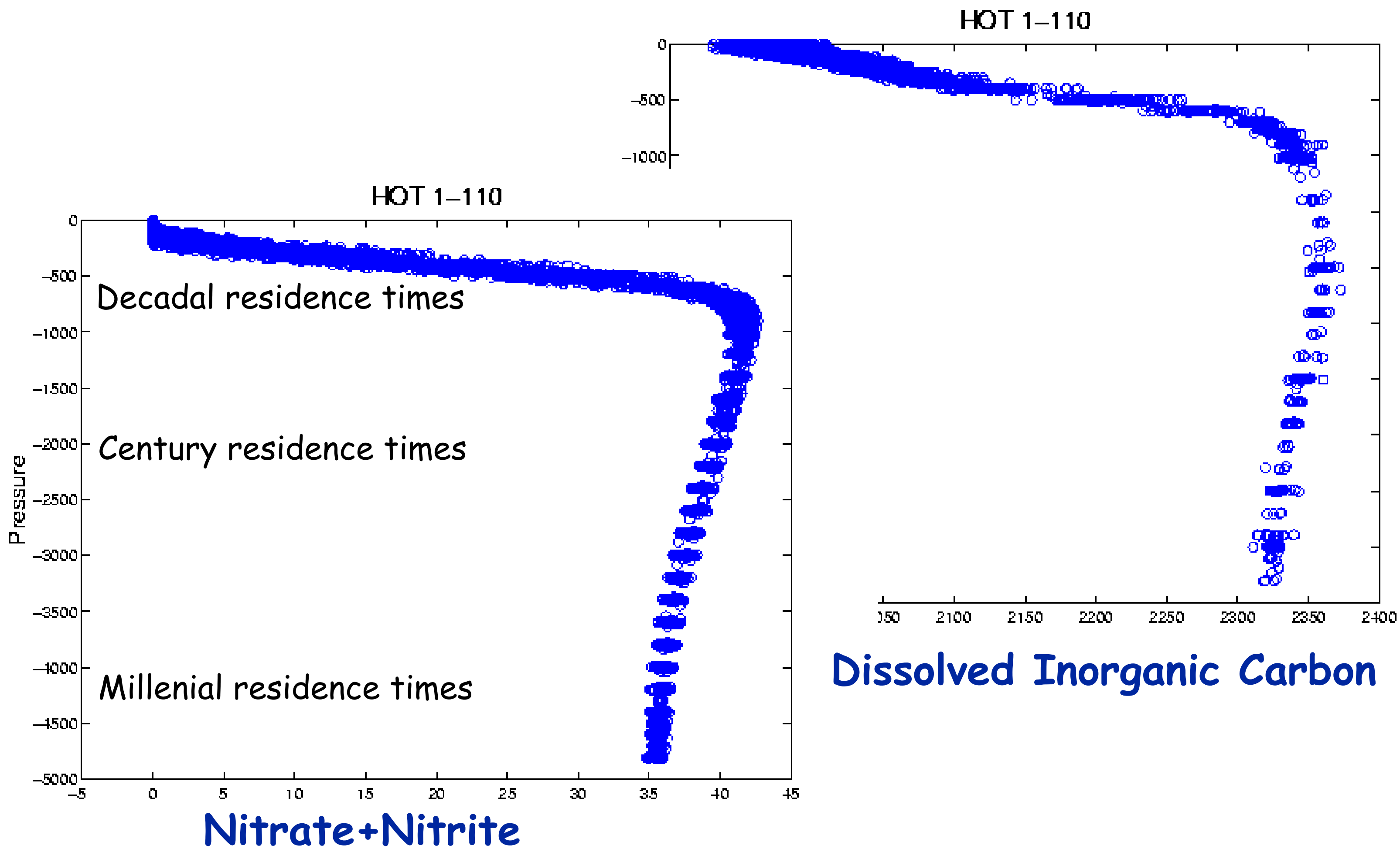
- Planktos (conversations only, pre-2001)
- Climos (discussions 2006-Present, no contract relationship at present)
- Proteus Environmental Research.LLC (R&D Incubator and Venture Fund, have personal equity and significant management roles)

Carbon Storage in the Sea - Biogeochemical Mechanisms

- Relative use of surface macronutrients
  - Residual Nitrate (HNLC)
  - Residual Phosphate in the absence of NO_3
- Changes in C:N:P of export
- Changes in remineralization length-scale
- Changes in PIC rain rate ratios with POC

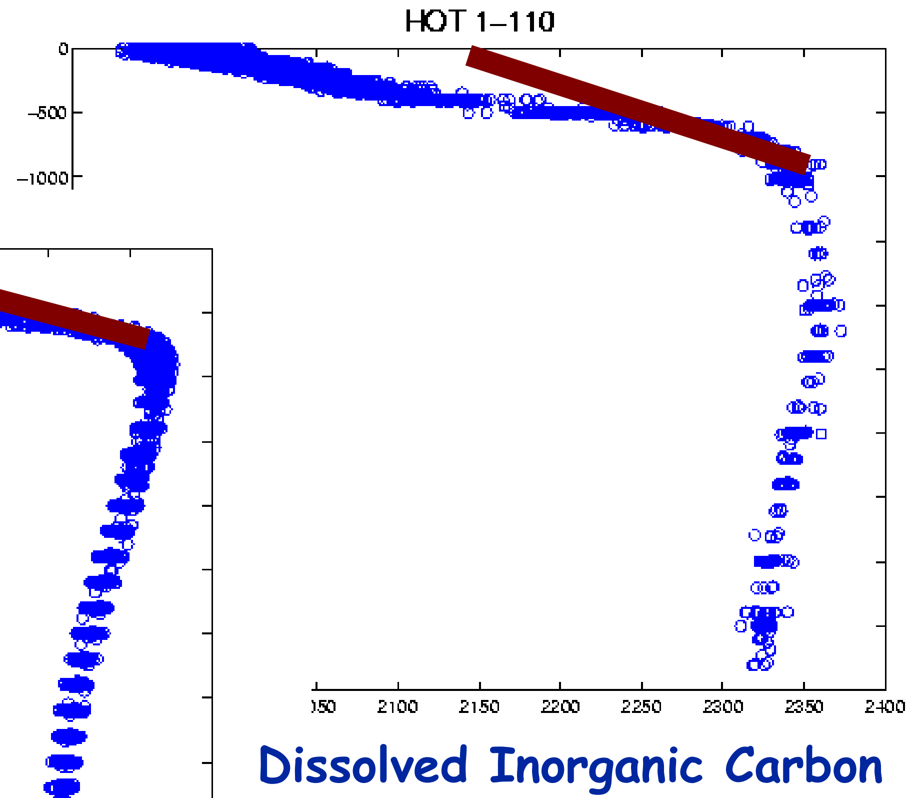
All of these are Time-Shifting

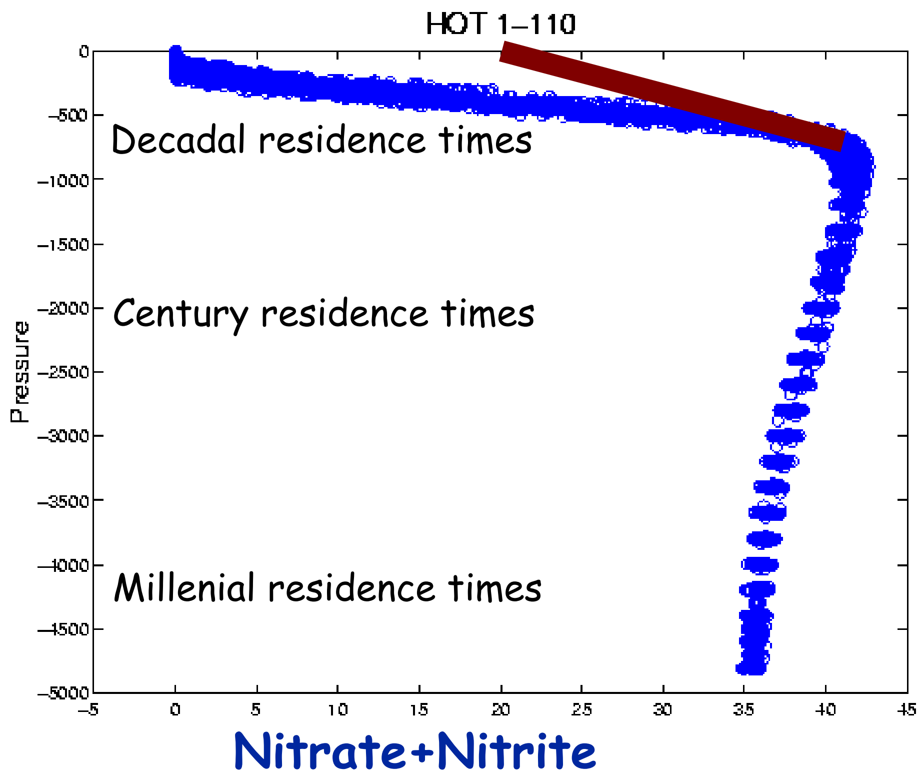
Ocean biology maintains a vertical DIC gradient - ocean biology is limited by the supply of nutrients:



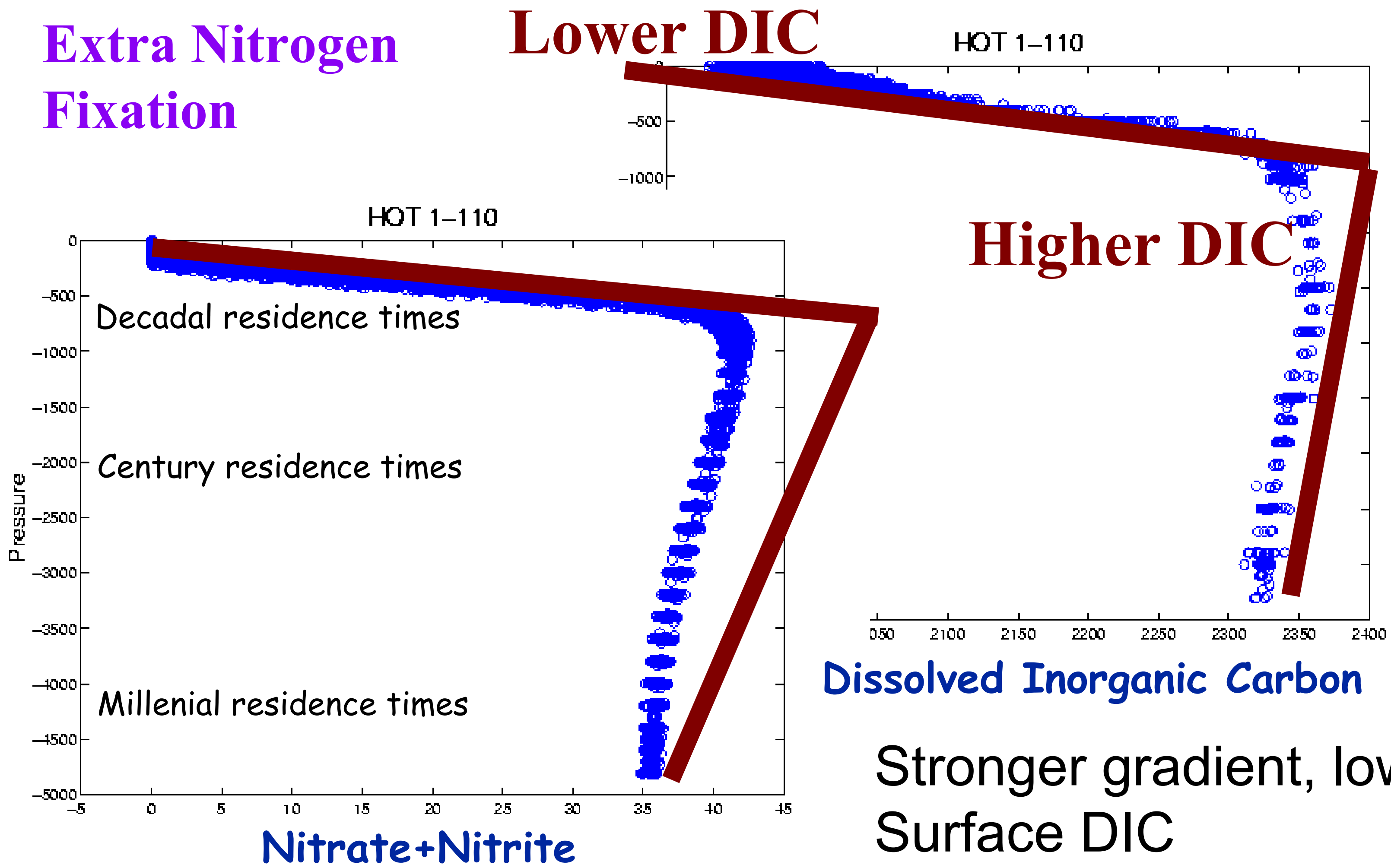
Incomplete Nutrient Utilization in the Surface Waters (HNLC)

(Leaves un-used DIC in the surface and more CO2 in the atmosphere)



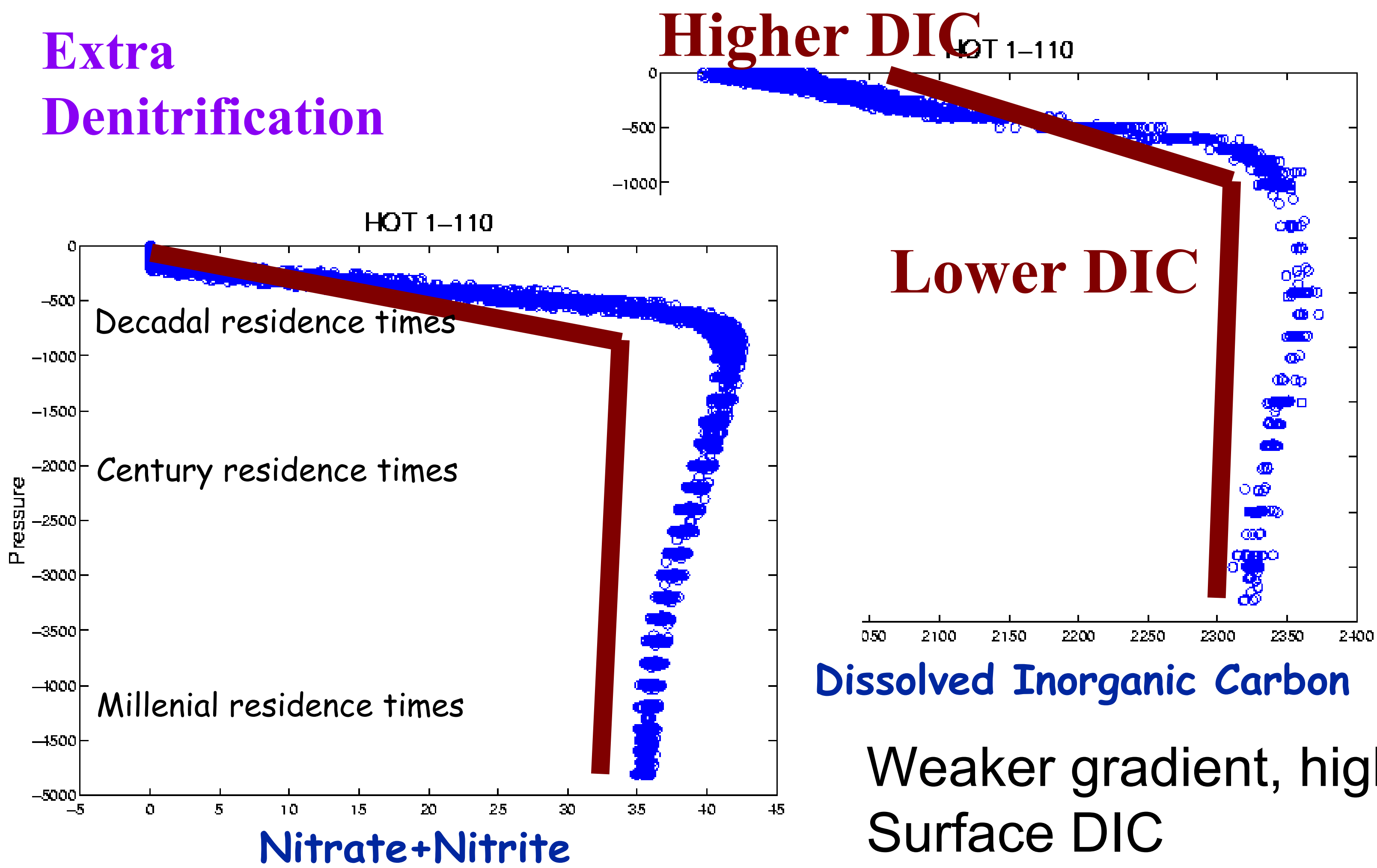


Changes in Total Nitrate Stock
Nitrogen Fixation - Denitrification Balance



Stronger gradient, lower Surface DIC

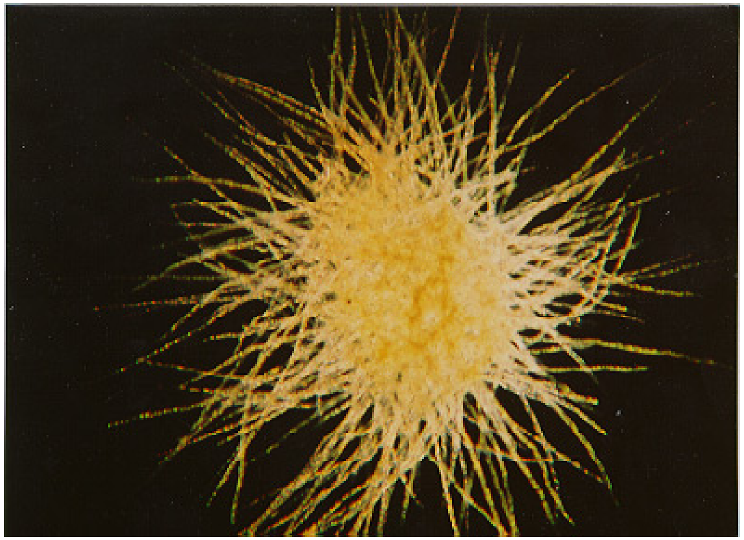
Changes in Total Nitrate Stock
Nitrogen Fixation - Denitrification Balance

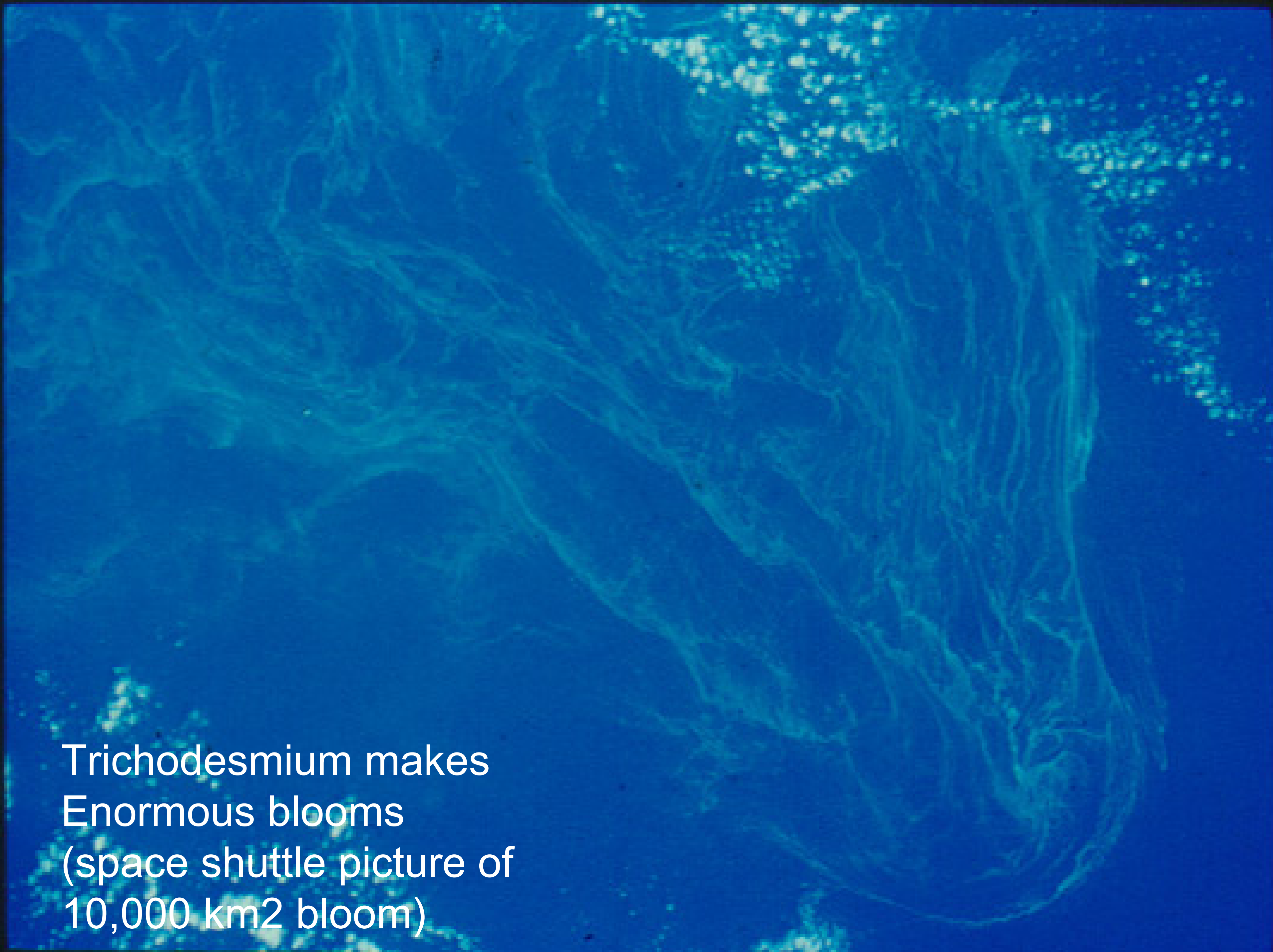


Weaker gradient, higher Surface DIC

Trichodesmium spp.

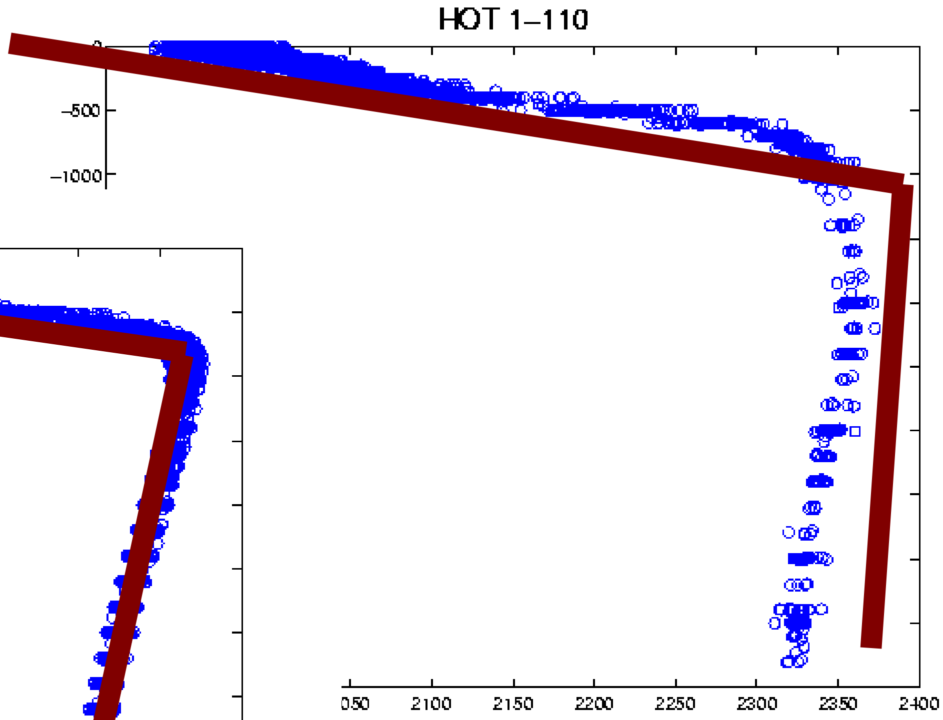
Best Known Planktonic Diazotroph



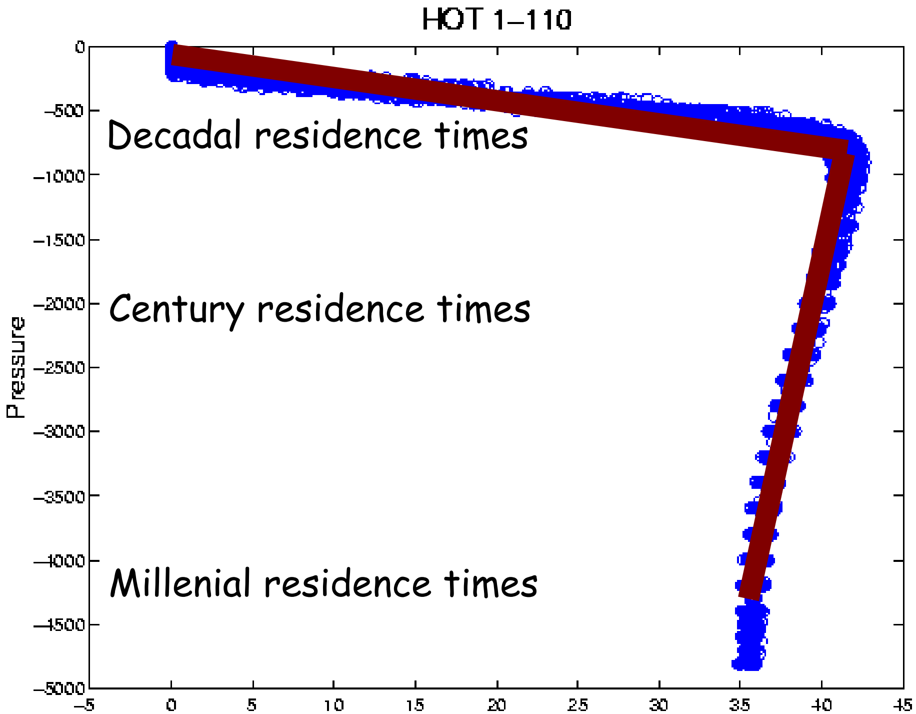

Trichodesmium makes
Enormous blooms
(space shuttle picture of
10,000 km2 bloom)

Changes in C-N-P stoichiometry

Increase C:N or C:P
Of export



Dissolved Inorganic Carbon

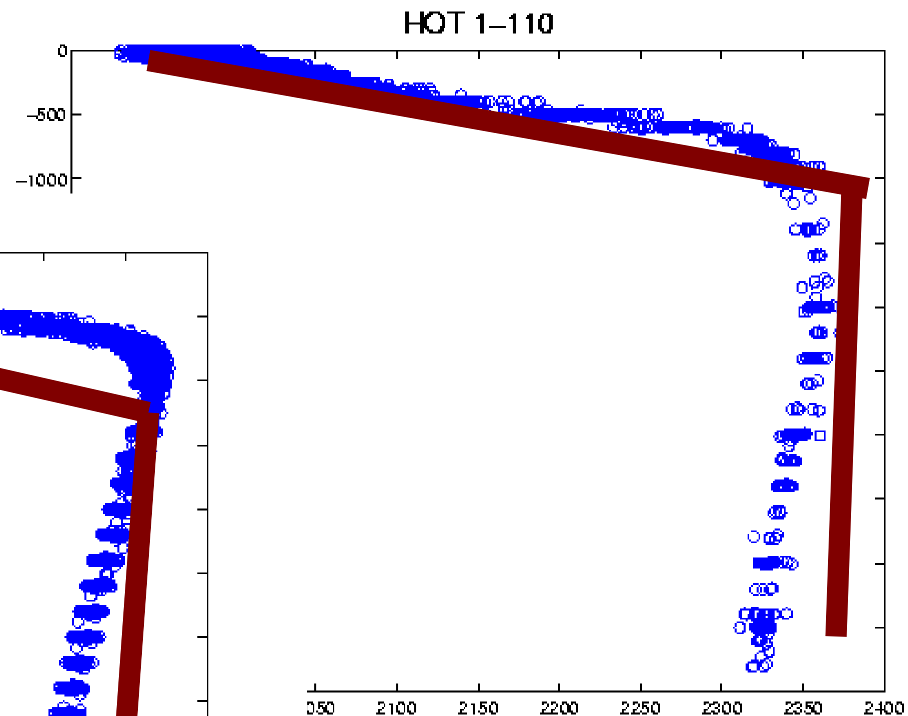


Nitrate+Nitrite

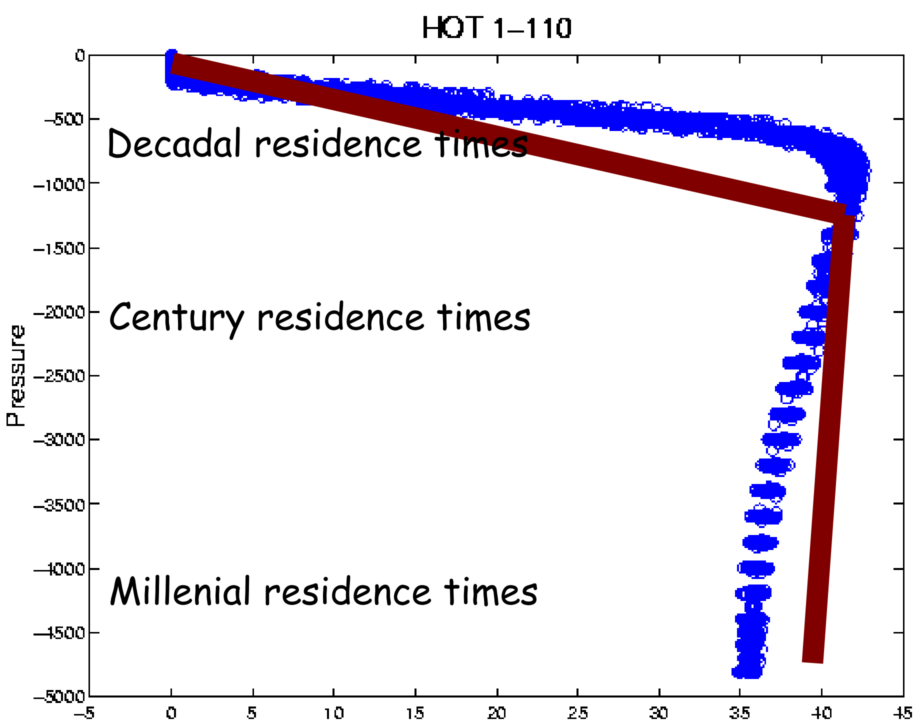
Pump more carbon, lower
Surface DIC

Changes in remineralization length-scales

Increase depth of remineralization

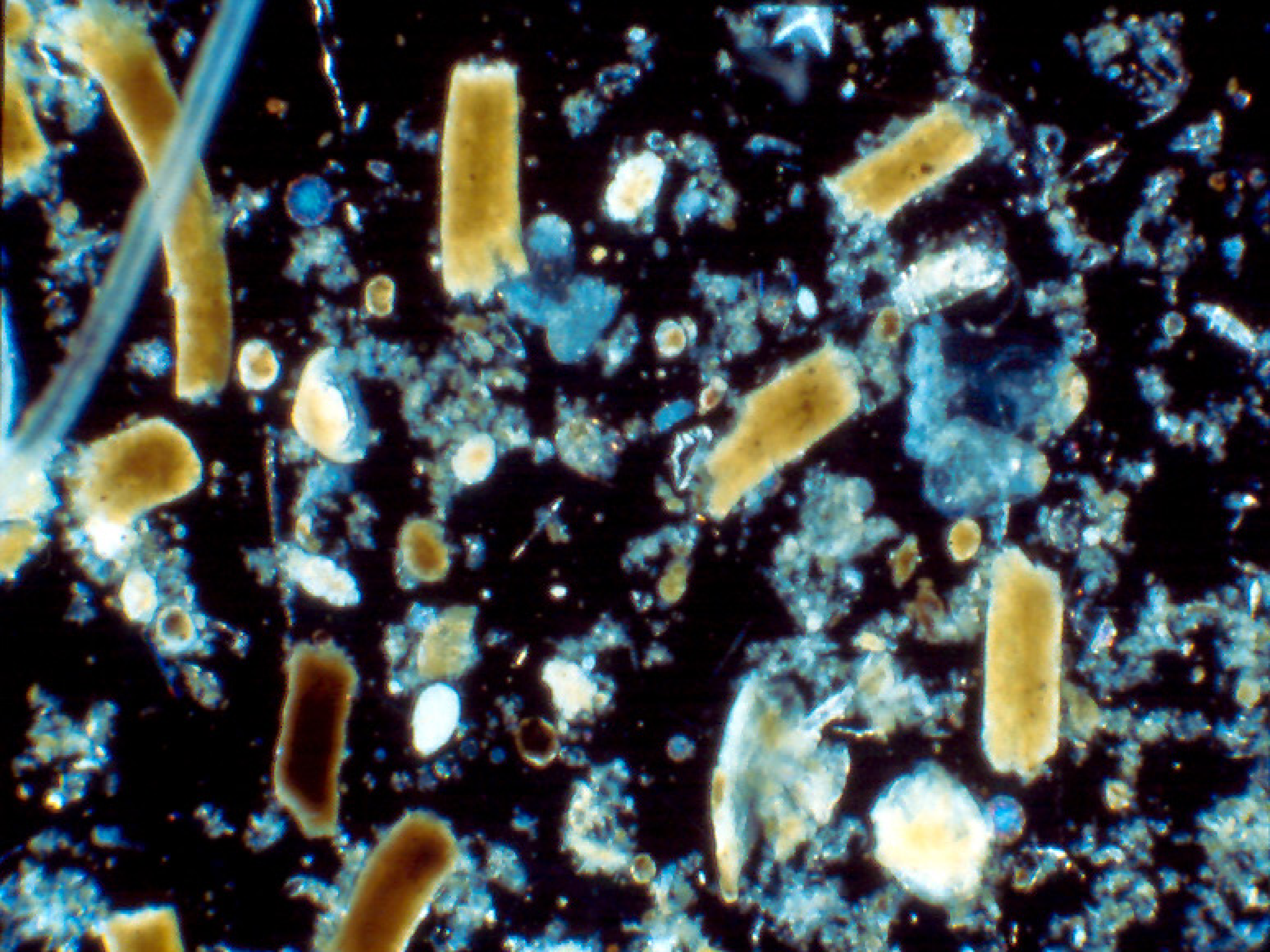


Dissolved Inorganic Carbon



Nitrate+Nitrite

Push carbon deeper, lower Surface DIC



Changes in PIC:POC rain

- Changes in carbonate fluxes impacts the alkalinity of the surface ocean
- Changes in surface alkalinity changes pCO2
- Secondary issues with other gases.

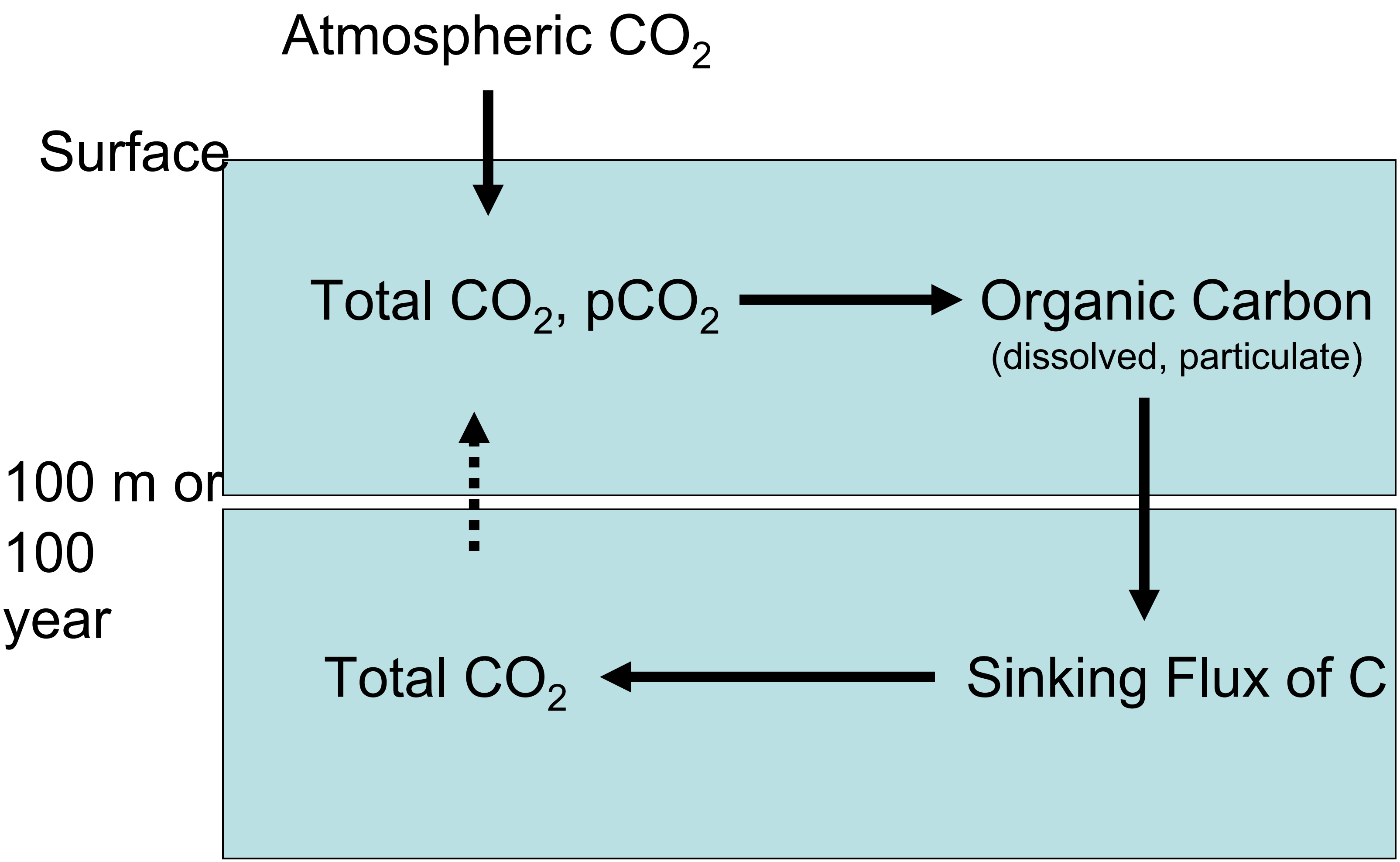
Carbon Storage in the Sea - Mechanisms
Focus on Nitrogen Fixation

- Relative use of surface macronutrients
  - Residual Nitrate (HNLC)
  - Residual Phosphate in the absence of NO_3
- Changes in C:N:P of export
- Changes in remineralization length-scale
- Changes in PIC rain rate ratios with POC

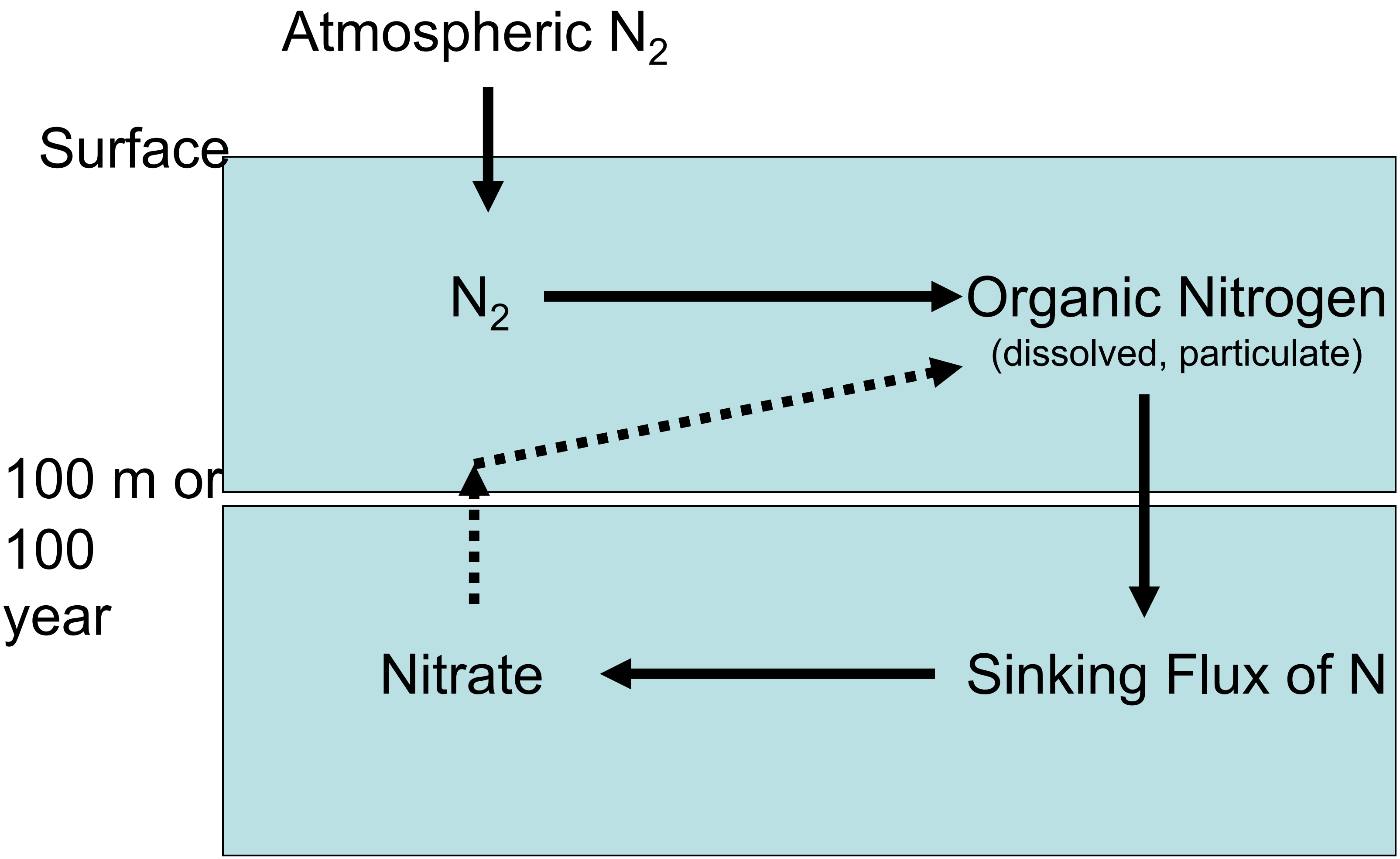
Sequestration Time-scale

- How long will this carbon stay below the surface mixed layer?

How to Understand and Measure the Effect: Create Mass Balance Model for Mixed Layer



How to Understand and Measure the Effect: Create Mass Balance for Mixed Layer

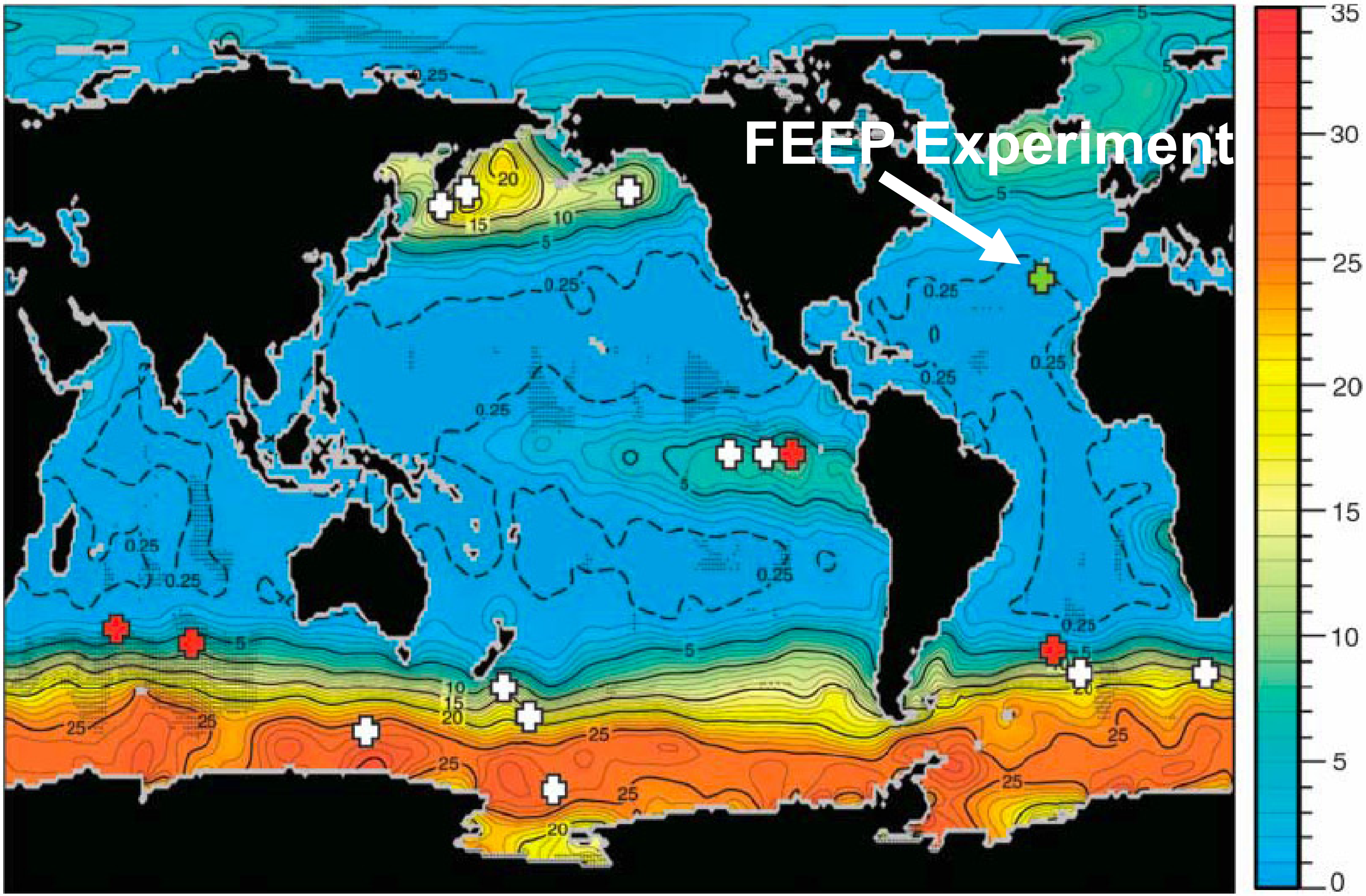


Sequestration Time-scale

- Biological re-use should keep carbon and new nitrate below the surface for extended periods
- Carbon storage until:
  - Upwelled in HNLC area and extra nitrate is left un-used (if that happens)
  - Passes through denitrification zone, followed by upwelling to the surface without the extra nitrate
- Both of these time-scales can be centuries when the correct location is chosen

Fe Addition and Nitrogen Fixation - Existing Data

- FeeP - Fe and SRP addition in NE Atl.
- Bottle Incubations (Fe, SRP, dust)
- Amazon Plume (High Fe, PO4)
- HOT data - recurring summer signal (Karl)



Boyd et al., 2007

FeeP (Rees, et al., 2007)

- Added Fe and PO4 to a low Fe and P area of NE Atlantic
  - 25 km^2 patch of Fe only
  - 25 km^2 patch with Fe and P
- Followed for about 3 weeks
- Fe+P patch, *Trichodesmium* increases
- N fixation rates increased 6 fold and 4.5 fold respectively

Nitrogen Fixation

- FeeP - Fe and SRP addition in NE Atl.
- Bottle Incubations (Fe, SRP, dust)
  - Lots of experiments with variable results
  - Often both addition of Fe and Dust stimulate nitrogen fixation
  - Always questions about how to extrapolate to nature

Fe and Dust Addition Experiments in Pacific (Sohm data)

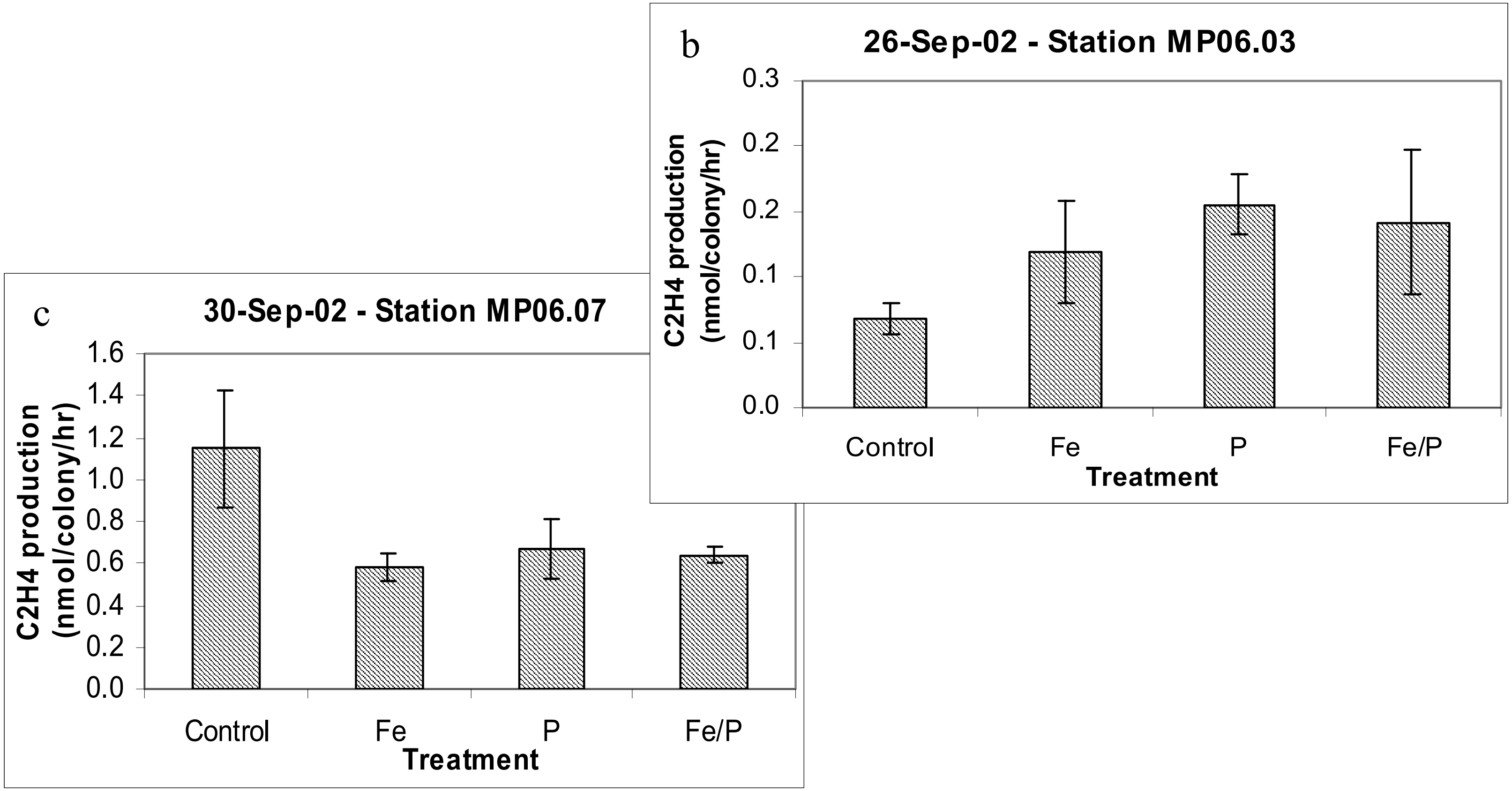
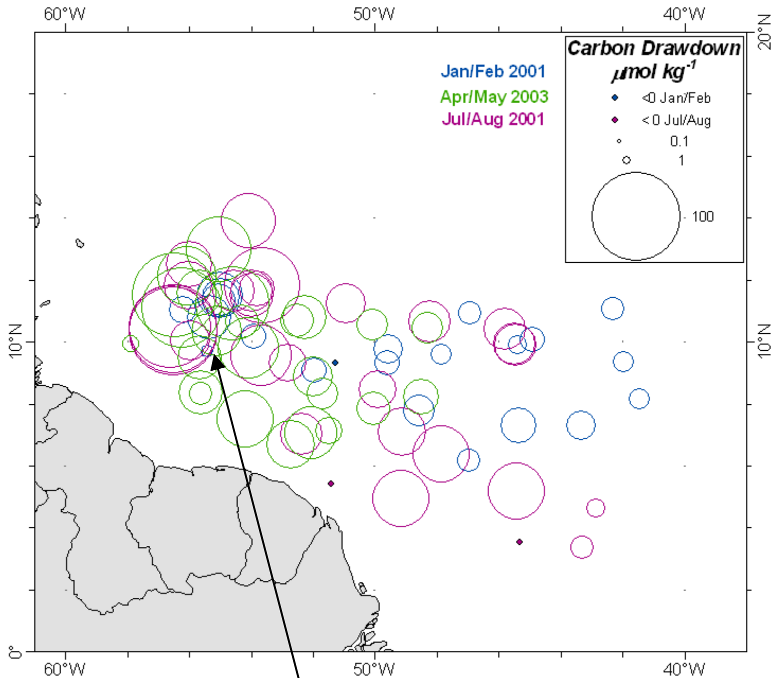


Figure 3 Acetylene reduction rates with nutrient additions to culture and field samples of *Trichodesmium*. a) Phosphate additions of 20 and 45 µM phosphate to culture grown on 5 µM phosphate (10 times less than in standard YBCII media). b) and c) 10 nM Fe and 100 nM PO_4^{3-} additions to colonies picked from net tows in the North Pacific Subtropical Gyre. D) Incubation of colonies from the North Pacific Subtropical Gyre and incubated for 0, 24 and 48 hours before initiation of acetylene reduction assay.

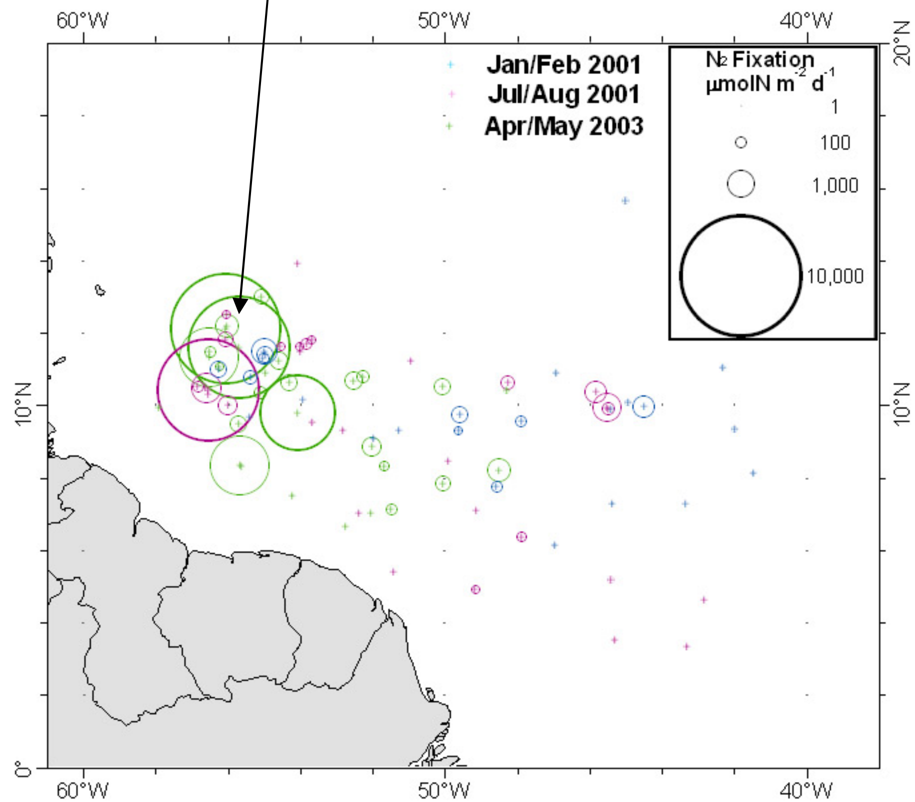
Nitrogen Fixation

- FeeP - Fe and SRP addition in NE Atl.
- Bottle Incubations (Fe, SRP, dust)
- Amazon Plume (High Fe, PO4)
  - Mimics Fe patch after the nitrate and ammonia have been used up - Amazon plume is still Fe, PO4 and Silica rich water diluted into open ocean seawater.

Amazon Plume Data (Cooley et al)



N-fixation blooms in Amazon plume



Highest carbon Drawdown in center Of N-fixation blooms

Amazon Plume Data (Cooley et al)

Range of DIC uptake Is similar to HNLC results

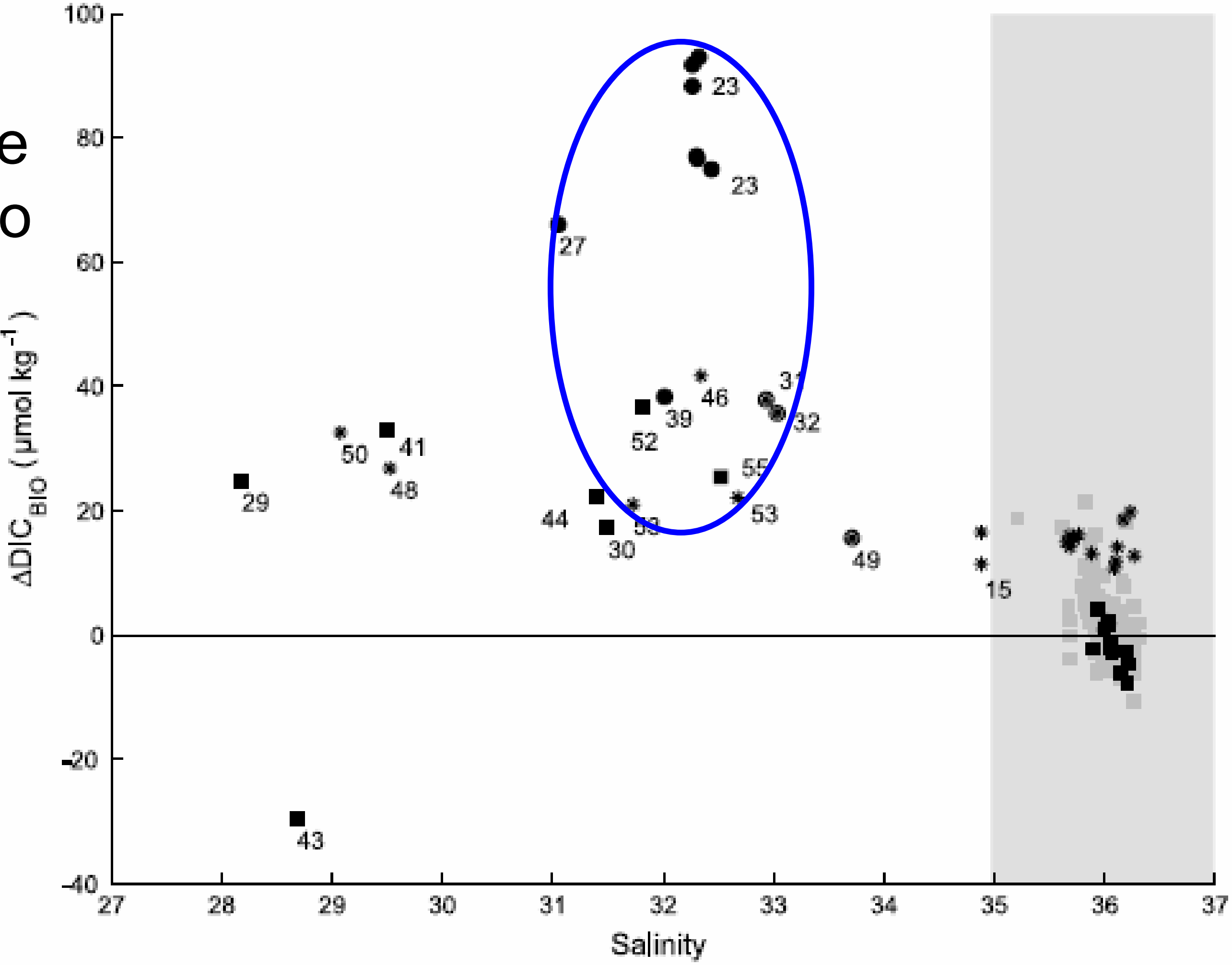


Figure 6. Community impact on DIC (ΔDIC_{BIO}), calculated with the mixing model, plotted against salinity. The 95% confidence interval error bars are within the size of the marker. Station numbers are shown for summer samples. Endmembers used to calculate ΔDIC_{BIO} included: $A_s = 2359.4 \pm 5.9$, $S_s = 36.07 \pm 0.10$, $DIC_s = 2024.5 \pm 6.8$, $S_r = 0 \pm 0$. The shaded region above salinity 35 indicates data outside the influence of the plume. Markers indicate the prevailing macroscopic nitrogen-fixing organisms observed at a station: square, none; circle, *Richelia*; asterisk, *Trichodesmium*; circle and star superimposed, *Richelia* and *Trichodesmium* together.

Nitrogen Fixation

- FeeP - Fe and SRP addition in NE Atl.
- Bottle Incubations (Fe, SRP, dust)
- Amazon Plume (High Fe, PO4)
- HOT data - recurring summer signal (Karl)
  - Indicate recurring blooms of diazotrophs every summer in N. Pacific Gyre, lead to high export to depth, strong delN15 signal

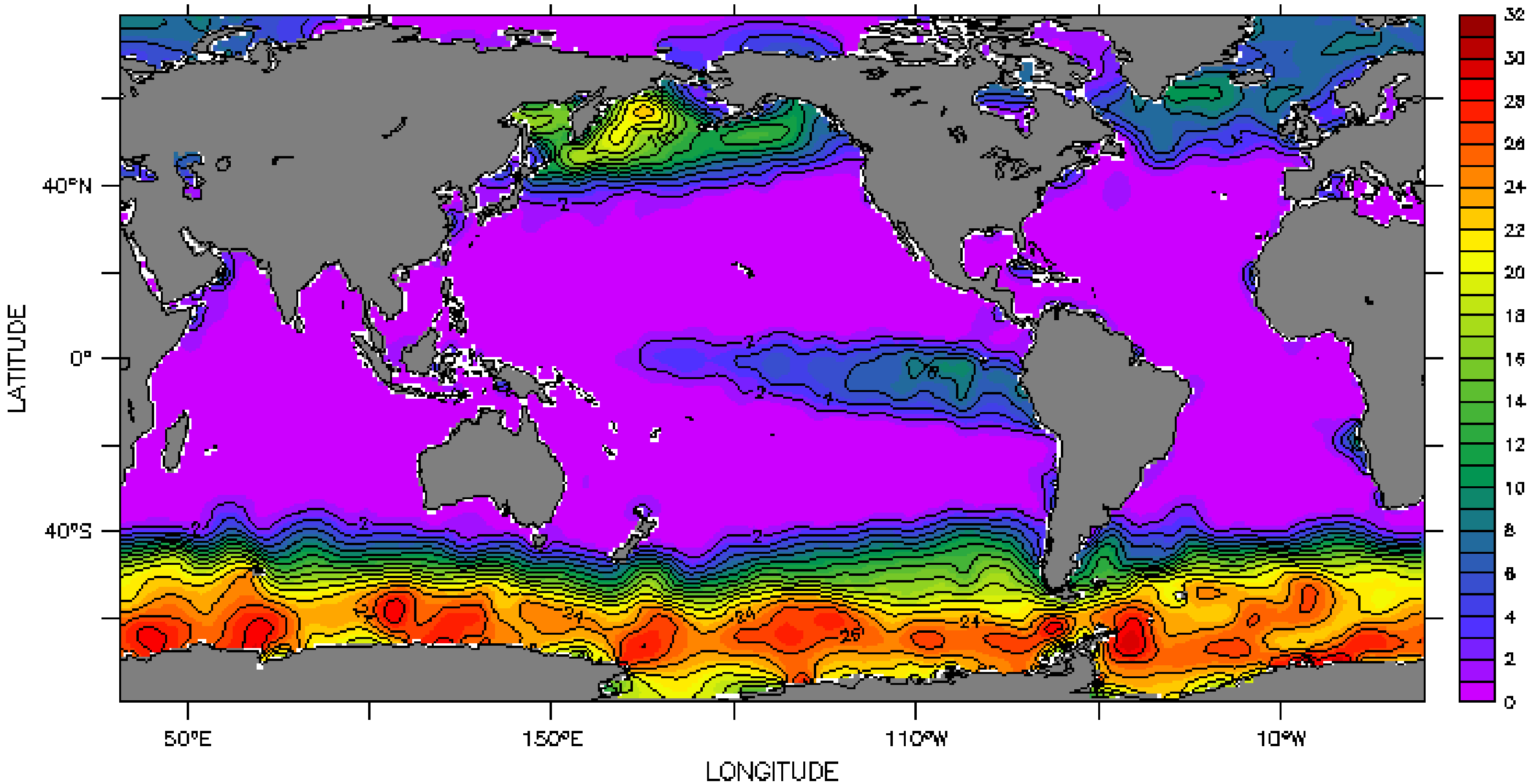
Conclusions From Previous Research

- Reasonable likelihood that nitrogen fixation is influenced by availability of Fe in the North Pacific and that addition of Fe will stimulate growth of diazotrophs (variable N:P)
- Growth of diazotrophs can lead to DIC drawdown
- Increases in total reactive nitrogen (ultimately nitrate) could impact air sea partitioning of CO2 until those waters experience denitrification (100s to 1000 years).

Site Selection

- Nitrate near detection
- Phosphate measurable
- Fe low
- Diazotrophs present, but not growing because of Fe stress
- Shallow Mixed Layers and Warm Waters
- Subsurface conditions conducive to sequestration and minimal negative environmental impacts

Most of the ocean shows near-complete nutrient utilization



Surface Nitrate (μmoles/kg)

MOORE ET AL.: GLOBAL ECOSYSTEM-BIOGEOCHEMICAL MODEL

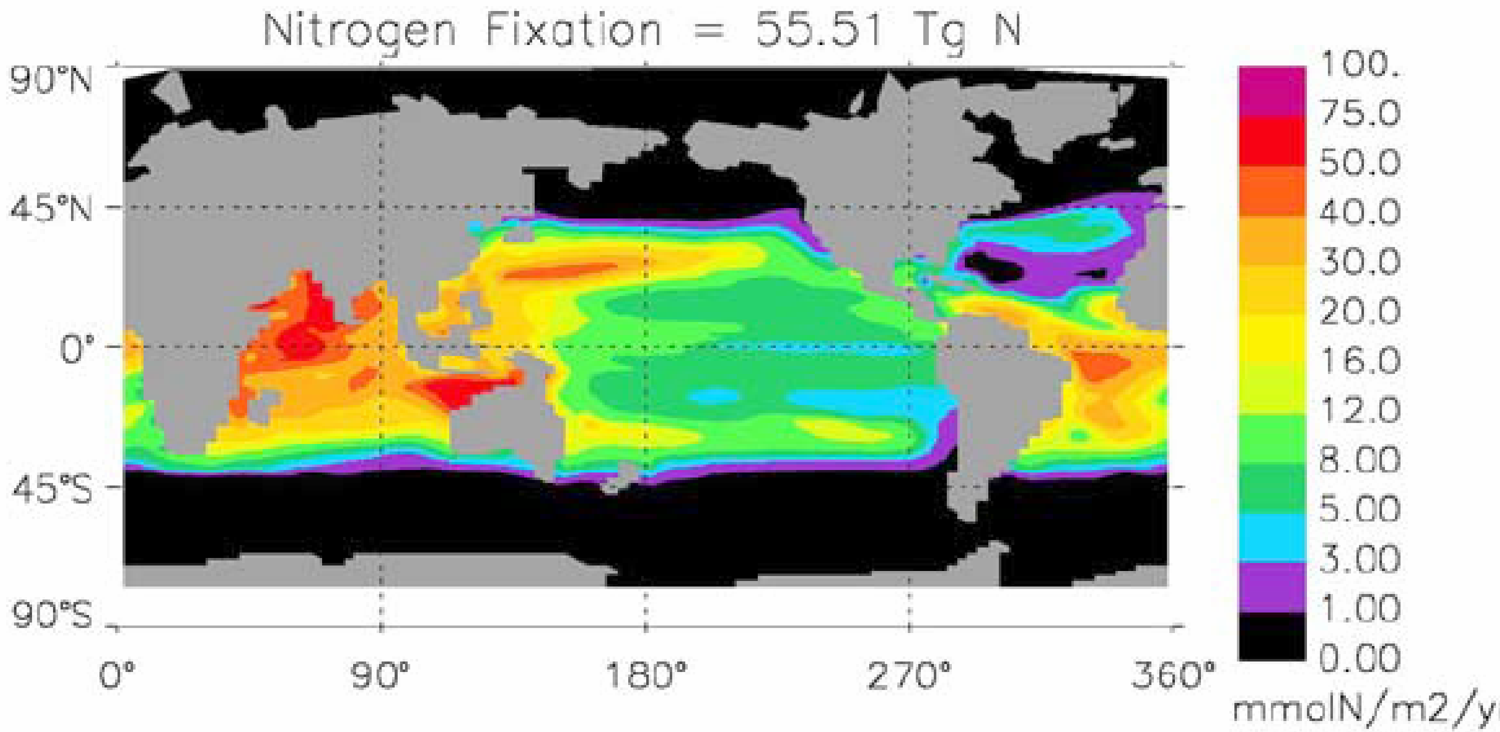
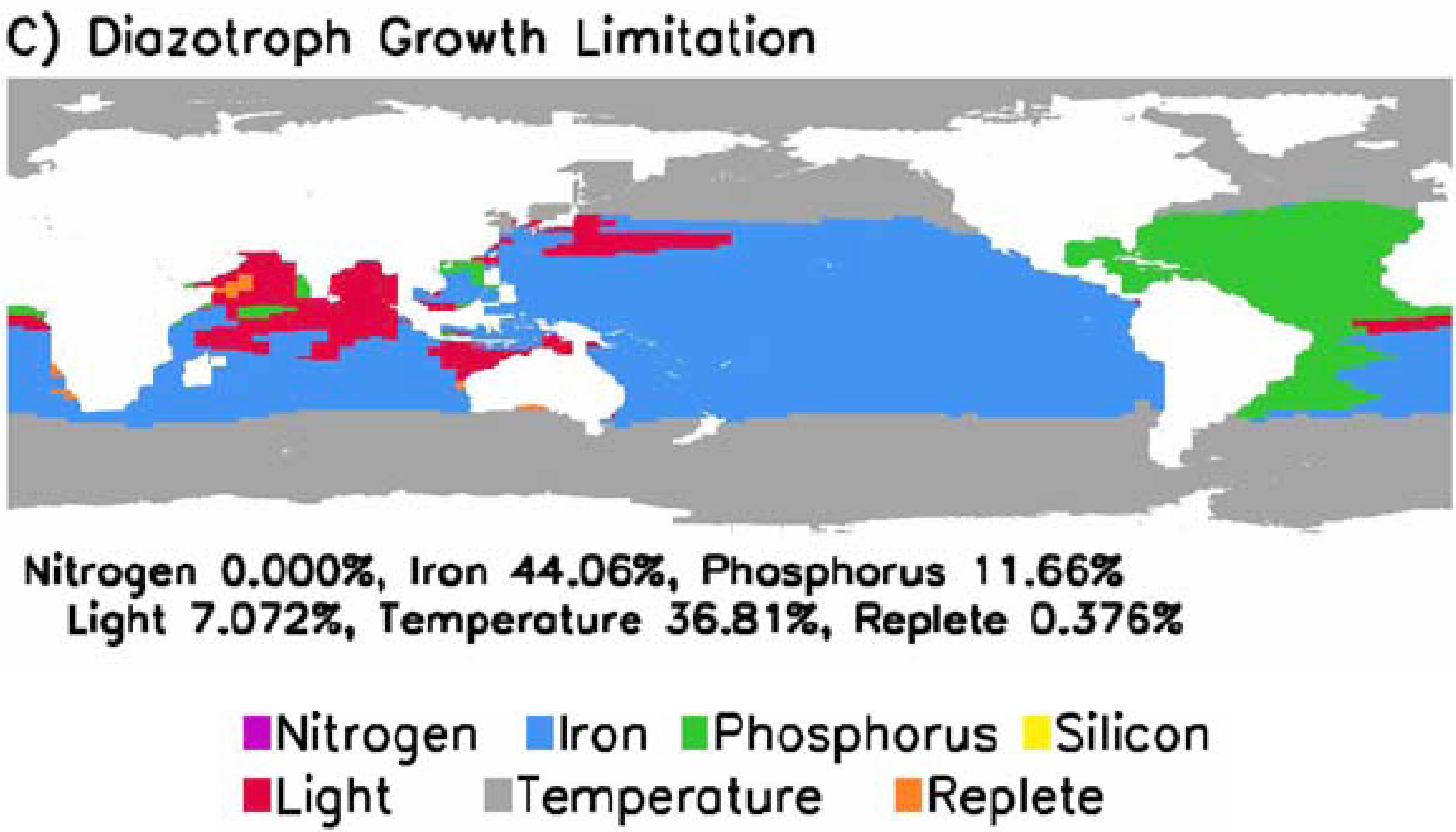


Figure 6. Annual nitrogen fixation rates by the diazotrophs are displayed.

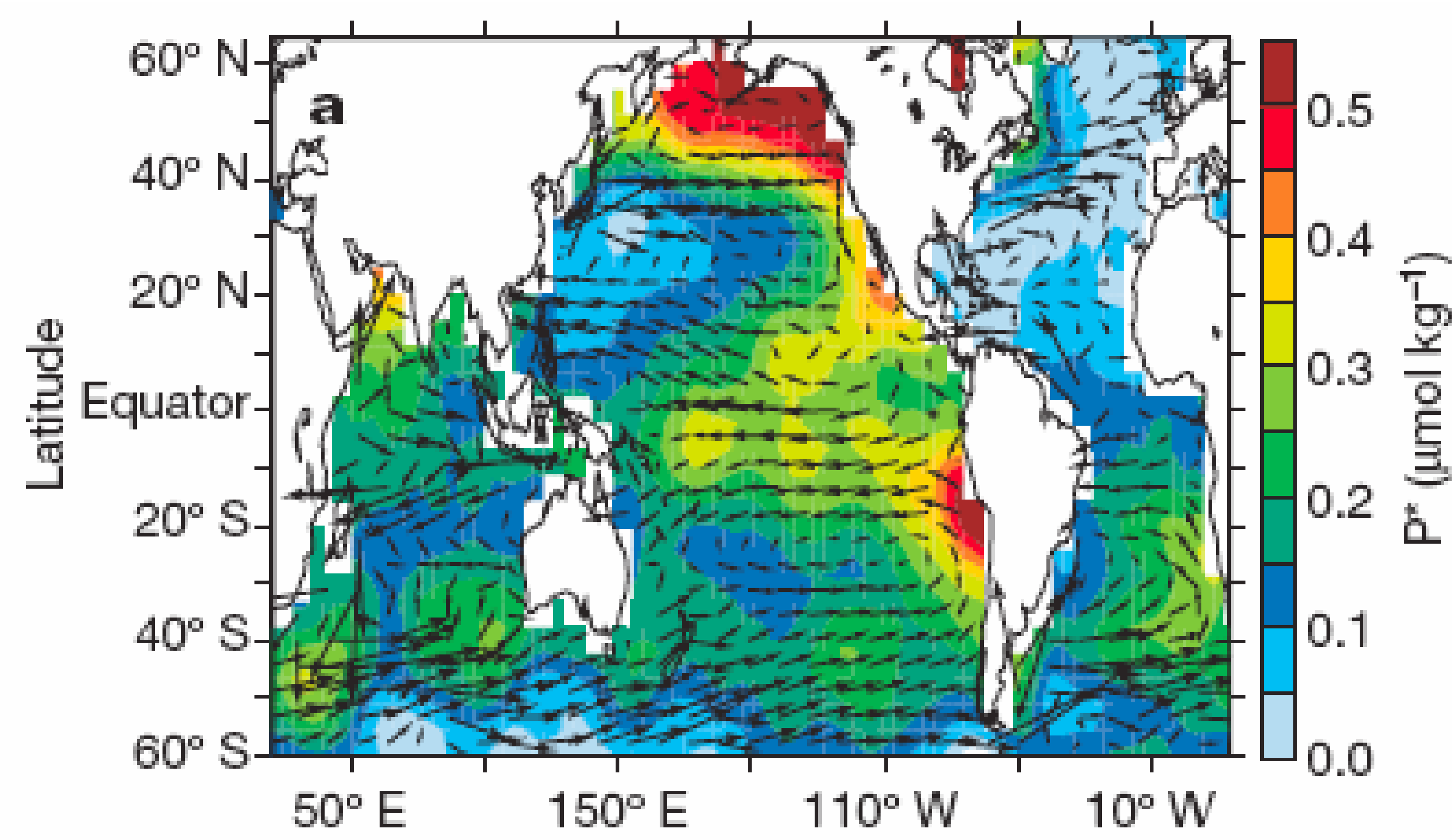
Look for areas of low but positive nitrogen fixation

Moore et al., 2004



Find areas where diazotrophs limited by Fe

Moore et al., 2004



Pick areas with “extra” phosphate

Deutsch et al., 2006

Compelling Logic?

- The best place for nitrogen fixation is where there is excess phosphate - usually derived from the upwelling of waters that recently experienced denitrification, but that have not yet experienced N fixation.

Environmental Impact Issues

- Other Trace Greenhouse Gases
  - N_2O, methane, DMS
- Harmful algae or other ecosystem distortions
- Oxygen anomalies
- Acidification Issues
  - Reduce surface acidification
  - Increase deep-sea acidification
  - Volumes different - impact should be less

Back to Conflict of Interest

- Academic role is analogous to university-run trials of new drugs or biomedical devices
- Commercial linkages are inherent
- Disclosure of potential conflicts and formal management are critical
- Appearance is as important as reality
- Learn from the other fields

We have to do this well!

Disclose and Manage

- Assume outsiders will think the worst
- Hidden ties, no matter how innocent can look bad (particularly when coupled to non-disclosure agreements)
- Over-disclosure is fine - fine line between internal disclosures and public knowledge
- External reviews and layers of checks and balances provide real protection
- Guard academic freedom (particularly for graduate students and Assistant Professors)

Some of Our Plans

- Independent data analysis of 5-10% of samples - hired by university
- Independent assessment of process and methods - hired by company
- Use full assets of university contract and IP offices
- Independent faculty and university oversight of contract research when faculty have equity stake in the company (esp. for verification projects)
- Independent co-advising for graduate students funded under contracts (use techs!)

Familiarize Yourself with Your Institutional Policy

- Conflict of Interest Policy
- Conflict of Commitment Policy
- IP Licensing Policy and Process
  - Protectable IP
  - Know-how
- Rules and Traditions for Commercial Activities within Academia
  - Medical School
  - School of Engineering

Thank you

Questions?