The marine microbial habitat revealed with chemical sensors

Ken Johnson
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M B A R I

the David & Lucile Packard FOUNDATION

NSF

Lecture 1/Wed morning “Where do nutrients come from? Physical and biological supply terms”

- Using chemical sensors to understand the microbial role in nutrient supply

Lecture 2/Thurs morning “Drifting toward metabolic balance”

- Using chemical sensors to examine the balance of carbon production in the ocean.

Lecture 3/Thurs afternoon “Iron: the other limiting nutrient”

- What’s the latest, from sedimentary chemistry to global engineering.

J. Johnstone, Condition of Life in the Sea, 1908

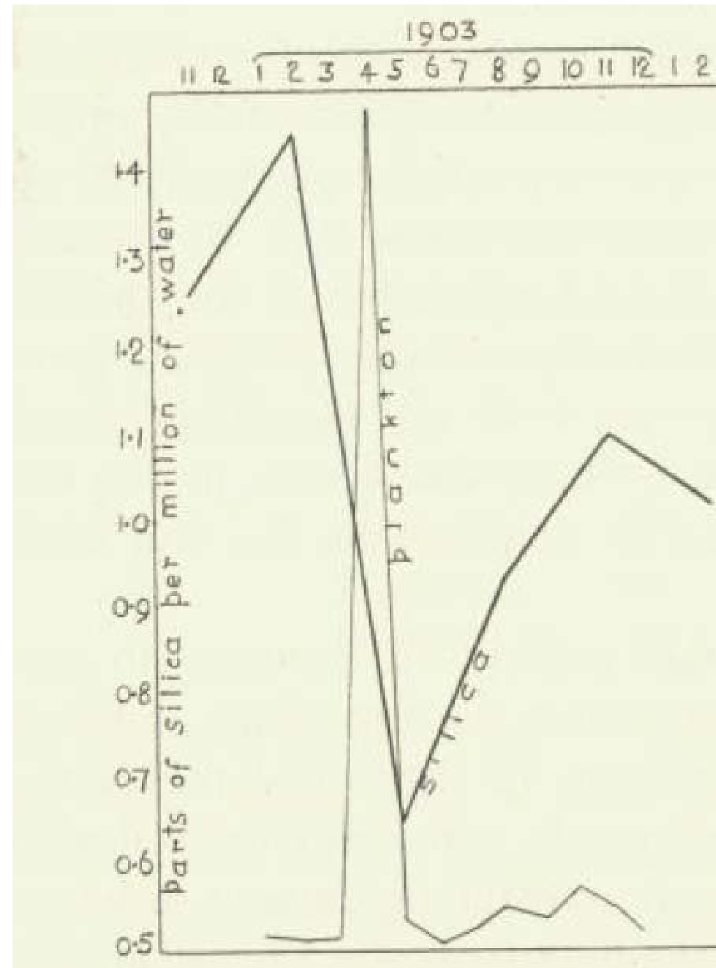
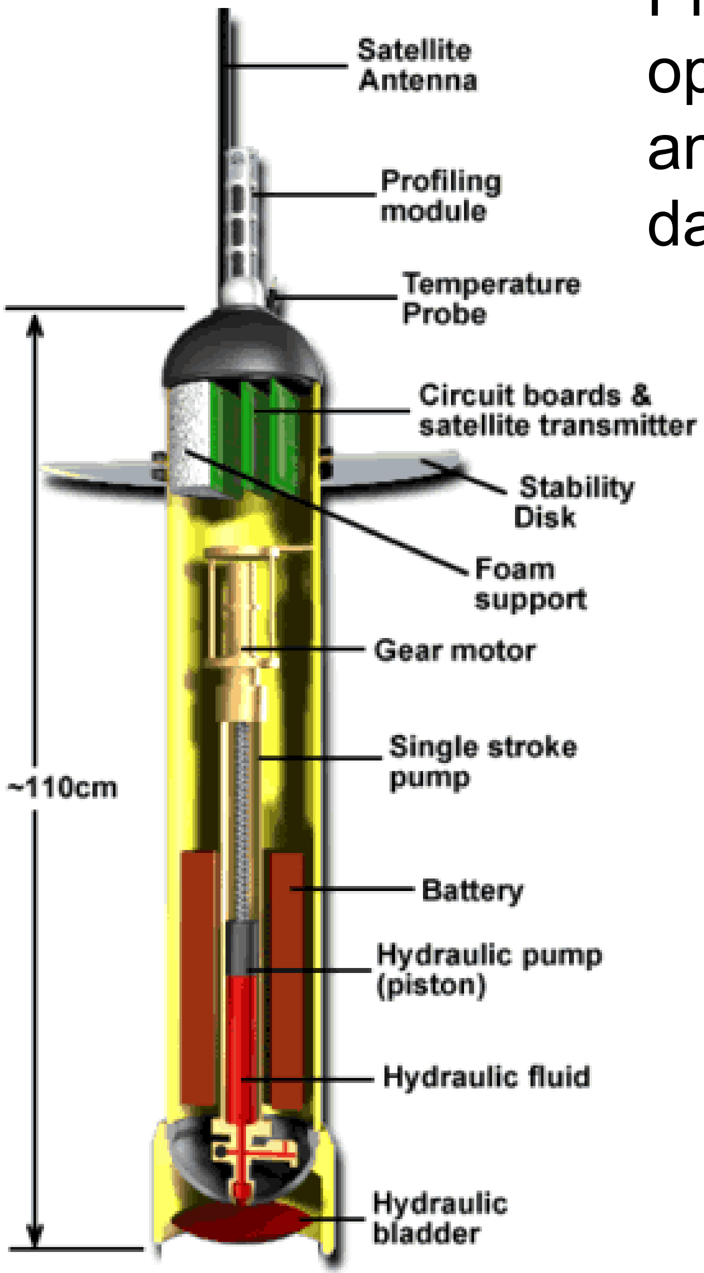
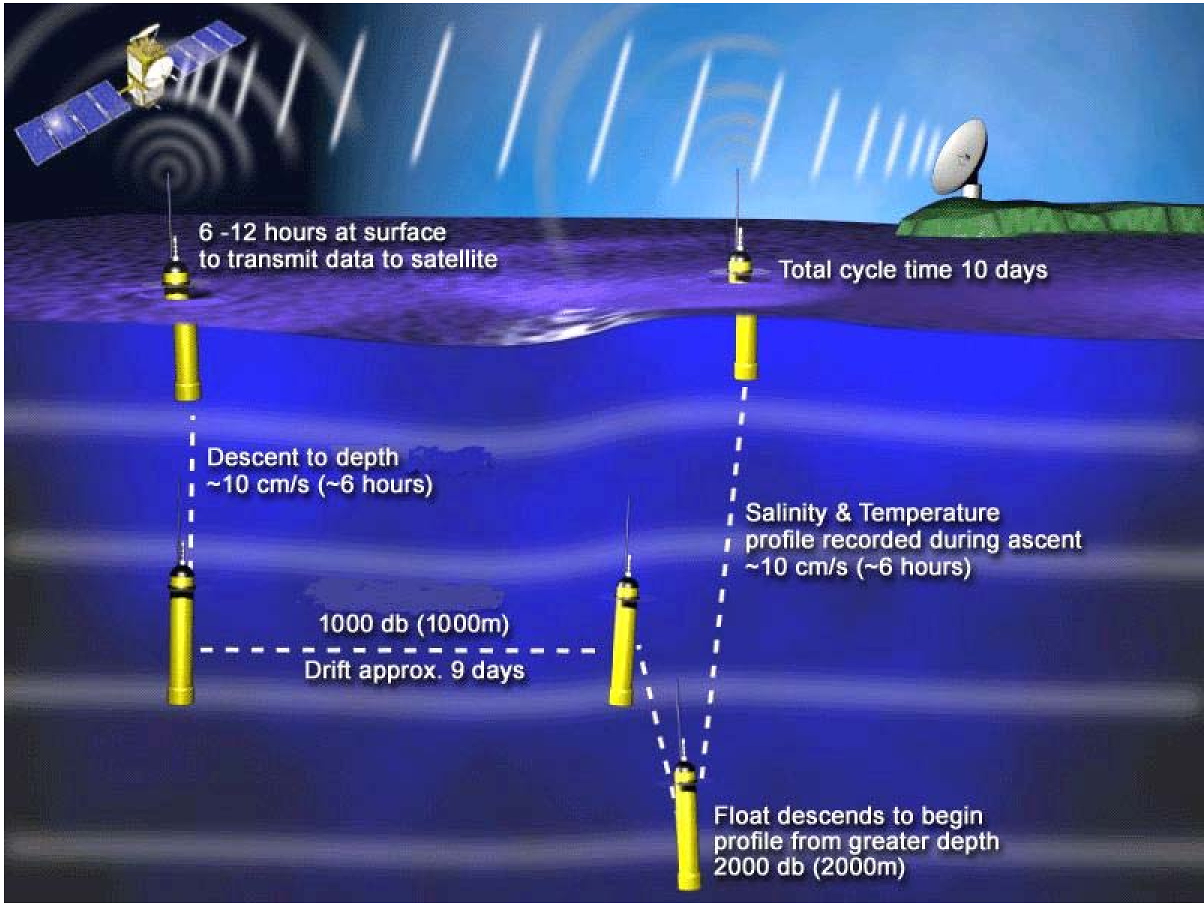


Fig. 30. Variation of plankton and silicic acid i

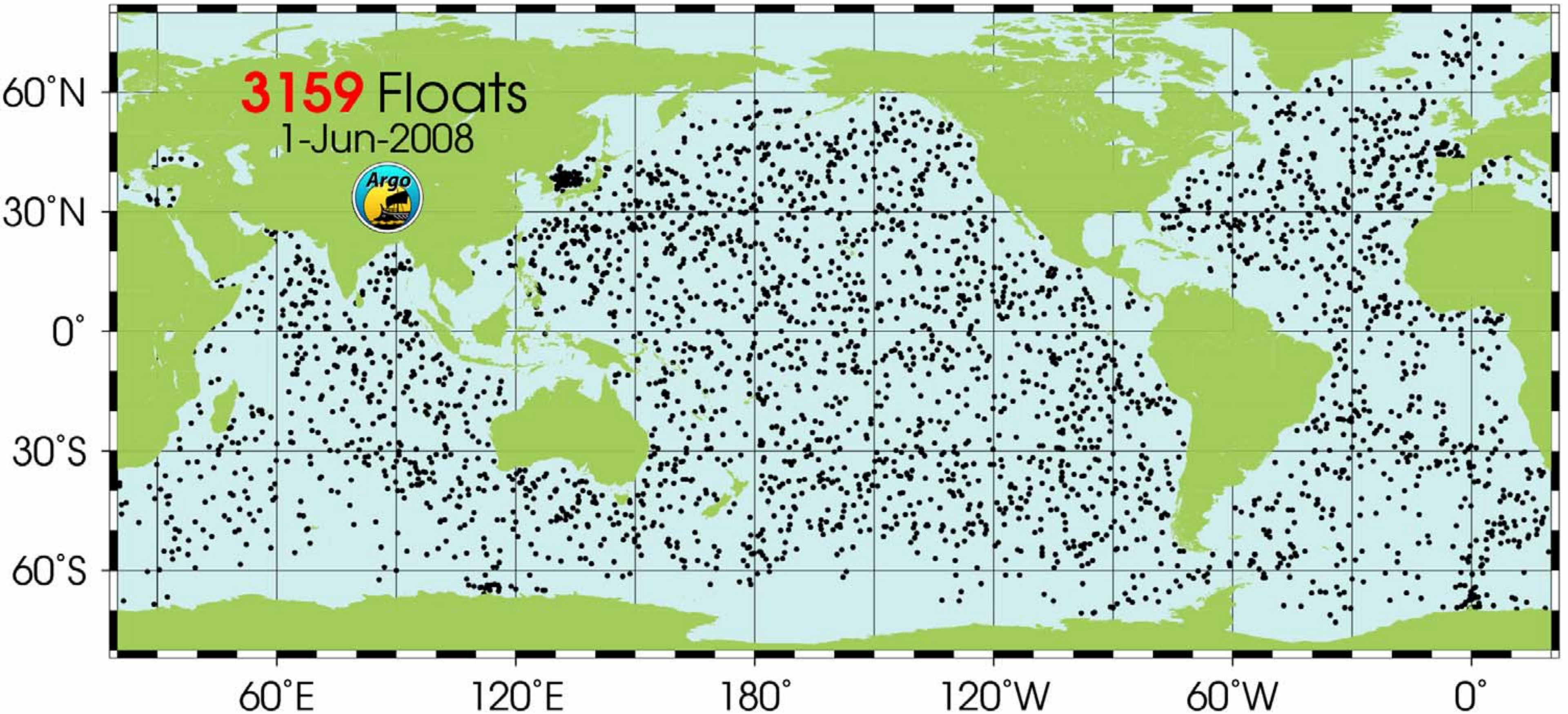
Profiling floats provide access to the open ocean. All we need are sensors and the scientific inspiration to use the data.

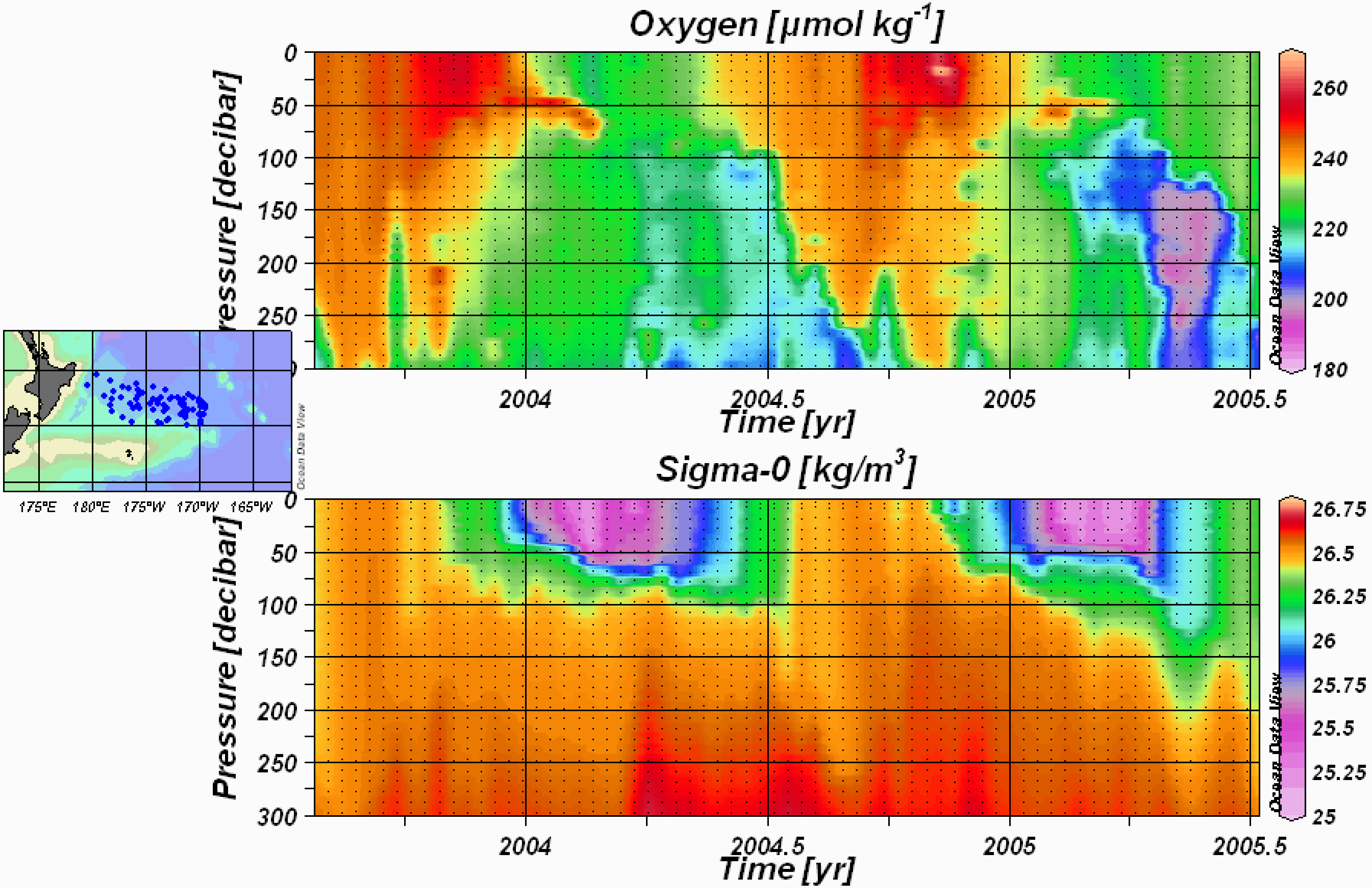




Symposium 1/Saturday "How will we measure the response of carbon export to climate change?"

- If you had a global, wireless chemical sensor network, how would you apply the data to understand the changing microbial environment in the ocean?





Oxygen [µmol kg-1]
Pressure [decibar]
0
50
100
150
200
250
2004
2004.5
2005
2005.5
Time [yr]
260
240
220
200
180
Ocean Data View
38°S
42°S
46°S
175°E
180°E
175°W
170°W
165°W
Ocean Data View
Sigma-0 [kg/m3]
Pressure [decibar]
0
50
100
150
200
250
300
2004
2004.5
2005
2005.5
Time [yr]
26.75
26.5
26.25
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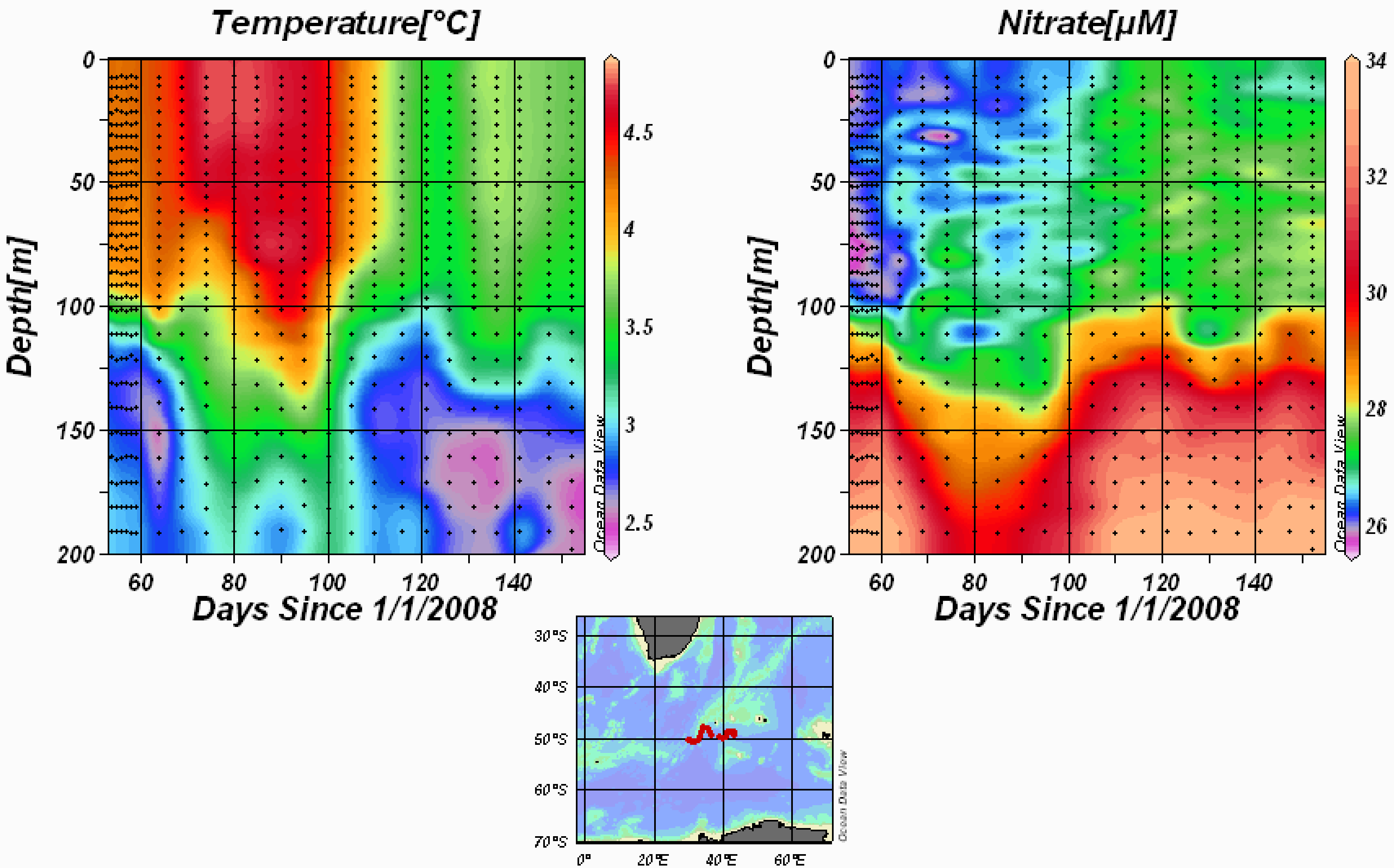
25.75
25.5
25.25
25
Ocean Data View


Temperature[°C]
Depth[m]
0
50
100
150
200
60
80
100
120
140
Days Since 1/1/2008
4.5
4
3.5
3
2.5
Ocean Data View
Nitrate[µM]
Depth[m]
0
50
100
150
200
60
80
100
120
140
Days Since 1/1/2008
34
32
30
28
26
Ocean Data View
30°S
40°S
50°S
60°S
70°S
0°
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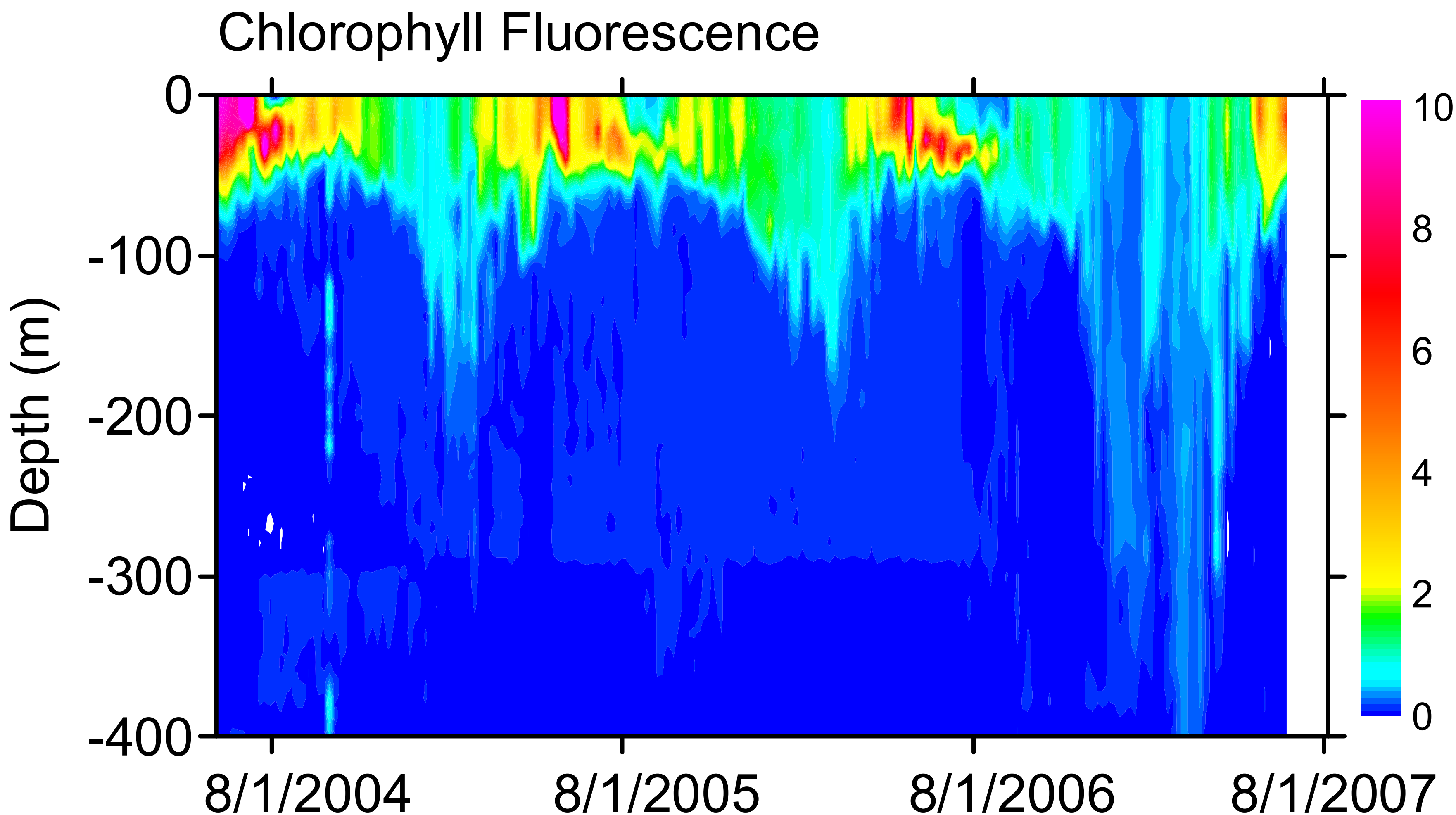
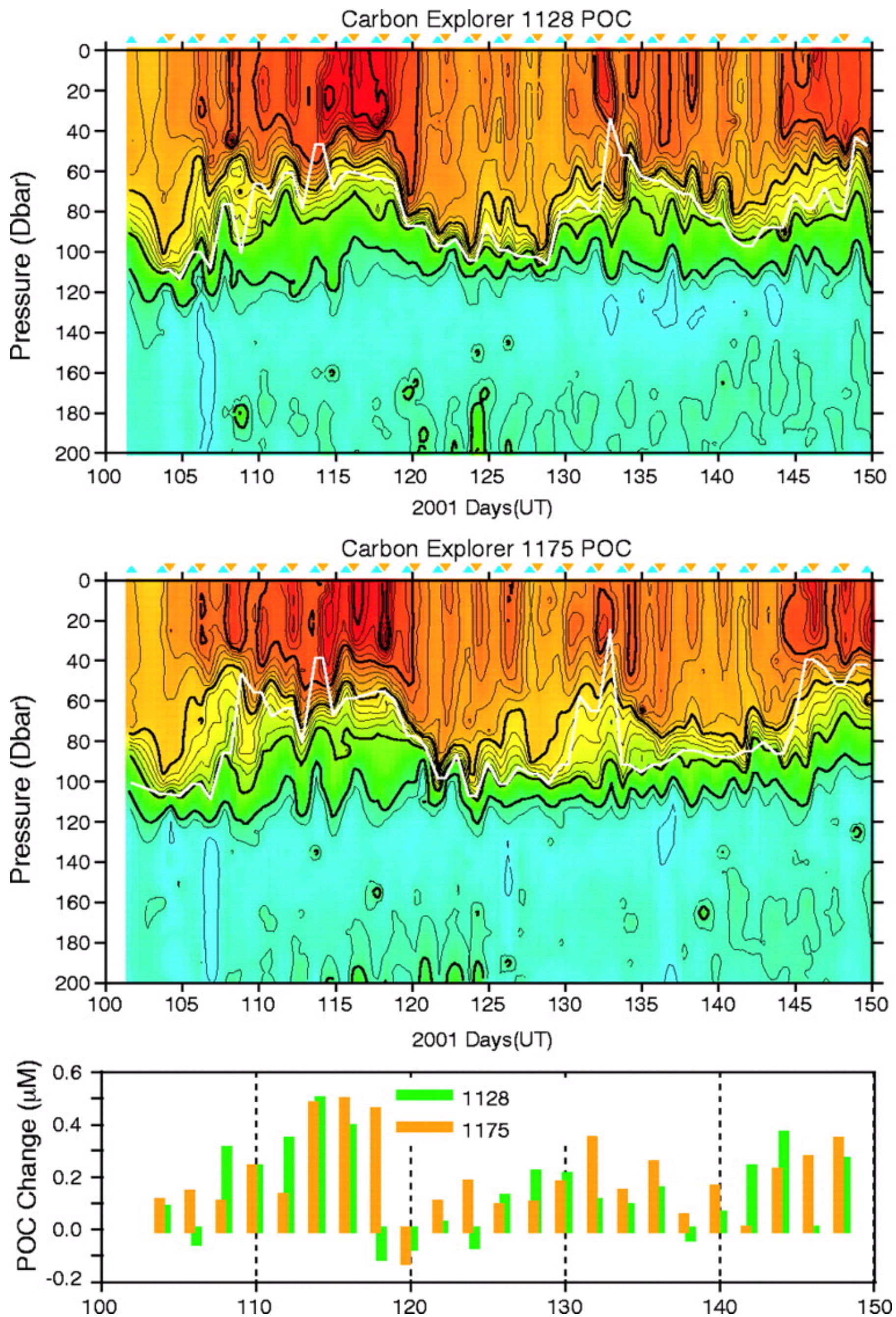
40°E
60°E
Ocean Data View

E. Boss et al., in press. Show 3 yrs of data for a fluorometer on a profiling float in the Labrador Sea.



Time series of POC variability from SOLO1128 and SOLO1175 in Subarctic N. Pacific inferred from transmissometer measurements (Bishop et al., 2002).



Bishop, J.K.B., R.E. Davis and J.T. Sherman. 2002. Science, 298: 817-821.

Bishop, J. K. B., T. J. Wood, R. E. Davis and J. T. Sherman. 2004. Science, 304, 417-420.

"How will we measure the response of carbon export to climate change?"

- In Saturday's Symposium, I'm going to propose a global sensor network deployed on floats and gliders.
- If I describe the basics of a global sensor array, are any students interested in proposing experiments with such a system that might address the effects of climate change on microbial processes, including carbon export? I.e., I'll give you time at the symposium to briefly describe the things you might be interested in doing.

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James Johnstone, Condition of Life in the Sea, 1908

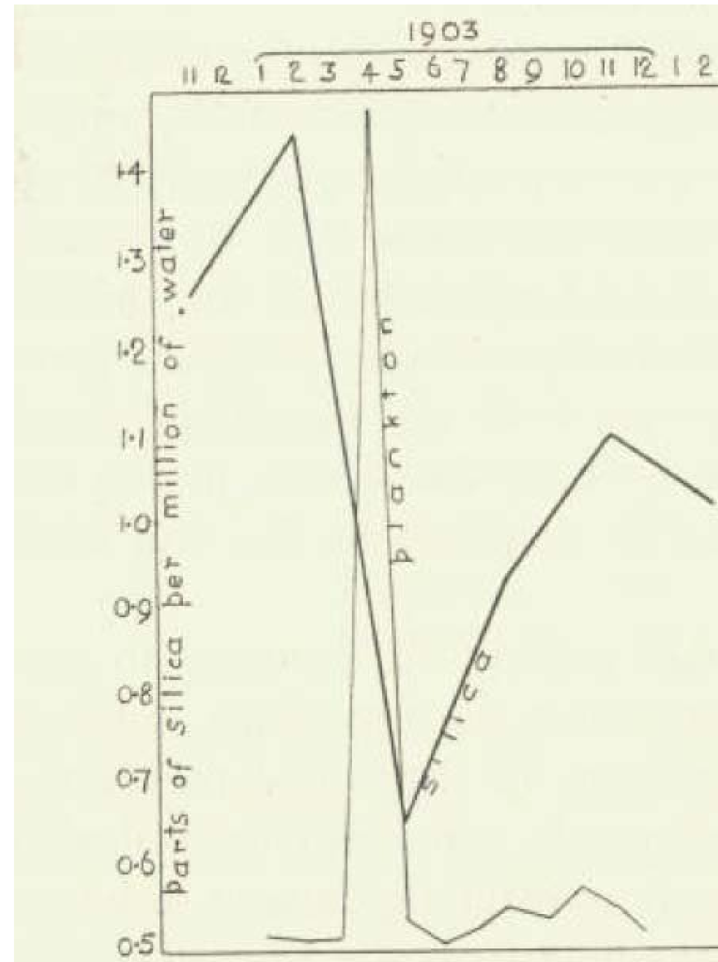


Fig. 30. Variation of plankton and silicic acid i

“Now what is the message there? The message is that there are no "knowns." There are things we know that we know. There are known unknowns. That is to say there are things that we now know we don't know. But there are also unknown unknowns. There are things we don't know we don't know. So when we do the best we can and we pull all this information together, and we then say well that's basically what we see as the situation, that is really only the known knowns and the known unknowns. And each year, we discover a few more of those unknown unknowns. It sounds like a riddle. It isn't a riddle. It is a very serious, important matter.”

Former Secretary of Defense Donald Rumsfeld

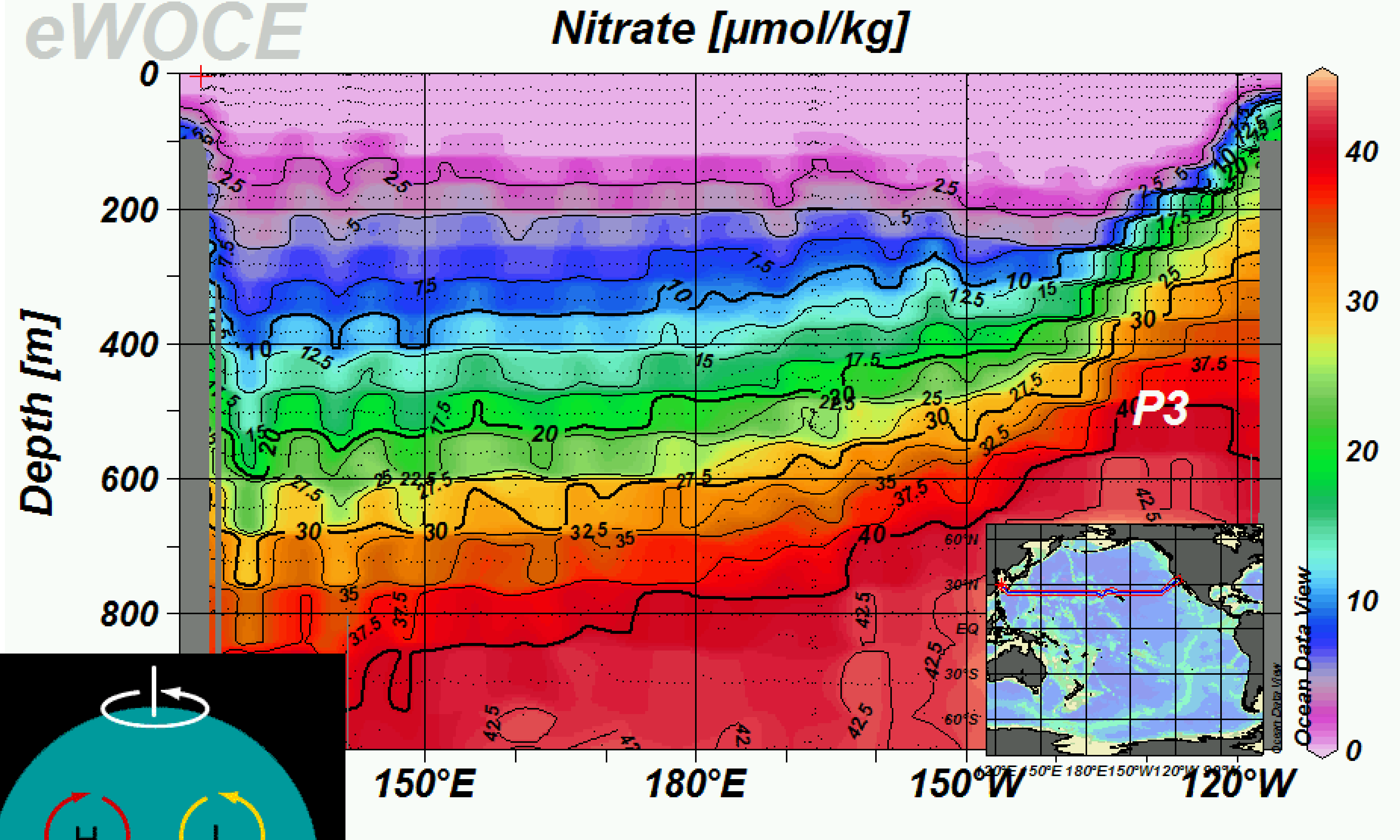
Three key knowns:

- Nitrate is depleted in the surface waters of most of the ocean and the low concentration limits growth rates and biomass accumulation of photoautotrophs.

- Concentrations of nutrients are linked because they are consumed and remineralized in relatively constant ratios (i.e., N/P or N/C approximately constant).

- Production of new organic material limited by rate at which fixed nitrogen is supplied to the euphotic zone.

N.b. - there are important exceptions to each of these points which point to unknown unknowns.


eWOCE
Nitrate [µmol/kg]
Depth [m]
0
200
400
600
800
150°E
180°E
150°W
120°W
P3
Ocean Data View
0
10
20
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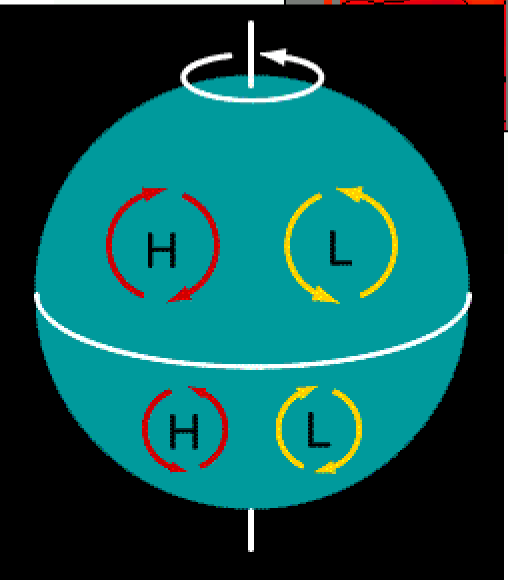
40
60°N
30°N
EQ
30°S
60°S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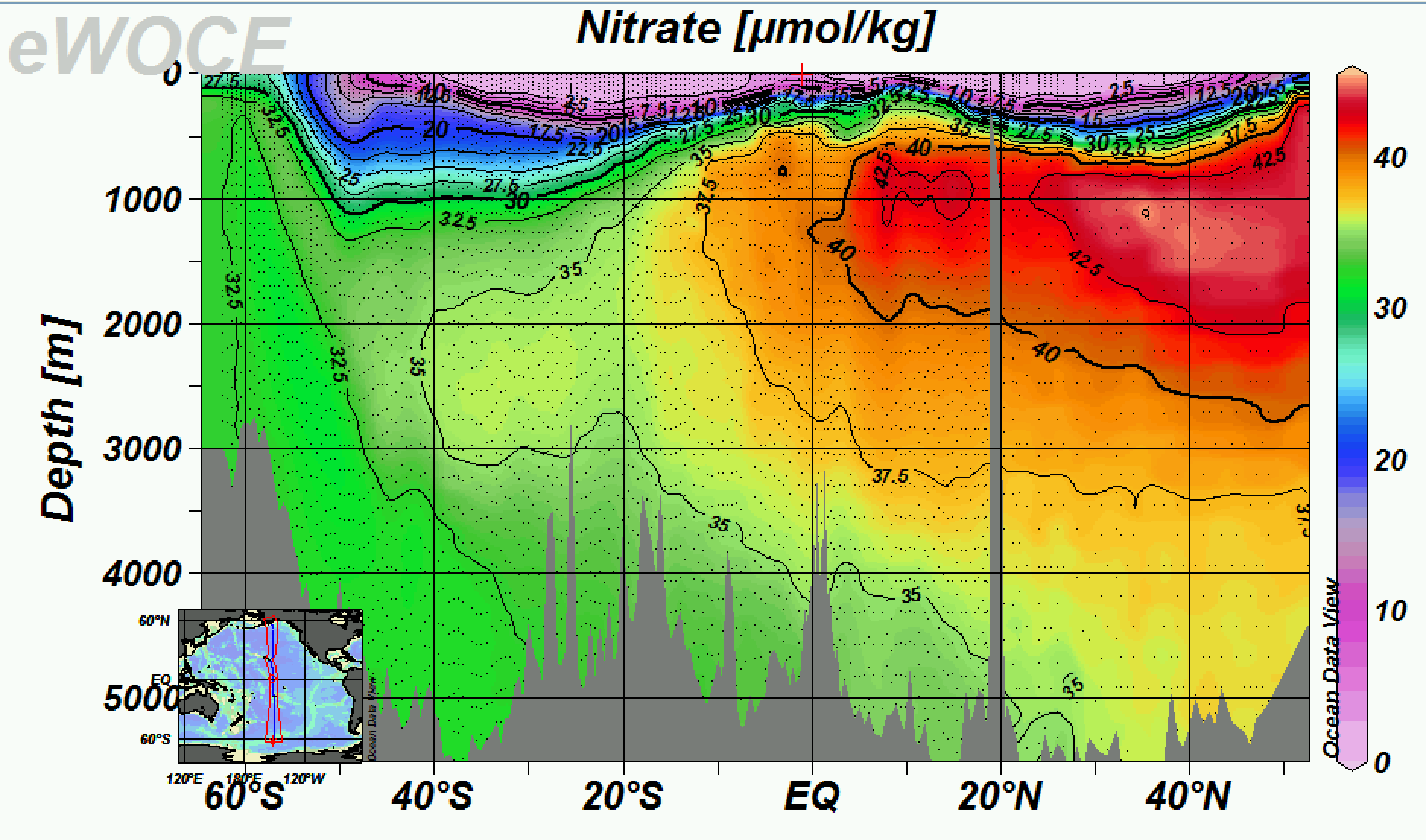
Abundant plant growth limited to regions where nutrients come to the surface.



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Extended

Elemental ratio of Phytoplankton

(Redfield Ratio)

To grow, plants need light and fertilizer:

$$(C_{124}\, N_{16}\, P_{1}\, S_{1.3}\, K_{1.7}\, Mg_{0.6}\, Ca_{0.5})_{1000}$$

$$Fe_{7.5}\, Zn_{0.80}\, Mn_{0.4}\, Cu_{0.4}\, Co_{0.2}\, Cd_{0.2}\, Mo_{0.03}$$

$$106\, CO_2 + 16\, HNO_3 + H_3PO_4 + 122\, H_2O \rightarrow (CH_2O)_{106}\, (NH_3)_{16}\, H_3PO_4 + 138\, O_2$$

add 30 Si if you are a diatom

if you can fix N_2 then substitute N_2 for the NO_3.....

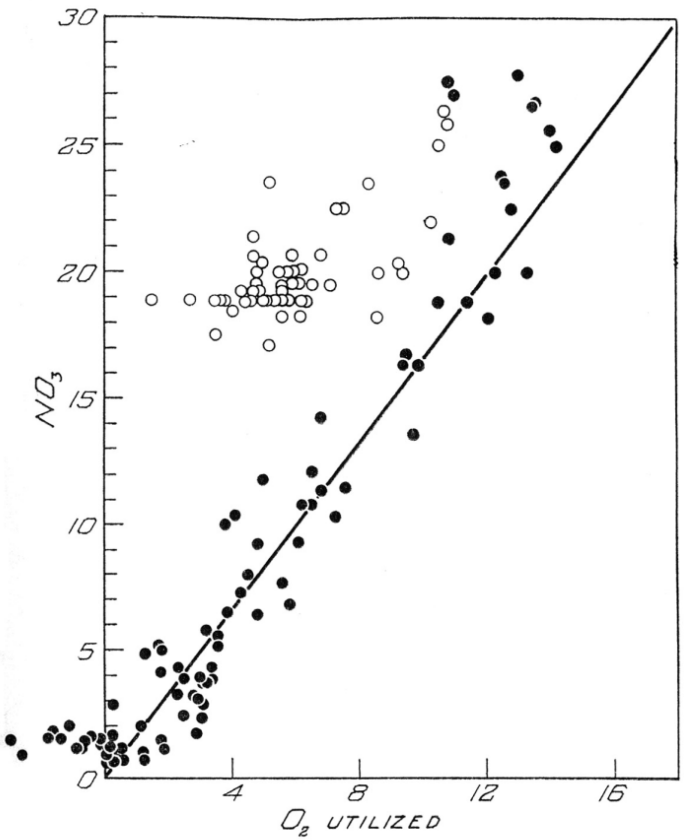
Ho et al., Journal of Phycology, 2003

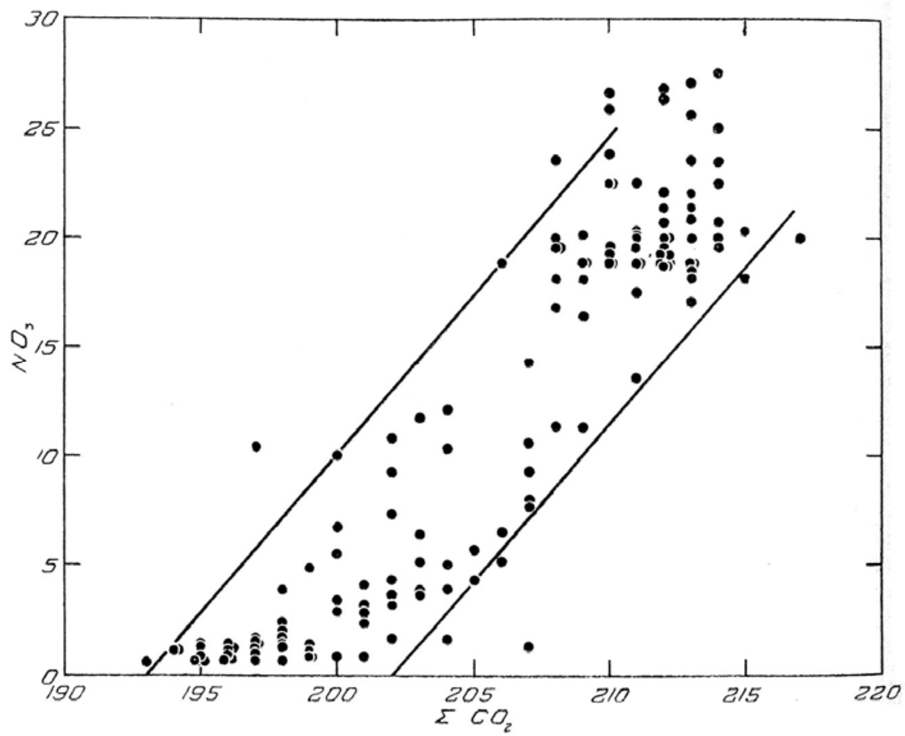
ON THE PROPORTIONS OF ORGANIC DERIVATIVES IN SEA WATER AND THEIR RELATION TO THE COMPOSITION OF PLANKTON[1]

1934

ALFRED C. REDFIELD

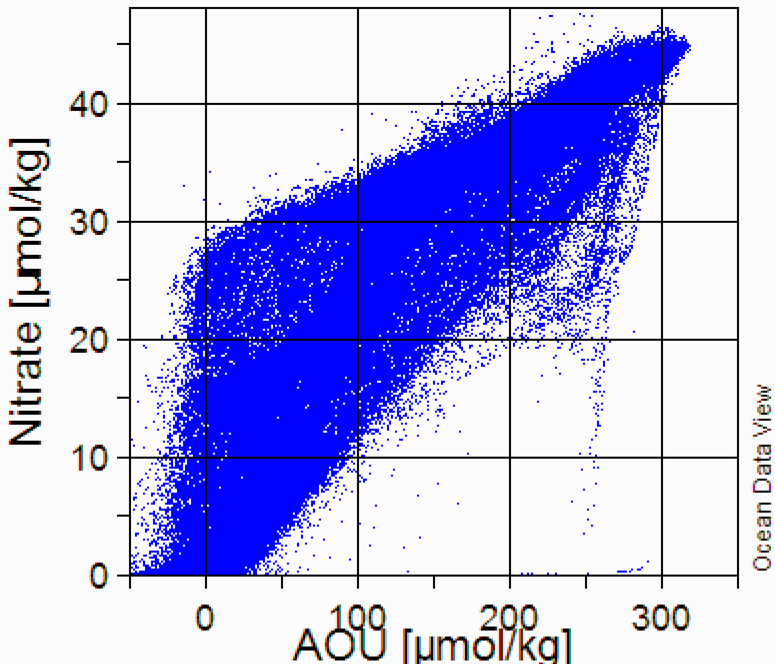
PROFESSOR OF PHYSIOLOGY, HARVARD UNIVERSITY, AND SENIOR BIOLOGIST. WOODS HOLE OCEANOGRAPHIC INSTITUTION

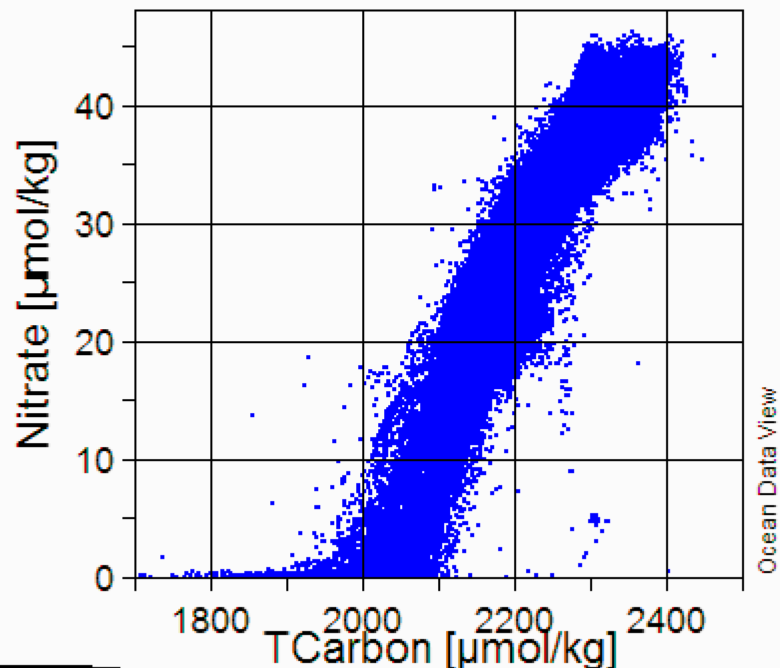


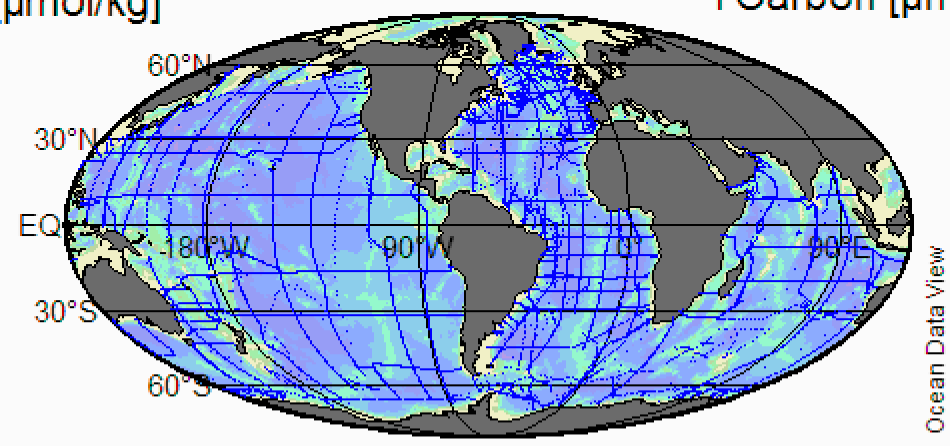


Redfield $-16\ NO_3^-$: $-106\ TCO_2$: $+138\ O_2$

In the nearly 80 years since Redfield's contribution, improved precision and more data allow us to explore variations of chemical ratio's in space – N*, P*.... Is the spatial resolution good enough?







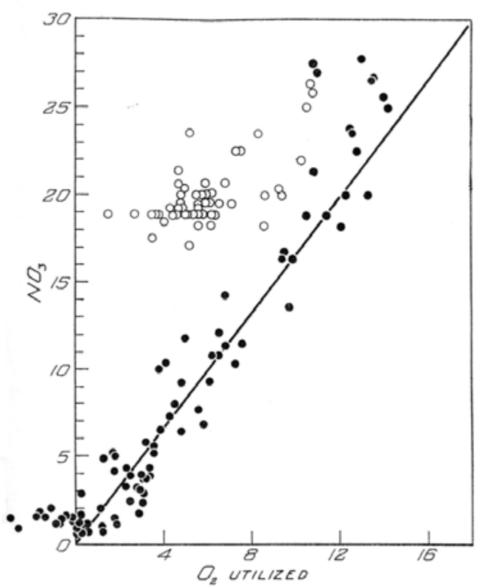
ON THE PROPORTIONS OF ORGANIC DERIVATIVES IN SEA WATER AND THEIR RELATION TO THE COMPOSITION OF PLANKTON[1]

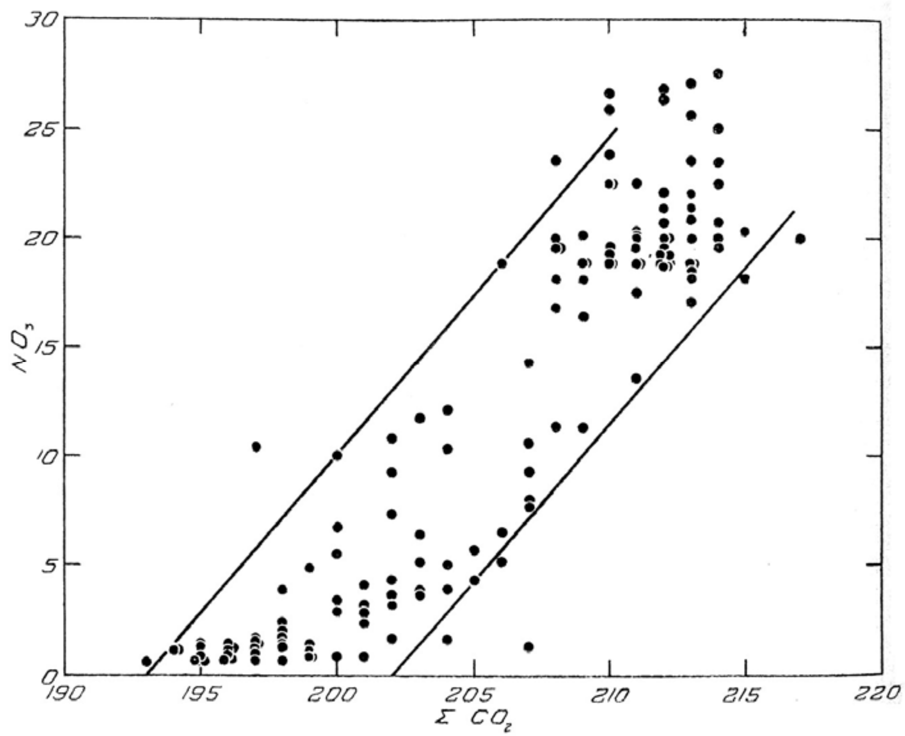
ALFRED C. REDFIELD

PROFESSOR OF PHYSIOLOGY, HARVARD UNIVERSITY, AND
SENIOR BIOLOGIST, WOODS HOLE OCEANOGRAPHIC INSTITUTION

(*Received September 5, 1933*)

"Chemical analysis shows that the animal and plant body is mainly built up from the four elements, nitrogen, carbon, hydrogen, and oxygen. Added to these are the metals, sodium, potassium and iron, and the non-metals, chlorine, sulphur and phosphorus. Calcium or silicon are also invariably present as the bases of calcareous or siliceous skeletons. All these, with some others, are indispensable constituents of the organic body, and in an exhaustive study of the cycle of matter from the living to the non-living phases, and *vice versa*, we should have to trace the course of each." JAMES JOHNSTONE, "Conditions of Life in the Sea," p. 273. 1908.





James Johnstone, The Condition of Life in the Sea, Cambridge Univ. Press, 1908

CHAPTER XII.

THE CIRCULATION OF NITROGEN.

CHEMICAL analysis shews that the animal and plant body is mainly built up from the four elements, nitrogen, carbon, hydrogen and oxygen. Added to these there are the metals, sodium, potassium and iron, and the non-metals, chlorine, sulphur and phosphorus. Calcium or silicon are also invariably present as the bases of calcareous or siliceous skeletons. All these, with some others, are indispensable constituents of the organic body, and in an exhaustive study of the cycle of matter from the living to the non-living phases, and *vice versa*, we should have to trace the course of each. But we are accustomed to regard nitrogen as the characteristic constituent of living substance and it will be sufficient to consider this element alone.

Three key knowns:

- Nitrate is depleted in the surface waters of most of the ocean and the low concentration limits growth rates and biomass accumulation of photoautotrophs.

- Concentrations of nutrients are linked because they are consumed and remineralized in relatively constant ratios (i.e., N/P or N/C approximately constant).

- Production of new organic material limited by rate at which fixed nitrogen is supplied to the euphotic zone.

N.b. - there are important exceptions to each of these points which point to unknown unknowns.

About 80% of primary production recycles thru microbial loop a. The inputs of “New” nutrients (b’+c+d) must balance export b’’

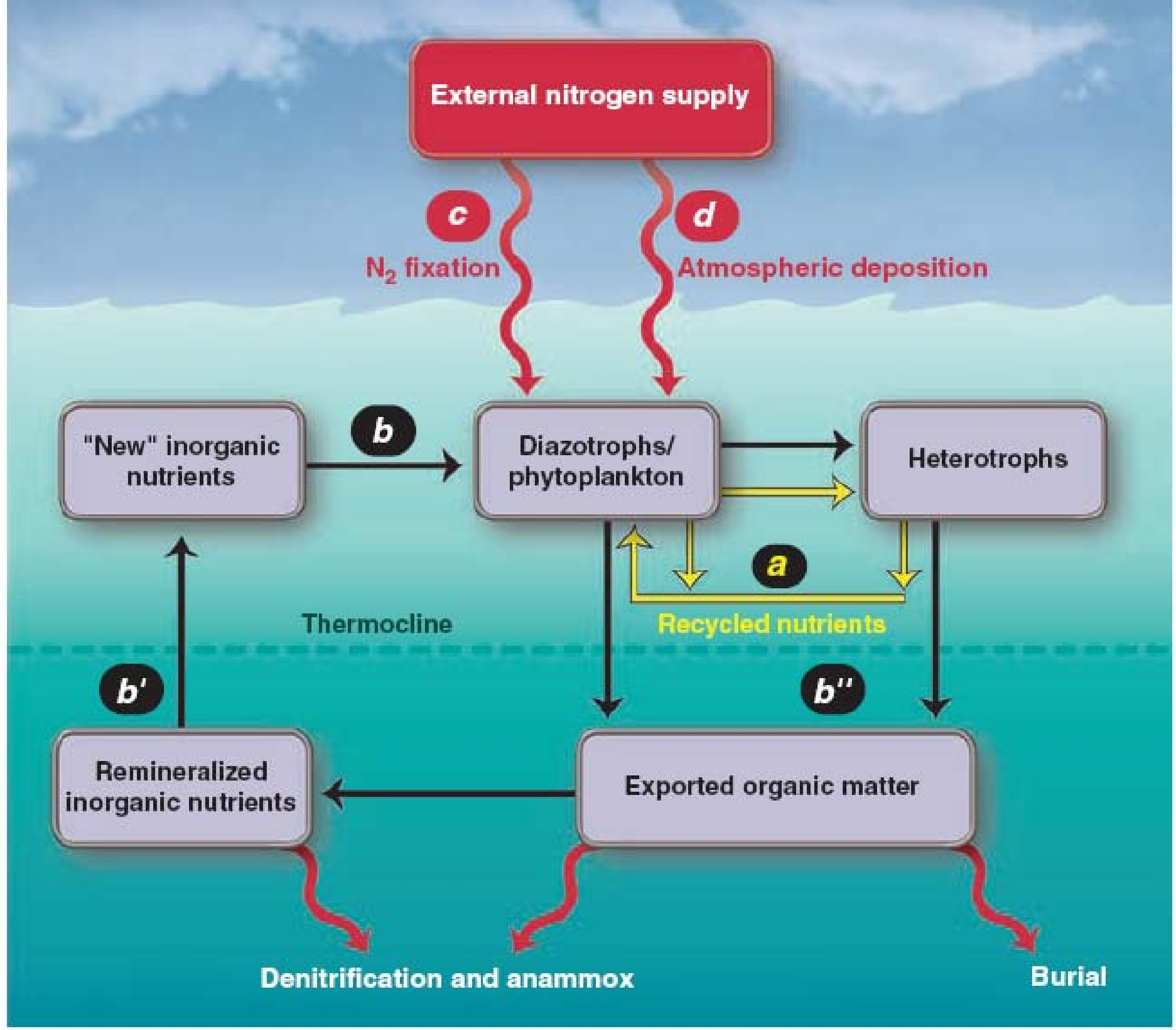


Fig. 2. Schematic of the processes supplying nutrients for surface primary production. See text for detailed description.

Impacts of Atmospheric Anthropogenic Nitrogen on the Open Ocean
R. A. Duce, *et al.*
Science **320**, 893 (2008);

Despite requirement for balance, estimates of export and new production are much higher …

than estimates of nutrient supplies by diffusion, entrainment, atmospheric deposition.

Are eddies a significant source?

How about N-fixation?

Williams and Follows, 2003

euphotic zone. This fraction is referred to as export production. Estimates of export production over subtropical gyres reach 0.48 ±0.14 mol N m^{-2} yr^{-1} in the Sargasso Sea from transient-tracer and oxygen diagnostics (Jenkins 1982, 1988; Jenkins and Goldman 1985), as well as 0.19 mol N m^{-2} yr^{-1} near Hawaii from sediment-trap estimates (Emerson et al. 1997).

For example, over the Sargasso Sea, the supply of nitrate from the traditionally considered sources only amounts typically to 0.21 mol N m^{-2} yr^{-1} (see the review by McGillicuddy et al. 1998); the separate contributions are 0.13 ±0.05 mol N m^{-2} yr^{-1} from entrainment (Michaels et al. 1994), 0.05 ±0.01 mol N m^{-2} yr^{-1} from diapycnic diffusion (Lewis et al. 1986) and 0.03 mol N m^{-2} yr^{-1} from atmospheric deposition (Knap et al. 1986). Accordingly, the shortfall in the nutrient supply over the Sargasso Sea needed to explain the transient-tracer and oxygen based estimates of export production is typically 0.27 mol N m^{-2} yr^{-1}. Part of this mismatch might be explained by a further source of nitrogen due to nitrogen fixation over the subtropical North Atlantic; this source is implied by a geochemical signal of an increased nitrate/phosphate ratio in the underlying thermocline (Michaels et al. 1996; Gruber and Sarmiento 1997).

Table 2. Atmospheric nitrogen deposition to the ocean in 2000 and its impact on productivity. Global-scale estimates of total primary production (*23*); new production (*24–26*); N_2 fixation (*2*, *6–8*). Most letters in italics refer to flux pathways in Fig. 2.

		Global ocean nitrogen (Tg N $year^{-1}$)	Resultant global ocean productivity (Pg C $year^{-1}$)
Total primary production (*a+b+c+d*)		~8800 (7000–10,500)	~50 (40–60)
New production (NP) (*b*)		~1900 (1400–2600)	~11 (8–15)
Marine N_2 fixation (*c*)		~100 (60–200)	~0.57 (0.3–1.1)
Total net N_r deposition (*d*) (NO_y+NH_x+Org. N_r)		~67 (38–96)	~0.38 (0.22–0.55)
Total external nitrogen supply (*c+d*)		~167 (98–296)	~0.95 (0.56–1.7)
Anthropogenic N_r deposition (AAN) (*e*)		~54 (31–77)	~0.31 (0.18–0.44)
Marine N_2 fixation as % NP N_r	= *c/b*	~5.3% (2.3–14.3%)	
Total N_r deposition as % NP N_r	= *d/b*	~3.5% (1.5–6.9%)	
AAN as % NP N_r	= *e/b*	~2.8% (1.2–5.5%)	
Total N_r deposition as % external N supply	= *d/(c+d)*	~40% (13–98%)	
AAN as % external N supply	= *e/(c+d)*	~32% (10–79%)	

Impacts of Atmospheric Anthropogenic Nitrogen on the Open Ocean

R. A. Duce, *et al.*

Science **320**, 893 (2008);
DOI: 10.1126/science.1150369

Vertical Nitrate Fluxes in the Oligotrophic Ocean

MARLON R. LEWIS, W. GLEN HARRISON, NEIL S. OAKEY,
DAVID HEBERT, TREVOR PLATT

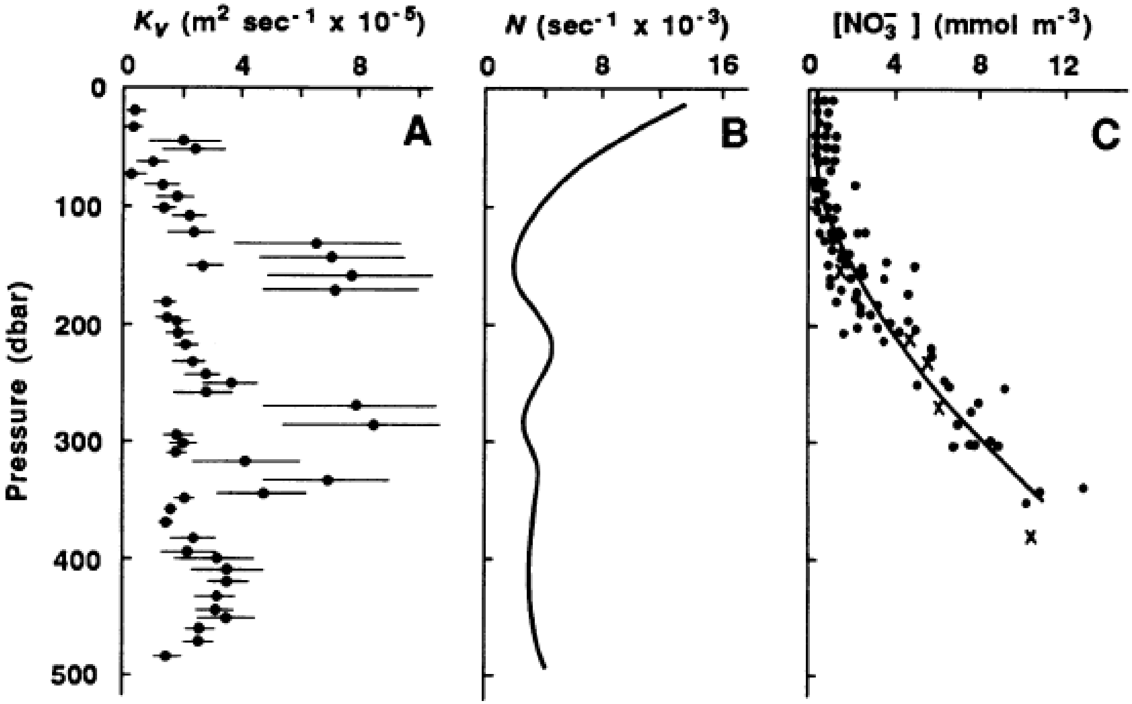


Fig. 1. Depth profiles (A) of eddy diffusivity, (B) buoyancy frequency, and (C) nitrate concentrations. Diffusivities are represented by 20-dbar averages calculated every 10 dbar, and the standard errors. For the nitrate profile, the solid line is the least-squares fit to Eq. 2. The x data points are from the GEOSECS expedition (*8*) in March.

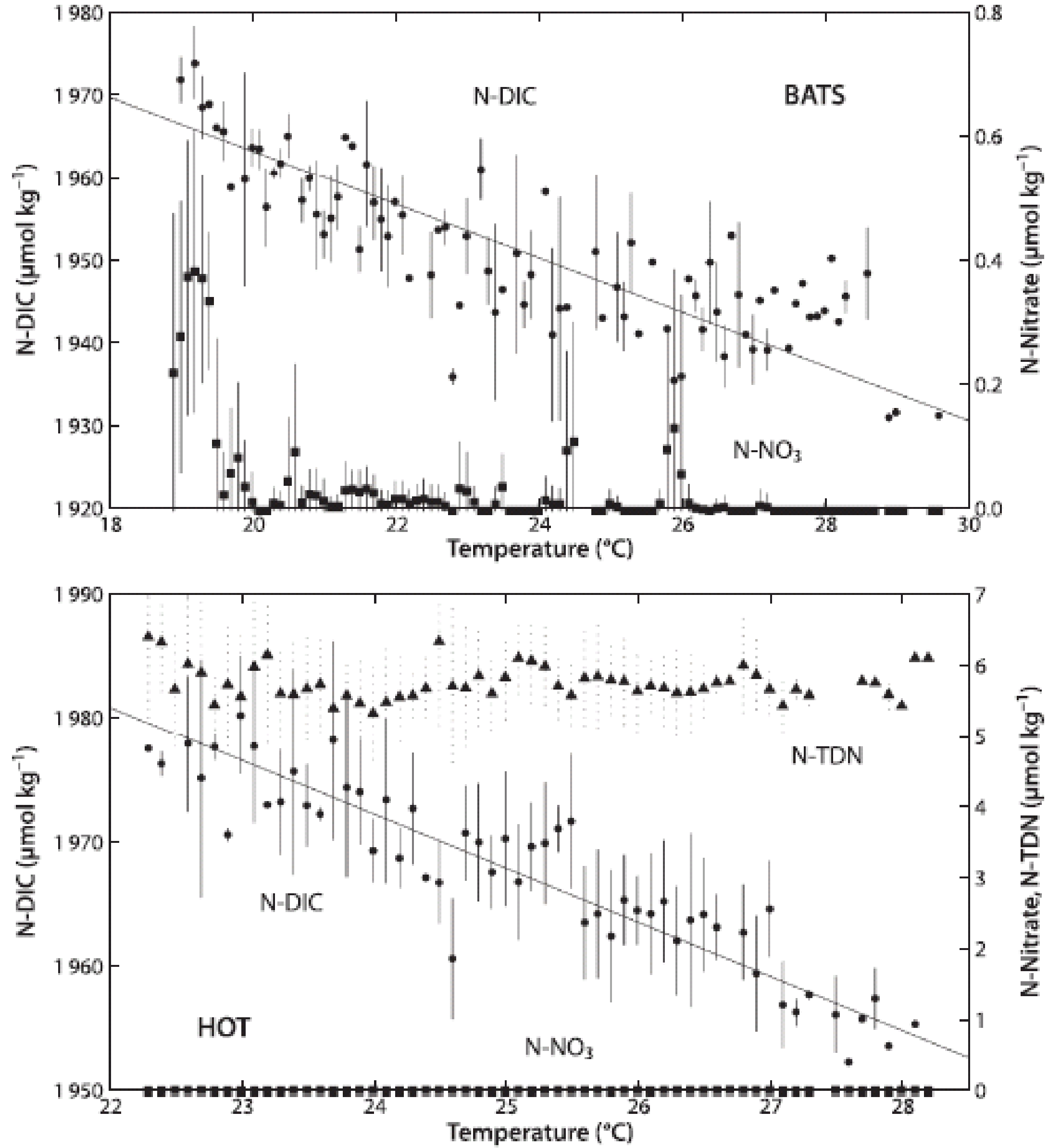
Low vertical fluxes imply "a biologically unproductive oligotrophic ocean".

Science, 234, 1986

The oligotrophic ocean is no longer considered “biologically unproductive”.

What supplies the nutrients to the oligotrophic ocean?

Fig. 10.11.
Relationships between carbon removal and fixed nitrogen in the surface waters of the subtropical North Atlantic (*top:* BATS) and subtropical North Pacific (*bottom:* HOT) during the period of summertime warming of the sea surface. At the BATS site, DIC normalized to a salinity of 35 (N-DIC) shows a systematic decrease with increasing temperature even in the absence of nitrate. At the HOT site, a similar summertime N-DIC drawdown in the absence of nitrate (the surface water nitrate concentration at Sta. ALOHA during the summer period is always less than 0.01 µmol kg^{-1}). Analyses of salinity-normalized total dissolved N (N-TDN) also failed to document a simultaneous loss of fixed N from the much larger pool of dissolved organic N



Chapter 10

Temporal Studies of Biogeochemical Processes Determined from Ocean Time-Series Observations During the JGOFS Era

David M. Karl · Nicholas R. Bates · Steven Emerson · Paul J. Harrison · Catherine Jeandel · Octavio Llinás
Kon-Kee Liu · Jean-Claude Marty · Anthony F. Michaels · Jean C. Miquel · Susanne Neuer · Y. Nojiri · Chi Shing Wong

Fasham et al., 2003

…. only the net biological production of organic matter can explain the Bermuda (and now Hawaii) mystery. There are three potential sources of new N: (*1*) N2-fixation, (*2*) atmospheric deposition, and (*3*) active transport via vertically migrating phytoplankton. A careful assessment of these potential sources at both sites has revealed a significant role for N2 fixation as a new export and production pathway (Michaels et al. 2000). This does not necessarily solve the BATS and HOT disappearing N-DIC mysteries, but it does provide a hypothesis for future field evaluation.

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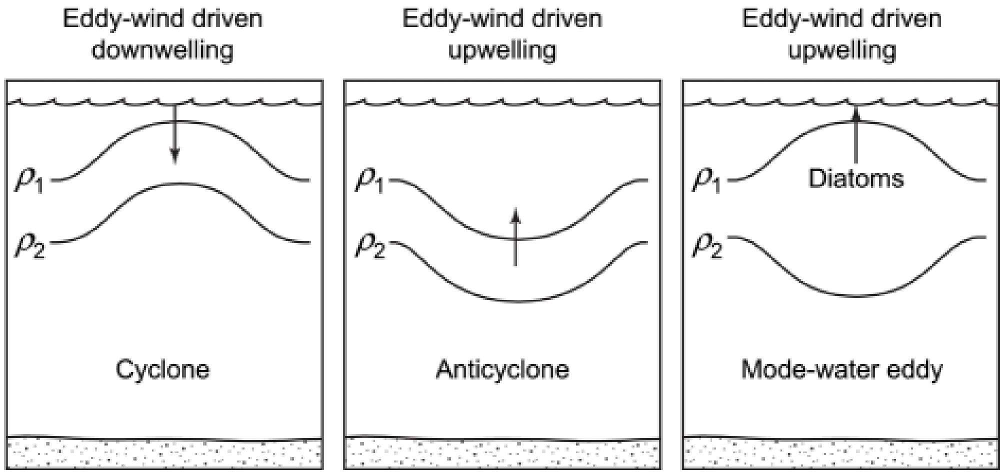
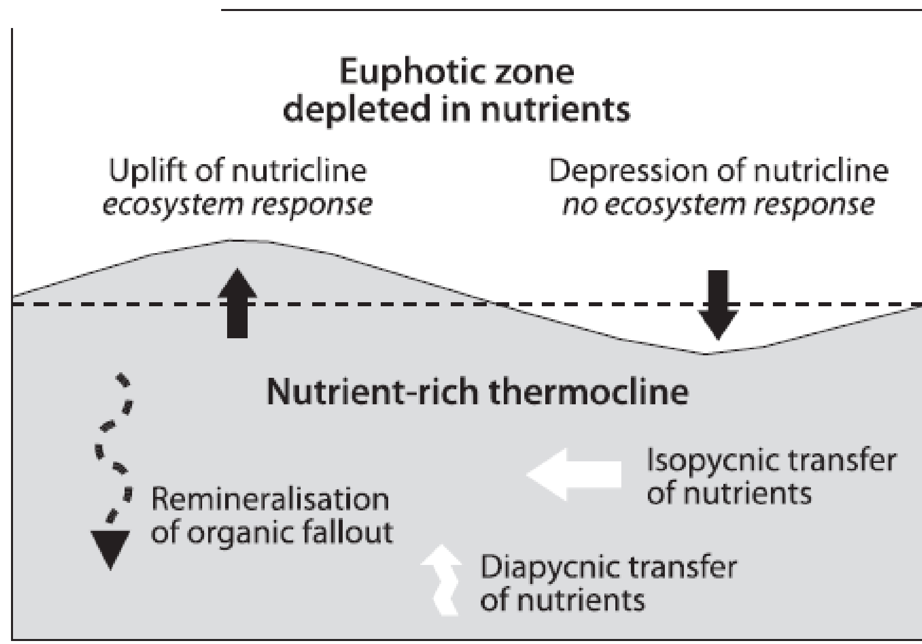
What about eddies? Cyclonic eddies cause thermocline to uplift, raising nutrients into euphotic zone.





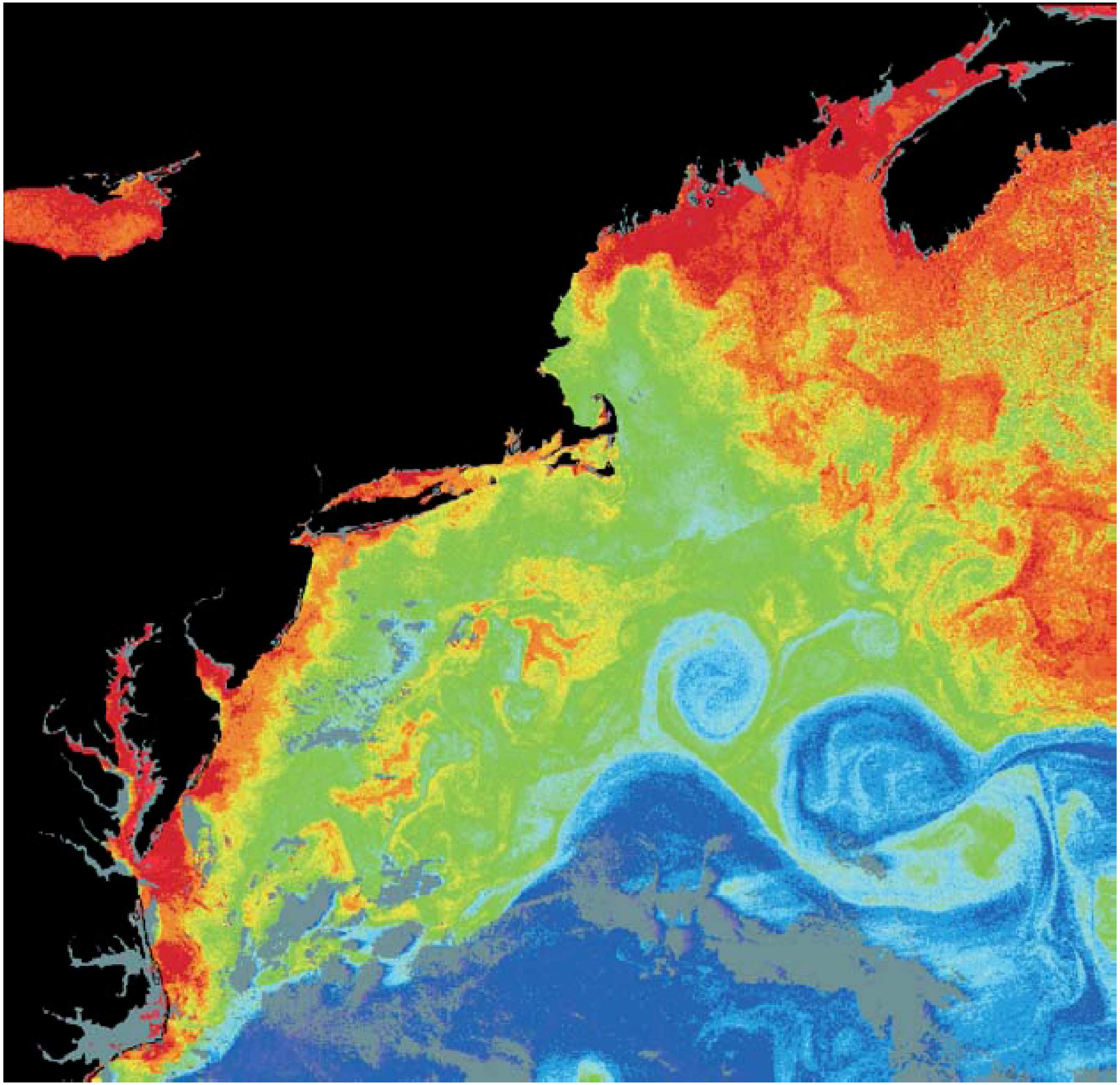


Fig. 2.15.
Chlorophyll picture derived from CZCS over the Northwestern Atlantic. Higher concentrations of chlorophyll (*red*) are evident along the coastal boundary and at higher latitudes. Lower concentrations (*blue*) correlate with the Gulf Stream boundary, the subtropical gyre and anticyclonic eddies. Note the range of physical processes revealed here including boundary currents, mesoscale eddies and finer-scale fronts and filaments (figure courtesy of NASA)

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Eddy/Wind Interactions Stimulate Extraordinary Mid-Ocean Plankton Blooms

Dennis J. McGillicuddy Jr.,[1]* Laurence A. Anderson,[1] Nicholas R. Bates,[2] Thomas Bibby,[3,4] Ken O. Buesseler,[1] Craig A. Carlson,[5] Cabell S. Davis,[1] Courtney Ewart,[5] Paul G. Falkowski,[3] Sarah A. Goldthwait,[6,7] Dennis A. Hansell,[8] William J. Jenkins,[1] Rodney Johnson,[2] Valery K. Kosnyrev,[1] James R. Ledwell,[1] Qian P. Li,[8] David A. Siegel,[5] Deborah K. Steinberg[6]

Episodic eddy-driven upwelling may supply a significant fraction of the nutrients required to sustain primary productivity of the subtropical ocean. New observations in the northwest Atlantic reveal that, although plankton blooms occur in both cyclones and mode-water eddies, the biological responses differ. Mode-water eddies can generate extraordinary diatom biomass and primary production at depth, relative to the time series near Bermuda. These blooms are sustained by eddy/wind interactions, which amplify the eddy-induced upwelling. In contrast, eddy/wind interactions dampen eddy-induced upwelling in cyclones. Carbon export inferred from oxygen anomalies in eddy cores is one to three times as much as annual new production for the region.

Understanding the controls on primary production in the upper ocean is of fundamental importance for two main reasons. First, primary productivity sets a first-order constraint on the energy available to sustain oceanic ecosystems. Second, fixation and subsequent sinking of organic particles remove carbon from the surface ocean (the so-called biological

But eddy driven upwelling that brings up NO_3, also brings up inorganic carbon and there should be no TCO_2 drawdown!

…. only the net biological production of organic matter can explain the Bermuda (and now Hawaii) mystery. There are three potential sources of new N: (*1*) N2-fixation, (*2*) atmospheric deposition, and (*3*) active transport via vertically migrating phytoplankton. A careful assessment of these potential sources at both sites has revealed a significant role for N2 fixation as a new export and production pathway (Michaels et al. 2000). This does not necessarily solve the BATS and HOT disappearing N-DIC mysteries, but it does provide a hypothesis for future field evaluation.

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Upward transport of oceanic nitrate by migrating diatom mats

Tracy A. Villareal*, Cynthia Pilskaln†, Mark Brzezinski‡,
Fredric Lipschultz§, Mark Dennett‖ & George B. Gardner¶

NATURE | VOL 397 | 4 FEBRUARY 1999 | www.nature.com

Buoyancy Regulation and the Potential for Vertical Migration in the Oceanic Cyanobacterium *Trichodesmium*

T.A. Villareal,[1] E.J. Carpenter[2]

MICROBIAL ECOLOGY

Microb Ecol (2003) 45:1–10

JOURNAL OF PLANKTON RESEARCH | VOLUME 27 | NUMBER 6 | PAGES 545–556 | 2005

Nitrogen inputs into the euphotic zone by vertically migrating *Rhizosolenia* mats

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Rhizosolenia mat nitrate release supplies at least 4–7% of the nitrate pool on daily basis, and possibly as much as 27%. Rhizosolenia mats are part of a large phytoplankton community that appears to migrate, and rates could be significantly higher. Literature reports suggest little or no nitrification in the upper euphotic zone, and thus biological transport and release of nitrate may be a major source to this region. This N release is uncoupled from upward CO_2 transport and, like N_2 fixation, provides a component of the N pool available for net carbon removal.

Singler and Villareal – SCUBA at 10 m, what's going on deeper?

Mann and Lazier, Dynamics of Marine Ecosystems

Typical tropical structure?

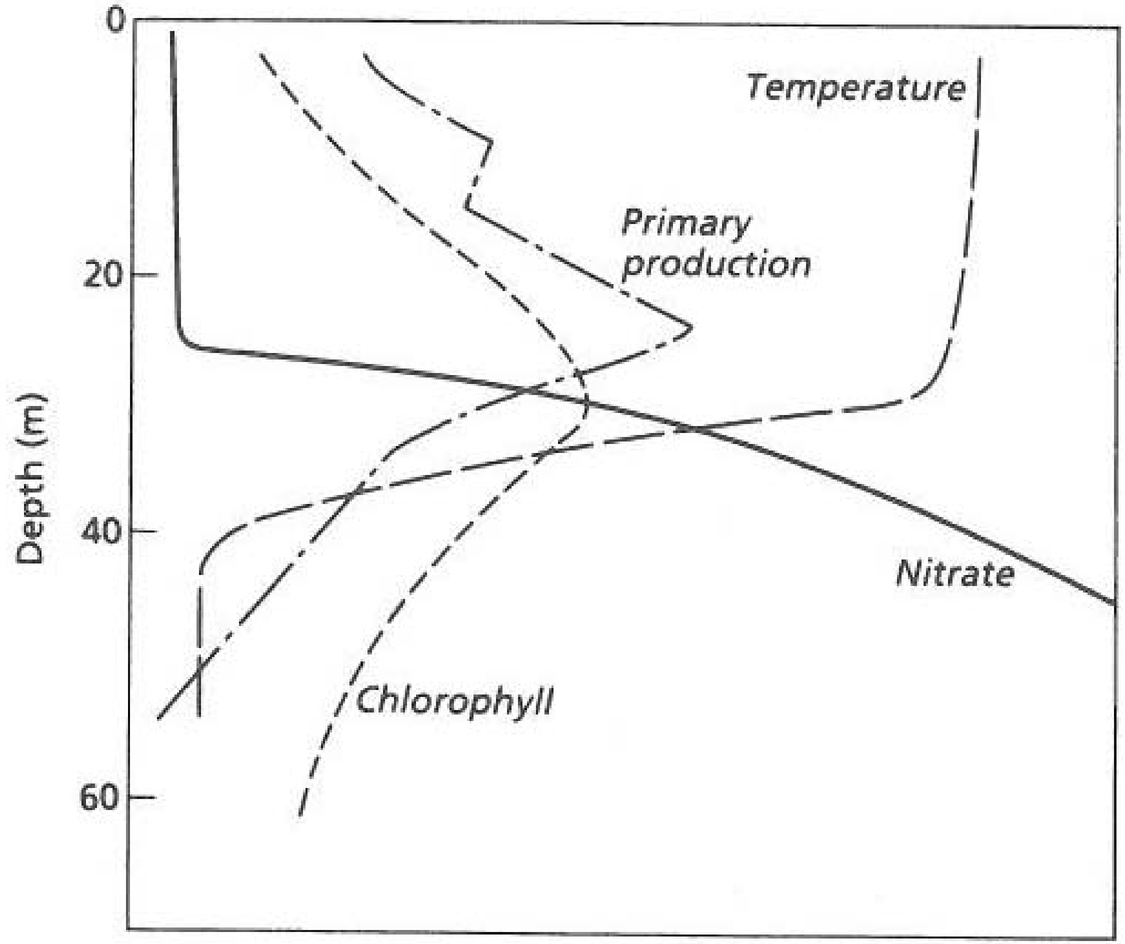
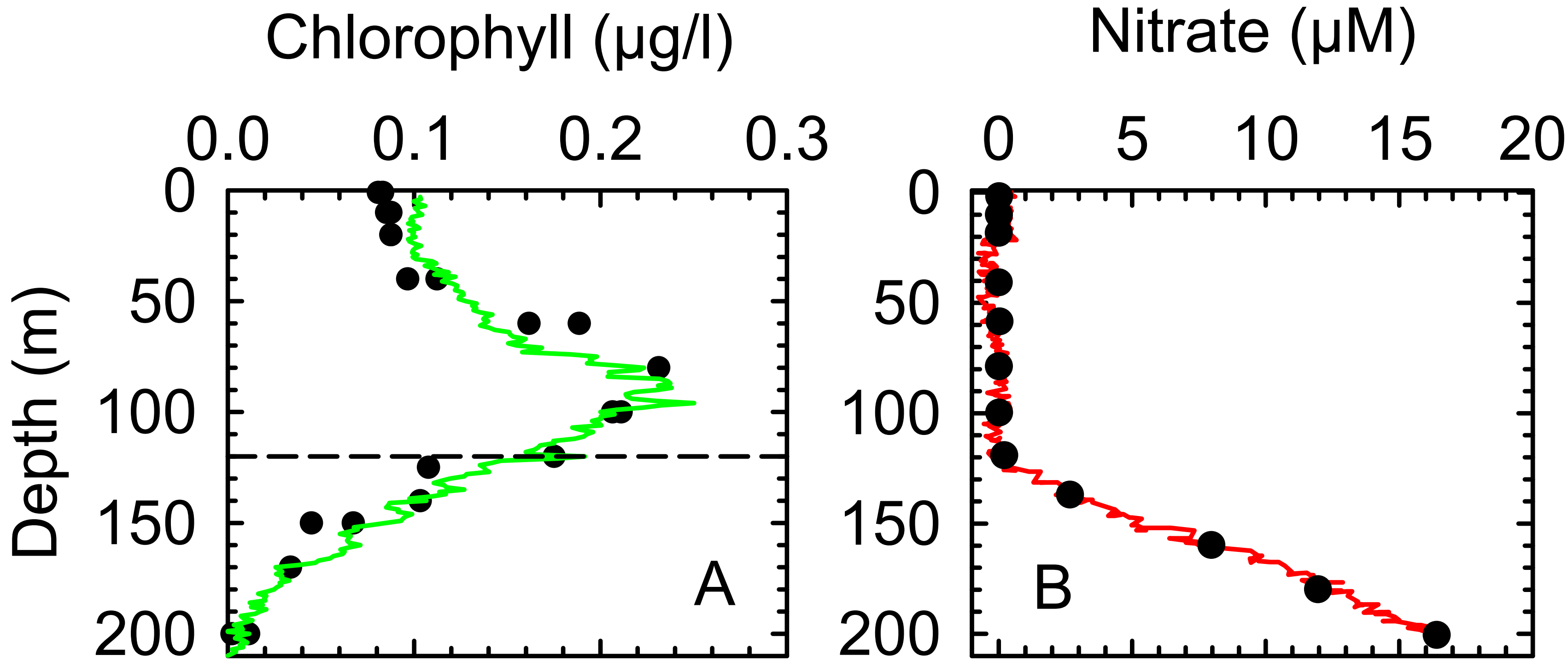
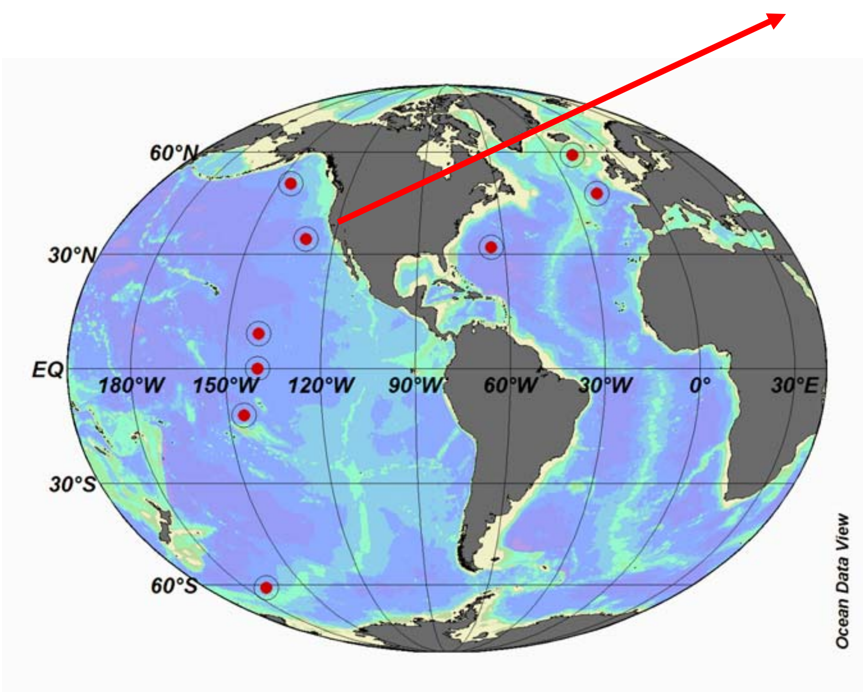
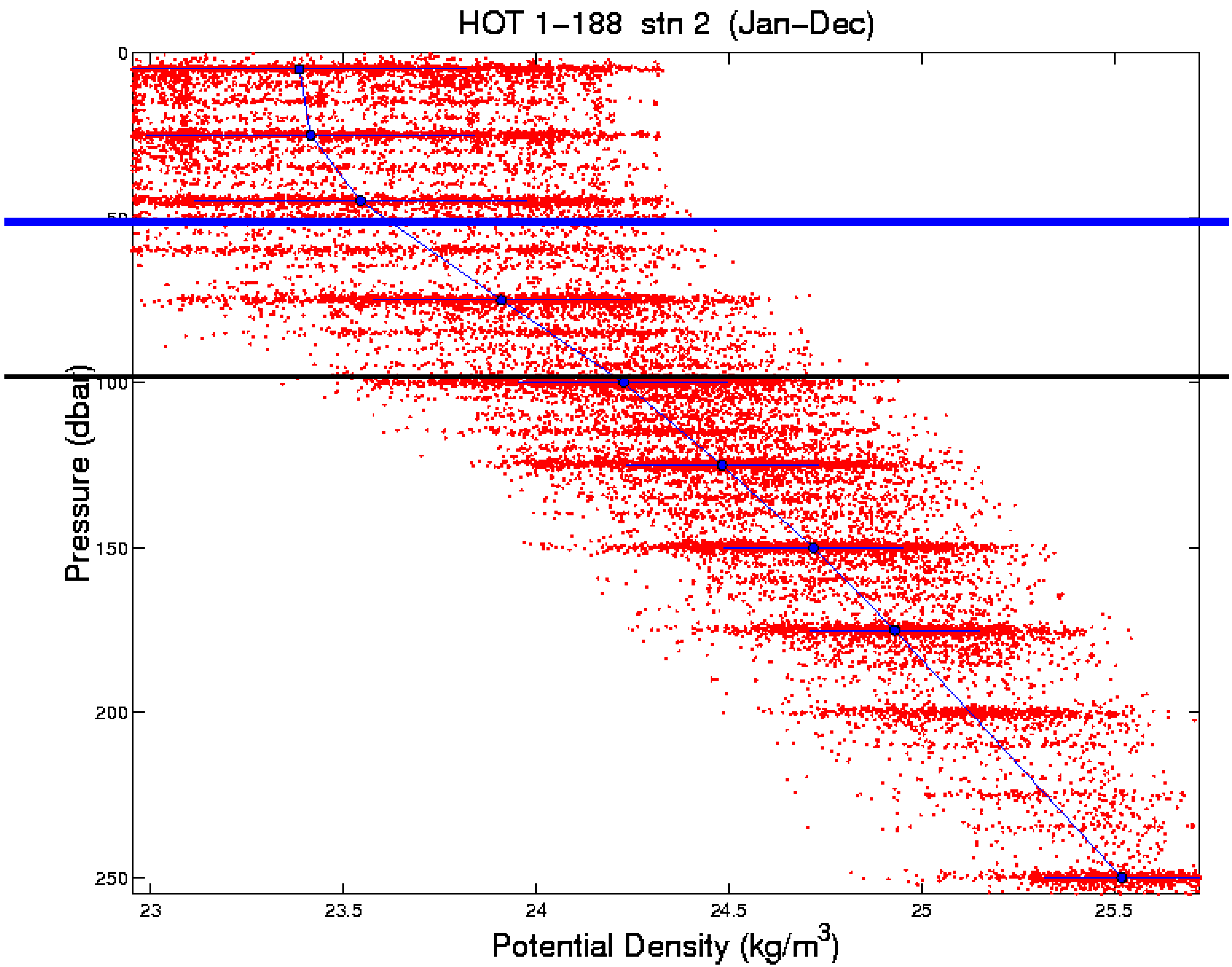


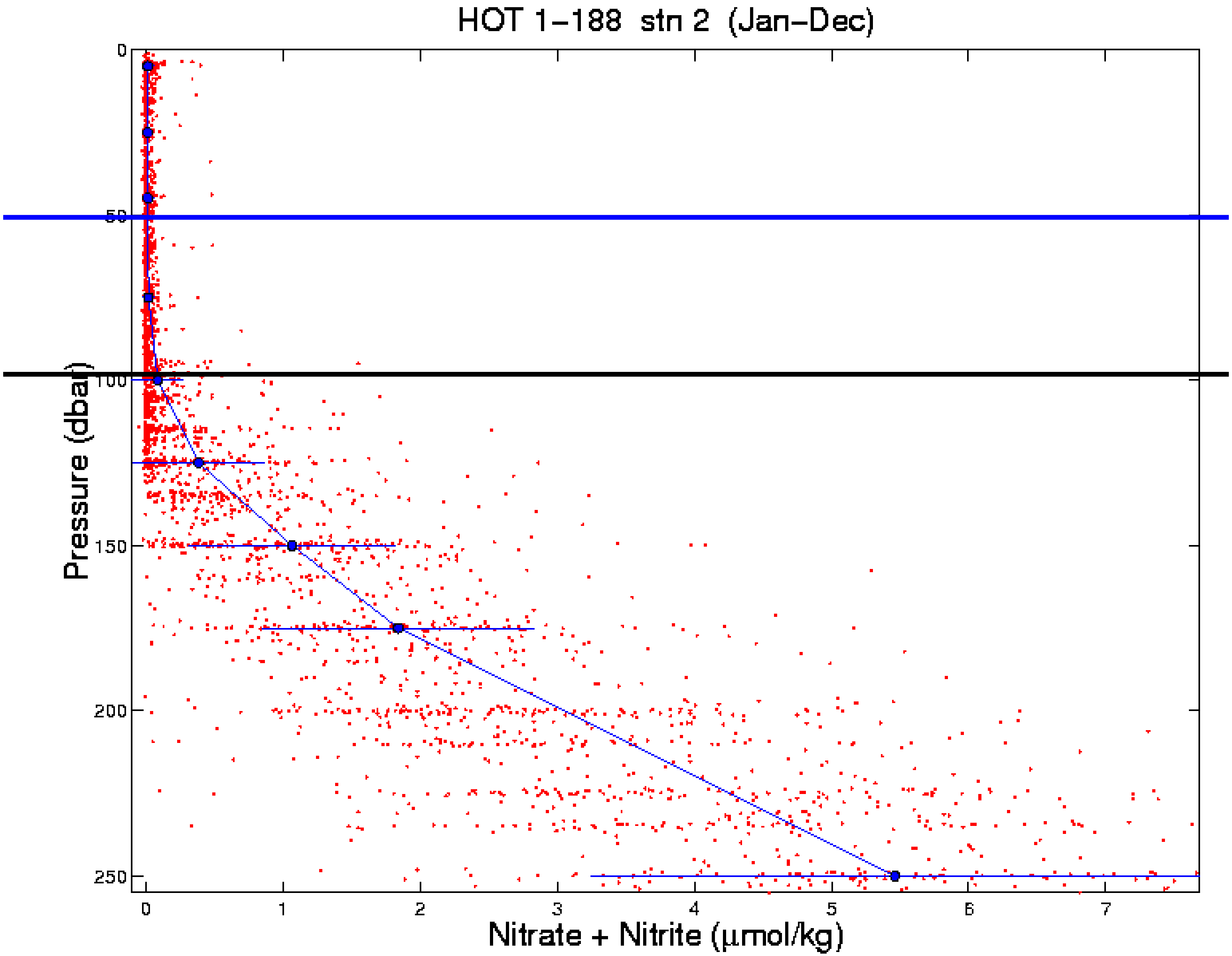
Fig. 3.01 Schematic diagram showing typical vertical structure of the water column in tropical latitudes ("typical tropical structure," TTS). Note that the thermocline and the nutricline are at the same depth. The peak of primary production is more shallow than the peak of chlorophyll (= phytoplankton biomass).

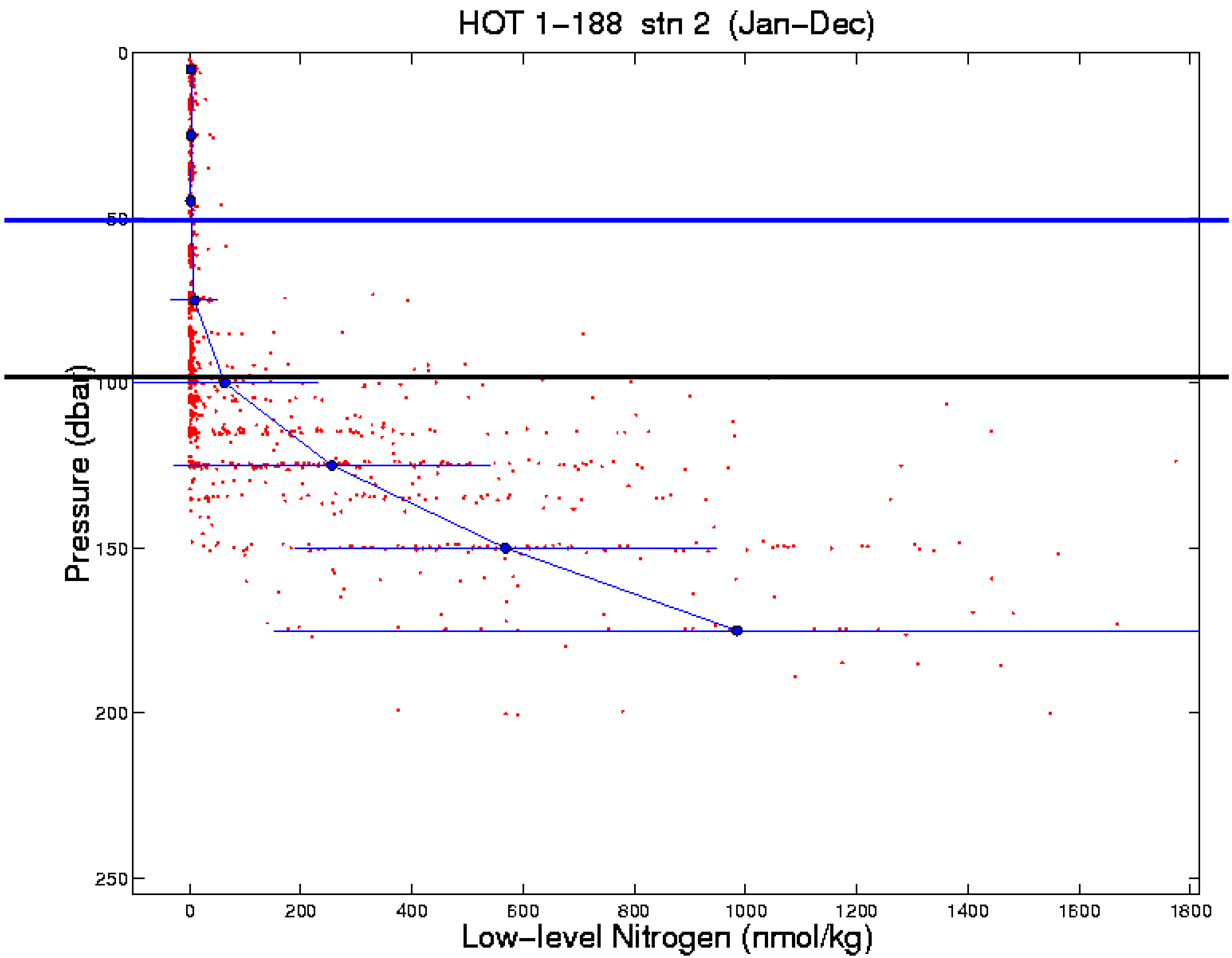


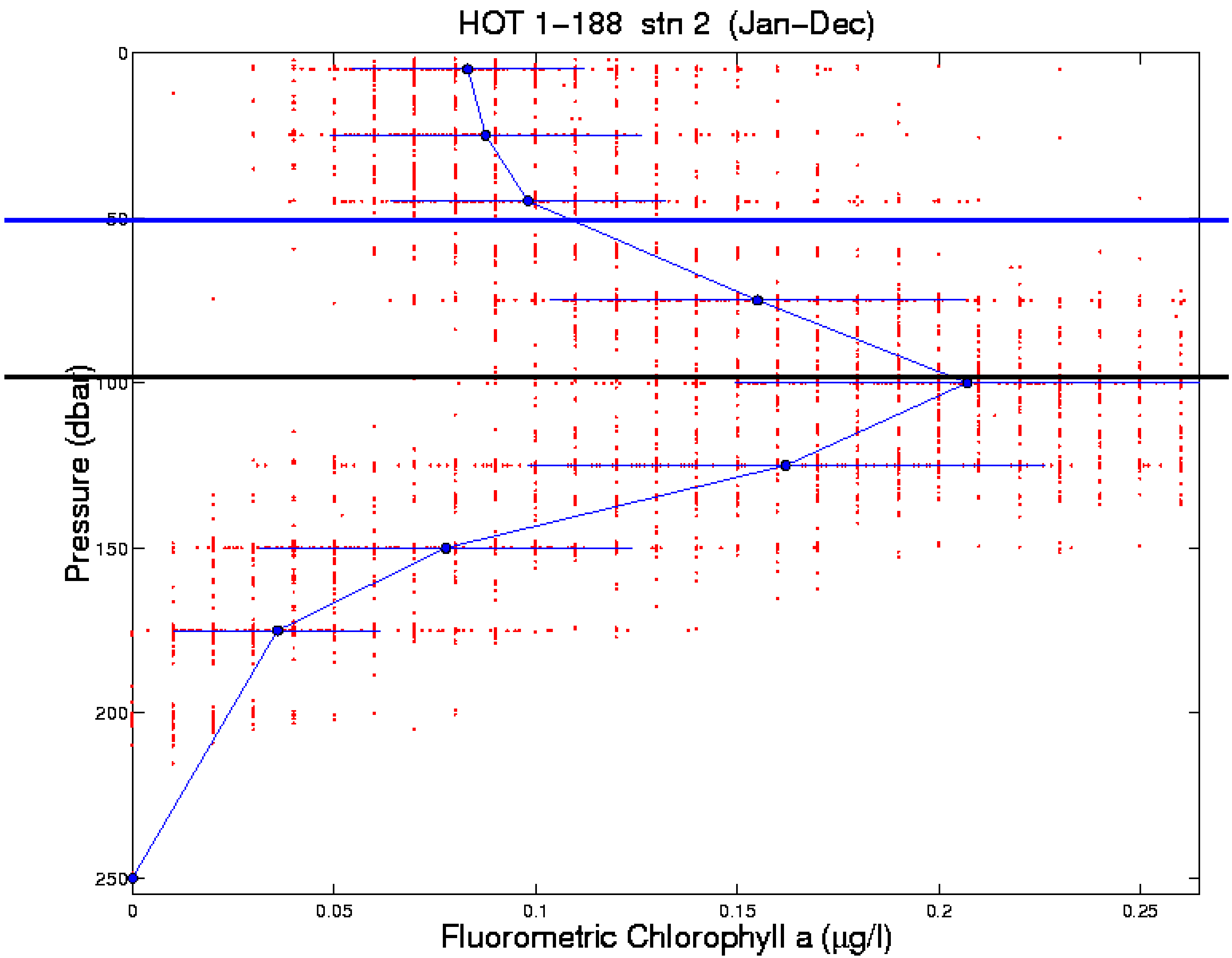


The classical paradigm: DCM is controlled by a balance between nitrate limitation at the surface and light limitation at depth (& turbulence, variable sinking, variable Chl/C…).

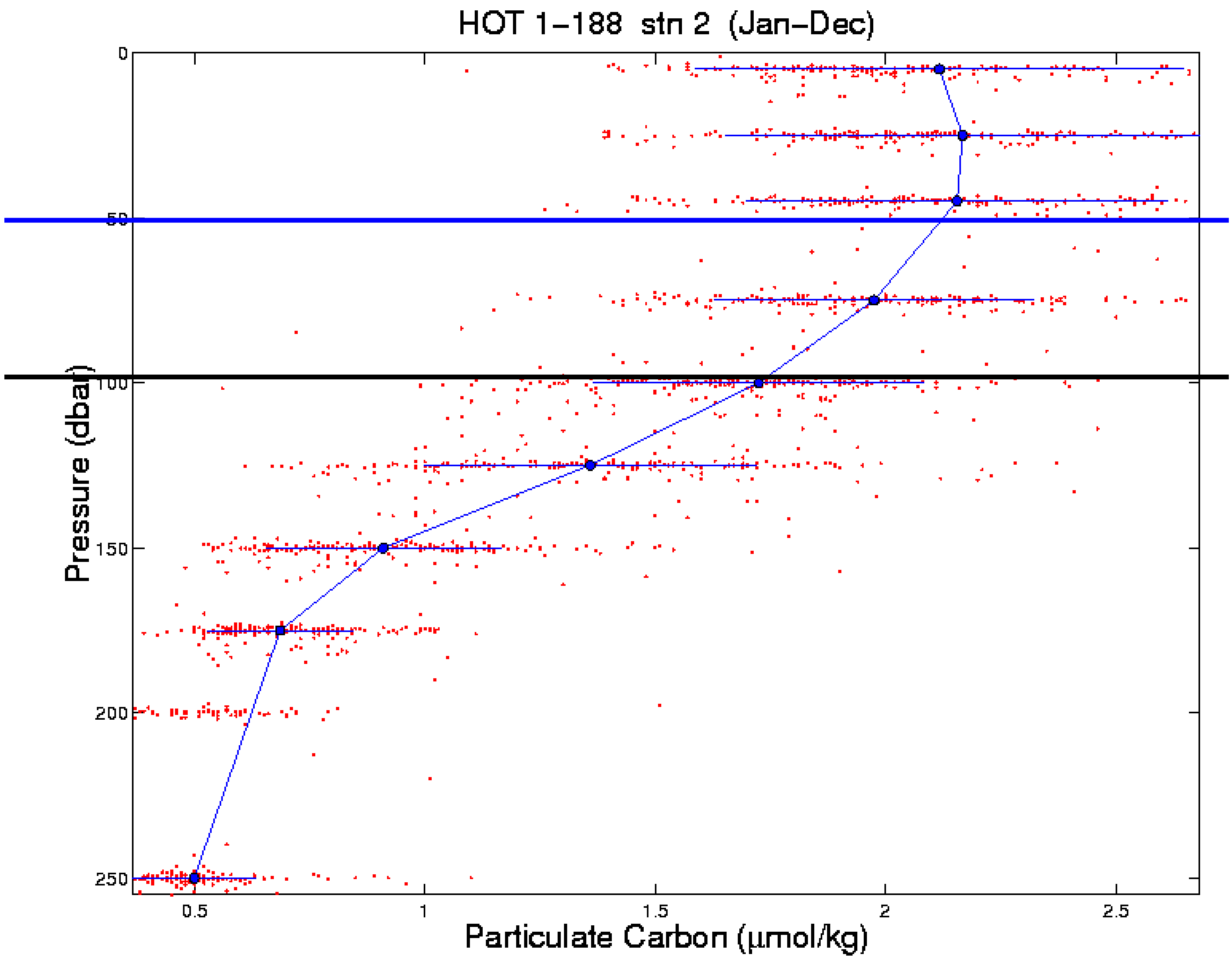

HOT 1-188 stn 2 (Jan-Dec)
Pressure (dbar)
Potential Density (kg/m3)
0
50
100
150
200
250
23
23.5
24
24.5
25
25.5


HOT 1–188 stn 2 (Jan–Dec)
Pressure (dbar)
0
50
100
150
200
250
0
1
2
3
4
5
6
7
Nitrate + Nitrite (µmol/kg)

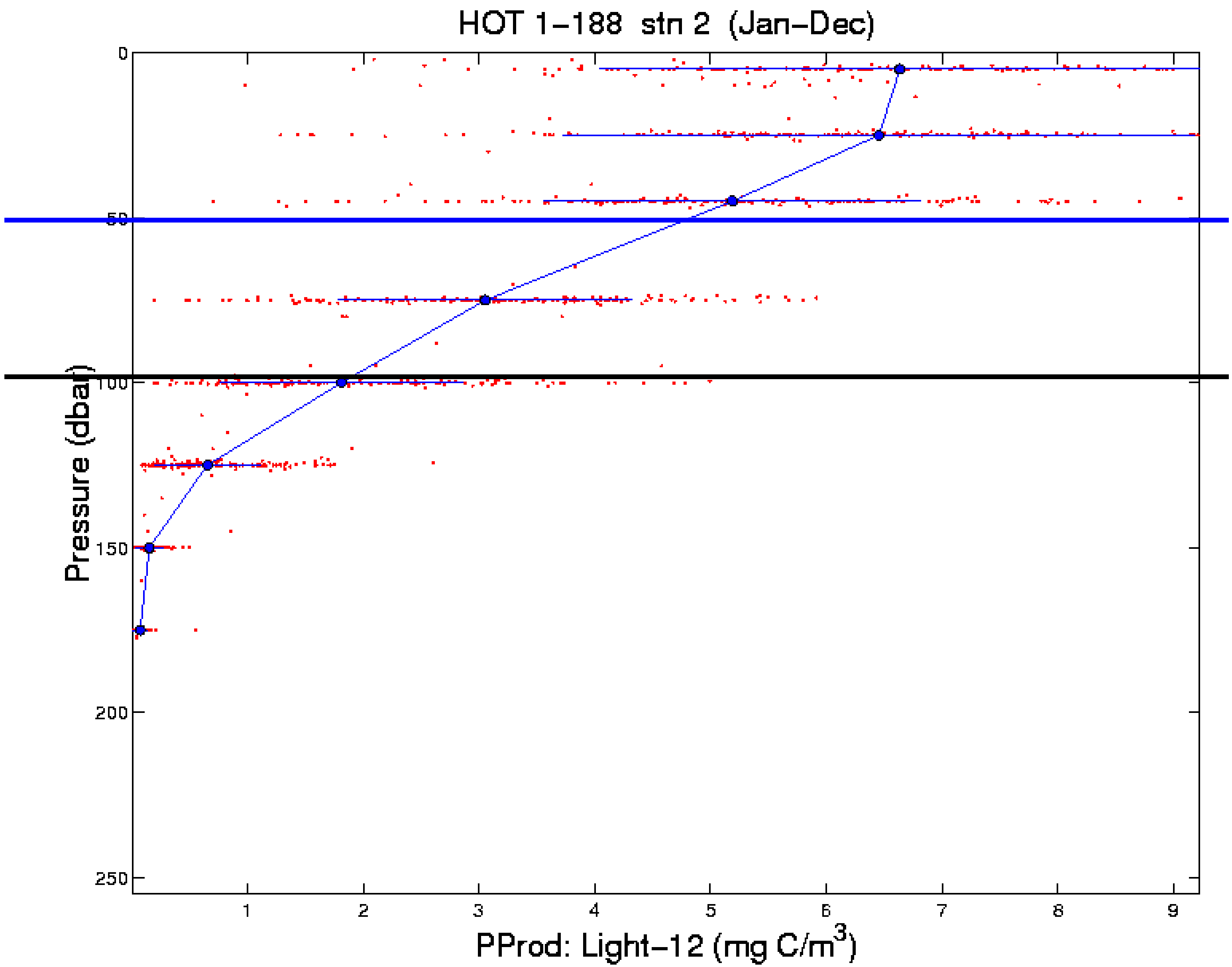

HOT 1-188 stn 2 (Jan-Dec)
Pressure (dbar)
Low-level Nitrogen (nmol/kg)
0
50
100
150
200
250
0
200
400
600
800
1000
1200
1400
1600
1800



HOT 1-188 stn 2 (Jan-Dec)
Pressure (dbar)
Fluorometric Chlorophyll a (µg/l)
0
50
100
150
200
250
0
0.05
0.1
0.15
0.2
0.25

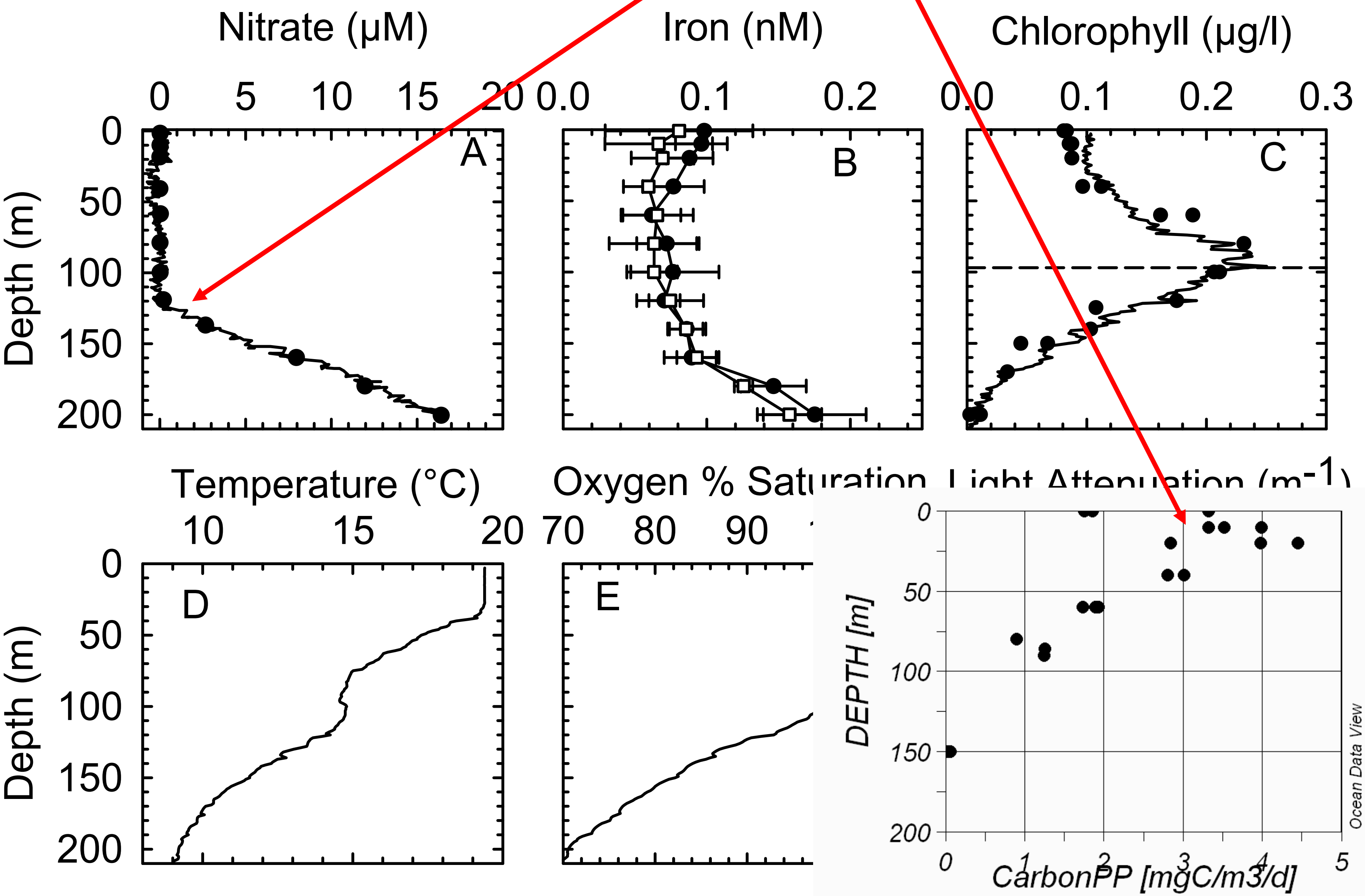


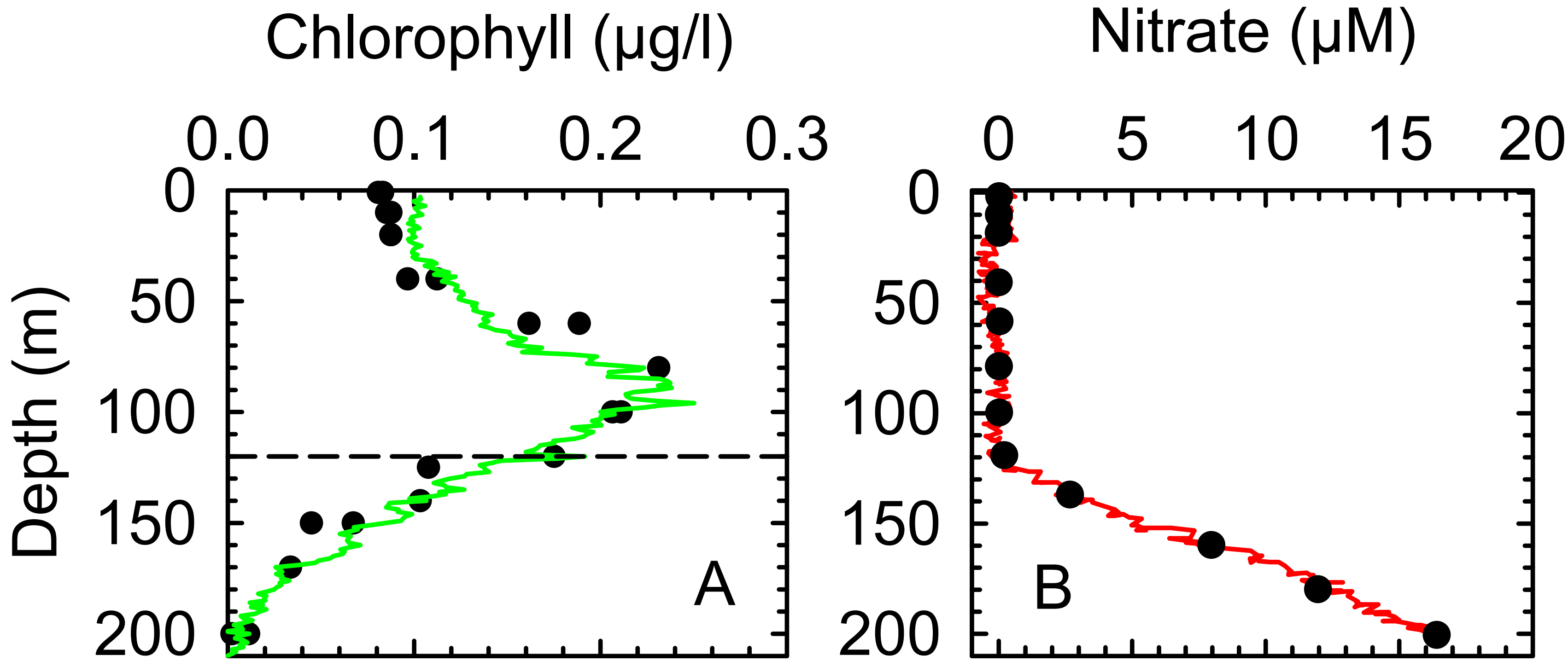
HOT 1−188 stn 2 (Jan−Dec)
Pressure (dbar)
Particulate Carbon (μmol/kg)
0
50
100
150
200
250
0.5
1
1.5
2
2.5

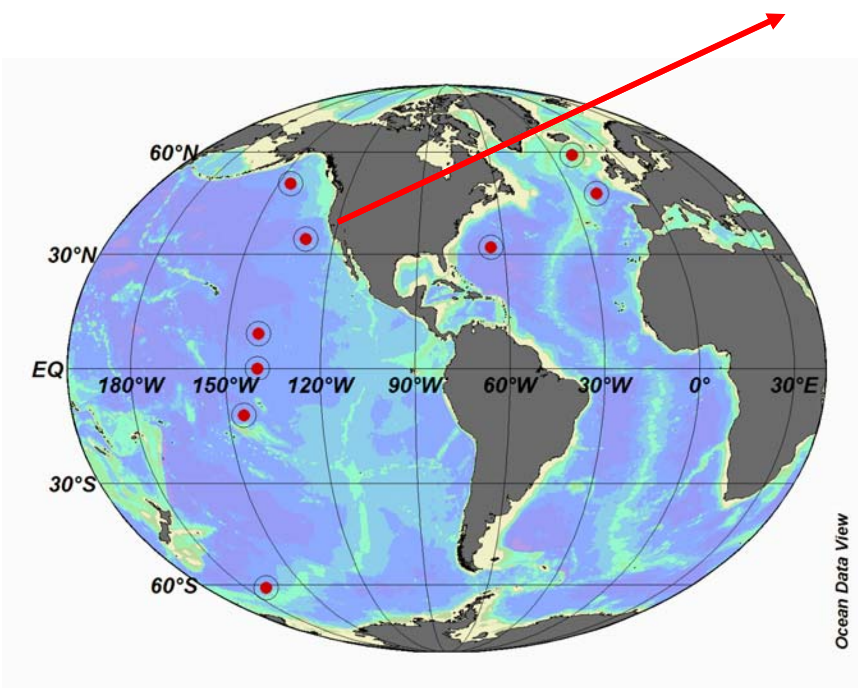


HOT 1-188 stn 2 (Jan-Dec)
Pressure (dbar)
PProd: Light-12 (mg C/m3)
0
50
100
150
200
250
1
2
3
4
5
6
7
8
9

FEVER 2005: biomass and primary production maxima are shallower than nitratecline. Is nitrate transported from here to here where production and biomass is highest? Tough to do by diffusion.

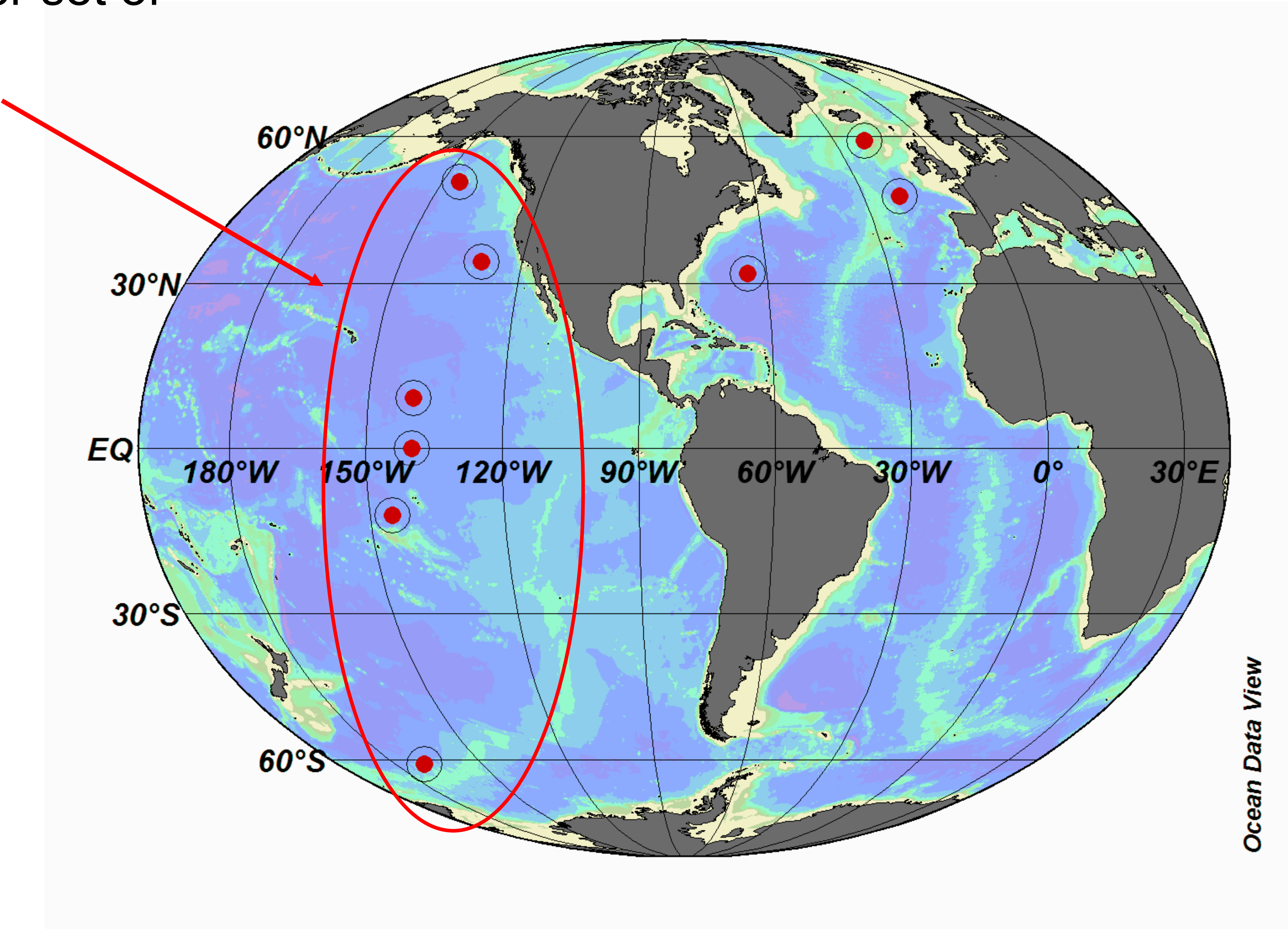




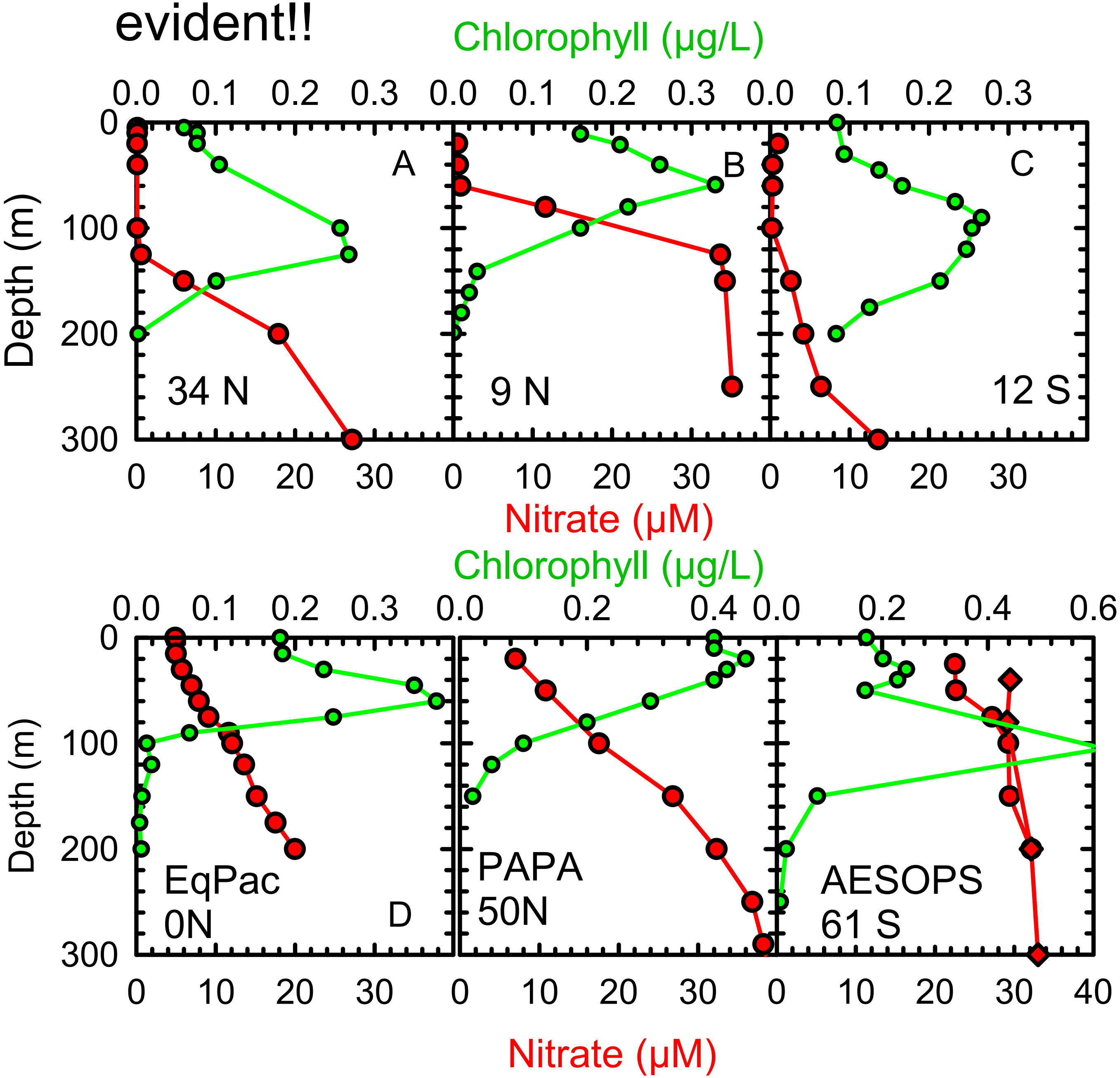


Why is there so much chlorophyll (and presumably biomass) below the nitracline?

Looking at a broader set of data:



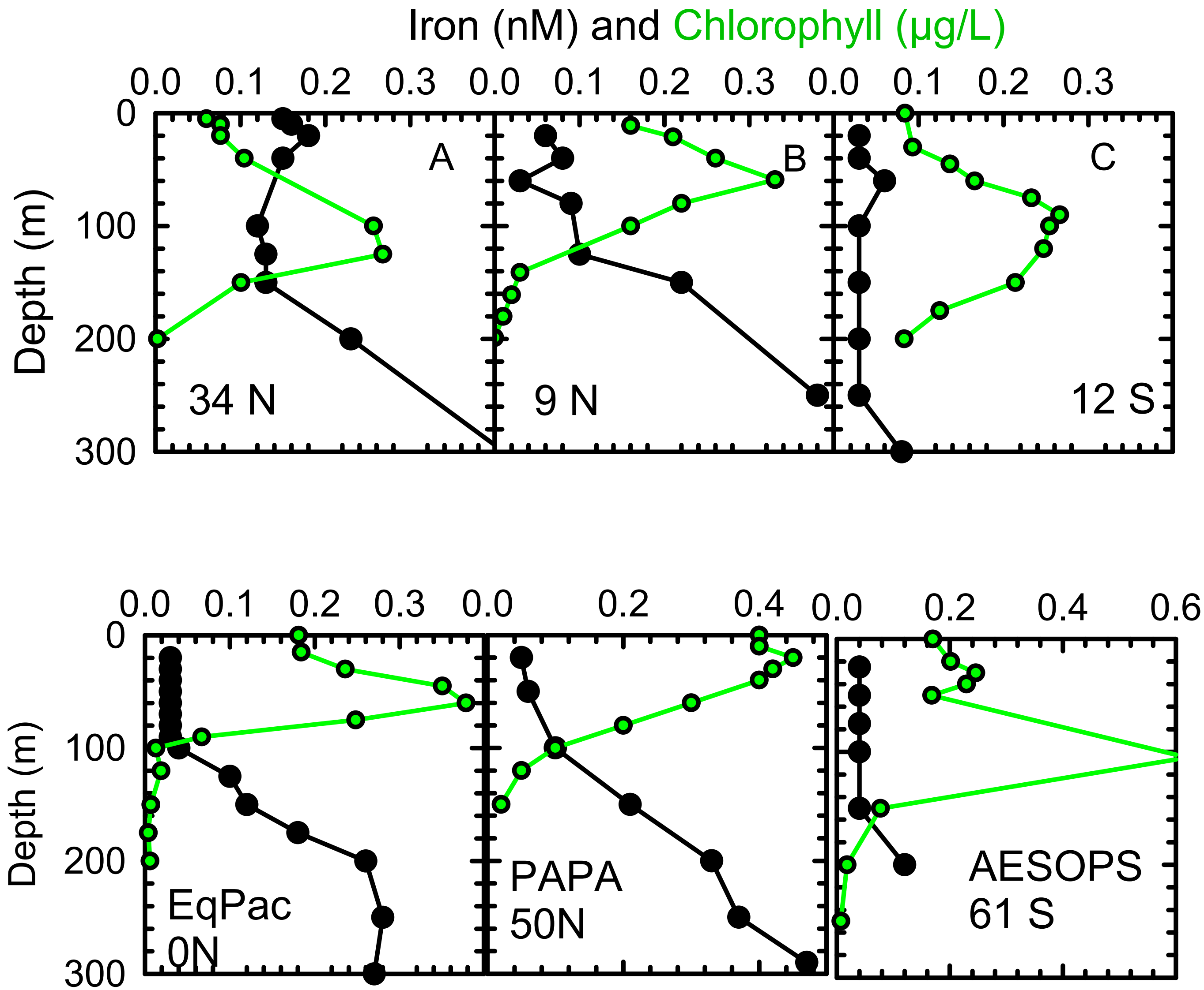
The linkage of chlorophyll to nitrate gradient is not very evident!!



Deep Chlorophyll Max near Nitracline.

Deep Chlorophyll Max but high nitrate all the way to the surface.

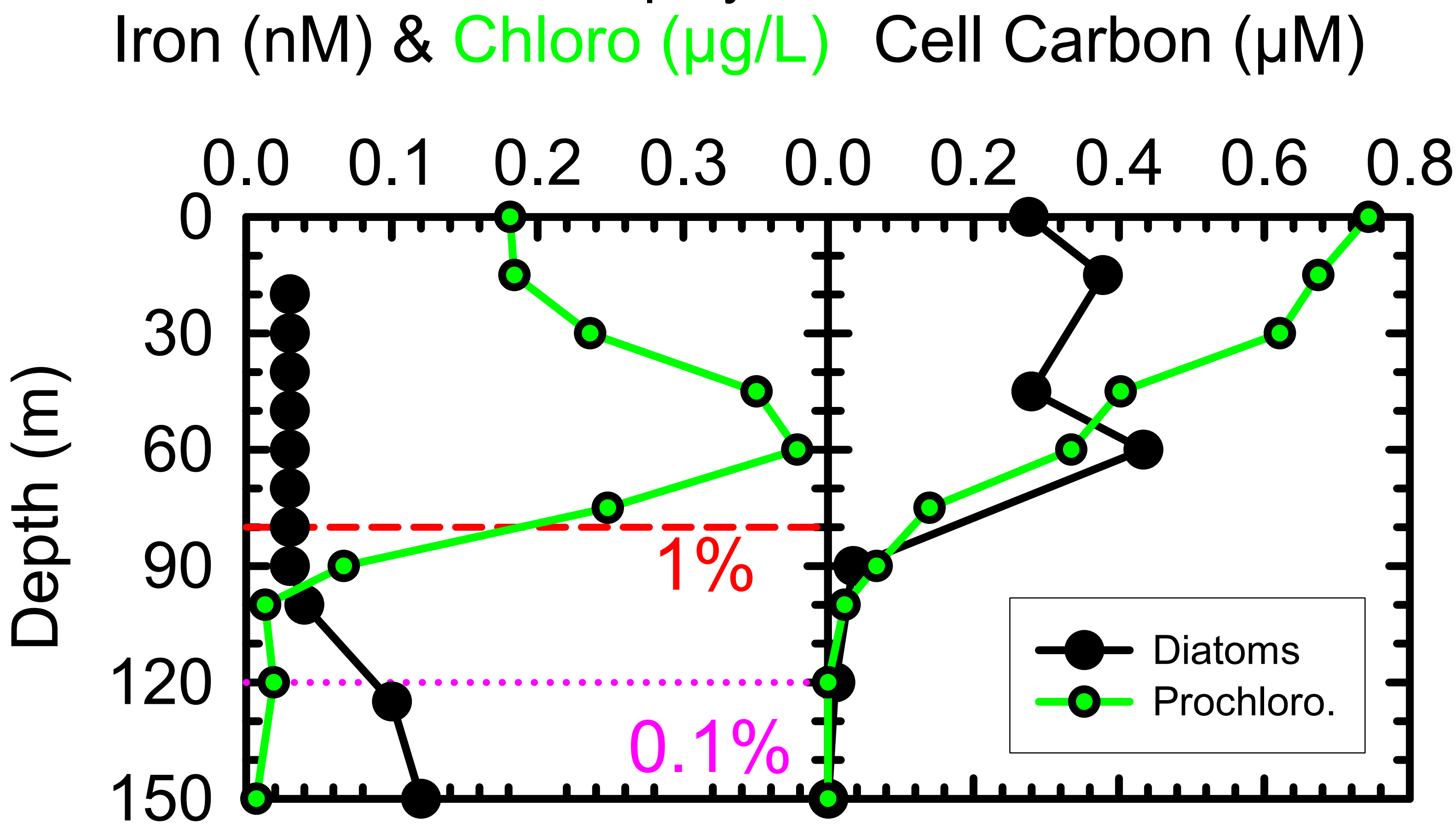
What is common in these profiles? The lower tail of the DCM ends at the ferricline!



Once there is a clear iron concentration increase, chlorophyll is no longer found.

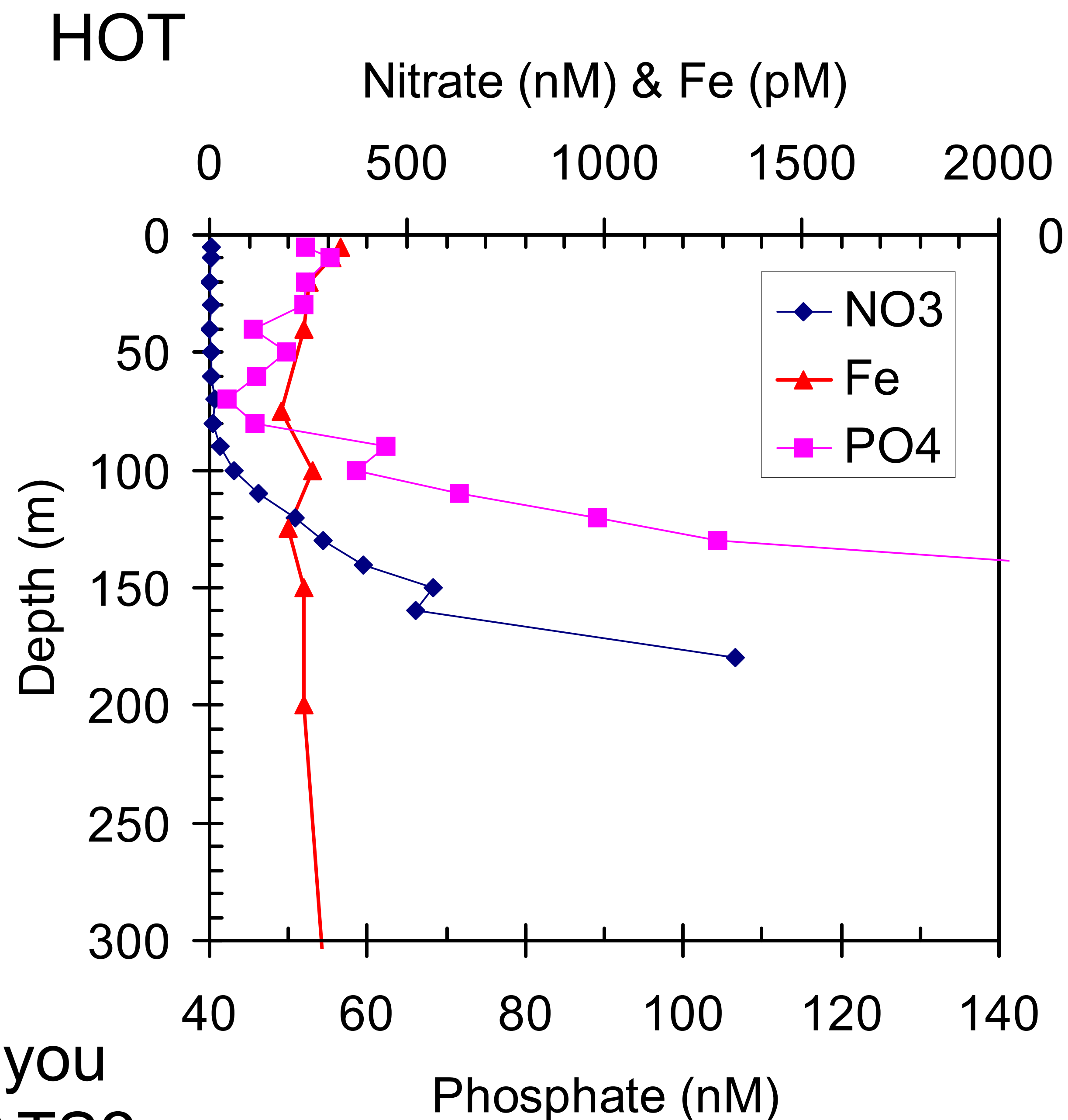
Presumably reflects iron uptake by phytoplankton at great depths, all the way to 250 m at 12 S and 150 m at 61 S.

A deep diatom community as well as bacterio-plankton are present at many sites (and no data at others). Can large diatoms migrate beneath euphotic zone to acquire Fe? Is nitrate transported from nitracline to surface? What role do picoplankton play?



US JGOFS EqPac – Oct 1992 0N, 140W

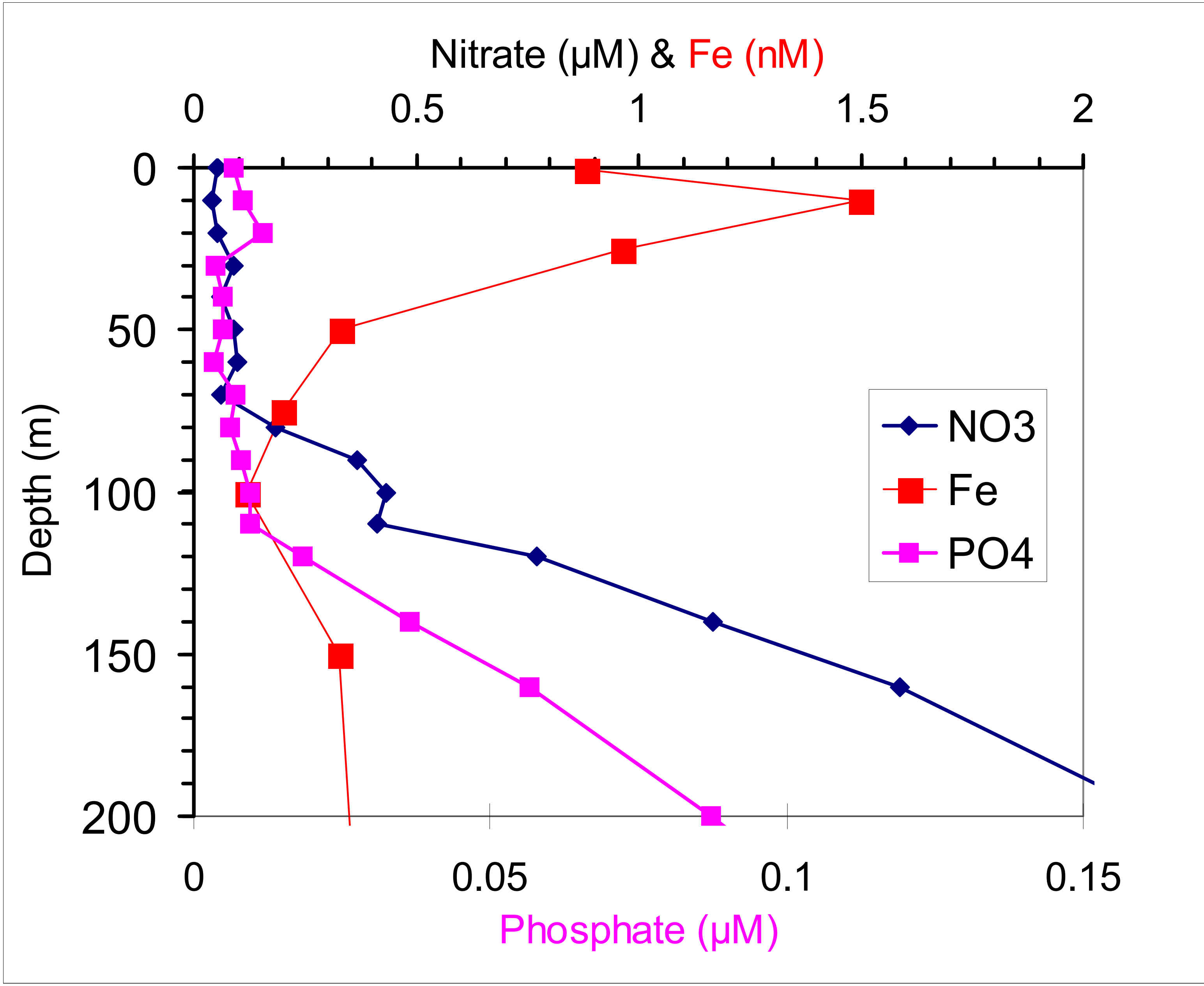
Vertical migration would separate the most limiting nutrient from others by driving it’s “cline” down to greater depth.



What would you predict at BATS?

BATS

Has lots of Fe. This enables N-fix. so PO4 becomes limiting



Even with N_2 fixation, where does required PO_4^{3-} come from?

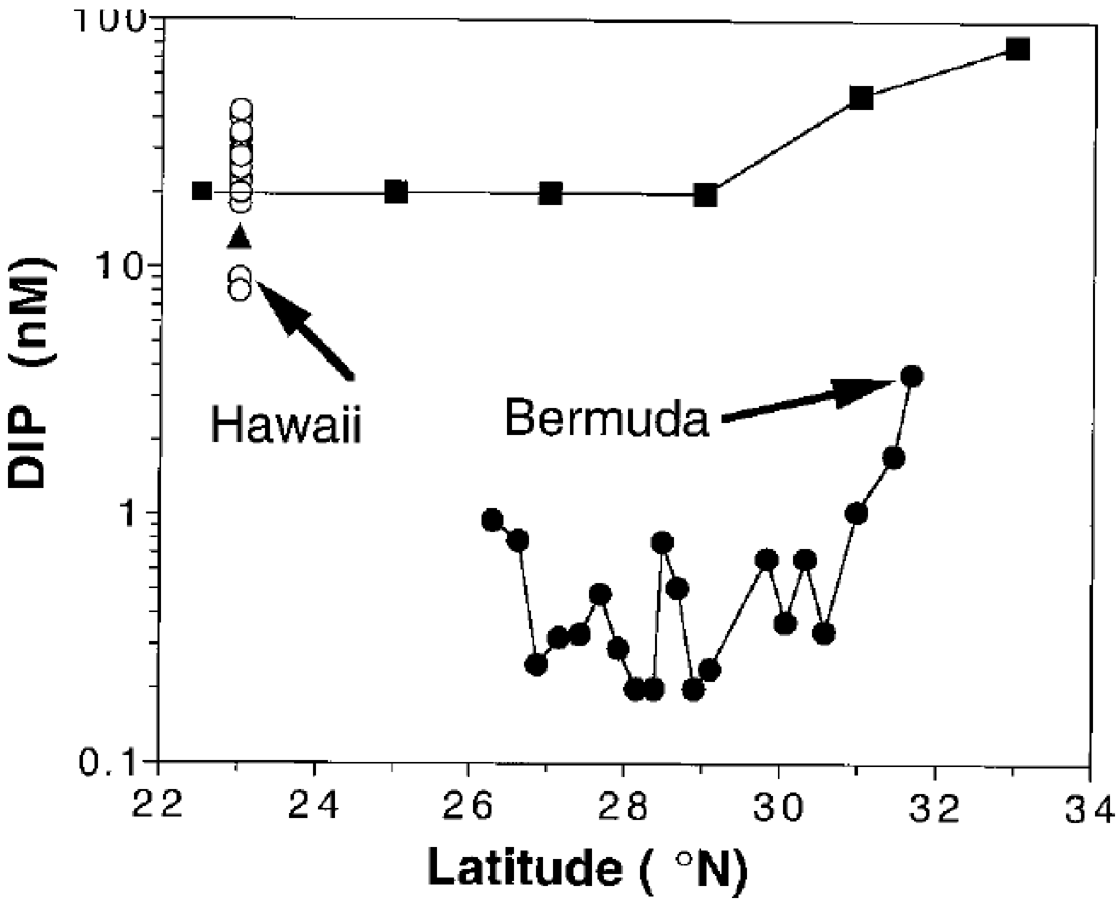


Fig. 1. Surface (~0.5 m) DIP concentrations along a transect from 31.67°N, 64.17°W to 26.10°N, 70.00°W in the Sargasso Sea in March 1998 are compared with those in the North Pacific gyre. –●–, western North Atlantic in March 1998; –■–, North Pacific in November 1997 (*37*); ○, North Pacific near Hawaii in 1991–97 (HOT 11-85) (*35*); ▲, Pacific near Hawaii in November 1998.

Phosphate Depletion in the Western North Atlantic Ocean

Jingfeng Wu,[1*] William Sunda,[2] Edward A. Boyle,[1]
David M. Karl[3]

Science
2000

$P^* = PO_4^{3-} - NO_3^-/15$; Deutsch et al., Nature, 2007

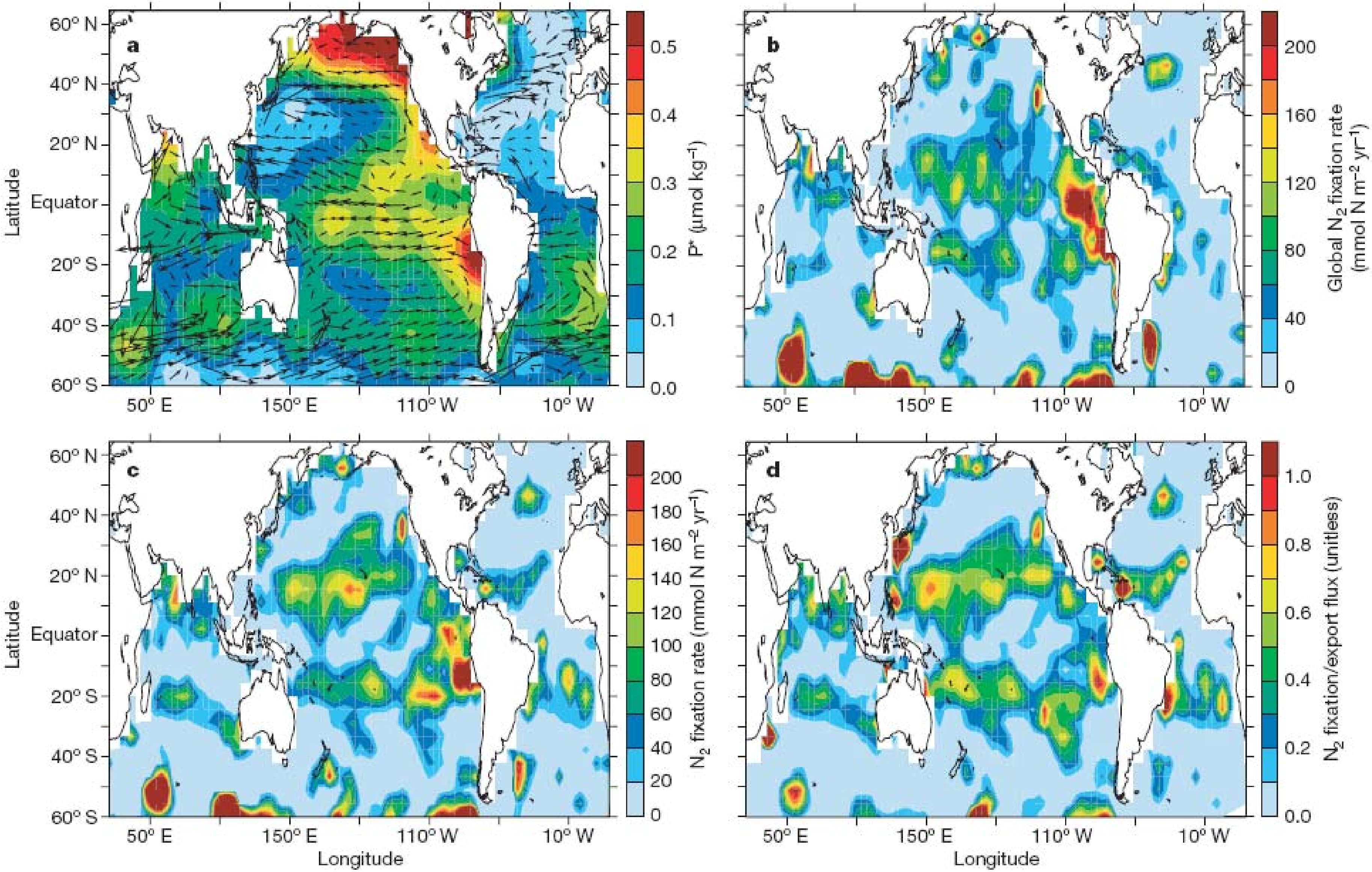
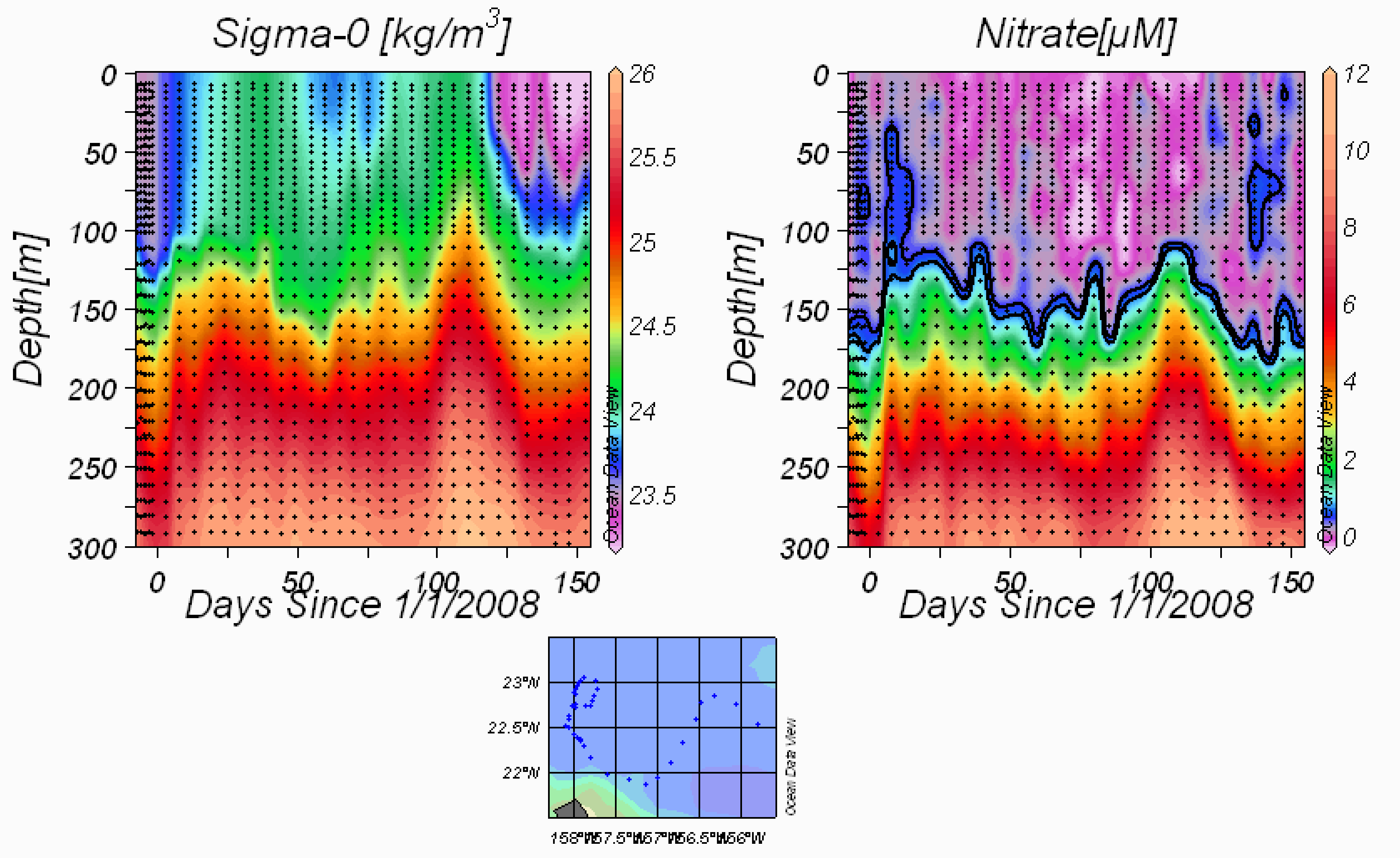


Figure 2 | Annual mean distribution of P*, ocean currents, and the N_2

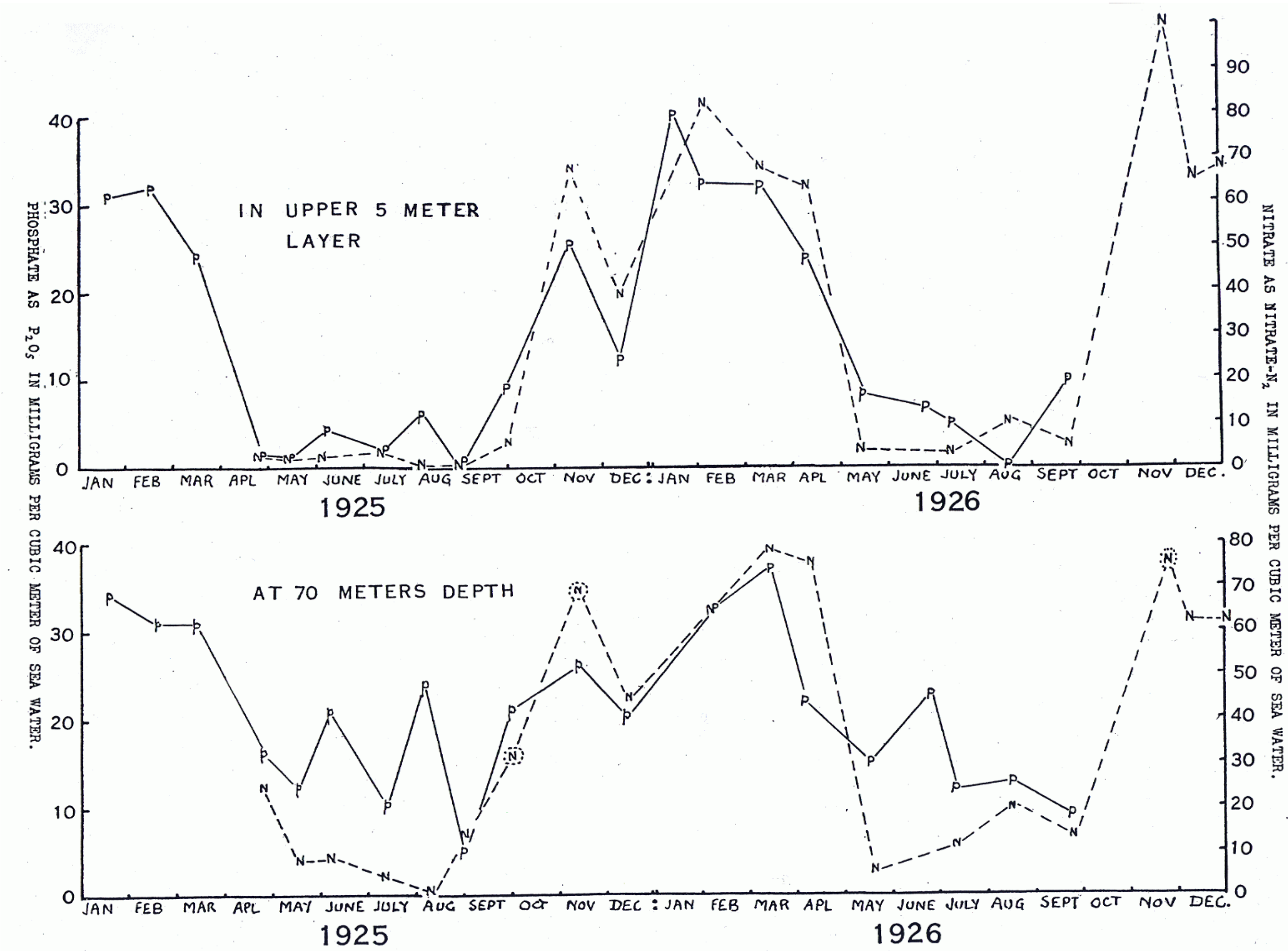
which requires an excess uptake of PO_4^{3-} relative to the biological N

What can higher resolution data tell us about in situ processes?

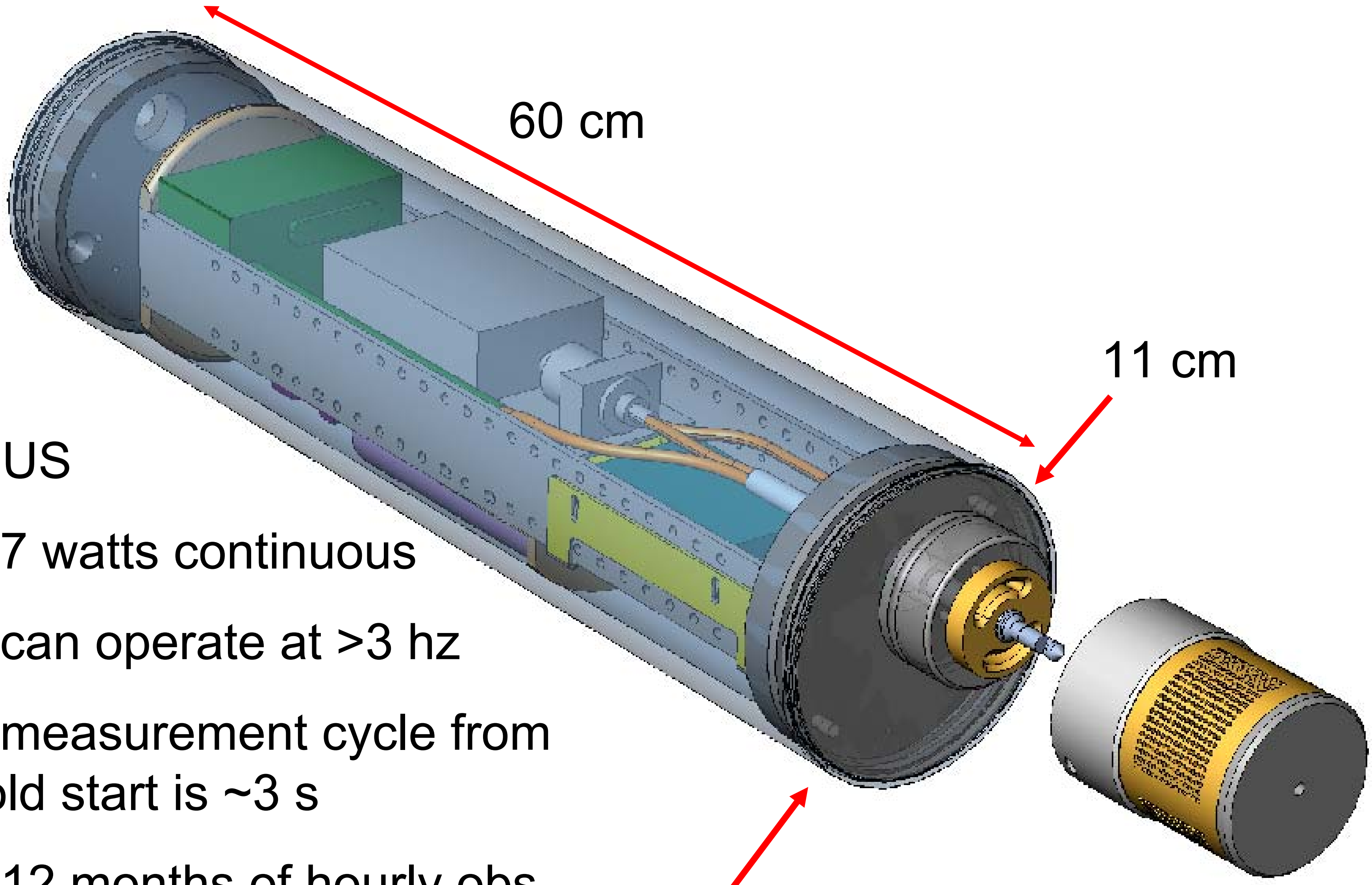


The state of the art in chemical observing for nearly 80 years. Harvey (1928) – Annual cycle of nutrients in the English Channel. We have to do better to resolve these questions.

Phosphate as P_2O_5 (μg/L)



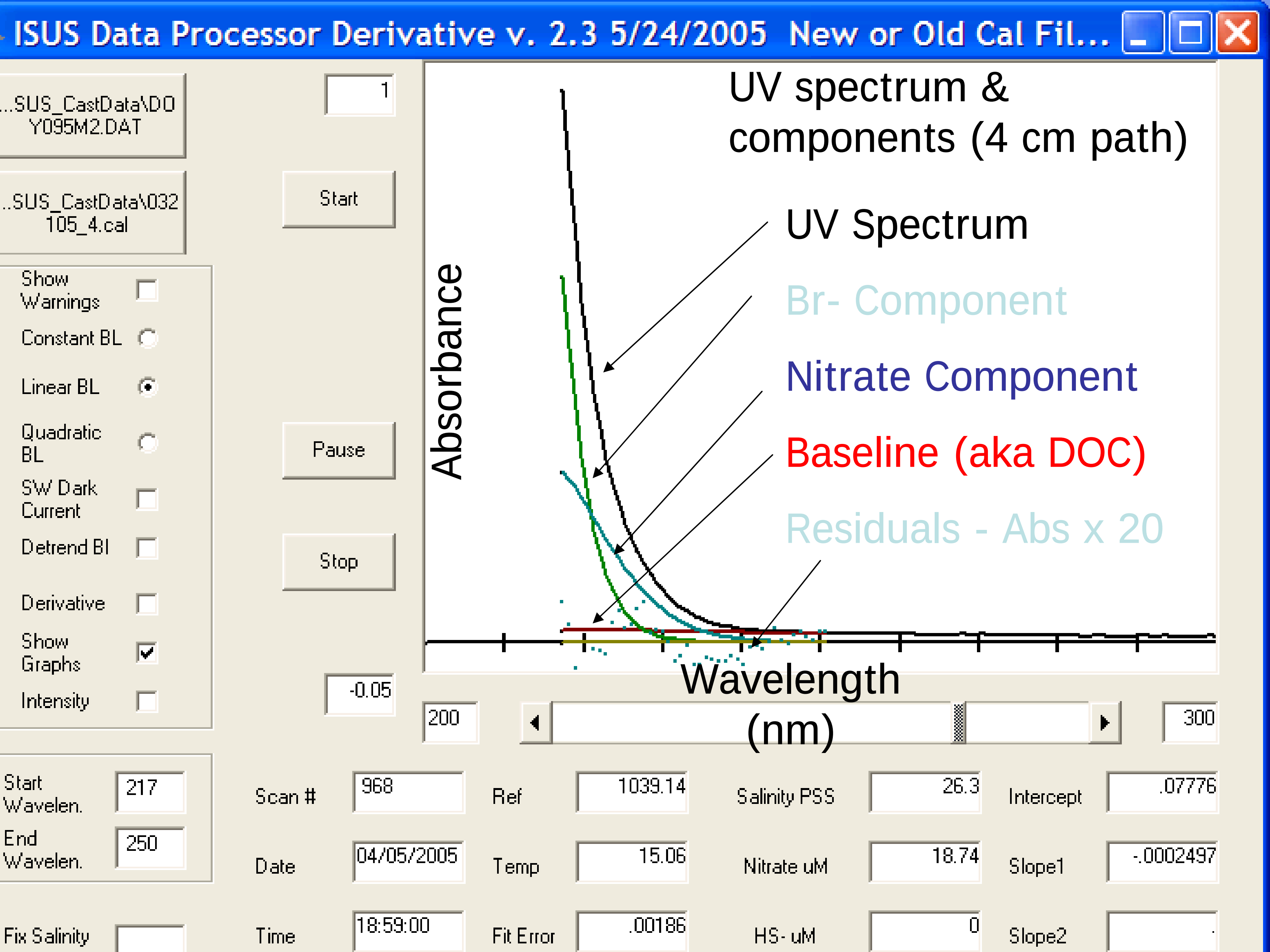
Nitrate as N_2 (μg/L)

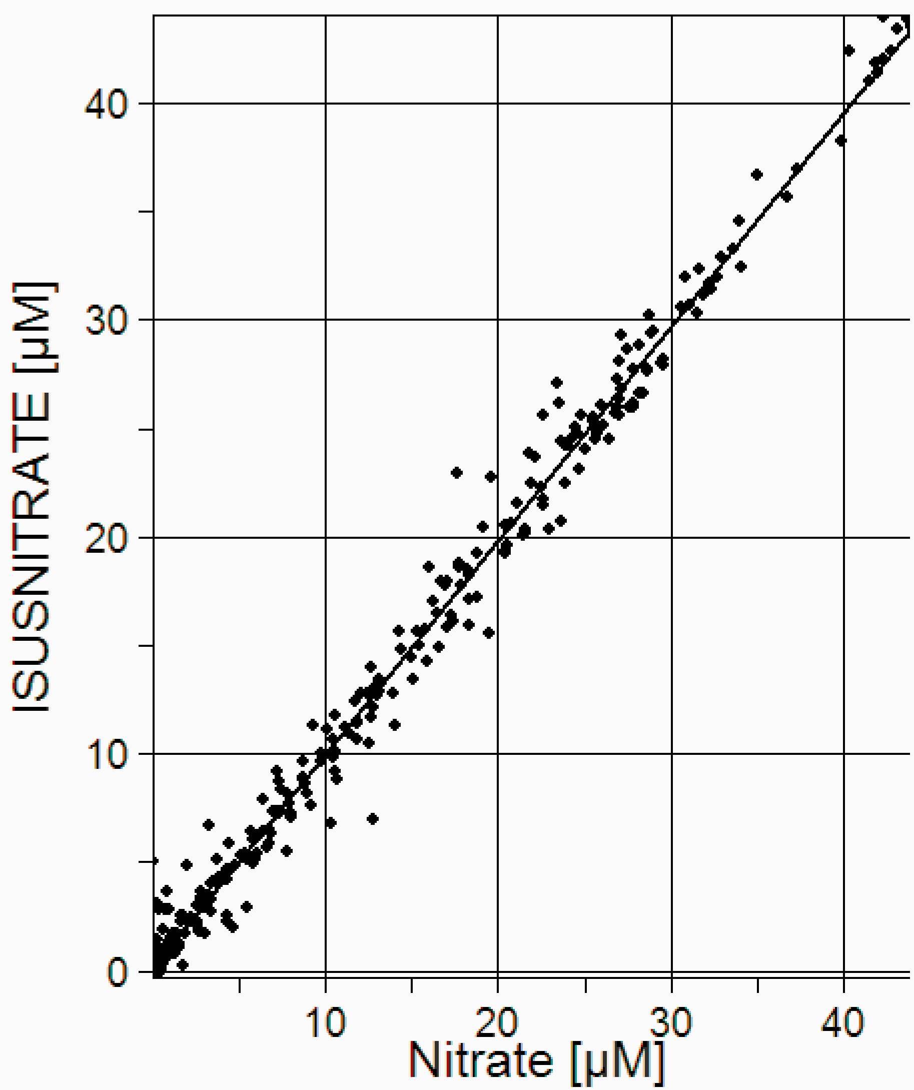


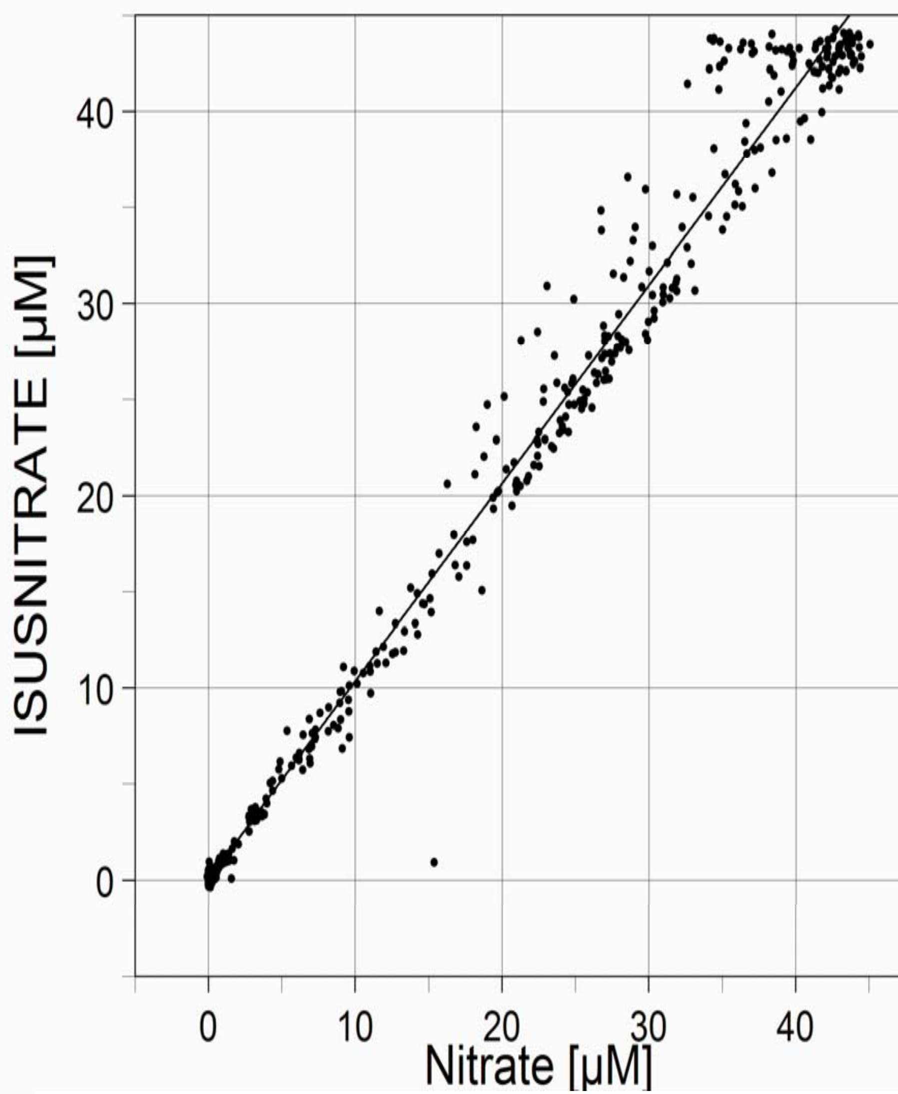
ISUS

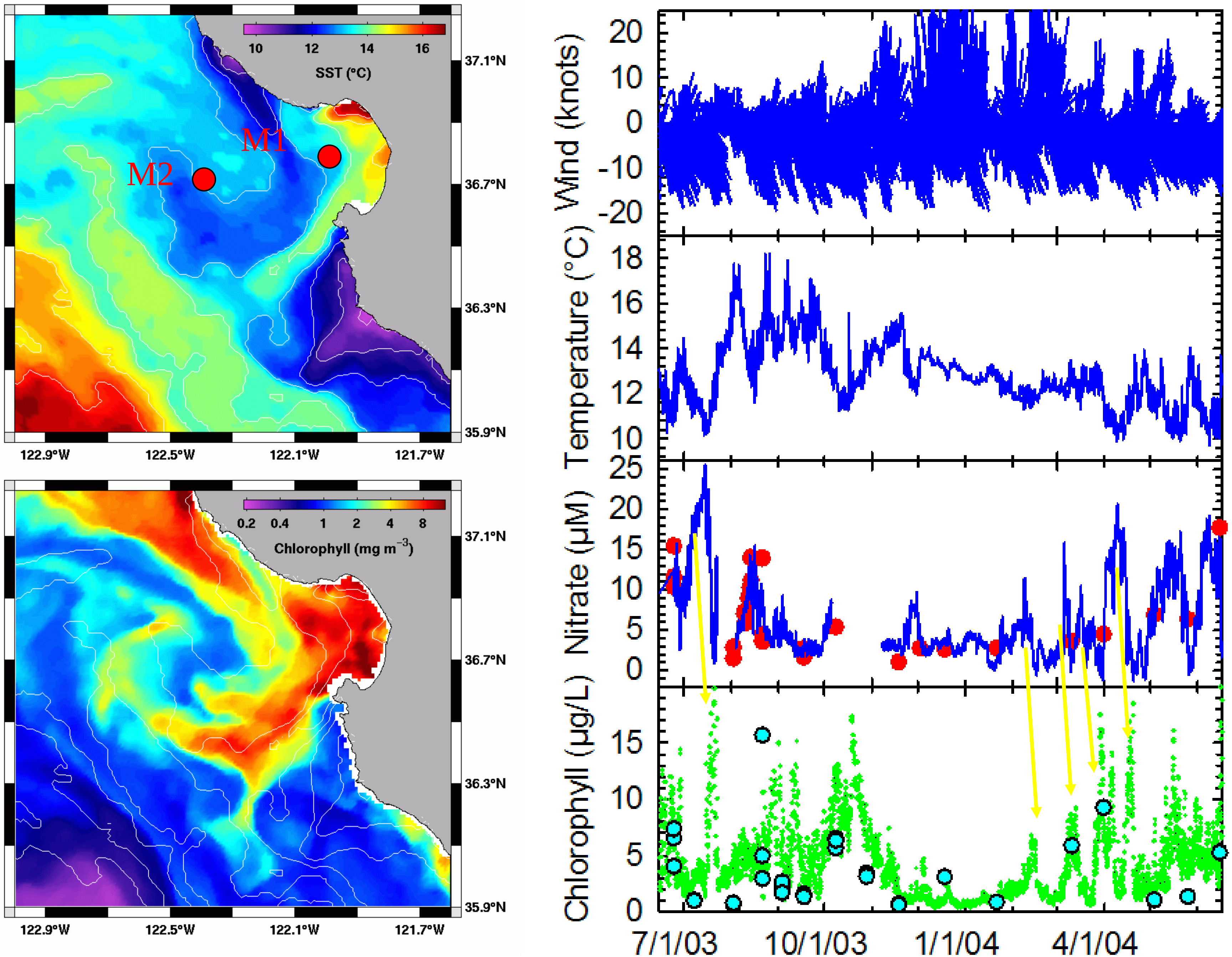
- 7 watts continuous
- can operate at >3 hz
- measurement cycle from cold start is ~3 s
- 12 months of hourly obs.
- precision ~ 0.07 µM (1 sd)

Johnson and Coletti, Deep-Sea Res., 2002


ISUS Data Processor Derivative v. 2.3 5/24/2005 New or Old Cal Fil...
..SUS_CastData\DO Y095M2.DAT
..SUS_CastData\032 105_4.cal
1
Start
Show Warnings
Constant BL
Linear BL
Quadratic BL
SW Dark Current
Detrend Bl
Derivative
Show Graphs
Intensity
Pause
Stop
-0.05
UV spectrum & components (4 cm path)
UV Spectrum
Br- Component
Nitrate Component
Baseline (aka DOC)
Residuals - Abs x 20
Absorbance
Wavelength (nm)
200
300
Start Wavelen.
217
End Wavelen.
250
Fix Salinity
Scan #
968
Date
04/05/2005
Time
18:59:00
Ref
1039.14
Temp
15.06
Fit Error
.00186
Salinity PSS
26.3
Nitrate uM
18.74
HS- uM
0
Intercept
.07776
Slope1
-.0002497
Slope2


ISUSNITRATE [µM]
Nitrate [µM]
0
10
20
30
40
10
20
30
40

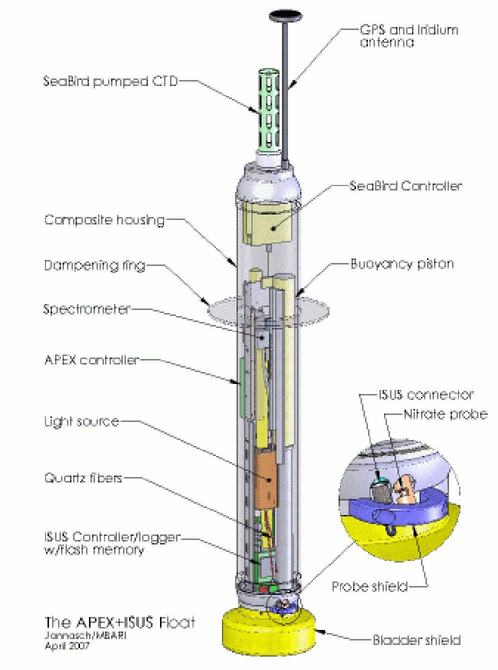

ISUSNITRATE [µM]
Nitrate [µM]
0
10
20
30
40
0
10
20
30
40

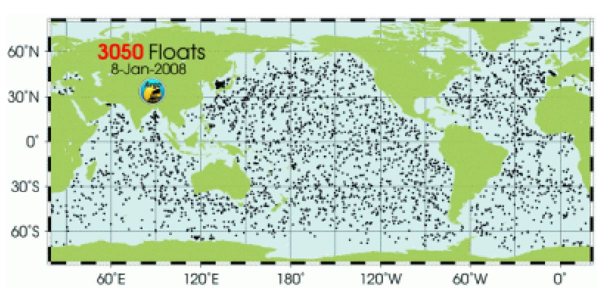

10
12
14
16
SST (°C)
M1
M2
37.1°N
36.7°N
36.3°N
35.9°N
122.9°W
122.5°W
122.1°W
121.7°W
0.2
0.4
1
2
4
8
Chlorophyll (mg m^{-3})
37.1°N
36.7°N
36.3°N
35.9°N
122.9°W
122.5°W
122.1°W
121.7°W
Wind (knots)
20
10
0
-10
-20
Temperature (°C)
18
16
14
12
10
Nitrate (μM)
25
20
15
10
5
0
Chlorophyll (μg/L)
15
10
5
0
7/1/03
10/1/03
1/1/04
4/1/04

Why measure nitrate? Nitrate is a key phytoplankton nutrient. The concentration of nitrate regulates phytoplankton growth in much of the ocean. In a warming climate, the transport of nitrate from deep water may diminish and reduce primary production in the ocean.

The ISUS nitrate sensor is integrated into the body of a Webb Research Apex profiling float that is of the type used in the Argo array. These floats are designed for an expendable deployment in the ocean.

- Floats park at 1000 m depth and profile to the surface at programmed intervals, typically 5 to 10 days. Measurements are made as the float rises. Results are transmitted to orbiting satellites and then to shore when the float reaches the surface. The float then returns to its parking depth.
- The Apex/ISUS float makes 60 measurements of nitrate and oxygen on each profile, and it measures temperature, salinity and pressure at 2 m intervals.
- Battery life is sufficient for approximately 260 vertical profiles from 1000 m depth.
- At a cycle time of 5 days, each float should profile for nearly four years.
- The precision of the ISUS nitrate sensor is near 0.2 micromoles per liter (1 SD).
- Absolute accuracy is about 0.5 micromoles per liter and can be improved by comparison to laboratory analyses to remove offsets.
- Data is available in real-time.

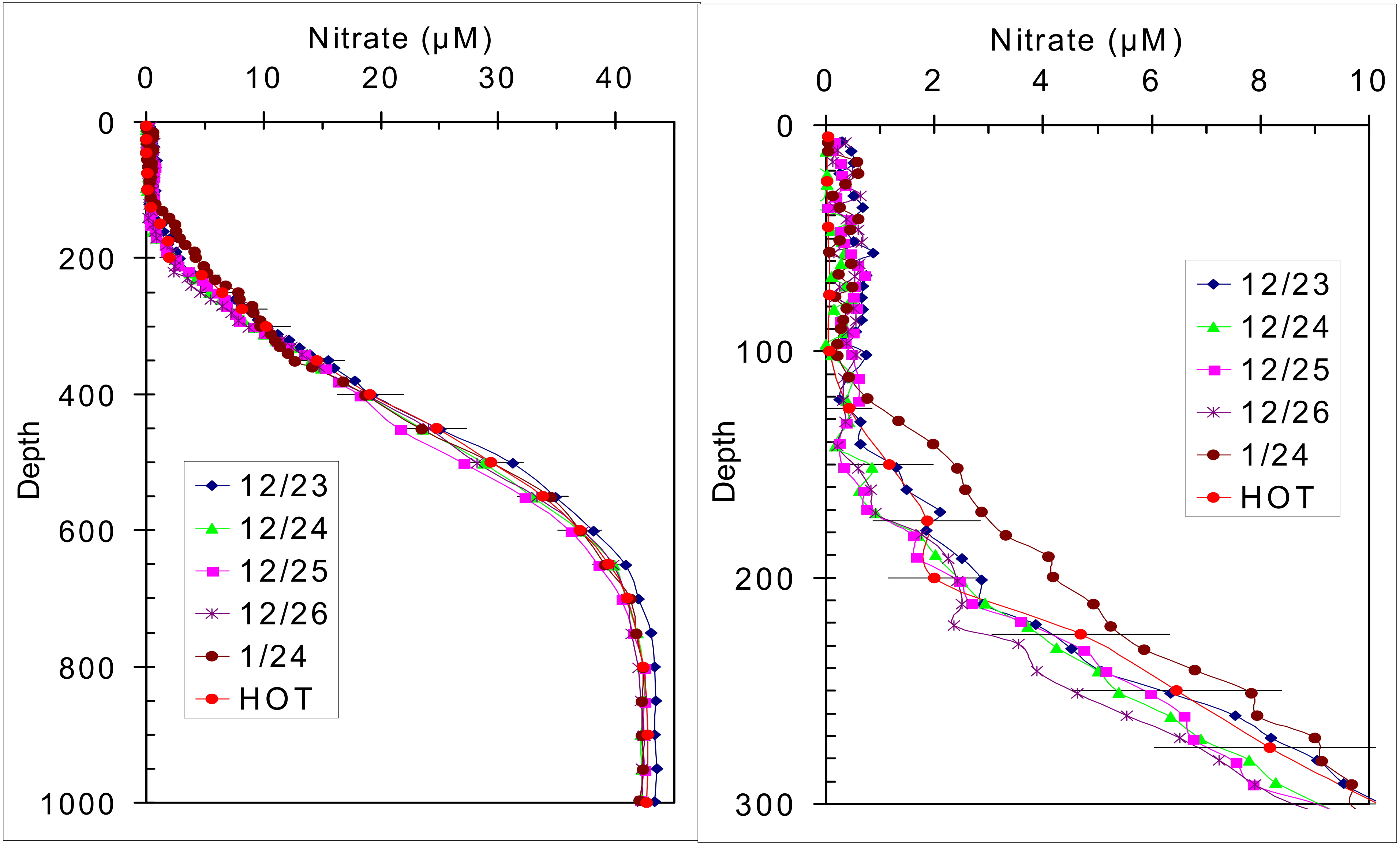




The Argo array consists of approximately 3000 profiling floats that are distributed throughout the world ocean. These floats are used to monitor the heat and salt budget of the ocean. Equipping such an array with biogeochemical sensors would allow scientists to monitor rates of primary production.

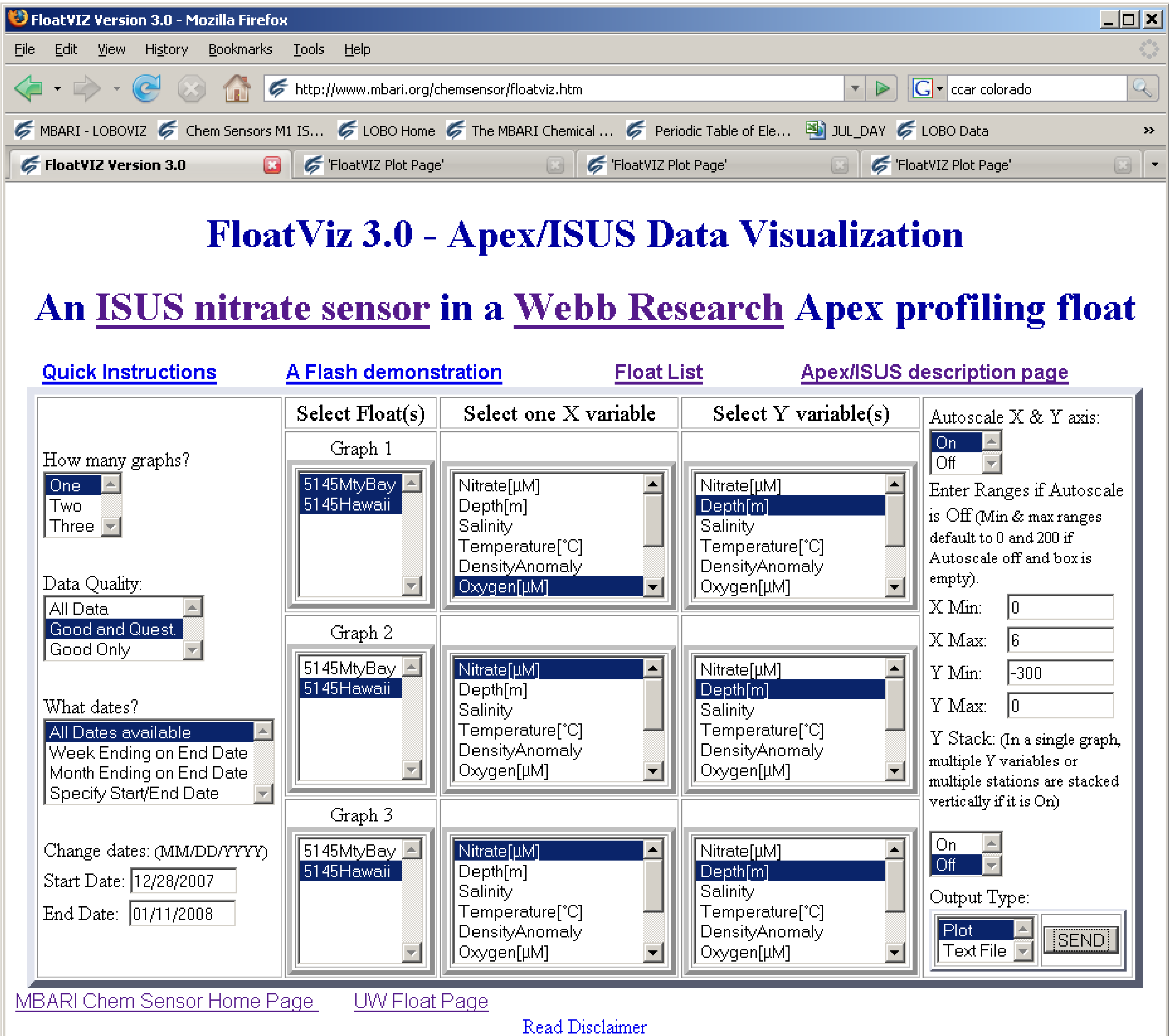
A plan to equip the Argo array with oxygen sensors now exists.

Integration of ISUS into the Webb Apex float was done by Dana Swift (UW), Luke Coletti and Hans Jannasch (MBARI).

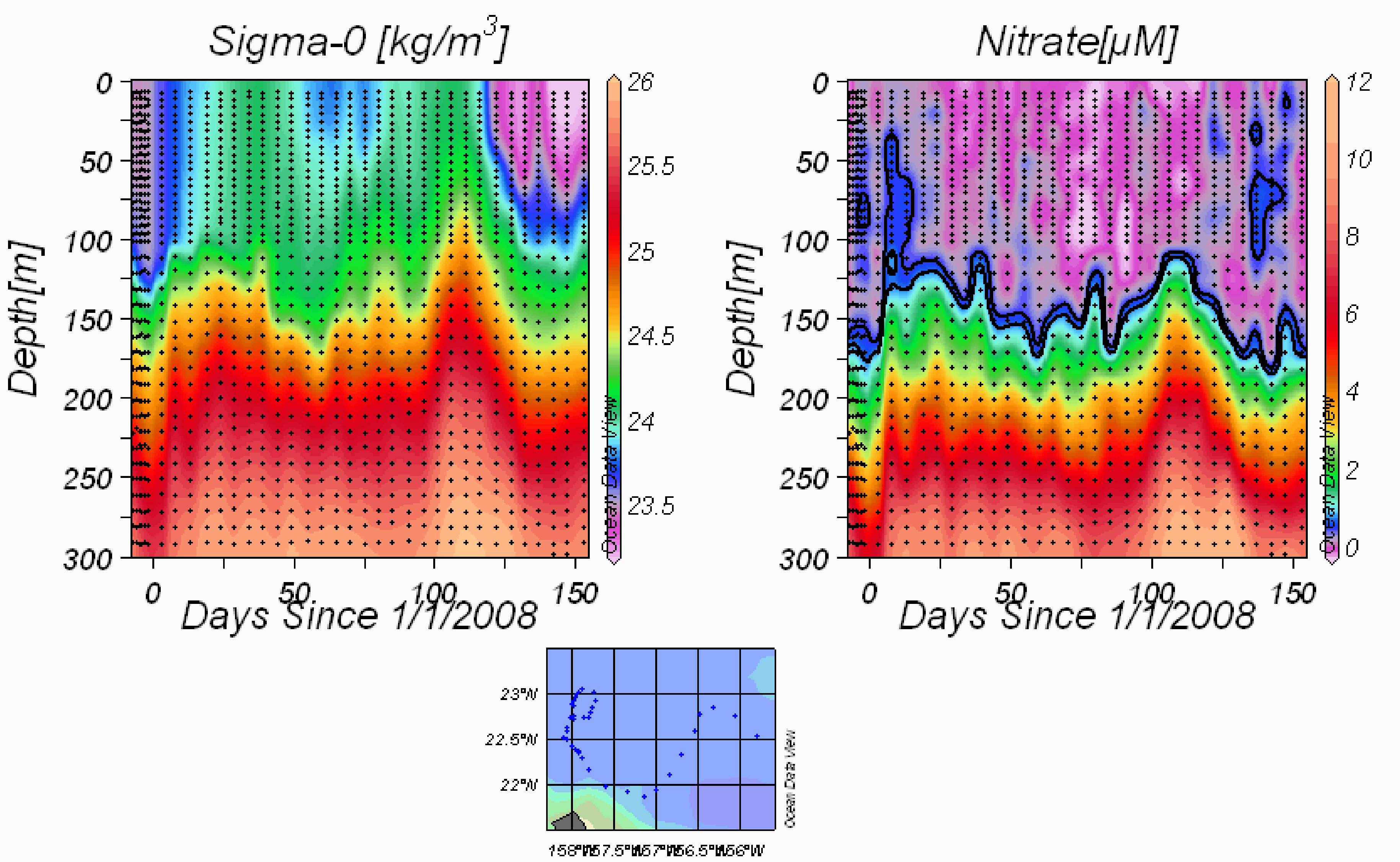


Nitrate (µM)
0
10
20
30
40
Depth
0
200
400
600
800
1000
12/23
12/24
12/25
12/26
1/24
HOT
Nitrate (µM)
0
2
4
6
8
10
Depth
0
100
200
300
12/23
12/24
12/25
12/26
1/24
HOT

Realtime delivery of data as numeric values or plots using the FloatViz system – http://www.mbari.org/chemsensor/floatviz.htm



160 days of nitrate profiles near HOT: 37 profiles to 1000 m at 5 day intervals x 61 measurements/profile = 2257 observations. Precision about 0.25 µM.



$NO = 138/16 * NO_3^- + O_2$; Broecker, Earth Planet. Sci. Lett., 1974

As O_2 is consumed, NO_3^- is remineralized and NO does not change.

We can make one correction to the formula.

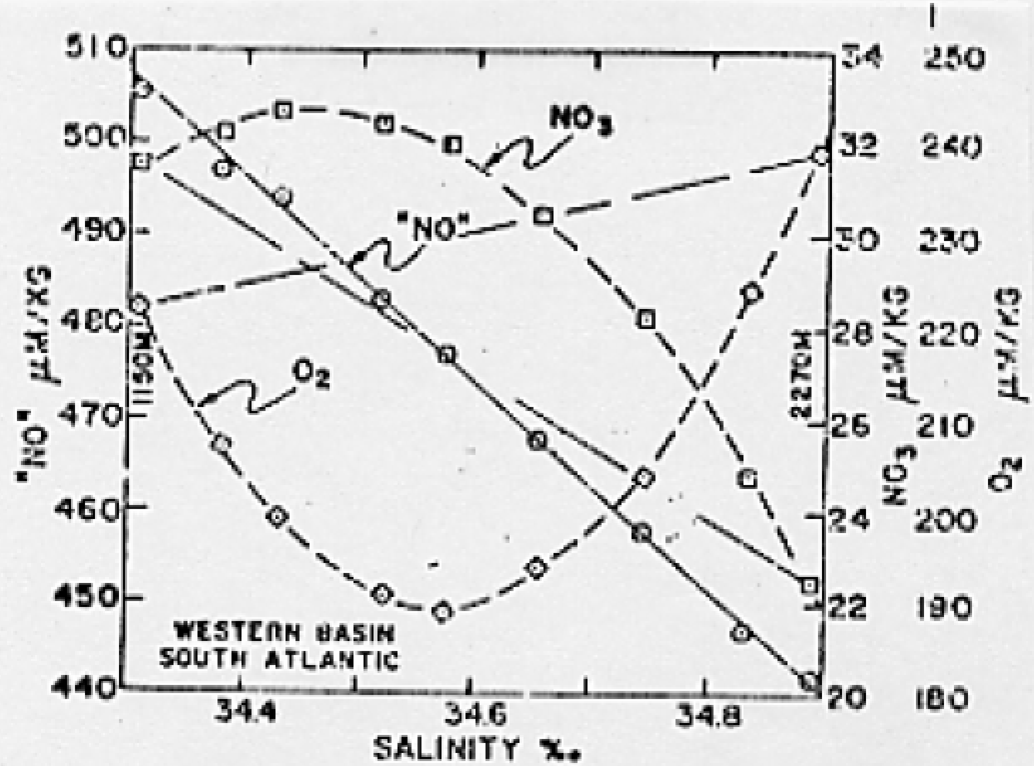
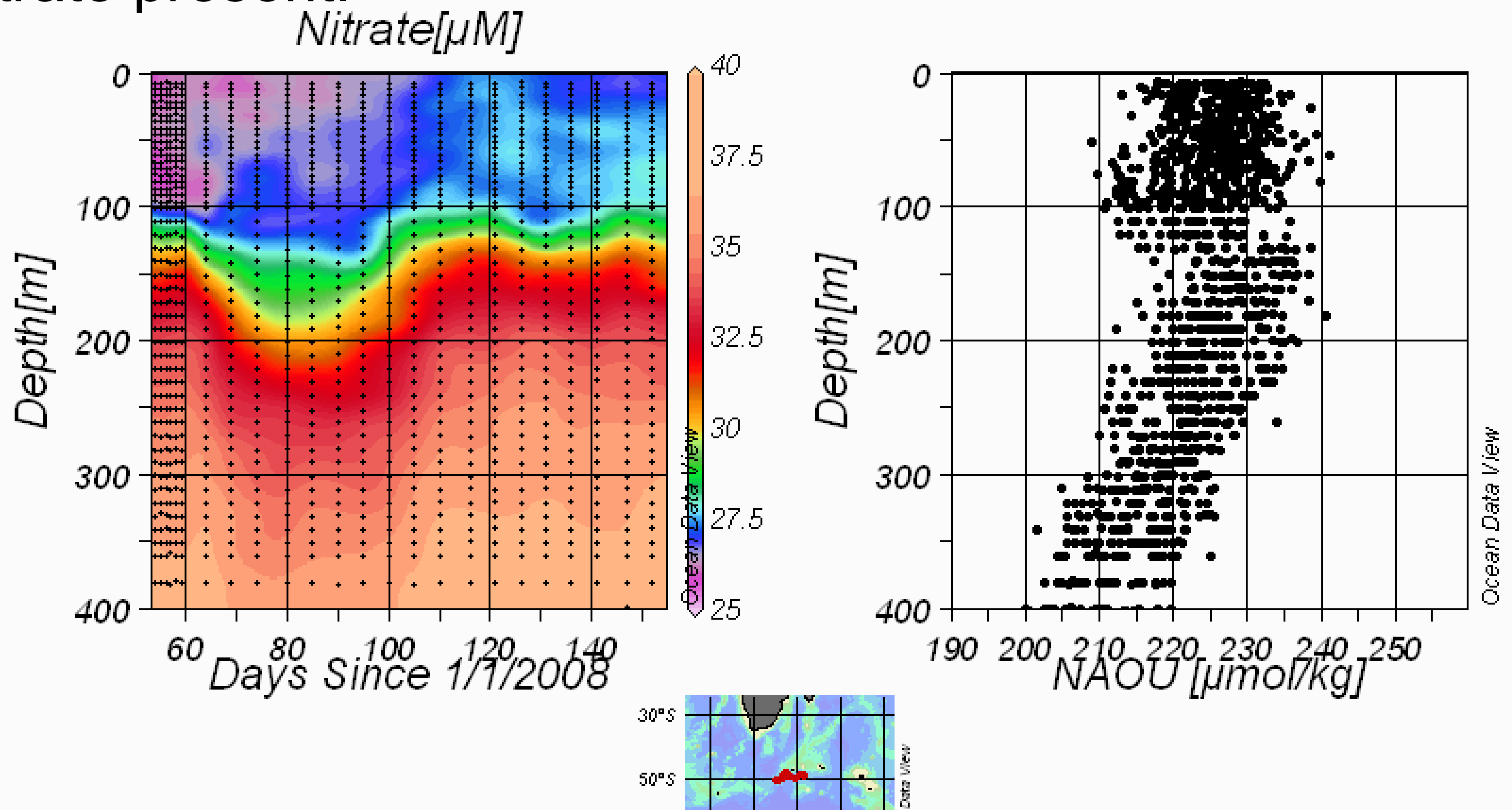


Fig. 5. "NO", NO_3, and O_2 versus salinity at Atlantic Geosecs station 60 in the western basin of the South Atlantic between the core of the AAIW (1150 m) and the top of the NADW (2270 m). The excess NO_3 content is just balanced by the O_2 deficiency yielding a straight line relationship between salinity and "NO".

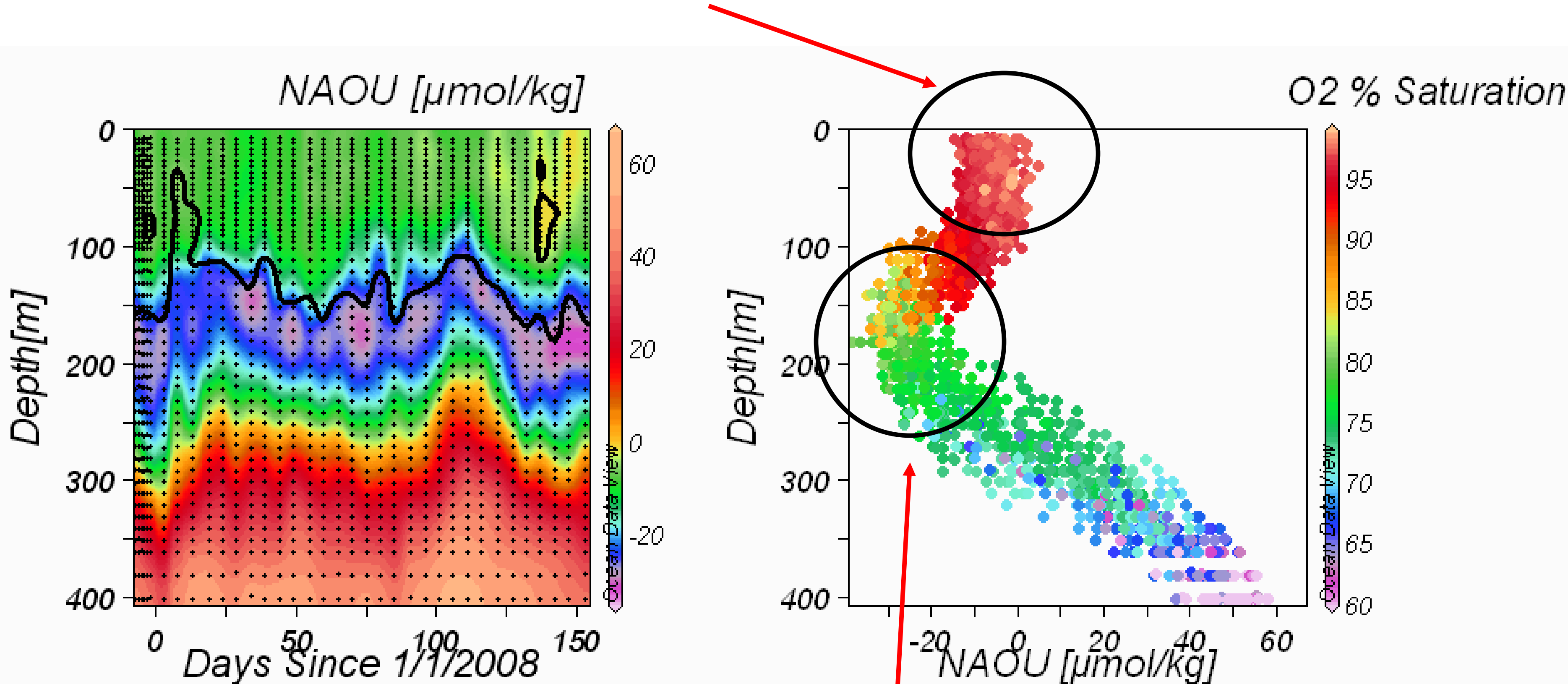
$$NAOU = 138/16 * NO_3^- + O_2 – O_2 \text{ Solubility at T, S}$$

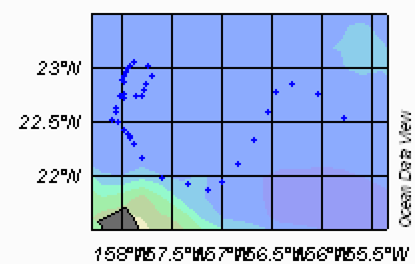
$$= 8.6 * NO_3^- - \text{Apparent } O_2 \text{ Utilization (AOU)}$$

NAOU miminizes variability by removing changes in O_2 due to solubility differences. It should be 0, unless preformed nitrate present.



O$_2$ production here.

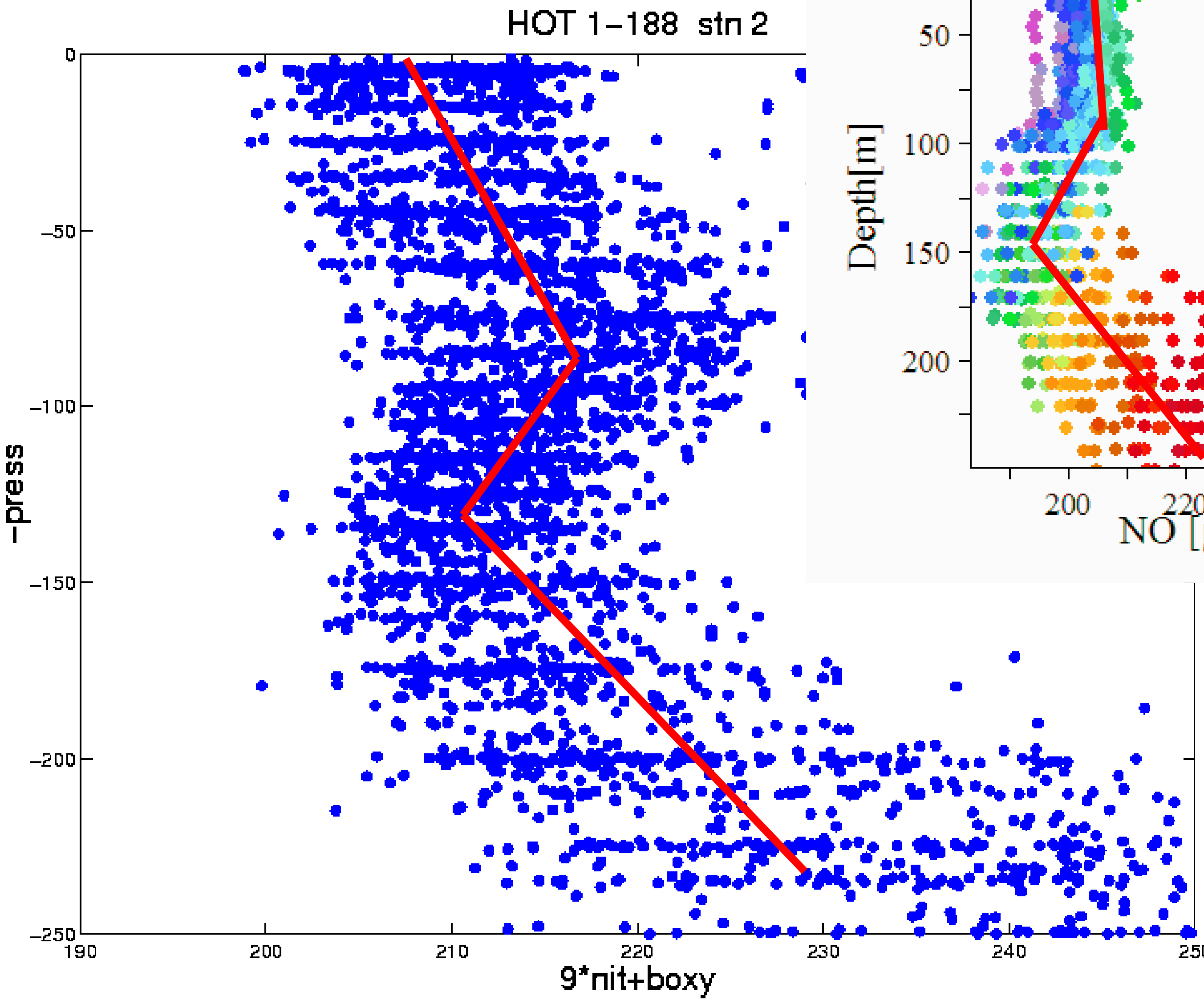


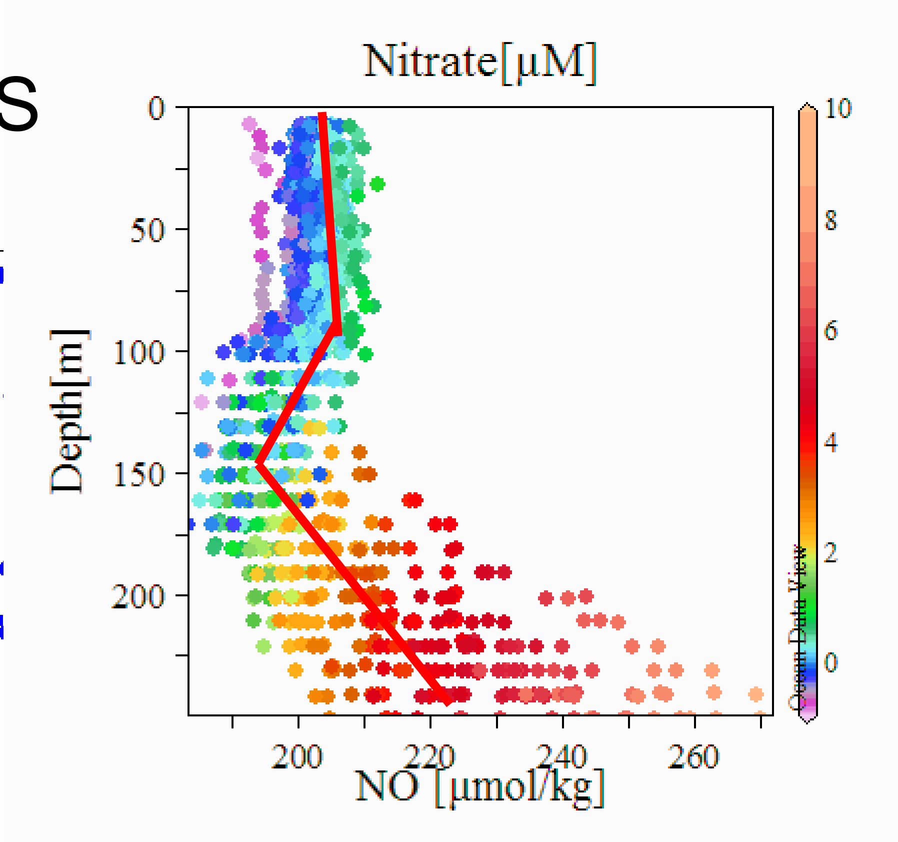


O$_2$ consumed here, but less NO_3^- than expected = NO_3^- Uptake?

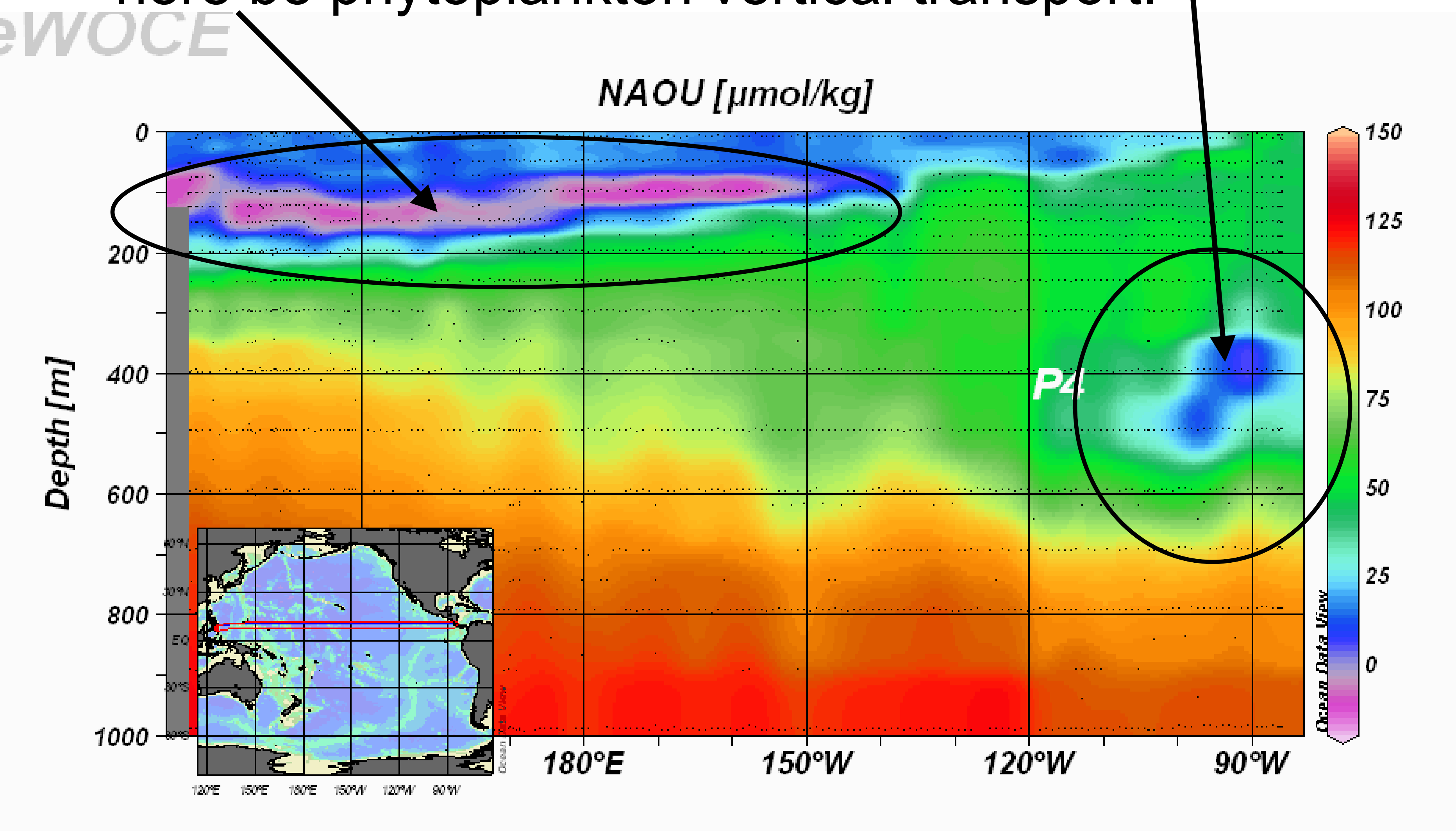
A mechanism to add nitrate to the euphotic zone without adding dissolved inorganic carbon

NO plotted using HOT-DOGS

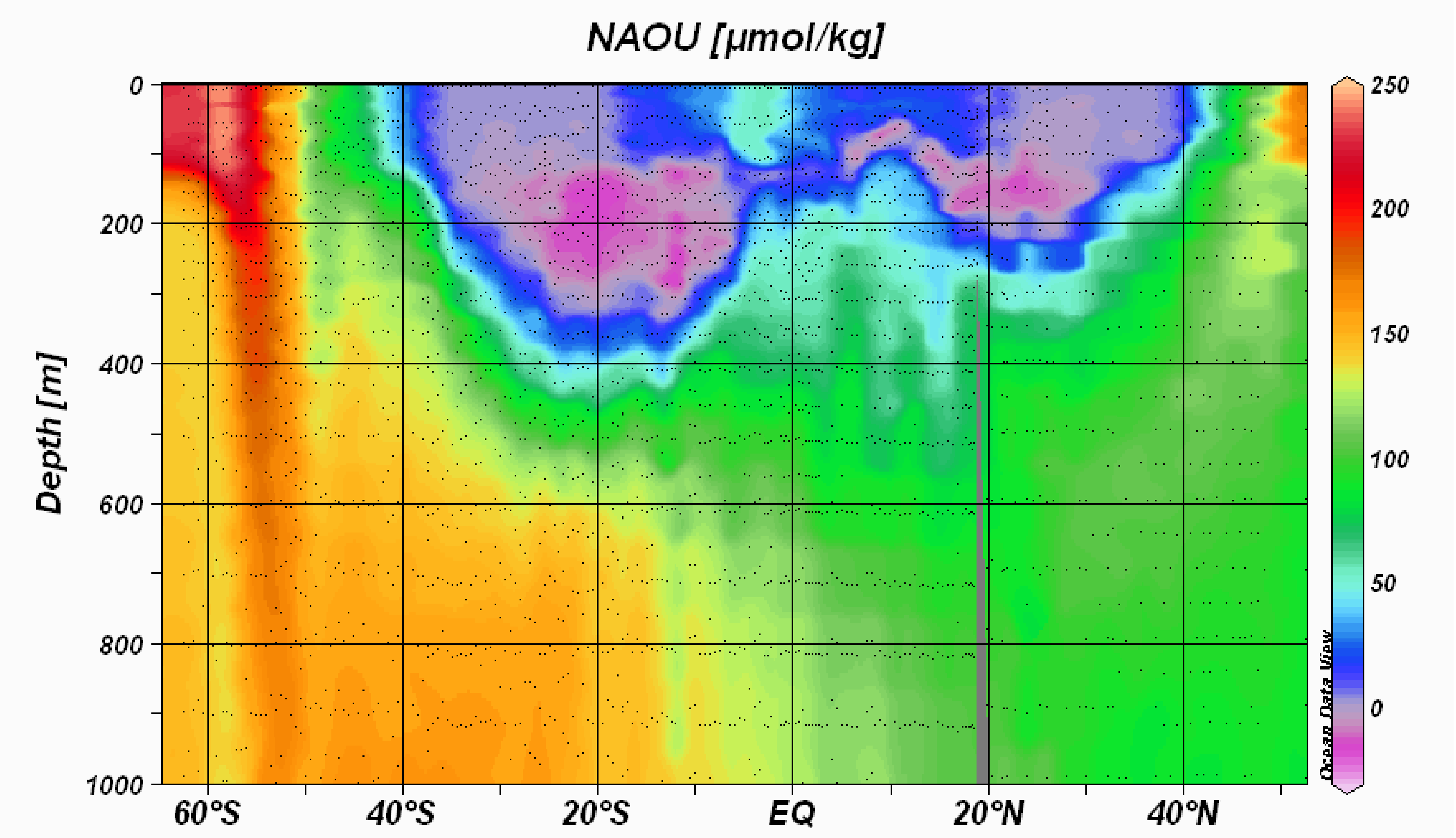




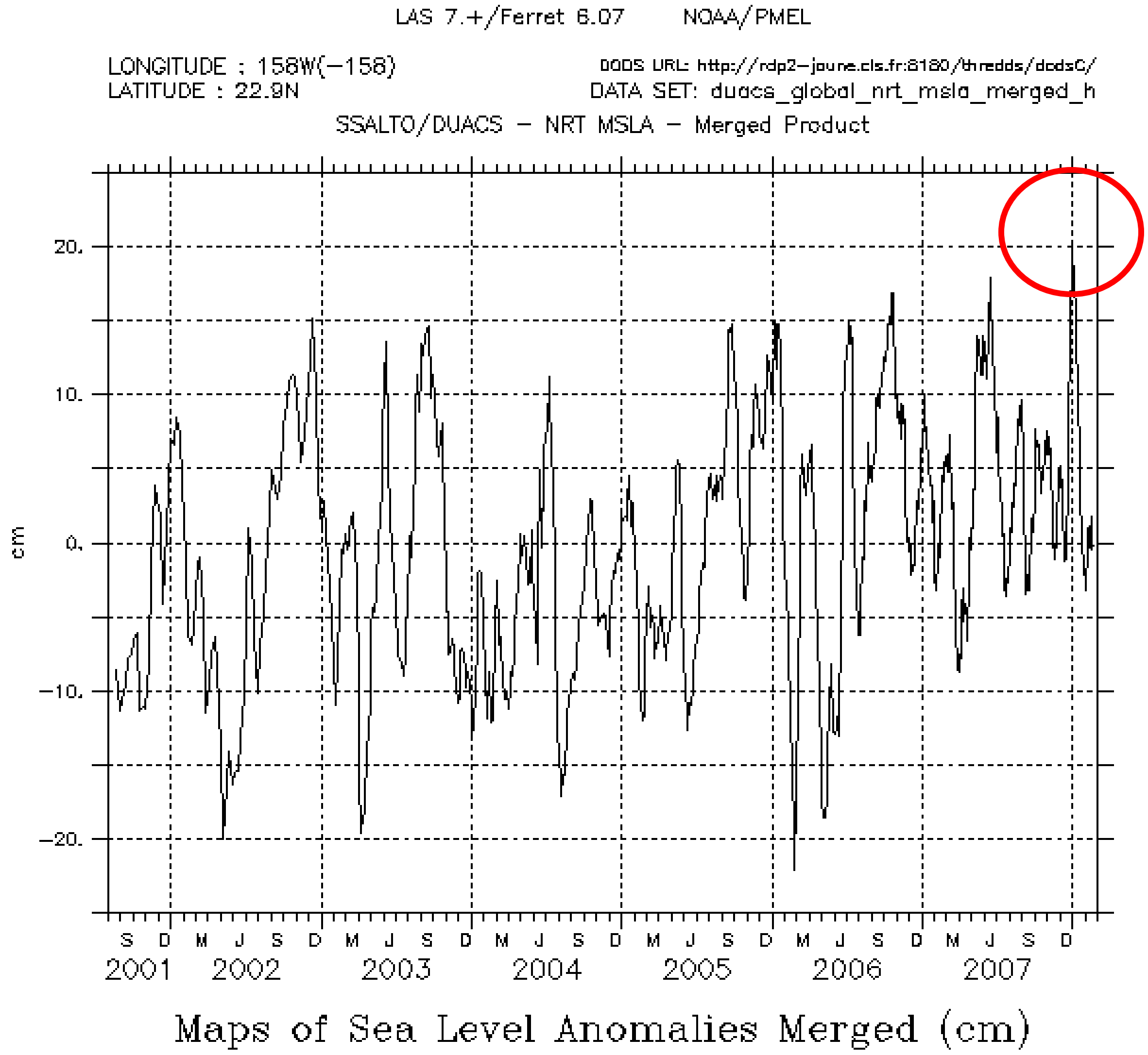
About the only way NAOU can be <0 is loss of nitrate, here by denitrification in the ETNP, here be phytoplankton vertical transport.



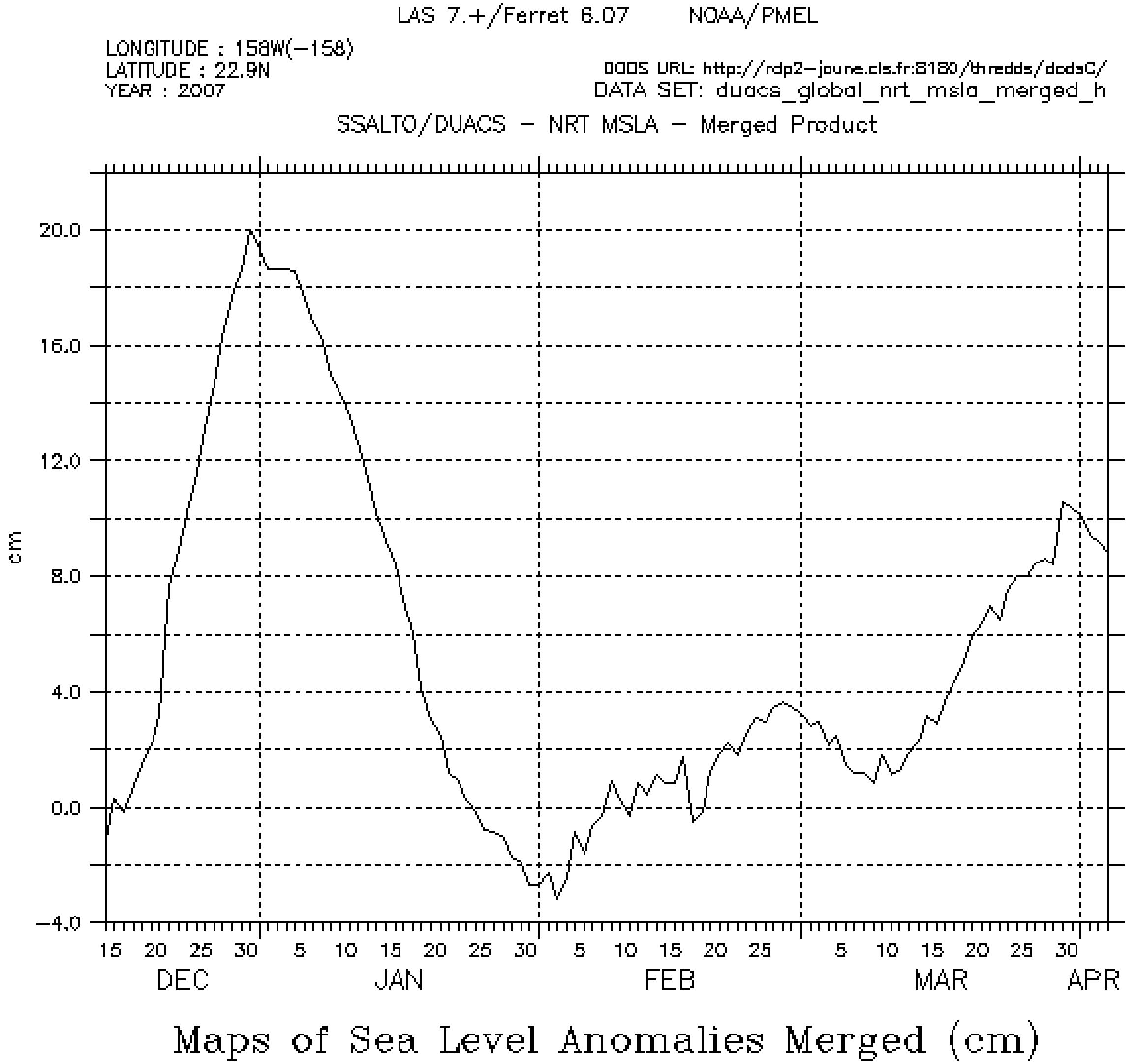
The large negative values in NAOU over large regions of the oligotrophic ocean indicate vertical migration to acquire nutrients is pervasive.



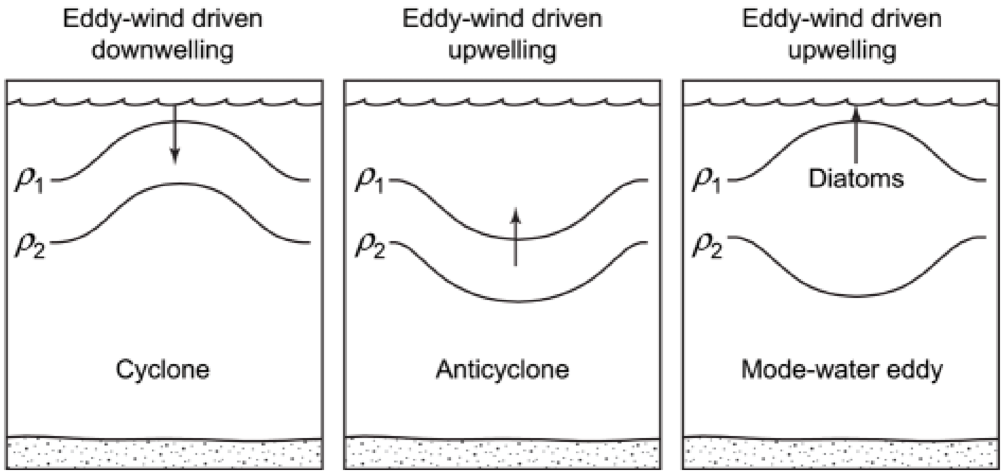
Still can't ignore eddies. Largest anomaly in sea surface height (+20 cm) occurs around January 1, 2008. Indicates a large, anti-cyclonic event.

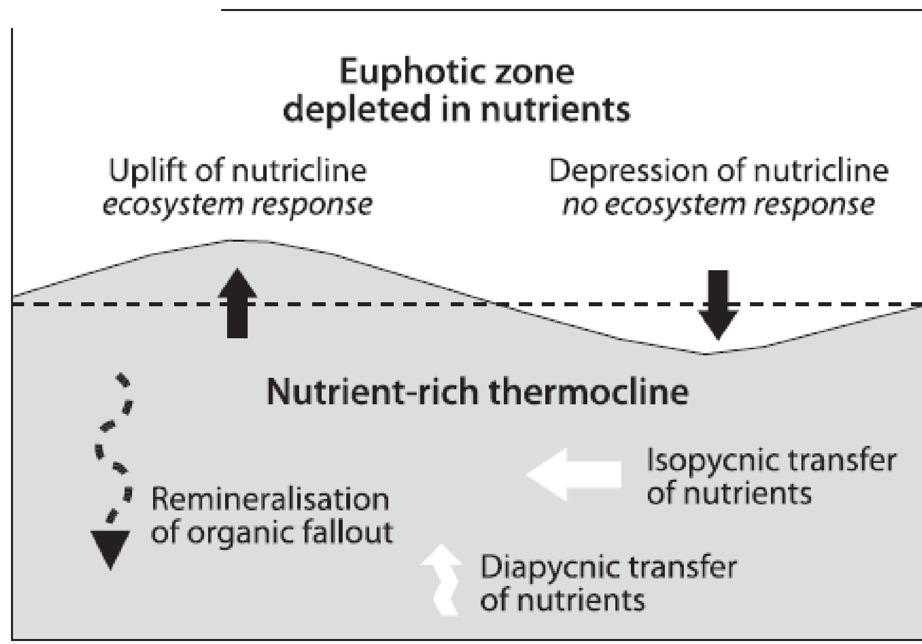


http://las.aviso.oceanobs.com/

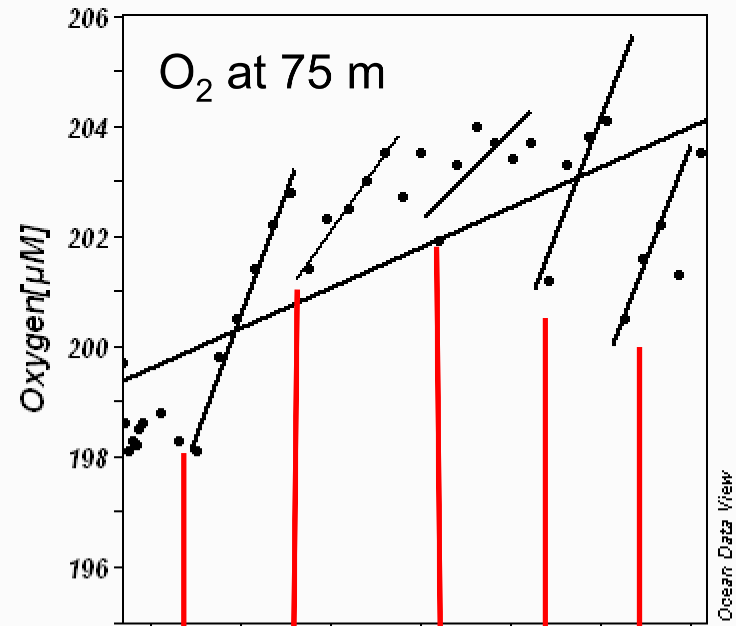


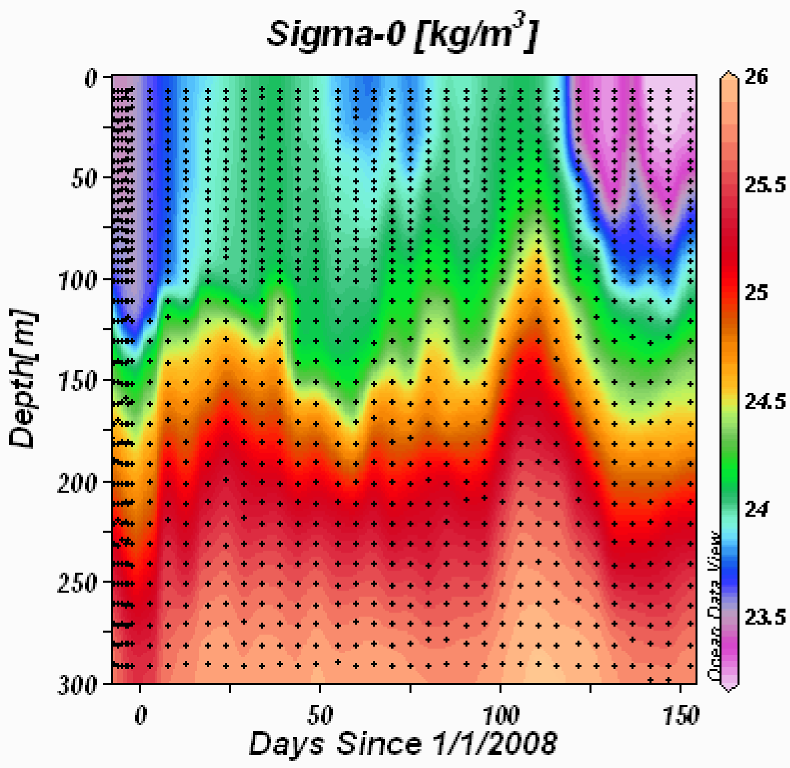
Anticyclones are supposed to depress the thermocline and have no ecosystem response.

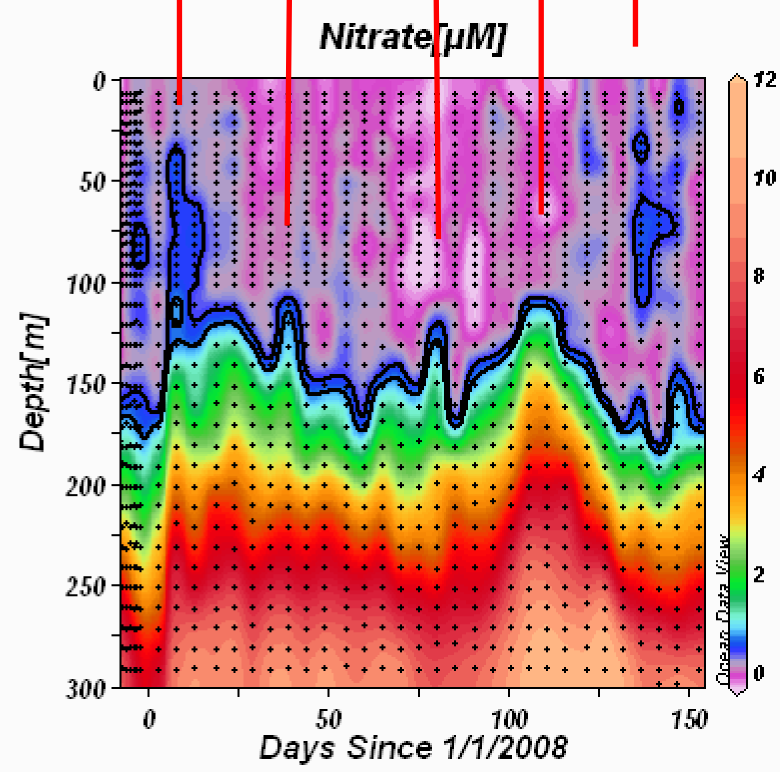




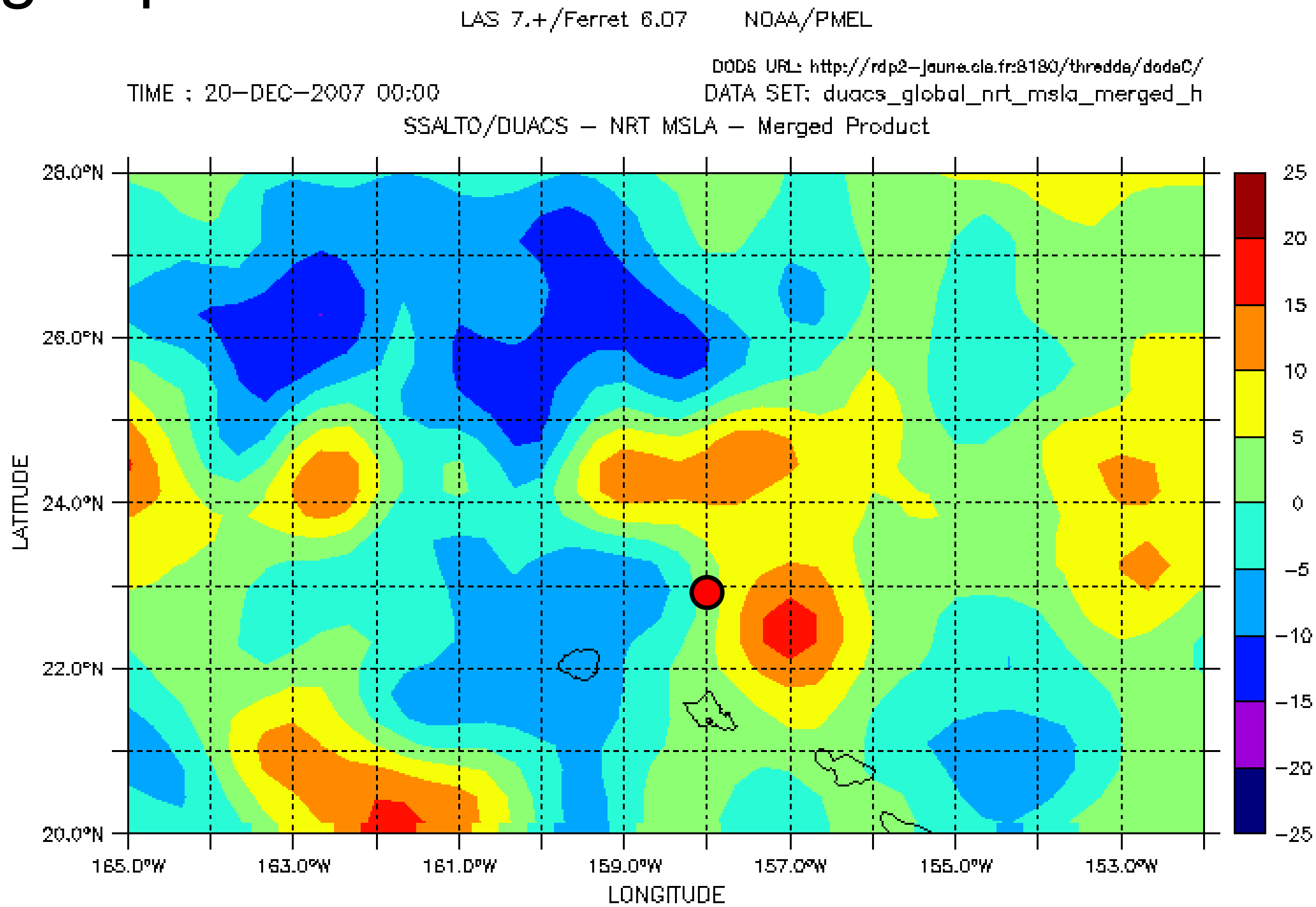
Five nitrate injection events drive increase in oxygen production rate. NO_3^- contours at 0.5 and 0.75 μM = 2 SD and 3 SD of data in upper 100 m. All NO_3^- data corrected for drift using 900 to 1000 m data. Lines on O_2 plot are least squares fits to data in the range spanned by the line. 5 day cycle time barely resolves these events.



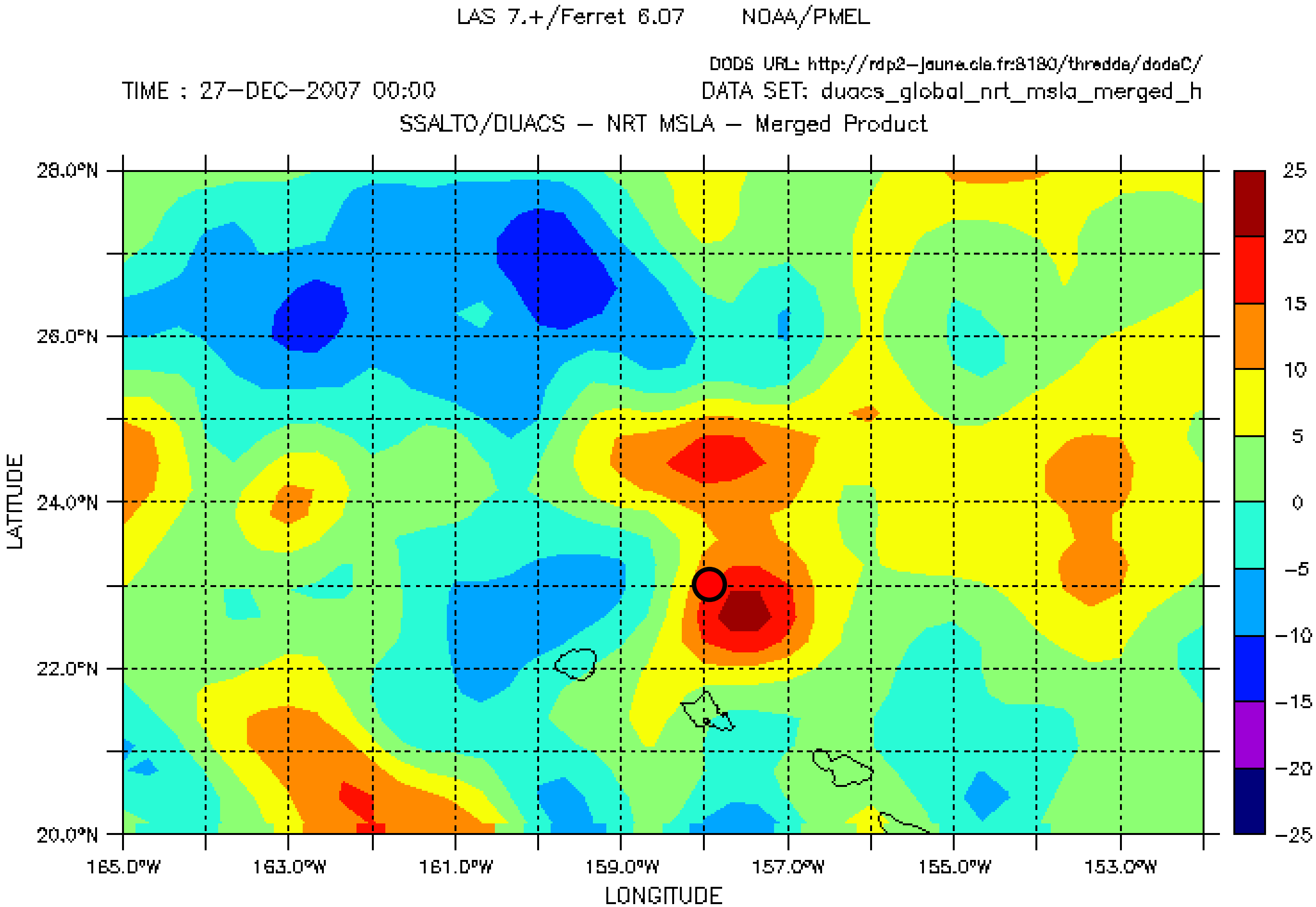




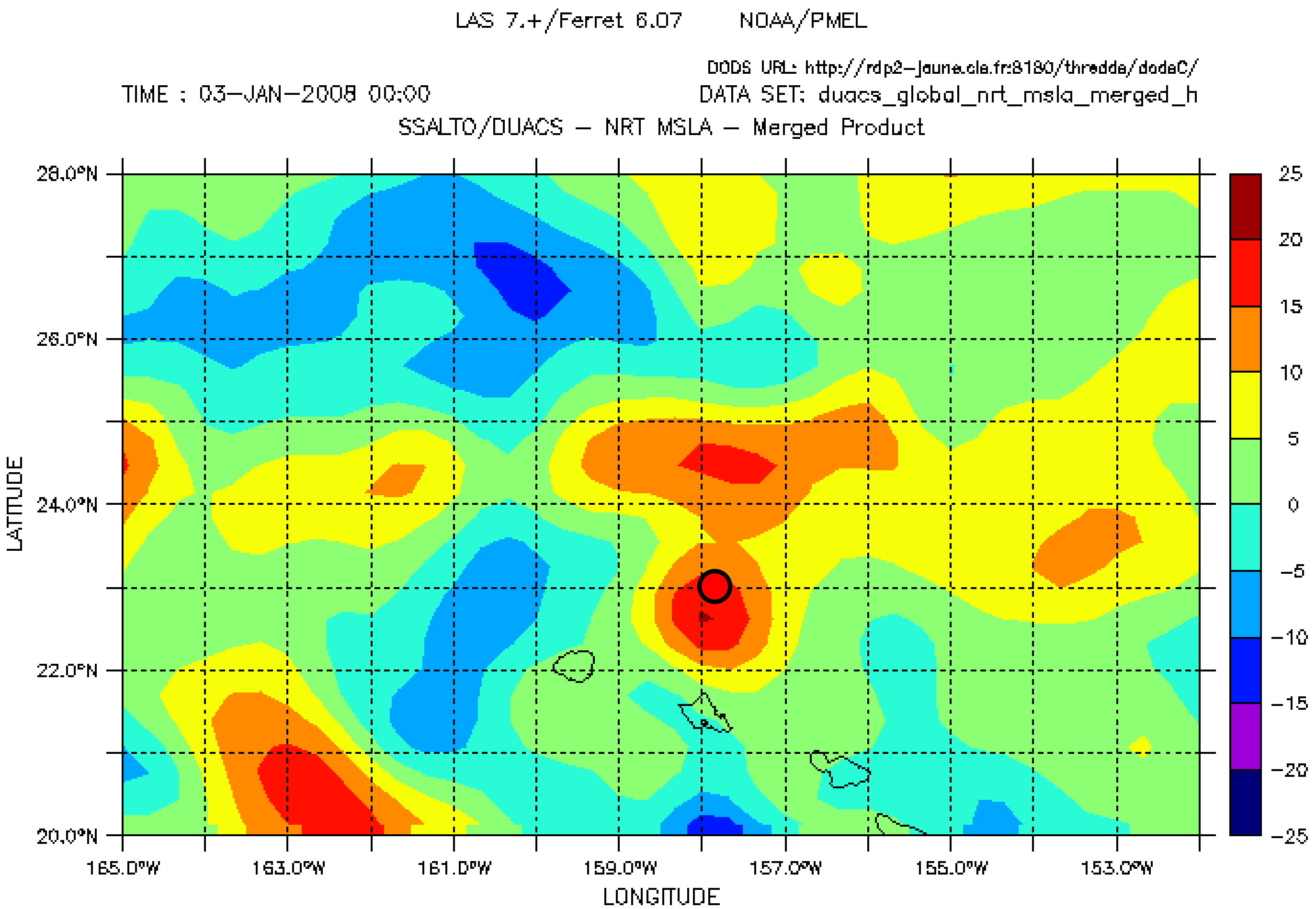
AVISO http://www.aviso.oceanobs.com, a merged product of all 3 satellite altimeters.



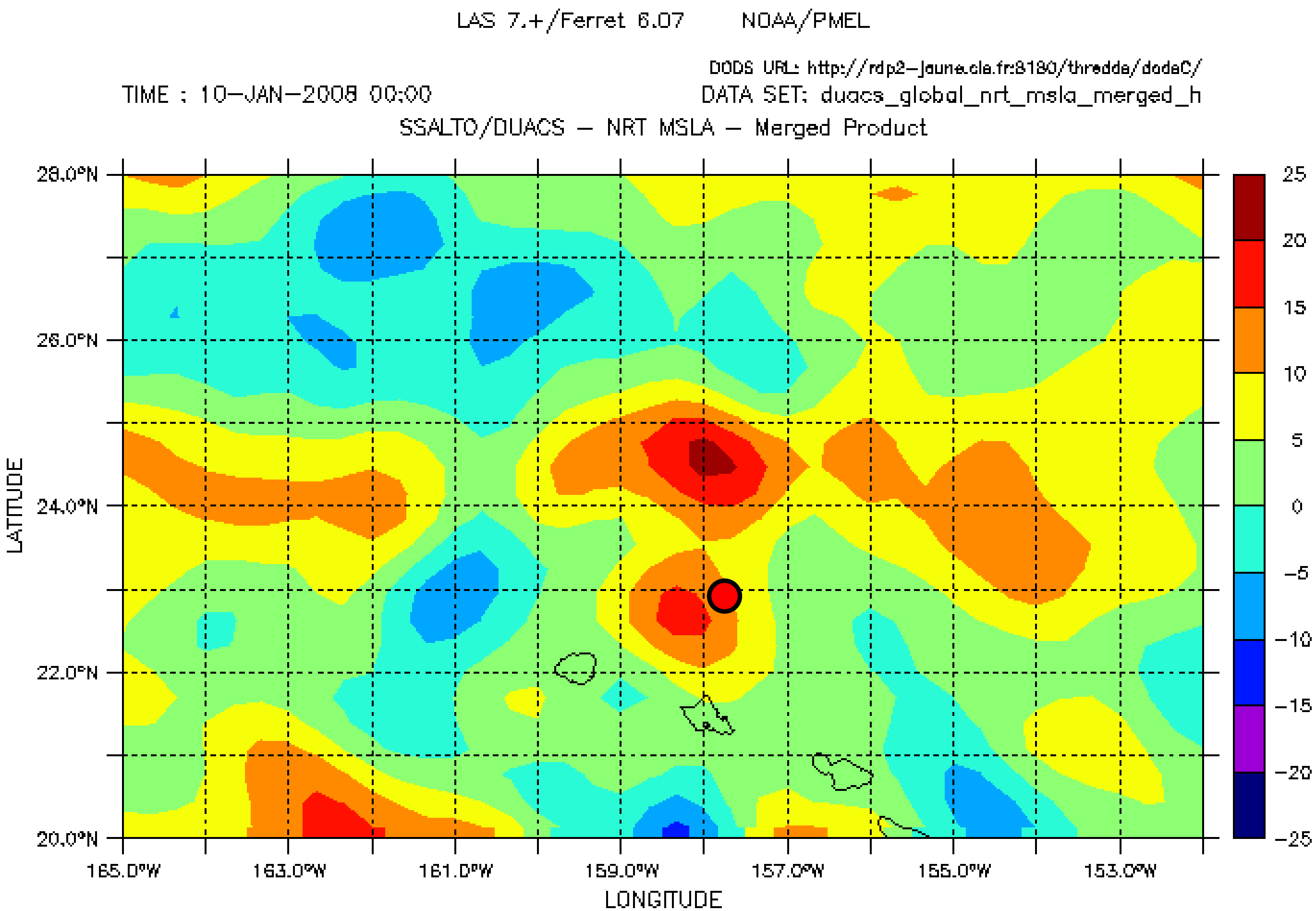
Maps of Sea Level Anomalies Merged (cm)



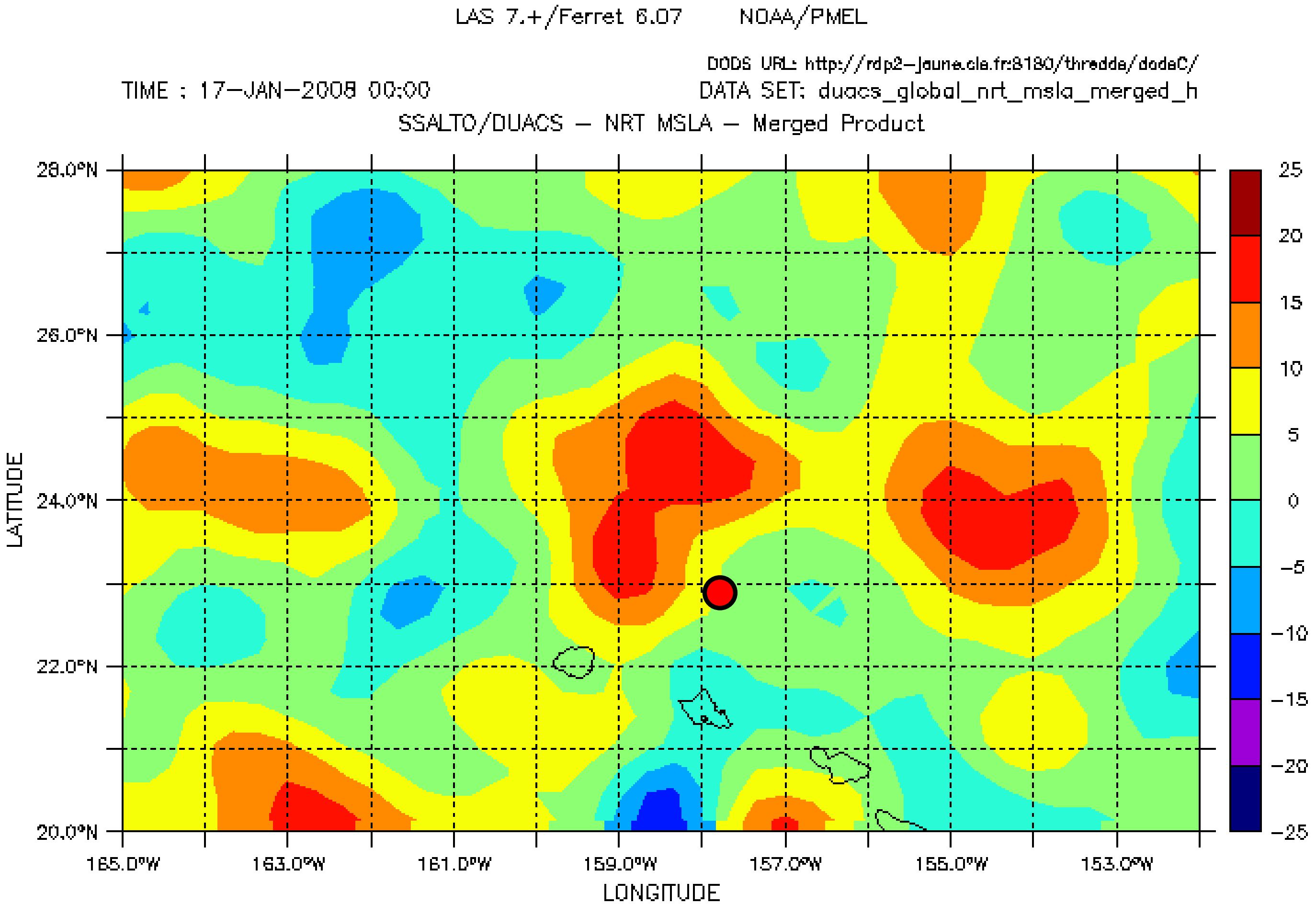
Maps of Sea Level Anomalies Merged (cm)



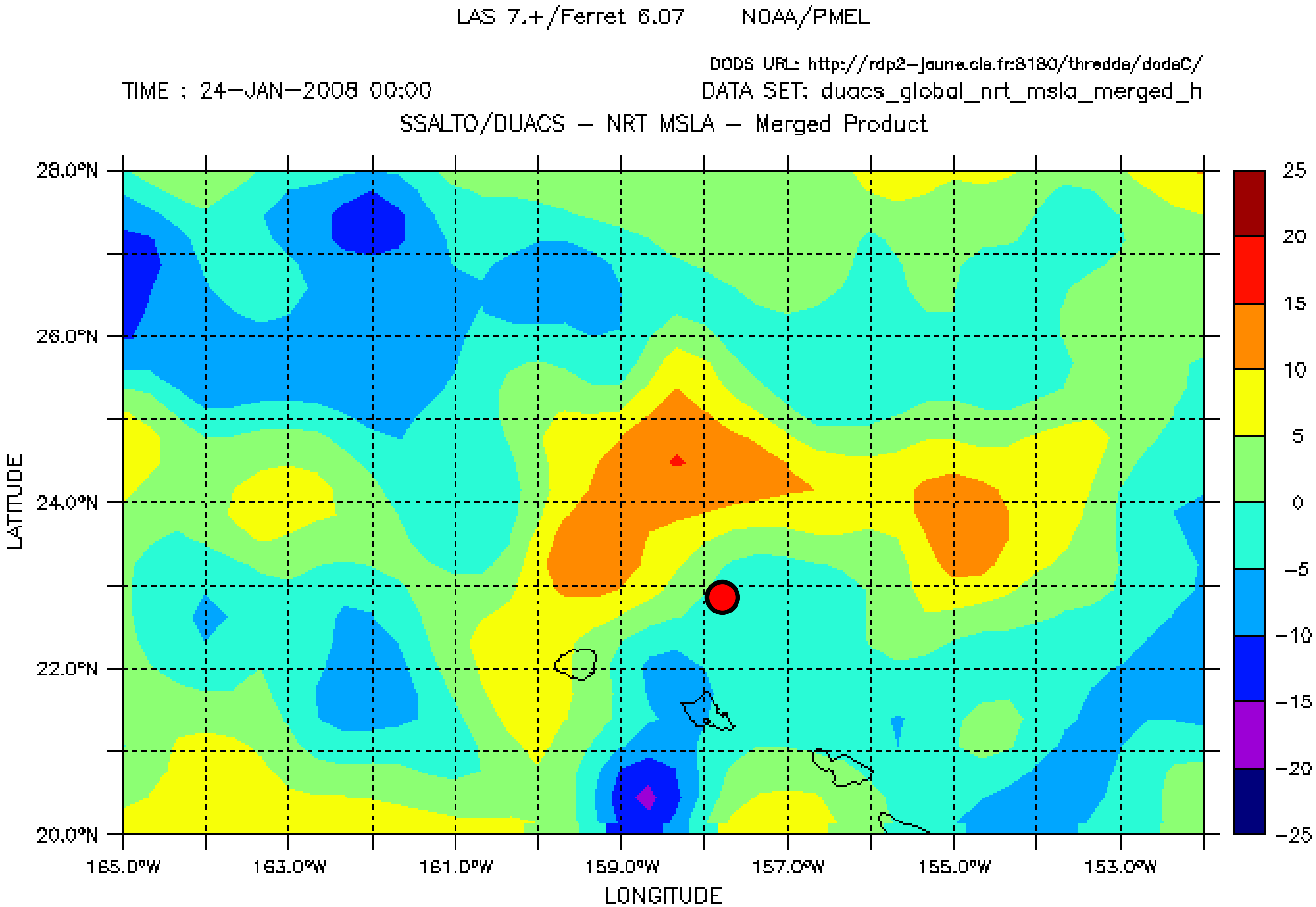
Maps of Sea Level Anomalies Merged (cm)



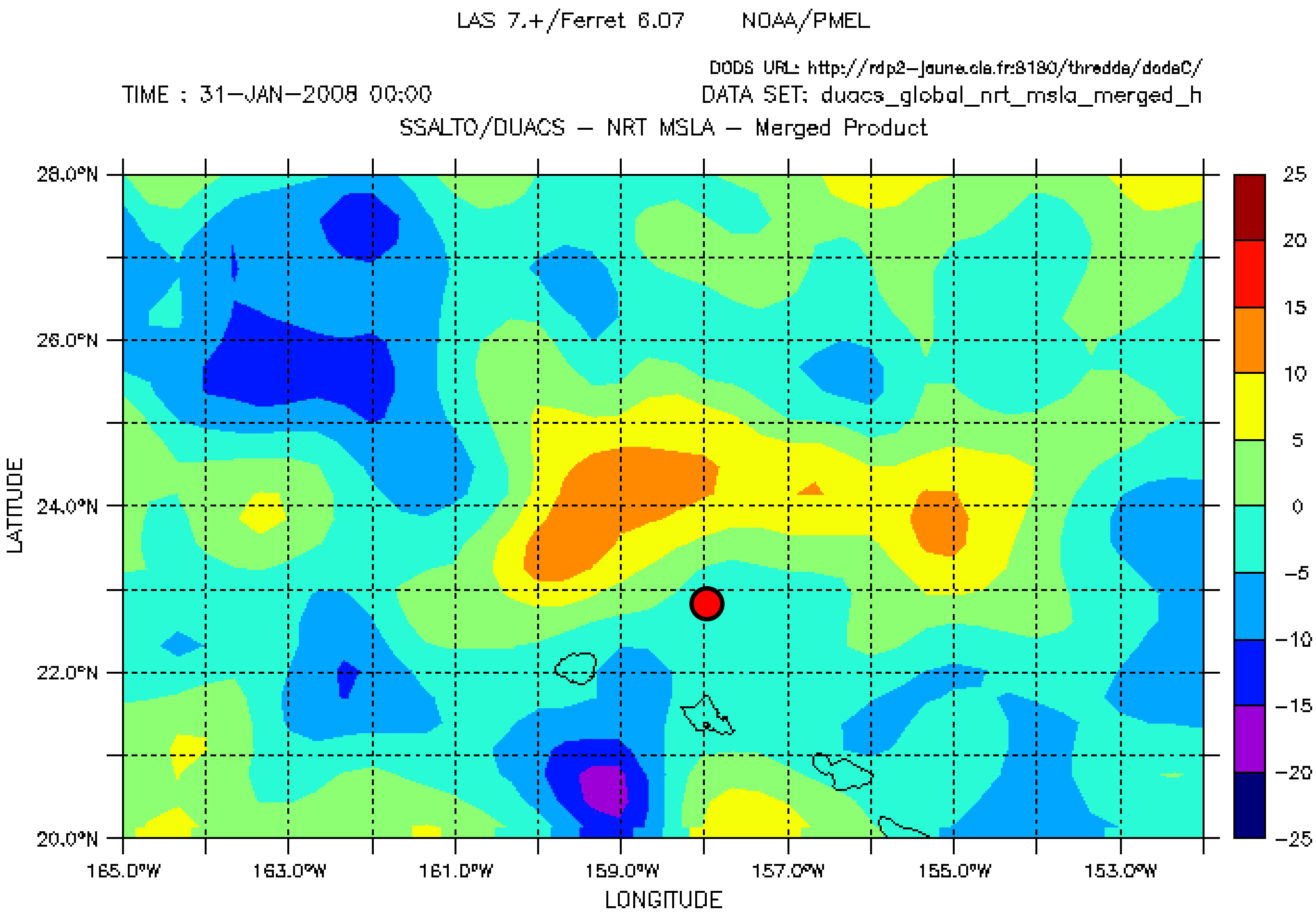
Maps of Sea Level Anomalies Merged (cm)



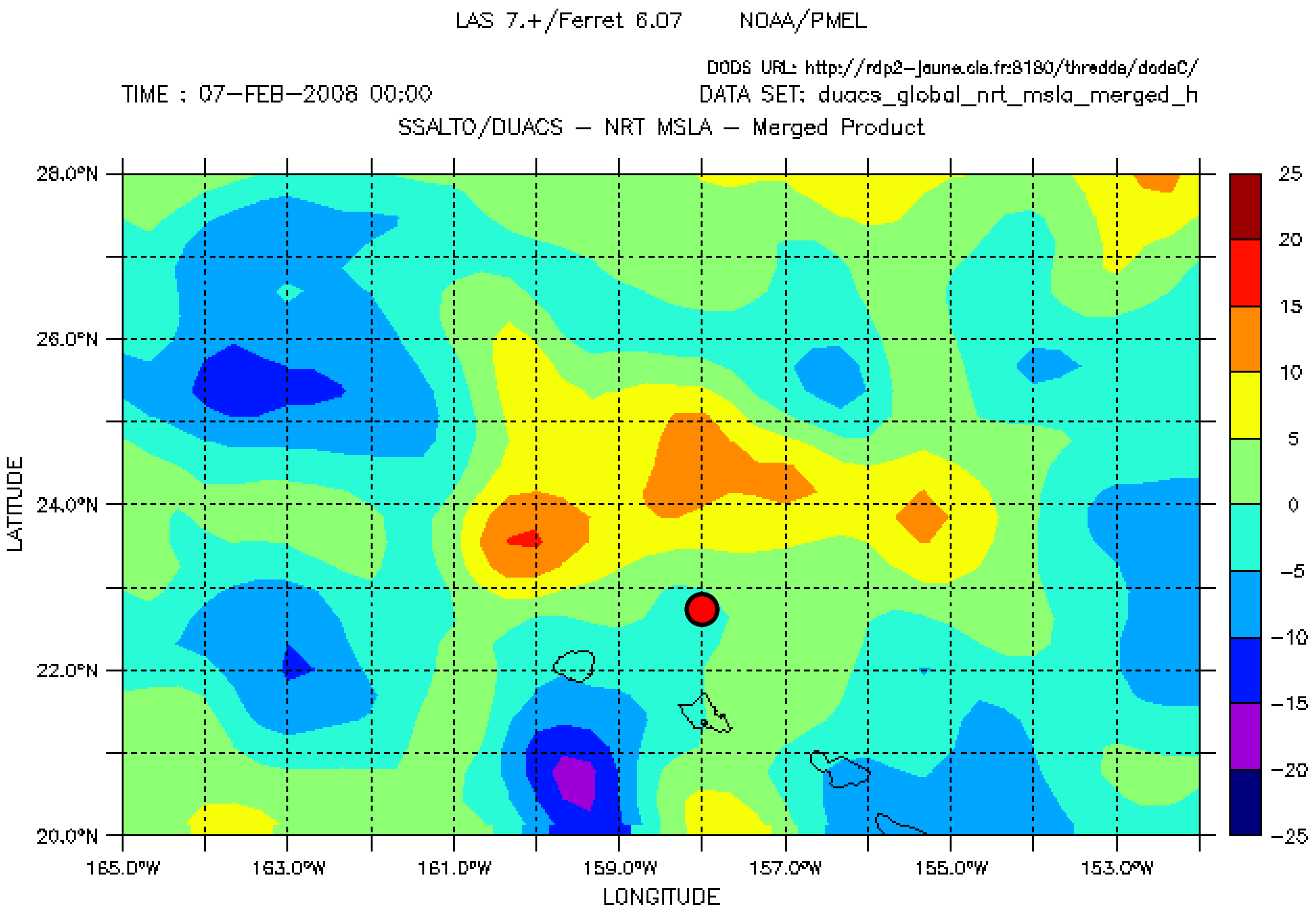
Maps of Sea Level Anomalies Merged (cm)



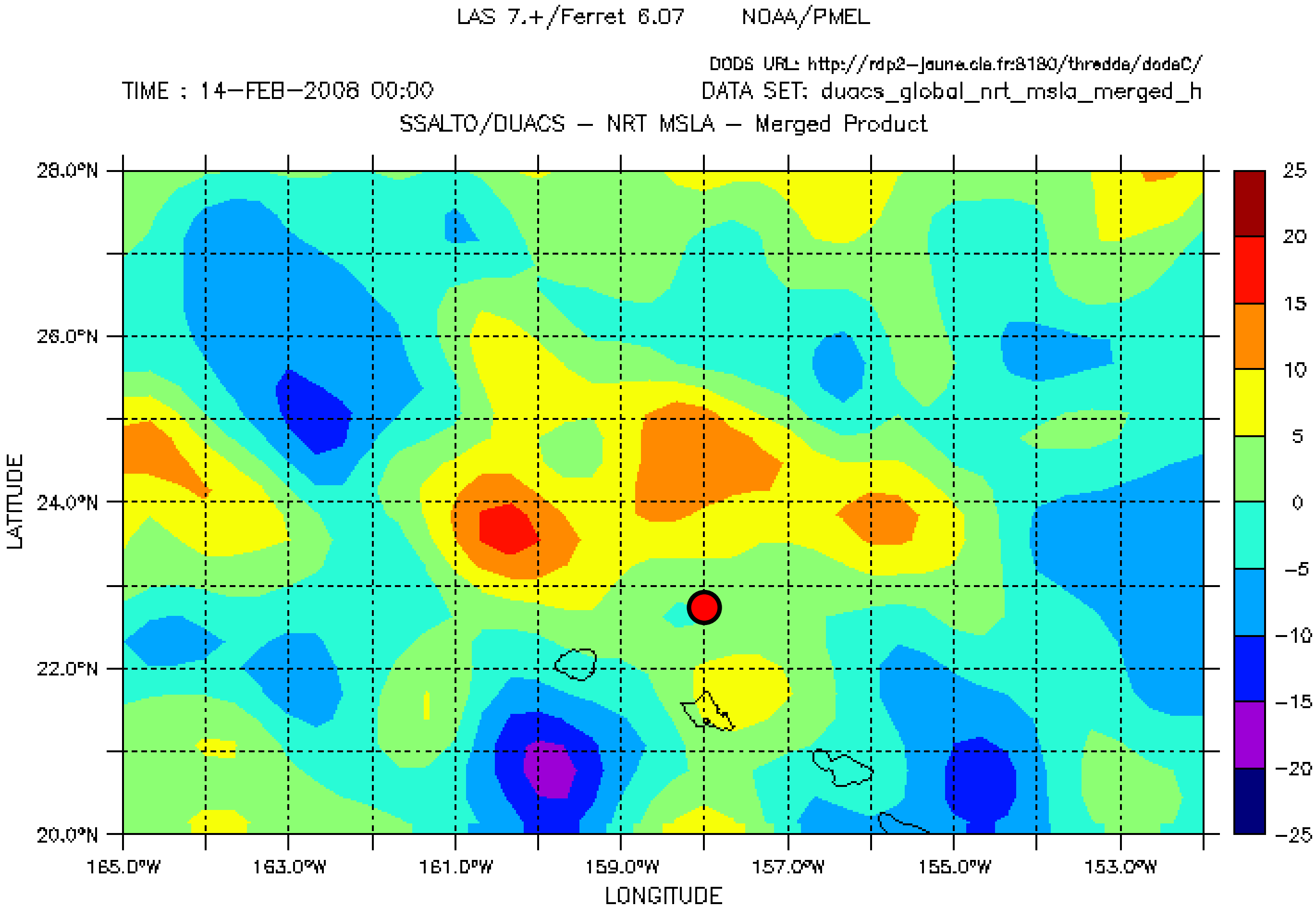
Maps of Sea Level Anomalies Merged (cm)



Maps of Sea Level Anomalies Merged (cm)



Maps of Sea Level Anomalies Merged (cm)



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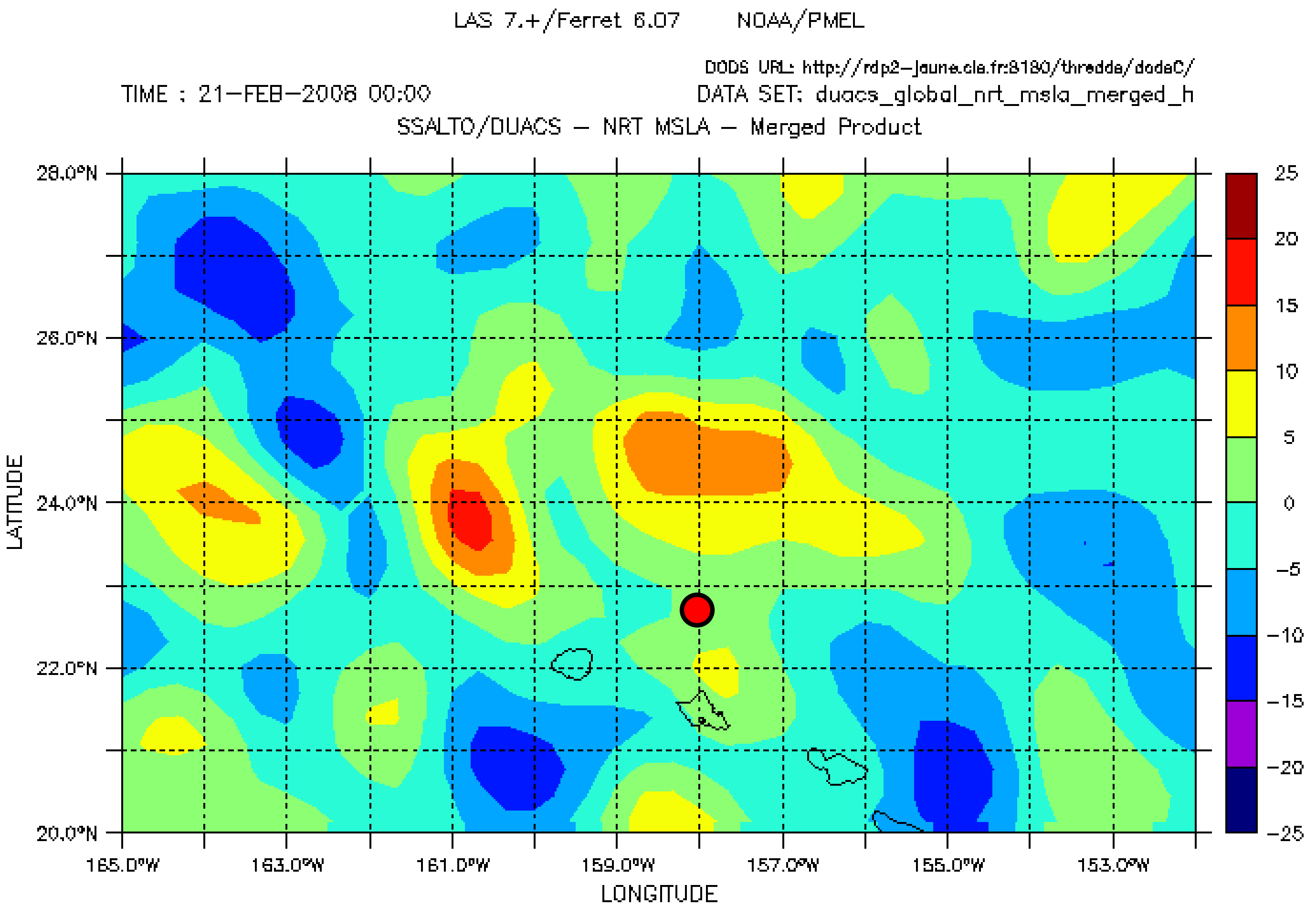

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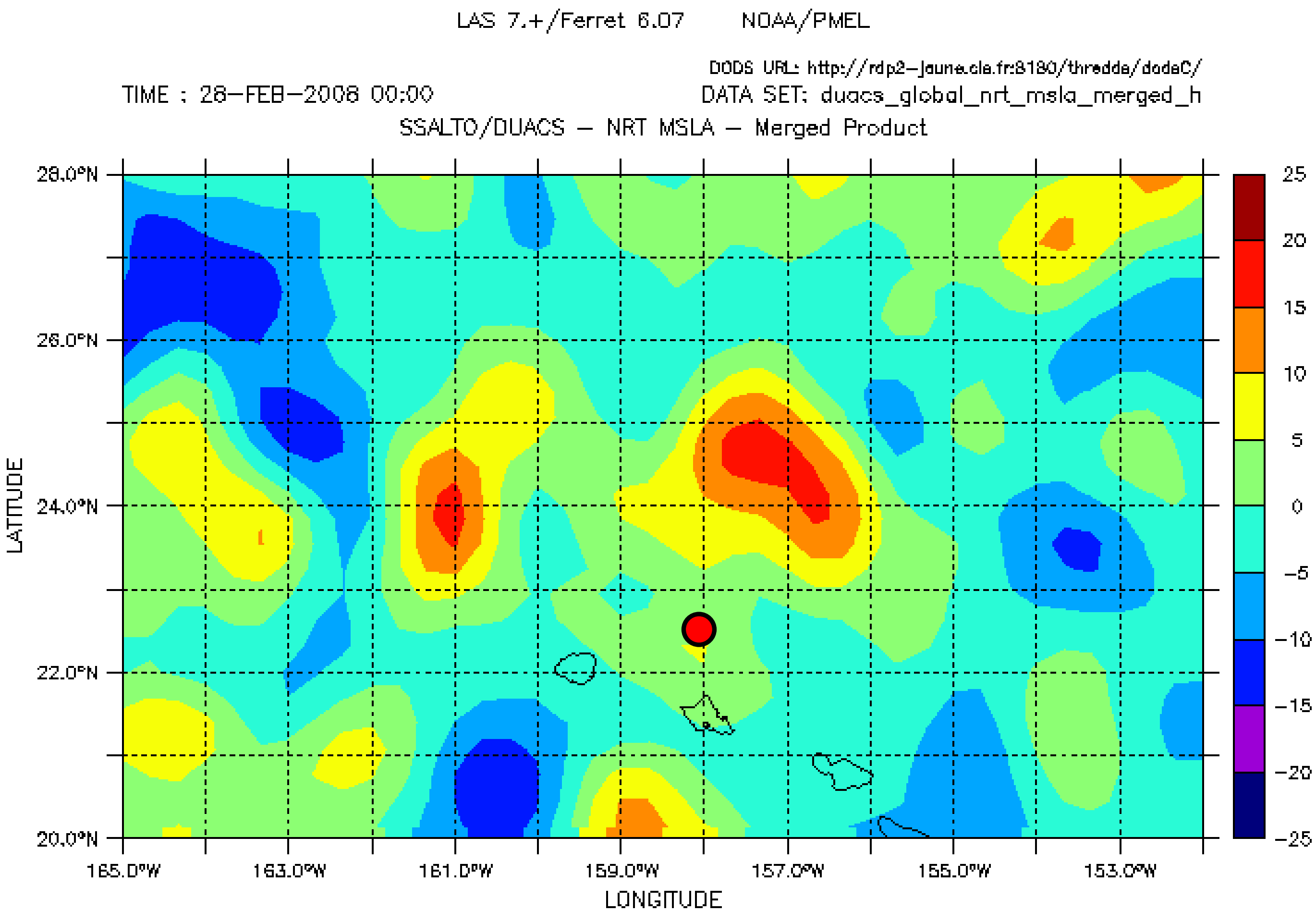
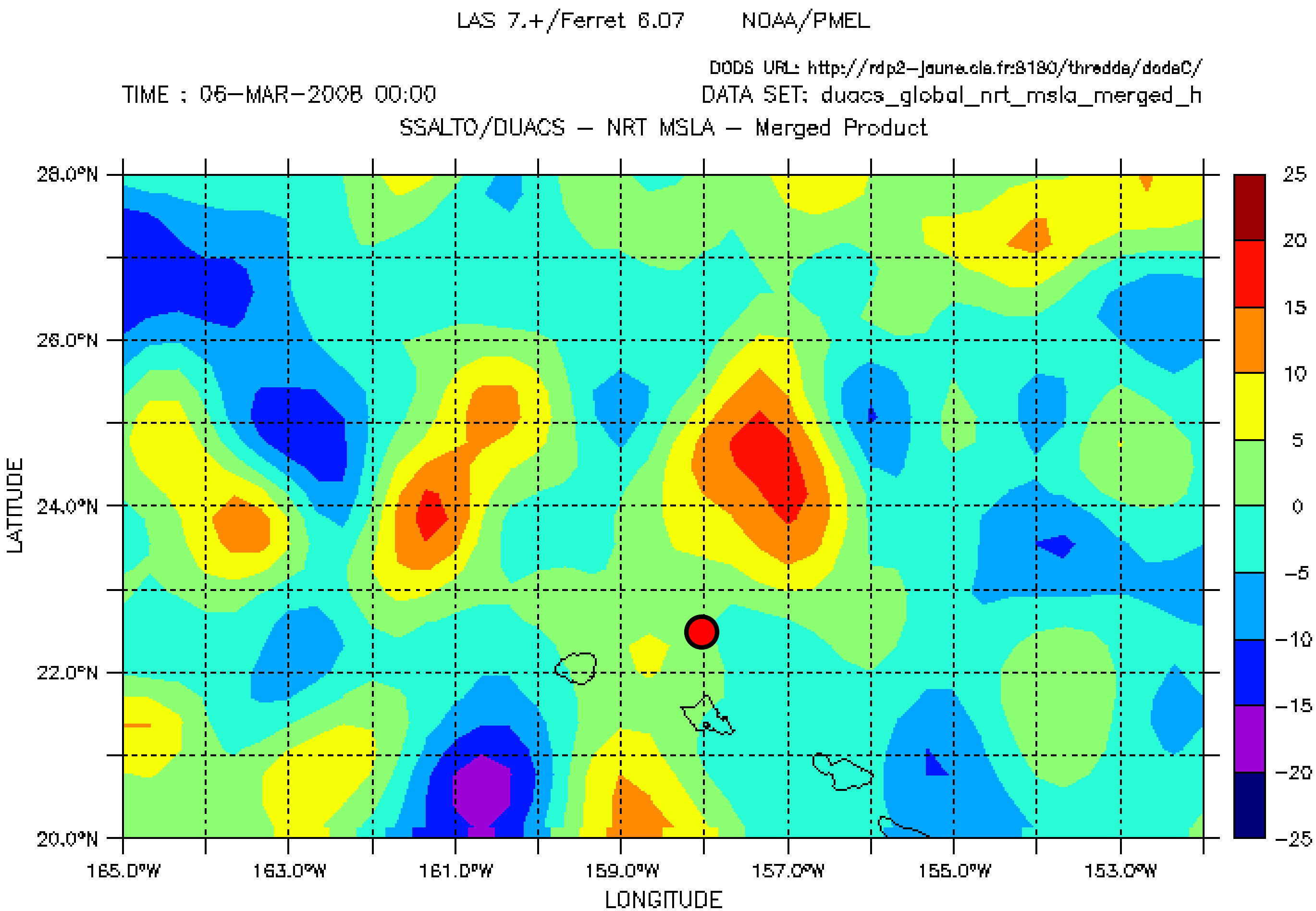
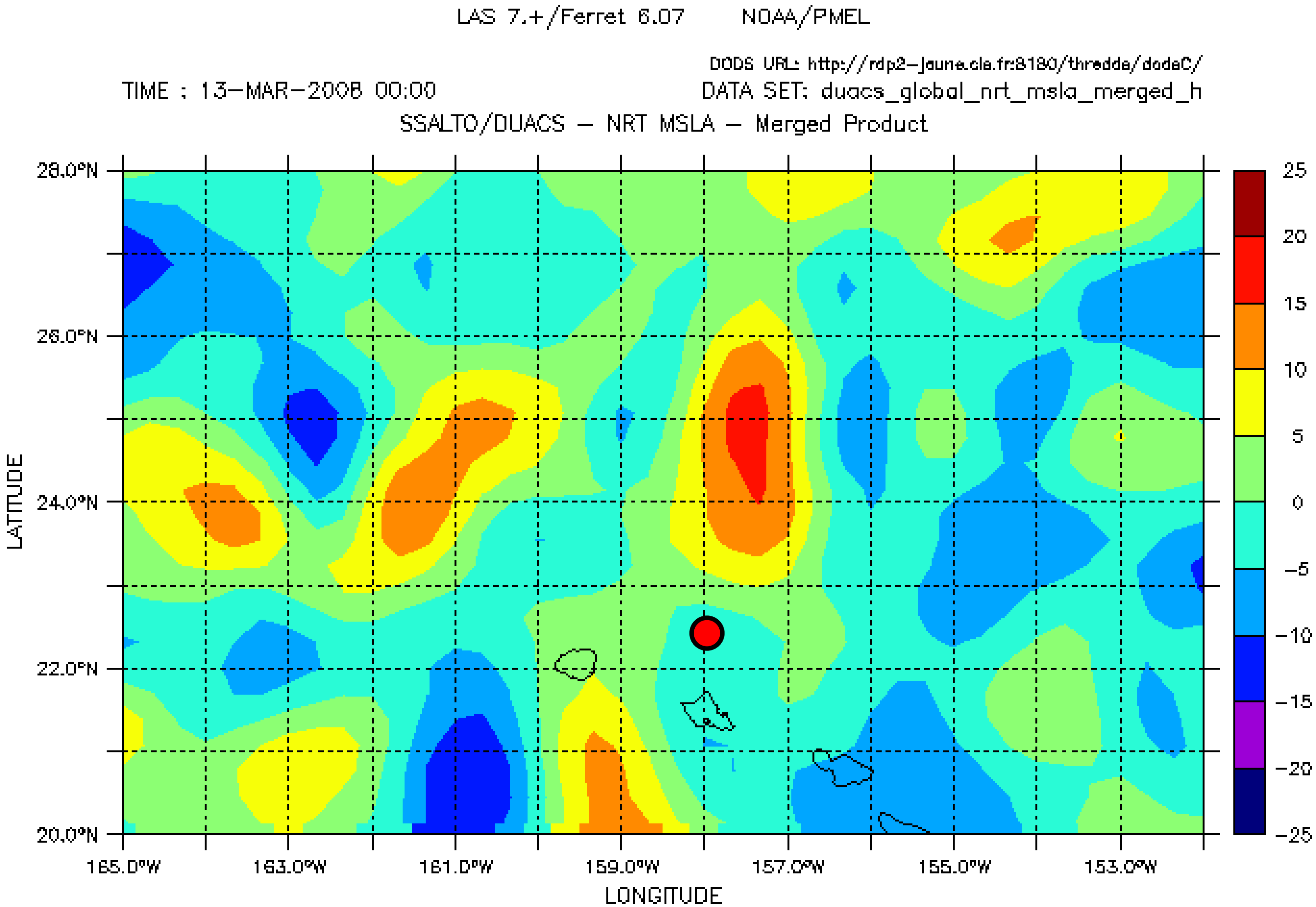


Maps of Sea Level Anomalies Merged (cm)



Maps of Sea Level Anomalies Merged (cm)



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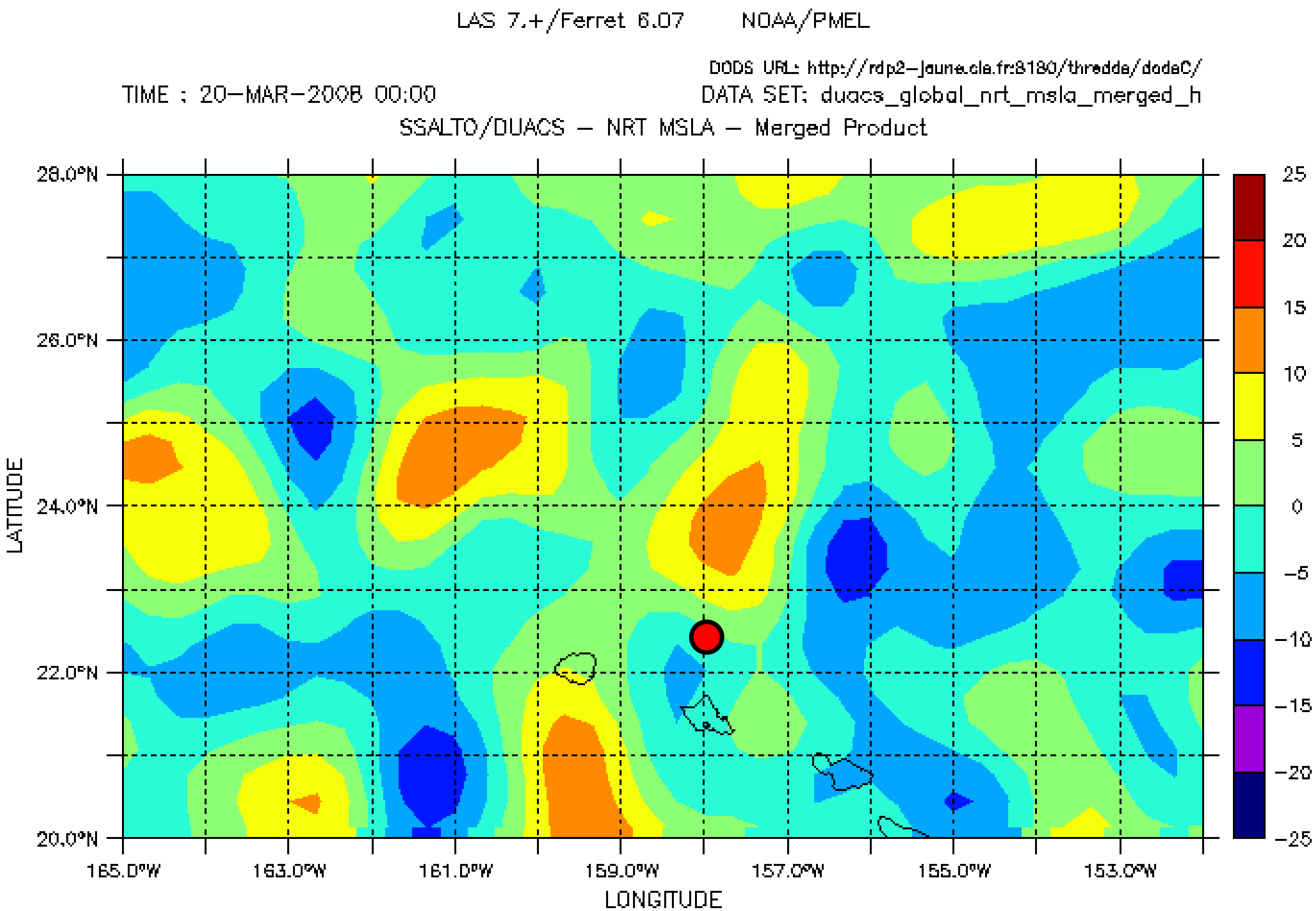

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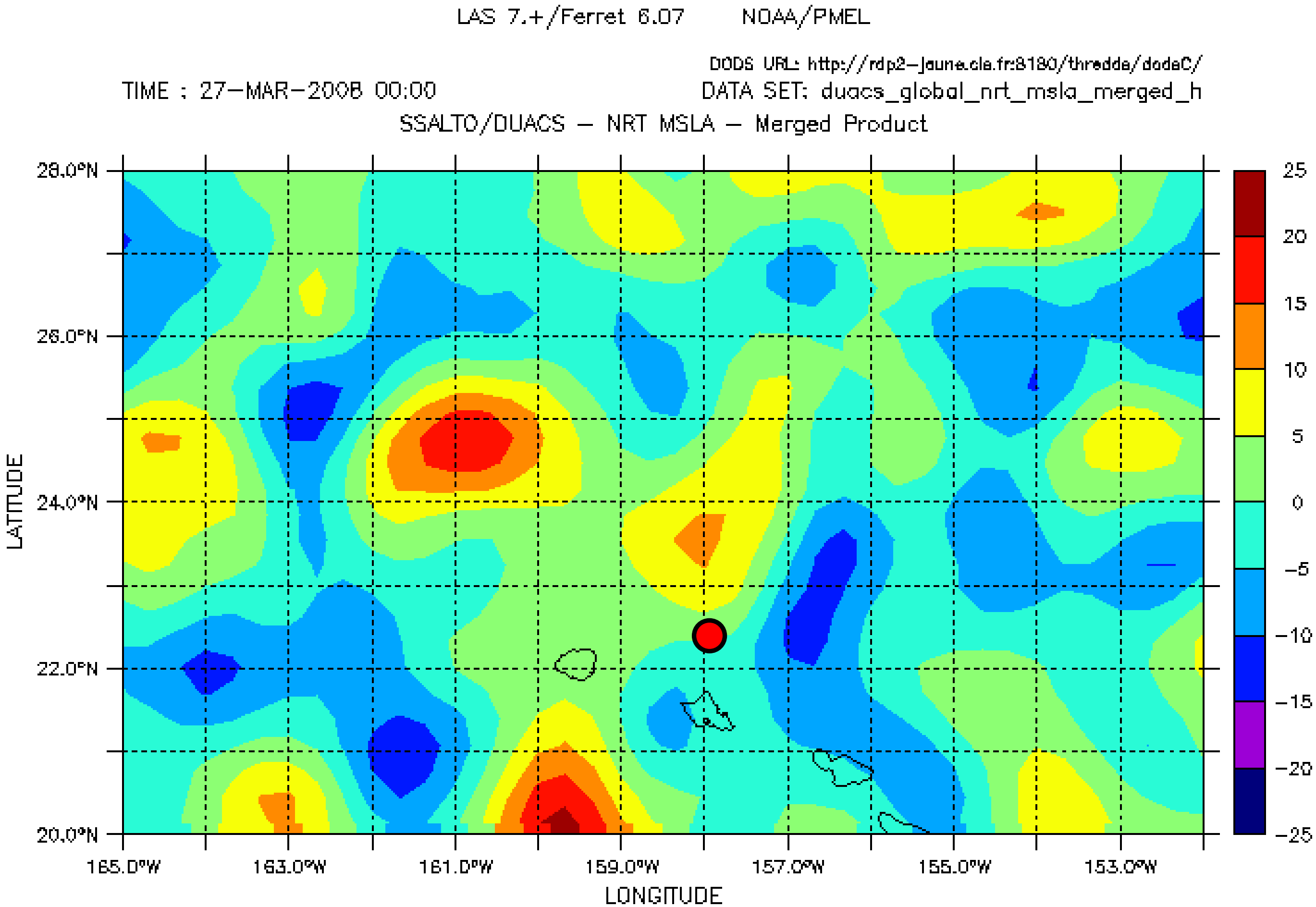

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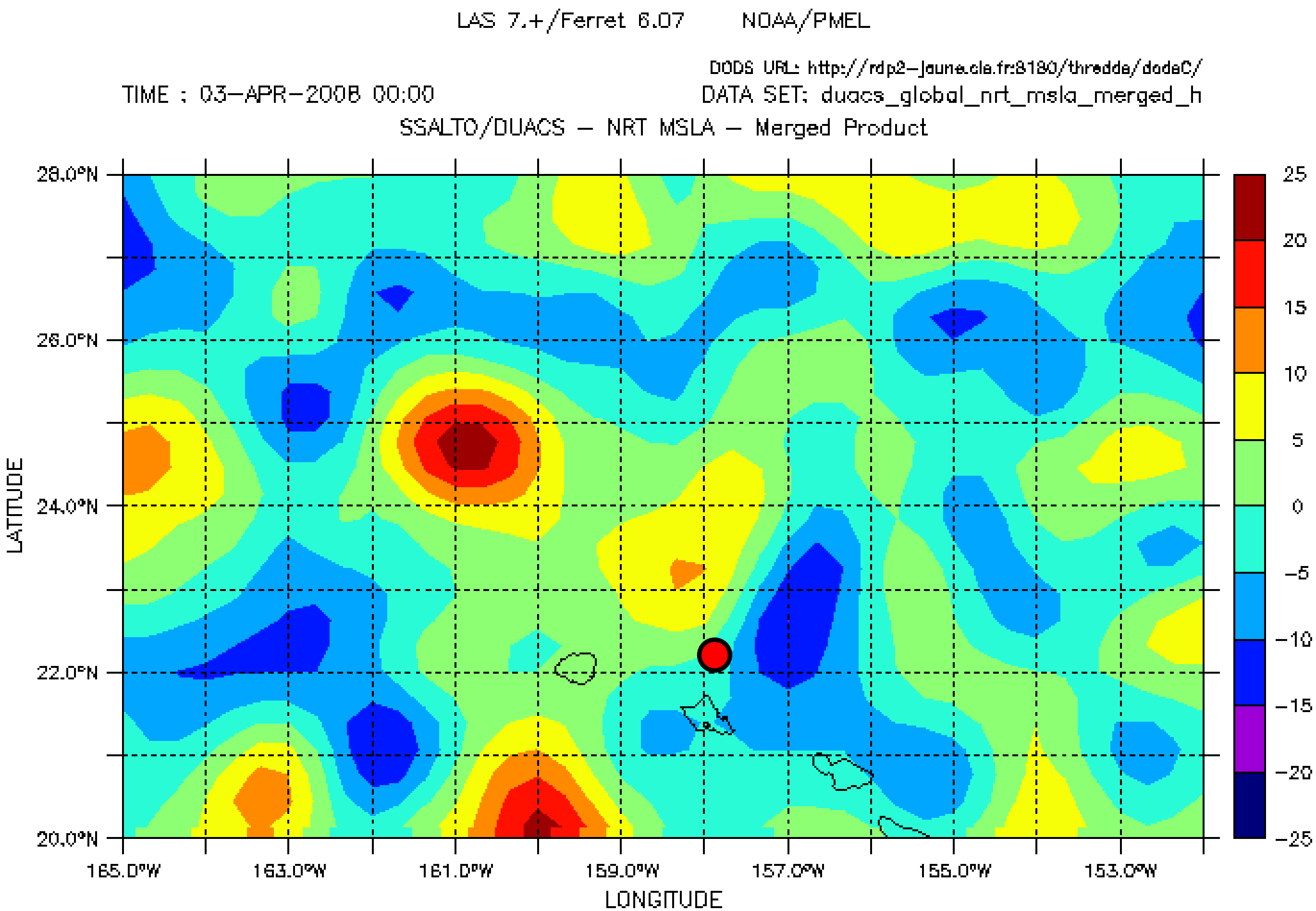

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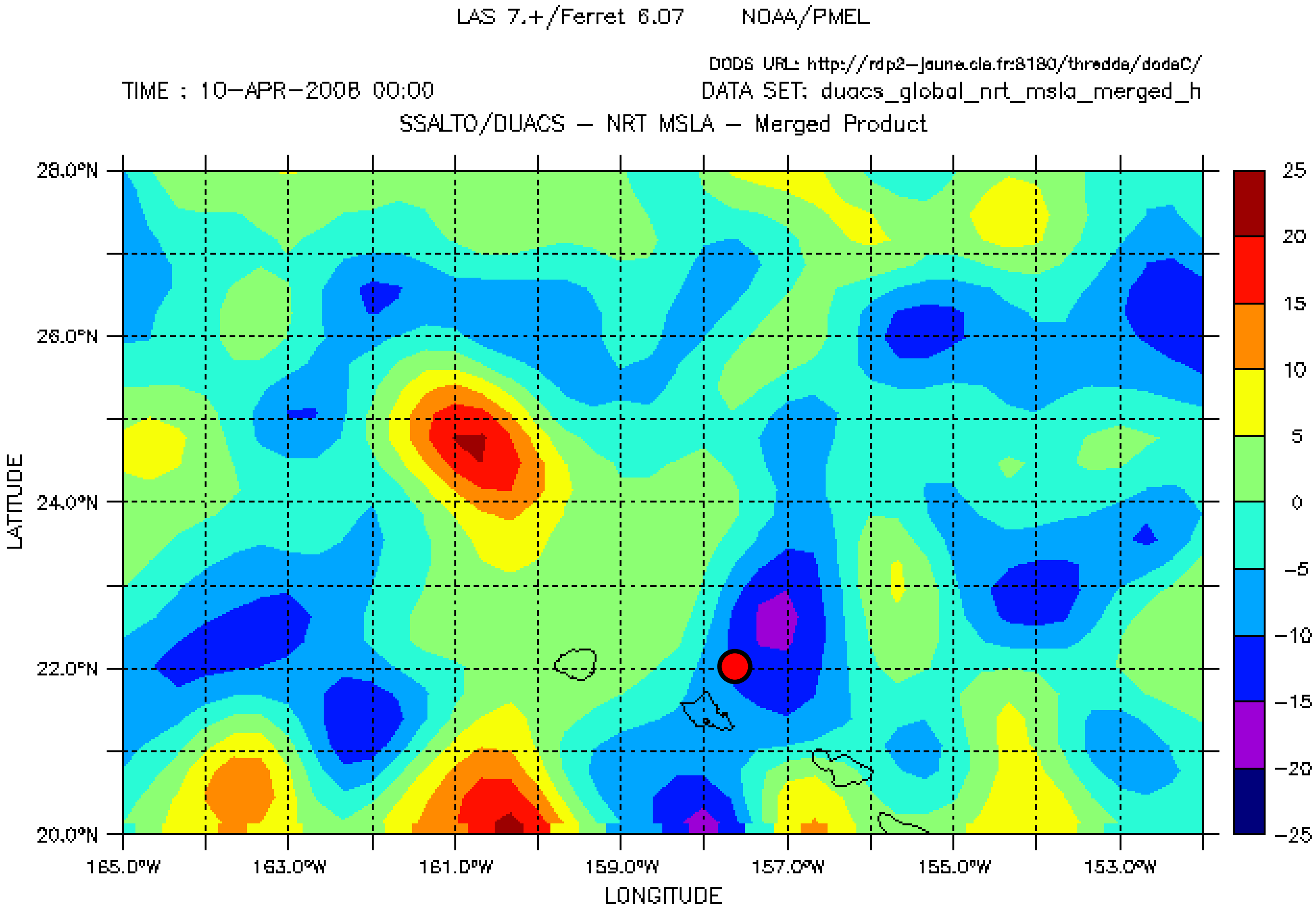

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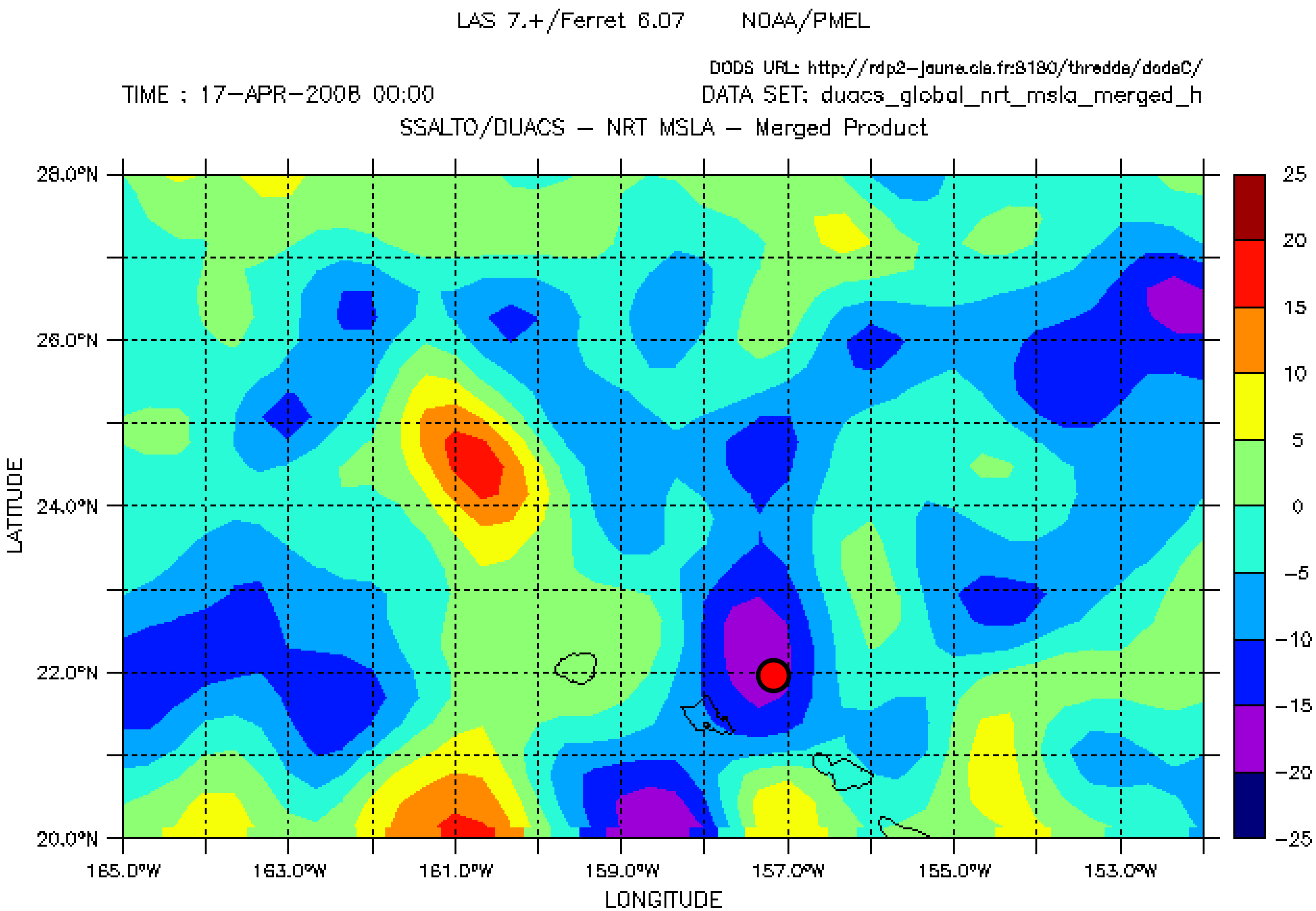
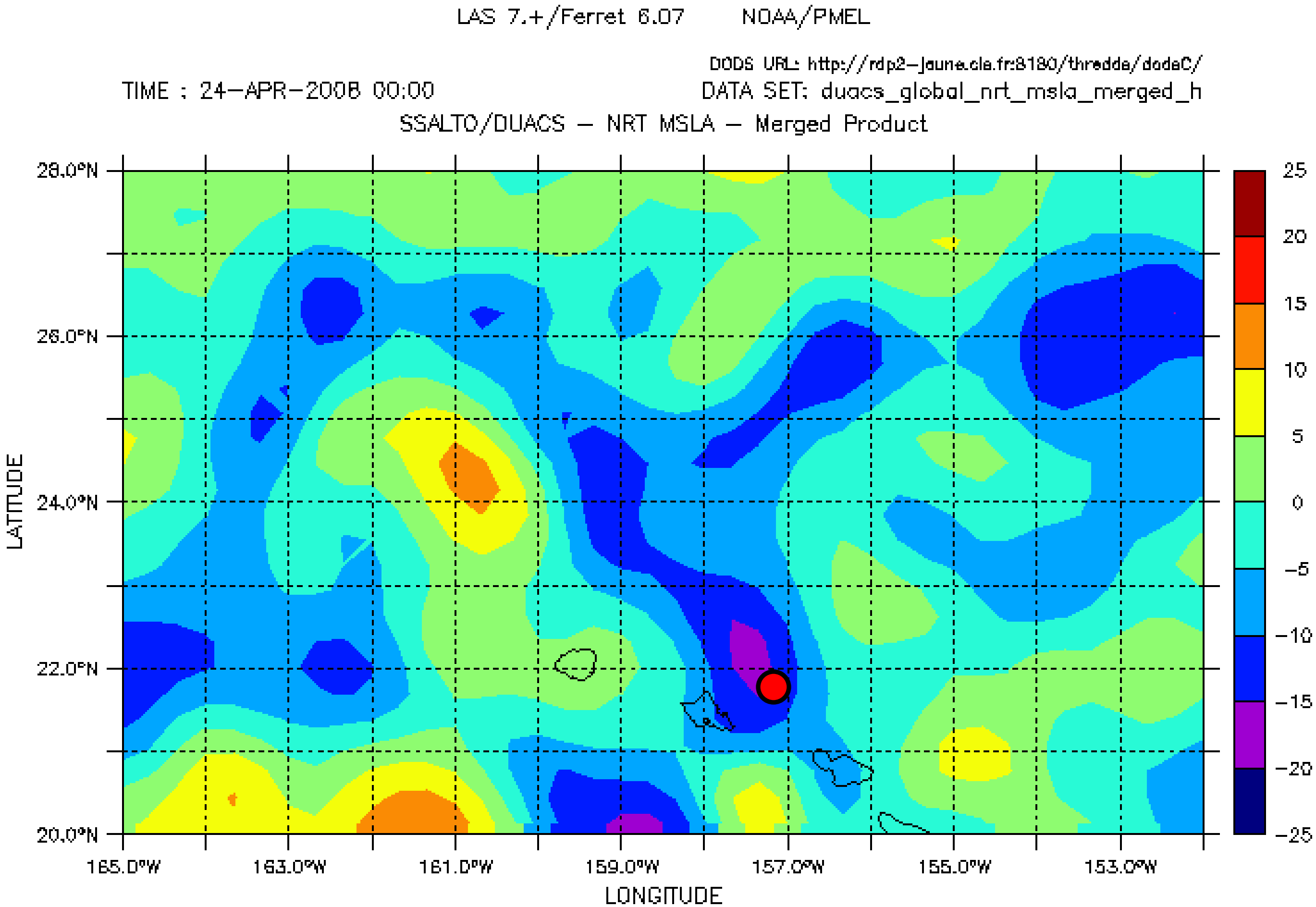
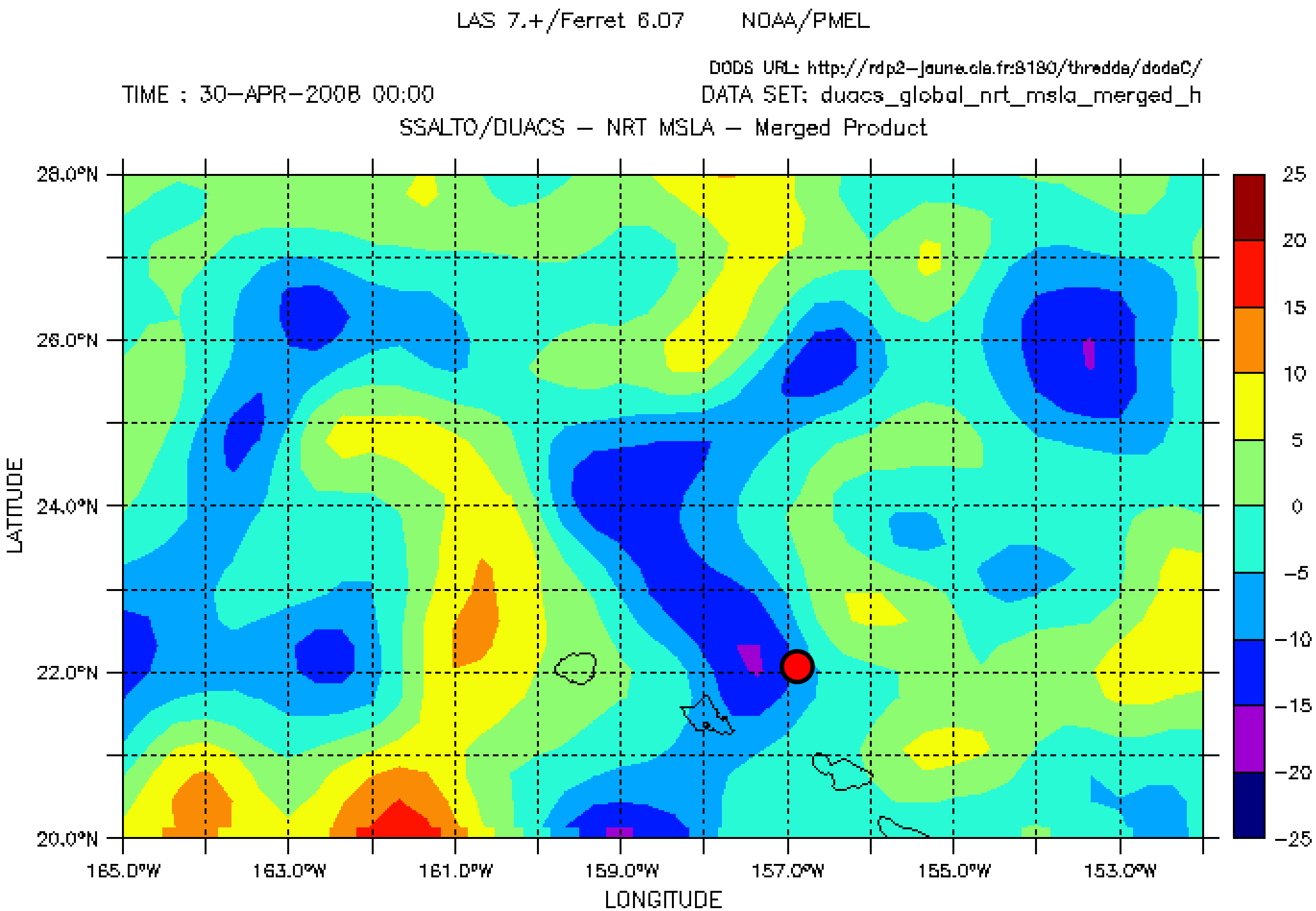


Maps of Sea Level Anomalies Merged (cm)



Maps of Sea Level Anomalies Merged (cm)



Maps of Sea Level Anomalies Merged (cm)

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Mechanisms for vertical nutrient transport within a North Atlantic mesoscale eddy

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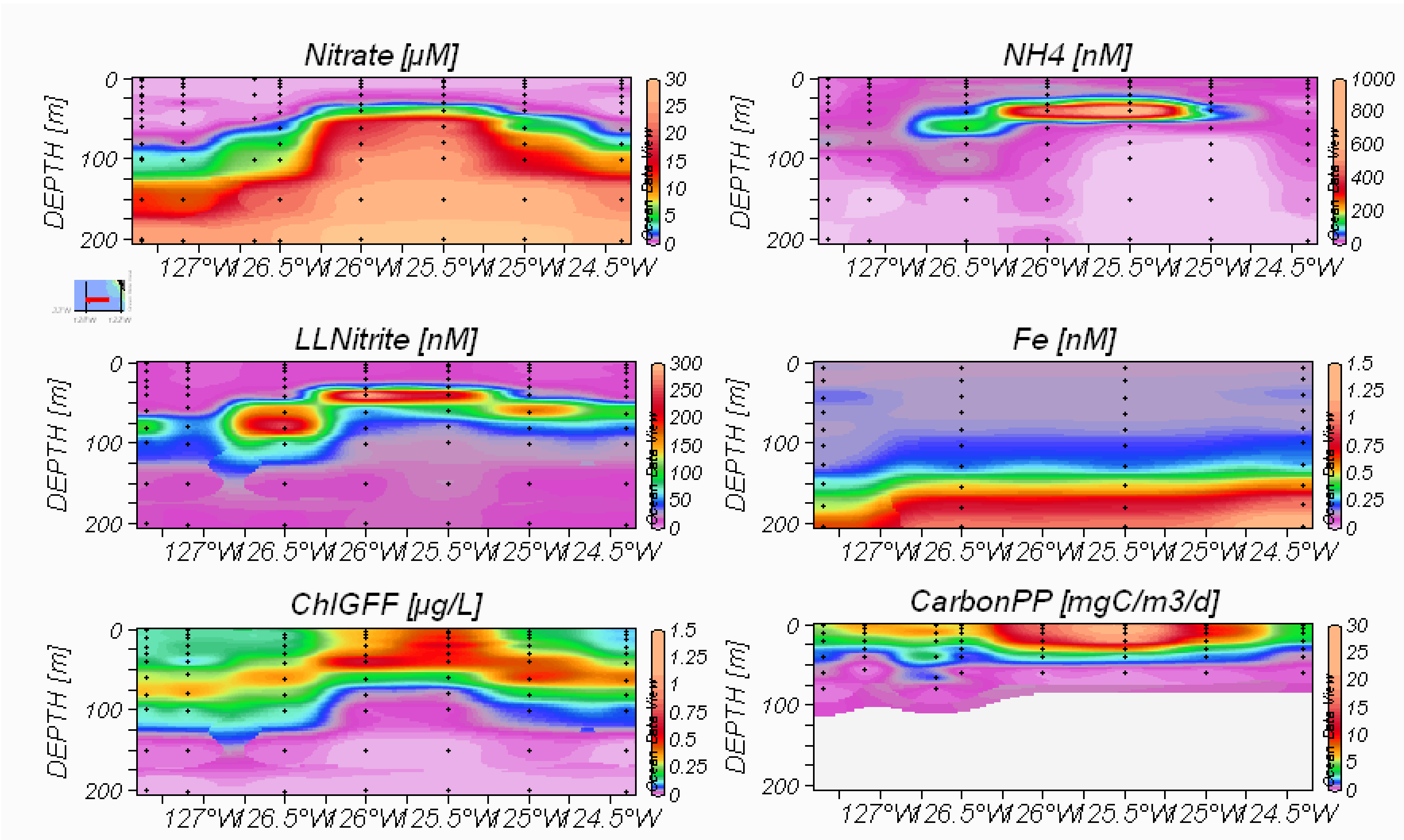
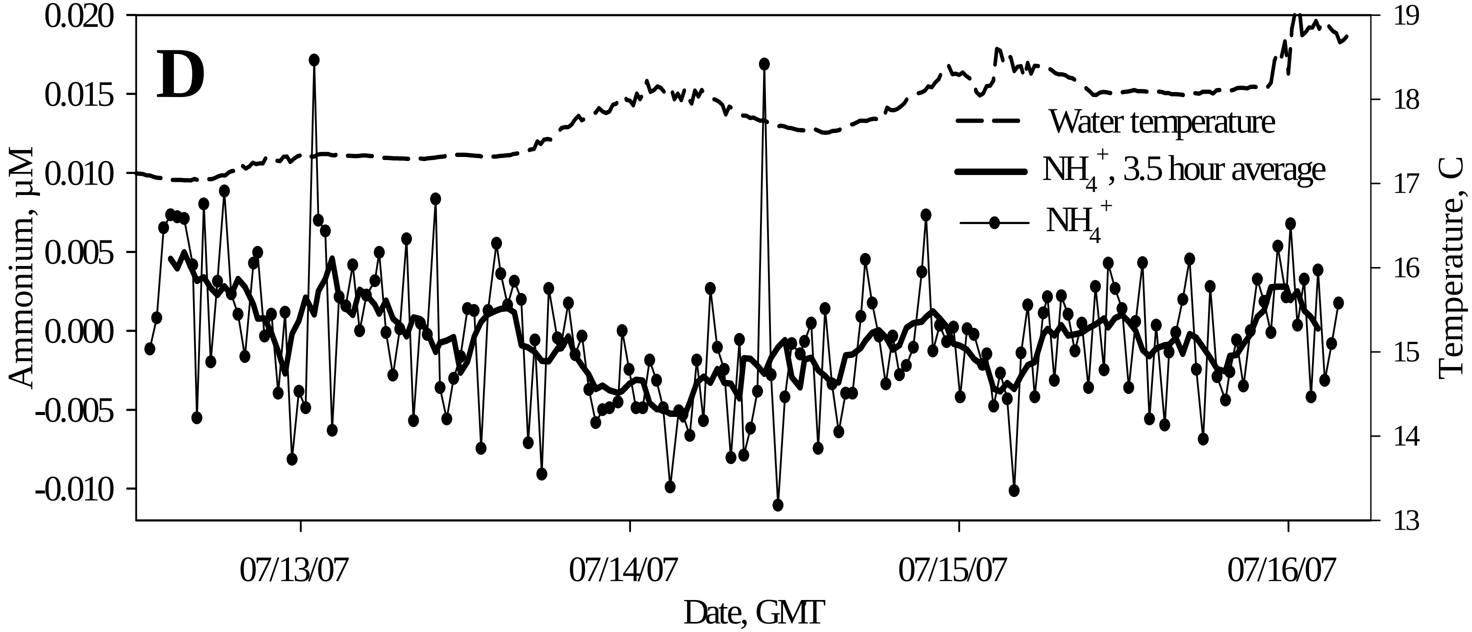
Abstract

Prompted by observational evidence for an enhanced source of surface nutrients within an anticyclonic eddy in the NE Atlantic, we investigate vertical transport processes that may produce such a phenomenon. For the eddy investigated, the dominant mechanism is found to be ageostrophic circulation resulting from a perturbation of the circular flow of the eddy. This can produce upwelling velocities of order 10 m d^{-1}.

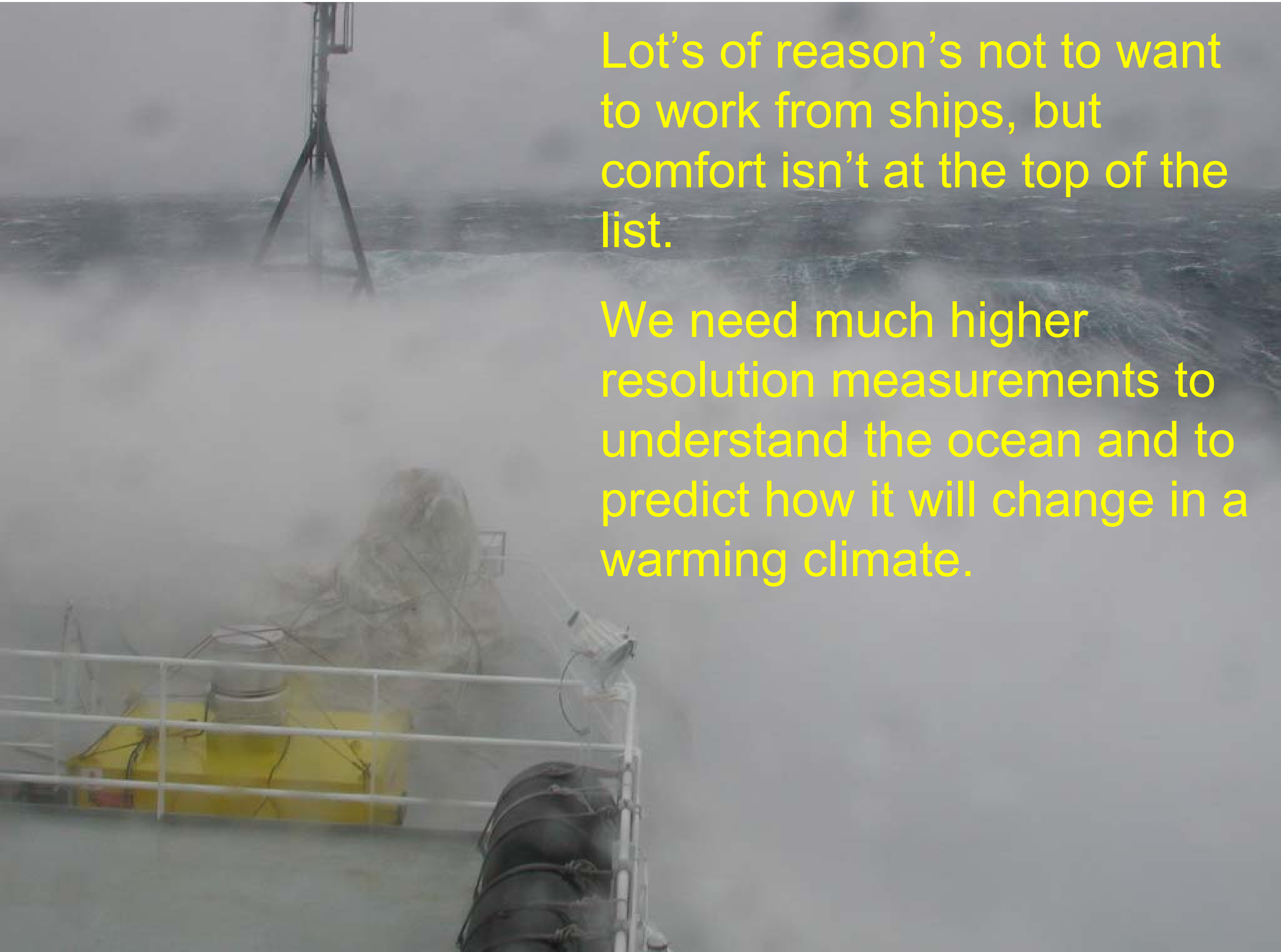
Where are we headed?

- Ammonium, the Rodney Dangerfield of nutrients. It gets no respect!





D
0.020
0.015
0.010
0.005
0.000
-0.005
-0.010
Ammonium, µM
19
18
17
16
15
14
13
Temperature, C
Water temperature
NH4+, 3.5 hour average
NH4+
07/13/07
07/14/07
07/15/07
07/16/07
Date, GMT



Lot’s of reason’s not to want to work from ships, but comfort isn’t at the top of the list.

We need much higher resolution measurements to understand the ocean and to predict how it will change in a warming climate.