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From: Larry Anderson
Date: May 22, 2008

North Atlantic Report #57:
Maltrud's Simulations with 3 Phyto Groups

1. Sinking POC Flux and Phytoplankton Groups

A movie of Sinking POC Flux compared with the 3 phytoplankton groups is at:
http://www.whoi.edu/science/AOPE/people/landerson/NATL/poc_phytob.avi
Phytoplankton are integrated to 104 m. The movie shows that both DIAT (diatoms) and SP (small phytoplankton) contribute to POC flux; DIAZ (diazotrophs) presumably also contribute, but as their biomass is generally over an order of magnitude less than either of the other two, DIAZ can to first order be neglected. DIAT and SP blooms are spatially mutually exclusive. It appears that SP make a larger relative contribution to POC Flux than DIAT (i.e. POC Flux is "yellow" when SP is yellow or when DIAT is red), but this may have to do with SP having lower Chl/N ratios than DIAT (Table 1), which can be corrected by plotting SPC and DIATC instead of SPCHL and DIATCHL. So it seems likely SP and DIAT make similar relative contributions to POC Flux, rather than diatoms making significantly more.

Fig. 1a shows annual averages. POC flux appears to be a linear combination of DIAT and SP, with DIAT dominating in the NE quadrant and SP in the NW. Sinking POC Flux at BATS is about 0.35 mol N/m^2/yr; note this does not include the DON flux. Fig. 1b shows that PON flux is actually maximal at 90 m depth, though not very different from 104 m.

Fig. 2a shows POC Flux at BATS is maximal in late winter, though it can have a smaller peak in summer. Fig. 2b shows these summer peaks appear to be related to eddies. Figs. 3 and 4 show phytoplankton species; these all have summer subsurface maxima that respond to summer eddies, such that it is hard to conclude the relative contribution of each phy-phytoplankton species to the eddy-induced POC summer peaks without more diagnostics (e.g. growth vs. horizontal advection budgets).

- Horizontally-smooth the POC flux in Fig. 1a, and make a vertical profile at BATS, to reconcile it with Fig. 1b, which is lower (0.22 vs. 0.35 mol N/m^2/yr).
- Redo movies, plots with SPC and DIATC instead of SPCHL and DIATCHL, when available; then can compute statistical regressions against POC Flux.
- Find out the exact parameter values and formulas that Mat used.
- Should the bio model be modified so that diatoms make a greater relative contribution to the sinking PON flux? Is there data to base this on? e.g. sinking rate? Otherwise, if diatoms and small phytoplankton behave similarly, no real need to model 2 functional groups.

2. Nitrate and Potential Density at BATS

The movie

http://www.whoi.edu/science/AOPE/people/landerson/NATL/mld.avi

shows that PP, Chl and PON flux are all highly correlated, and that they follow restratification i.e. where MLD (HMXL) was deep and recently became shallow. That is, they occur on the southern edge of retreats in winter mixing. The movie

http://www.whoi.edu/science/AOPE/people/landerson/NATL/mld2.avi

shows deepest winter mixed layers just south of the Gulf Stream (rather than north of it). Winter MLD deepening increases surface NO_3, while surface SiO_3 is never depleted, though SiO_3 less than about 1.0 μM can be limiting to diatoms (Table 1). Still, diatoms bloom in the NE quadrant, where SiO_3 is (consequently) low, such that diatoms appear to be controlling the SiO_3 distribution rather than vice versa. PP is not high where NO_3 is high if MLD is still deep. The movie

http://www.whoi.edu/science/AOPE/people/landerson/NATL/no3.avi

shows that DIAT and SP blooms occur as a result of winter mixing of NO_3 to the surface. SiO_3 does not appear to explain why DIAT bloom primarly in the NE quadrant and SP in the NW. Table 1 shows that the nutrient half-saturation constants for SP are all smaller than those for DIAT, while light-limitation factors and the maximum growth rate for SP and DIAT (not shown) are identical. This raises the question of why SP do not always outcompete DIAT. The only advantage DIAT seem to have is a lower grazing rate (Table 1), which could give them an advantage in spring, when grazing and growth are out of balance. This may not be the true cause for diatom blooms.

Figs. 4b and 5a shows that NO_3 at BATS in the 0.1° run is much higher than observed, reaching 3 μM in winter (due to 6 μM at 200 m depth; MLD appears to be ok) and with the summer nitracline at 60 m rather than 100 m. Is this due to bad physics or bad biology? Ivan Lima's 3.0-degree run, which has similar physics and biology (though not exactly the same), does have a good NO_3 profile at BATS (Fig. 5b). However the 3.0-degree run actually has a worse density distribution between 60-200 m than the 0.1° run (Figs. 6-8), and a worse 0-200 m density gradient. So one possibility is that, as the biological model parameters have been tuned at coarse-resolution (though not exclusively to BATS), the improvement in density due to eddy-resolution (or the wind-eddy interaction) has now changed the biological distributions, such that the biological model needs to be retuned. Alternatively, turning on the wind-eddy interaction after spin-up may have caused a transient lifting of the isopycnals ; if the biological vertical length/decay scales of PON and DON are correct, model NO_3 should return to observed after several more years. Or there is some problem with the nutrient concentration of Mode-water in the 0.1° run. What is odd is that NO_3 is higher than observed even though density is lower than observed.

- This assumes Mat Maltrud's run uses the parameter values published in Moore et al. (2002, 2004, 2006); confirm.
- Does the model Si concentration agree with BATS data?
- See if in the 0.1° model whether Z biomass dictates DIAT vs. SP blooms.
- Note a lower grazing rate is probably not why DIAT outcompete SP when nutrients are replete; rather, diatoms are able to convert internal NO_3 to NH_4 in the dark, which

other phytoplankton cannot do (Takabayashi et al., 2005, J. Phycology 41(1) p 84). So perhaps tha advantage of DIAT should be a lower kno3, or a higher maximum growth rate, rather than lower grazing. Search for refs on kno3 of diatoms vs. flagellates.

- Need a run exactly like the 0.1° run, but with coarser grid resolution, to see how eddy dynamics change the physics and biology.
- Mat said he would look into the time-evolution of how the density and nitrate distributions diverge from initialization (climatology).
- Are deeper winter MLDs south of the Gulf Stream consistent with Mode-water formation? Is the 0.1° model Mode water forming properly?
- Examine limitation factors, to see why SP and DIAT blooms occur.

3. Silicate at BATS

Fig. 9a shows observed silicate at BATS for 1993-1995. It is quite erratic, showing short timescale and interannual variability with the same magnitude of any seasonal signal. Fig. 9b shows annual-averaged vertical profiles for 1989 through 2006; the years are generally similar, suggesting they can be composited, though 1999-2000 are somewhat lower than the others, and 1989 has an erratic value at 10 m.

Fig. 10a,b show climatological monthly profiles computed from the 1989-2006 data. Surface silicate is highest in March and lowest at the end of summer (October) with a subsurface minimum near 70 m (indicative of diatom growth there). Still, silicate is always replete and should not limit diatom growth. That is, with a $ksio3$ of 1.0 μM (Table 1), these concentrations should reduce diatom growth rates to 41% of their maximum, but this reduced rate is not enough to limit their biomass accumulation (as does DIN). Note that the original data (Fig. 9a) show that there are short periods throughout the year when silicate is briefly drawn down to much lower concentrations, which is possibly the impact of eddies (compare Fig. 9a with 7a). That is, the sporadic silicate drawdown suggests diatoms may be more associated with eddies than the seasonal winter-spring bloom.

It is unclear why silicate at 200 m varies so much, and is highest in Jan (Fig. 10b), and why the 0-200 m vertical integrals in Oct and Jan are not equal. It could be related to seasonal renewal from horizontal advection, as little silica should dissolve above 200 m.

The 0.1° model has much greater silicate concentrations, vertical gradient and seasonality than observed (Fig. 11). In the model silicate is highest in Feb, but is significantly drawndown by the winter-spring bloom by Apr. This suggests the model spring diatom bloom is much larger than observed. The model is faithful however in that silicate at BATS is generally not limiting, and that a subsurface mimimum near 70 m develops by the end of summer (Fig. 11b), due to summertime diatom growth at the DCM.

- Compare interannual density anomalies and silicate, to see if silicate drawdown is associated with eddies; compare also with diatom pigments e.g. fucoxanthin (Steinberg et al., 2001, DSR II p 1405) or use the algorithm of Letelier et al. (1993) mentioned therein.

- Why are the model silicate concentrations so high? Due to the large-scale circulation? How can this be fixed? Ultimately we use the best physical simulation we can (viz. tune the physical parameters to optimize T and S to climatology) and then tune the biological parameters to optimize to the nutrient climatology. Model formulas might need to be modified for correct phenomenology.

- The first objective then is the best possible circulation. Examine the physical simulation for deficiencies, through comparison with Levitus T and S. (SSH variability was already examined in Report #54.) Get Mat's code. Examine the drag coefficient and surface fluxes used, to make sure correct. Test if increasing the drag coefficient by 10%, or using a more complex formula, improves the Gulf Stream separation (requires a 3- or 4-year physics-only run).

4. DIC at BATS

Observed DIC at BATS shows highest surface values in winter and lowest at the end of summer, though at 200 m eddy variability is evident (Fig. 12a). Annual averages (Fig. 12b) show 1989 is anomalously low and 2005-6 high, as well as 2004 above 60 m, so only years 1990-2003 will be used to make the monthly climatology.

The monthly climatology (Fig. 13) shows highest surface values in Mar-Apr and lowest in Sep-Oct; some of the DIC above 100 m may have outgassed to the atmosphere as the mixed-layer warmed. Fig. 14 shows the 0.1° model DIC. This agrees fairly well with the data, aside from an approximately 10 μM offset.

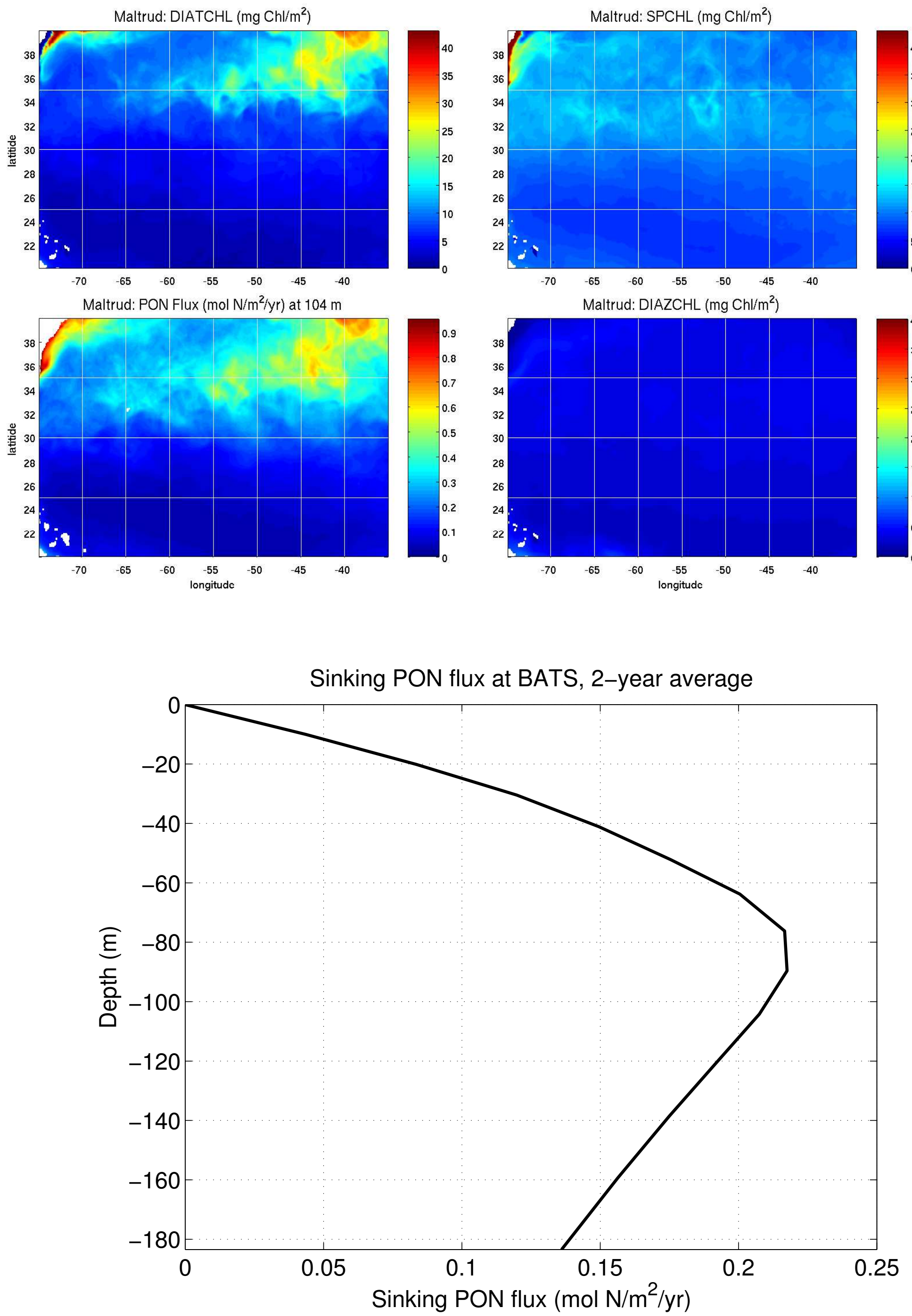
Note the observed DIC-cline extends to the base of the mixed layer (Fig. 18a) rather than to the nitracline (100 m). This also happens in the model, even though Redfield C:N is used (Fig. 19a). Thus while DIN gets consumed at the base of the euphotic zone, DIC can still diffuse up. So this difference between the nitracline and the DIC-cline (given that DIC is not depleted) is not necessariliy an indication of non-Redfield dynamics.

- Model DIC is 10 μM higher even though density is lower (Fig. 8b) i.e. the water is warmer. This is not a fault of solubility.

- Examine O_2, PO_4.

Table 1: Parameter values from Moore et al. (2002, 2004, 2006, 2007)

Parameter	SP	DIAT
kno3	0.5	2.5
knh4	0.005	0.08
kfe	60	150
ksi	0	1.0
kpo4	0.0003125	0.005
max grazing rate	2.75	2.0
max Chl/N ratio	2.3	3.0



Maltrud: DIATCHL (mg Chl/m2)
Maltrud: SPCHL (mg Chl/m2)
Maltrud: PON Flux (mol N/m2/yr) at 104 m
Maltrud: DIAZCHL (mg Chl/m2)
latitide
longitude
Sinking PON flux at BATS, 2−year average
Depth (m)
Sinking PON flux (mol N/m2/yr)

Fig. 1. 0.1° run.

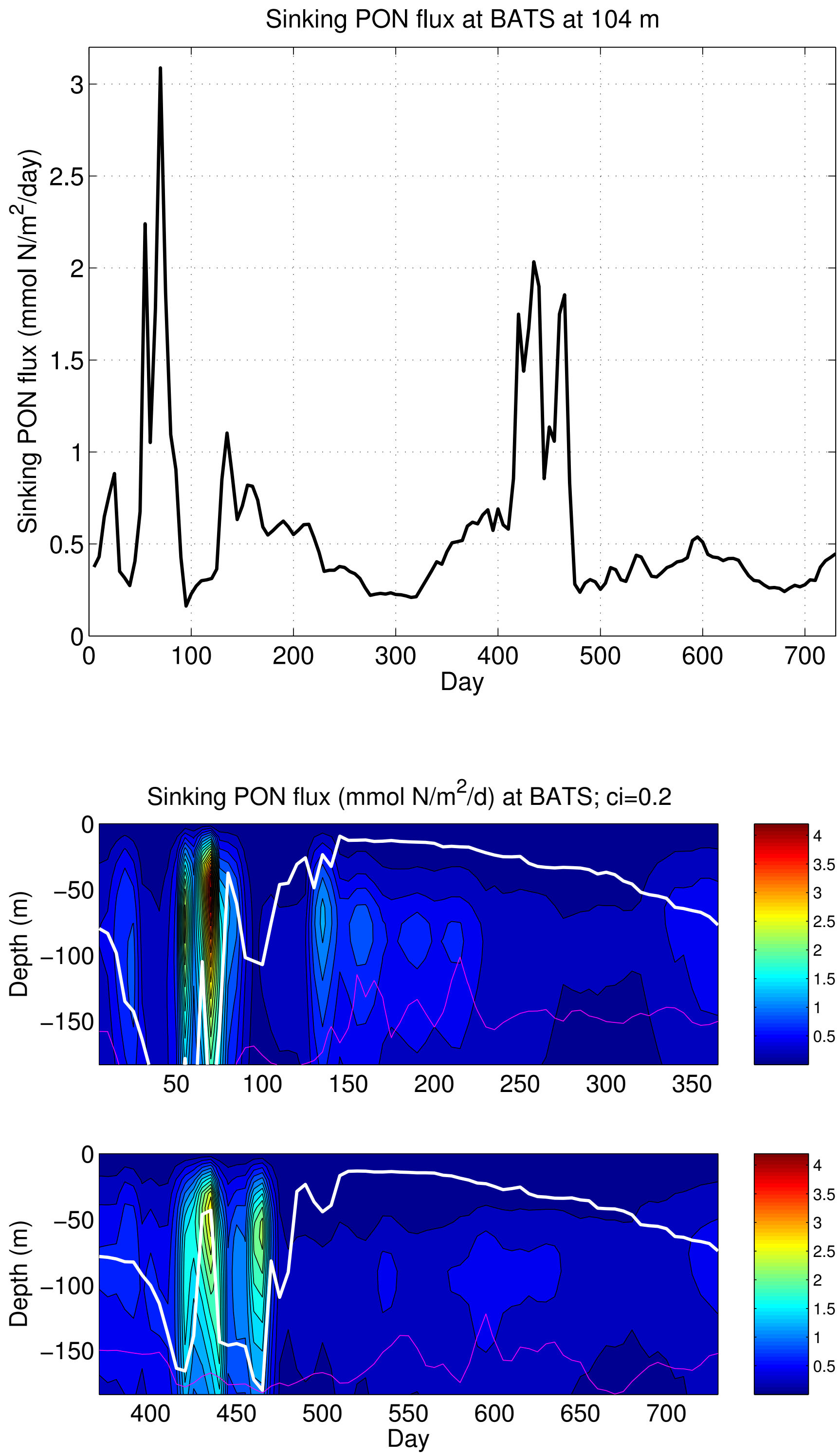


Fig. 2. (b) white line is MLD; magenta line is the σ_θ=26.1 isopycnal.

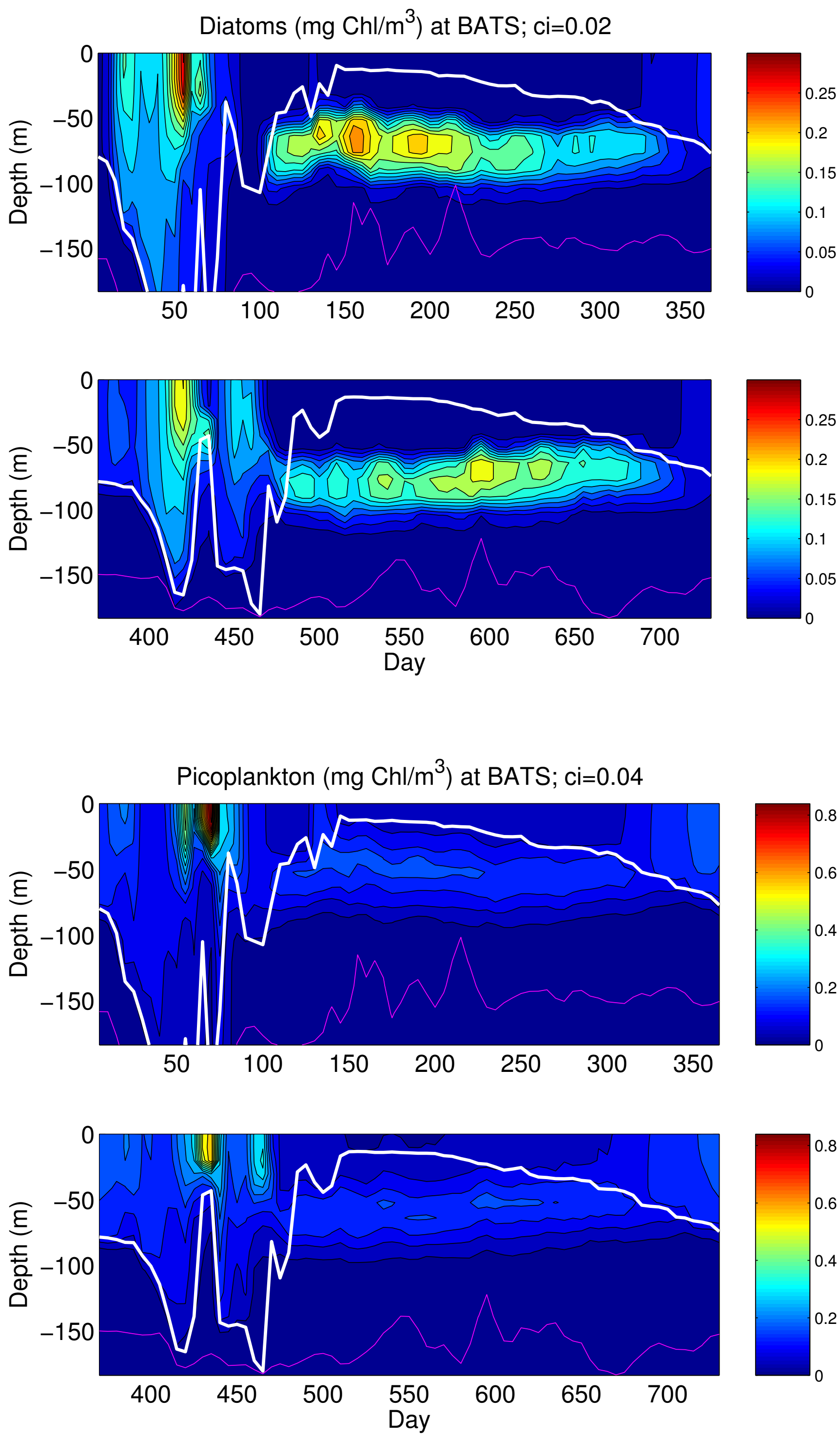

Diatoms (mg Chl/m^3) at BATS; ci=0.02
Depth (m)
0
−50
−100
−150
50
100
150
200
250
300
350
0.25
0.2
0.15
0.1
0.05
0
400
450
500
550
600
650
700
Day
Picoplankton (mg Chl/m^3) at BATS; ci=0.04
0.8
0.6
0.4
0.2

Fig. 3.

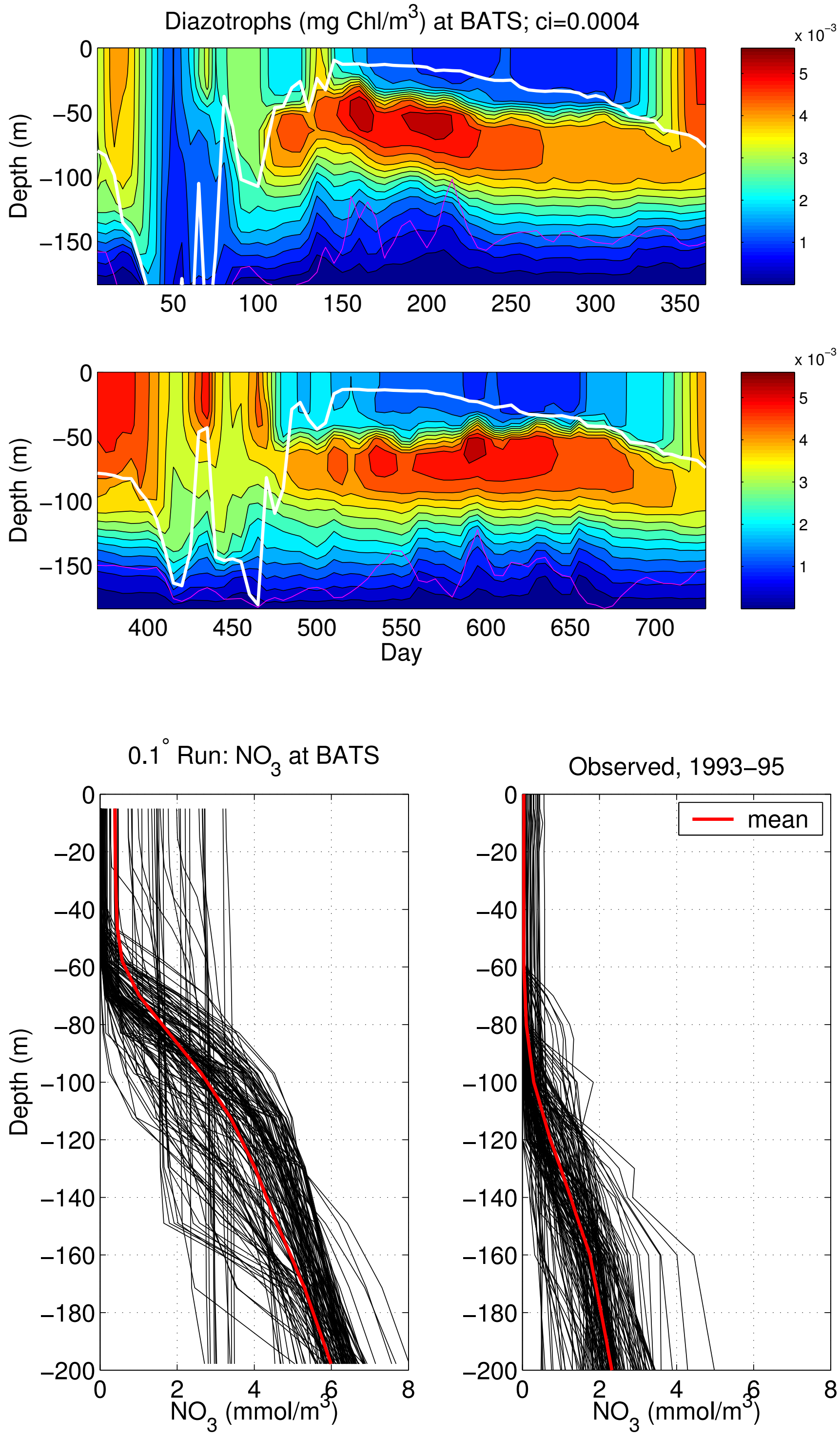

Diazotrophs (mg Chl/m3) at BATS; ci=0.0004
Depth (m)
Day
x 10−3
0.1° Run: NO3 at BATS
Observed, 1993−95
mean
NO3 (mmol/m3)

Fig. 4.

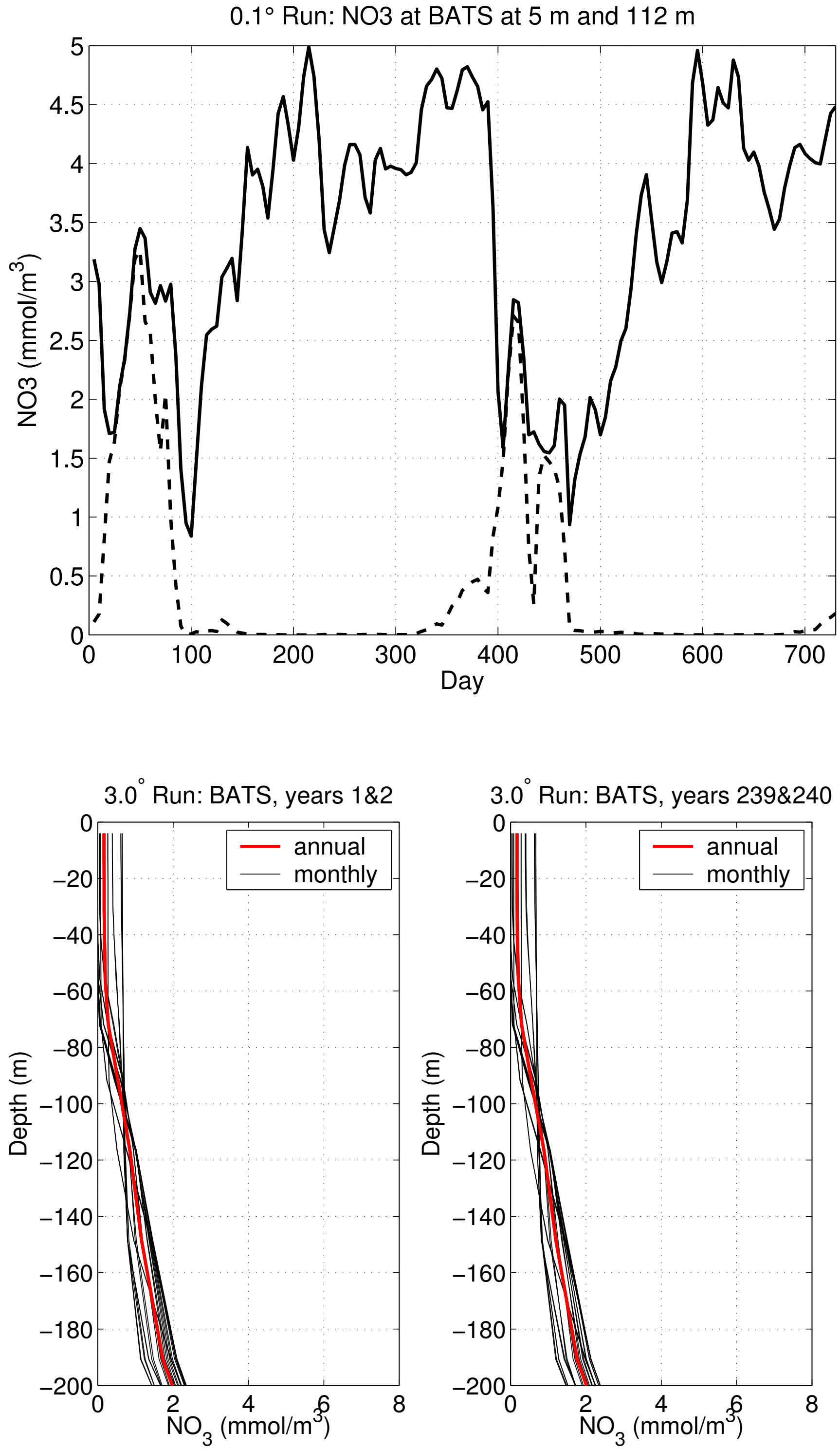

0.1° Run: NO3 at BATS at 5 m and 112 m
NO3 (mmol/m3)
Day
3.0° Run: BATS, years 1&2
3.0° Run: BATS, years 239&240
annual
monthly
Depth (m)
NO3 (mmol/m3)

Fig. 5.

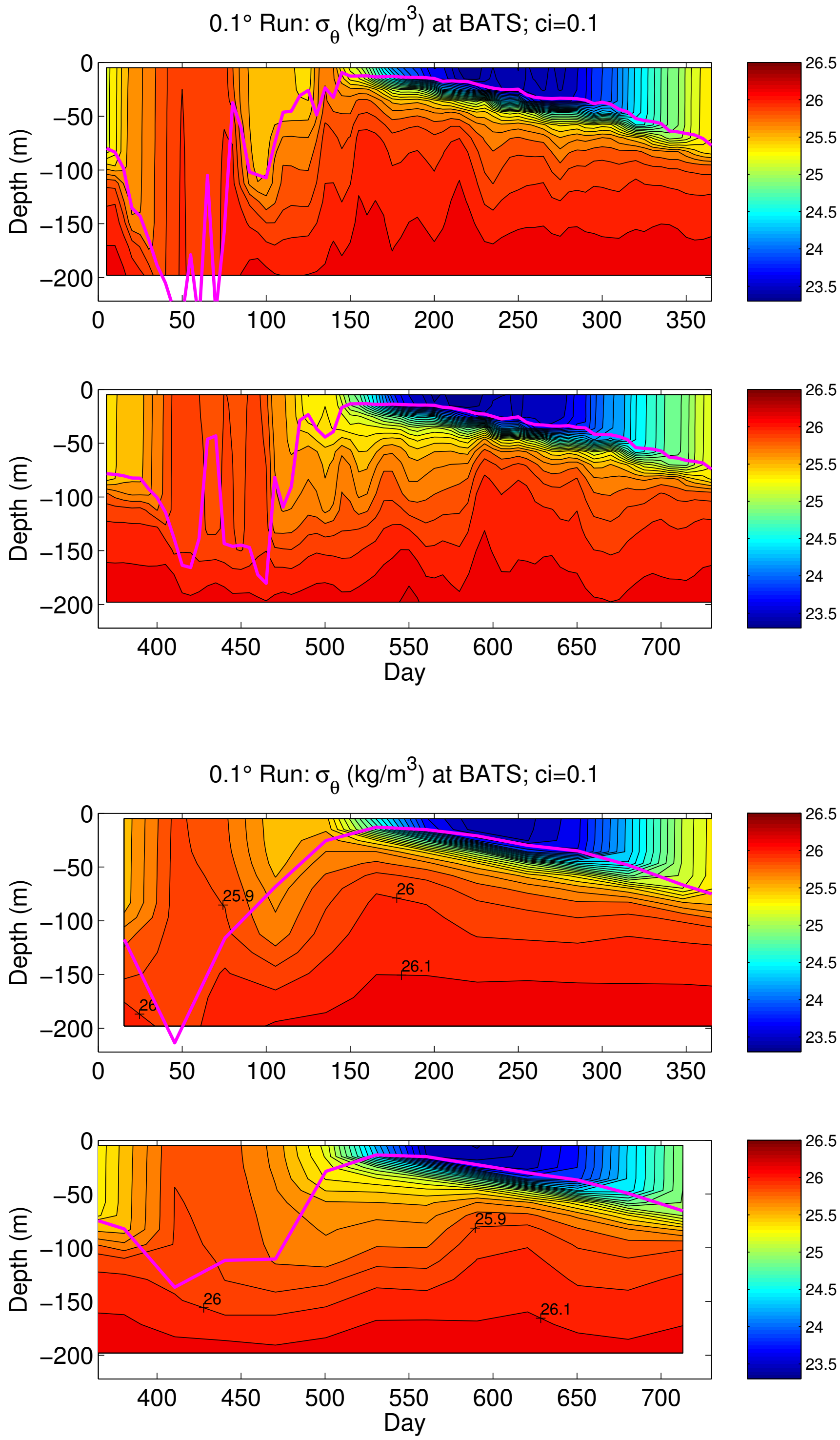
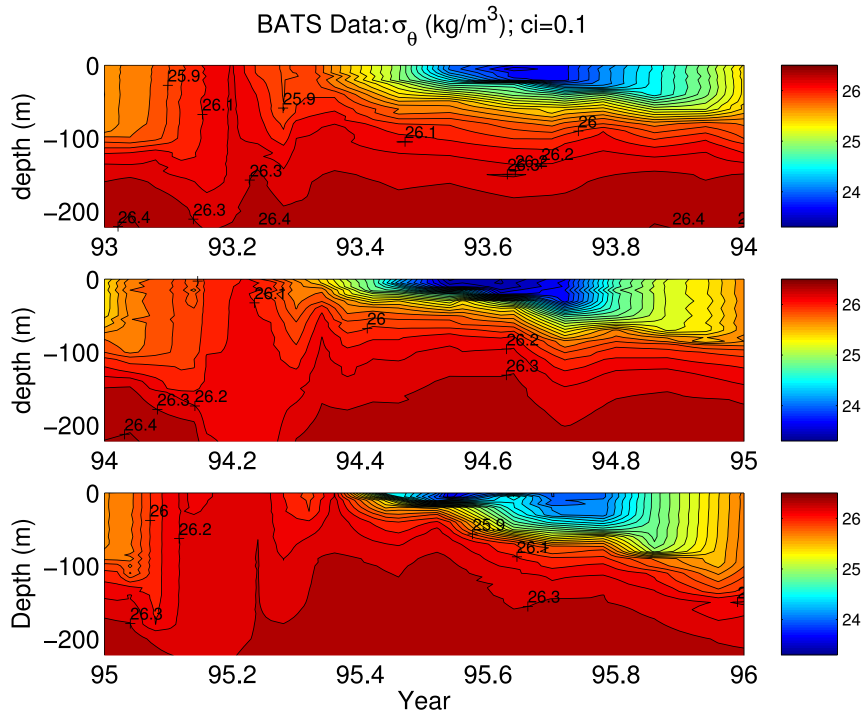


Fig. 6. (a) original; (b) monthly averages, to compare with Fig. 8a.



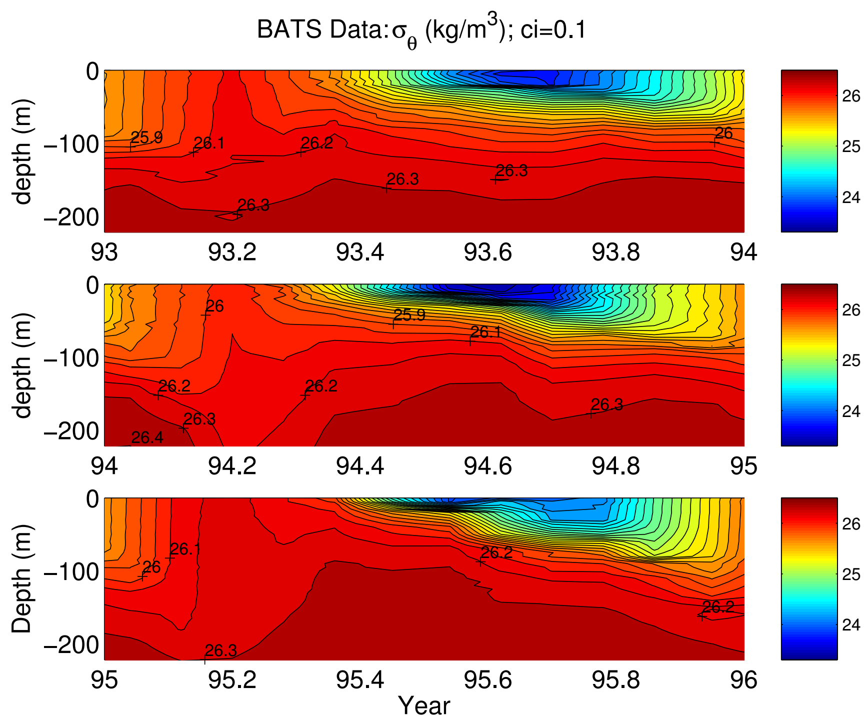
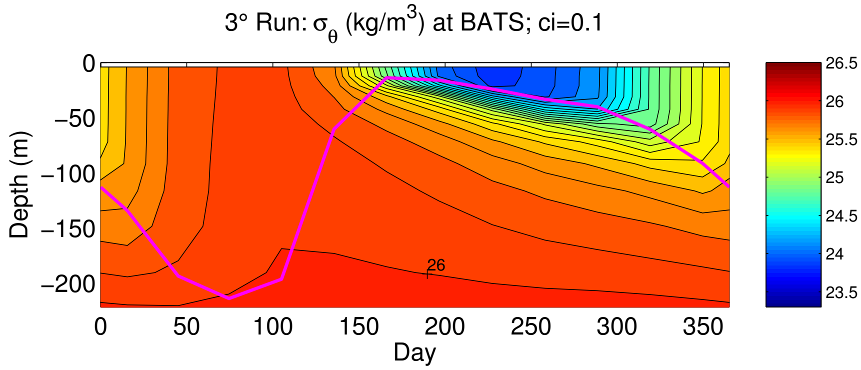


Fig. 7. (a) original; (b) monthly averages, to compare with Fig. 8a.



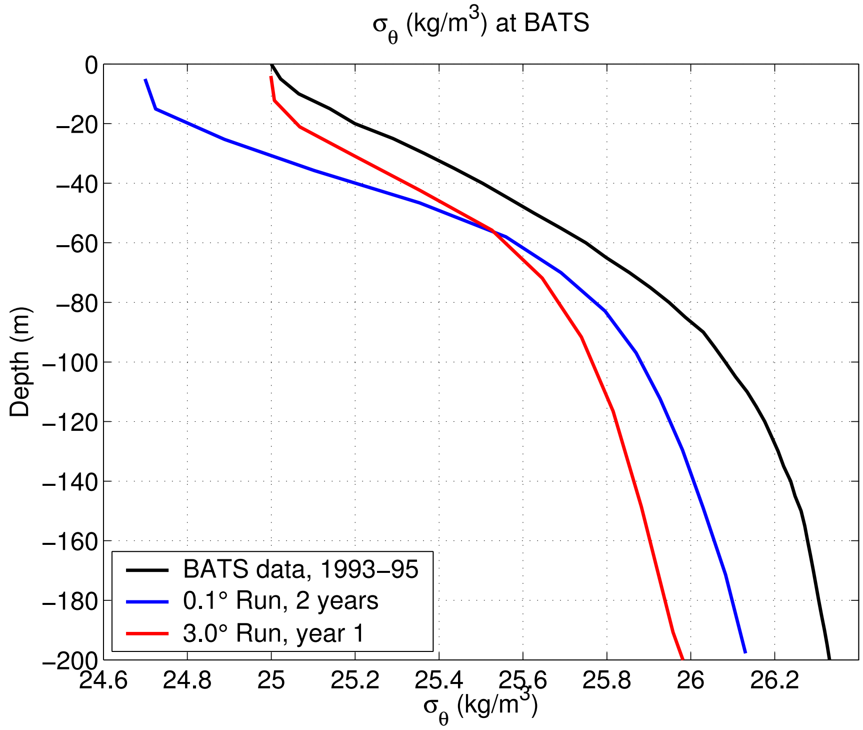
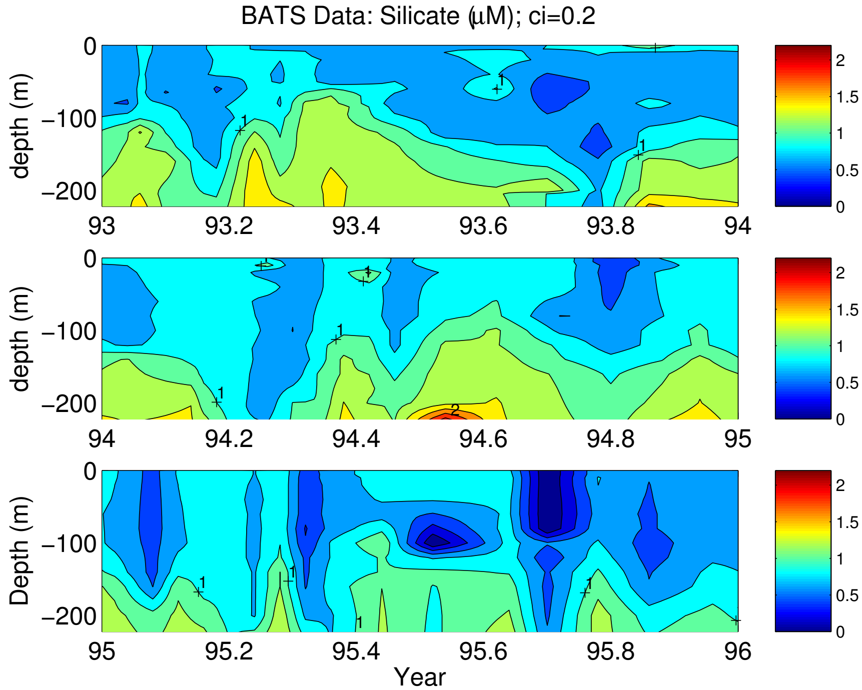


Fig. 8. (a) 3.0° run. (b) annual averages.



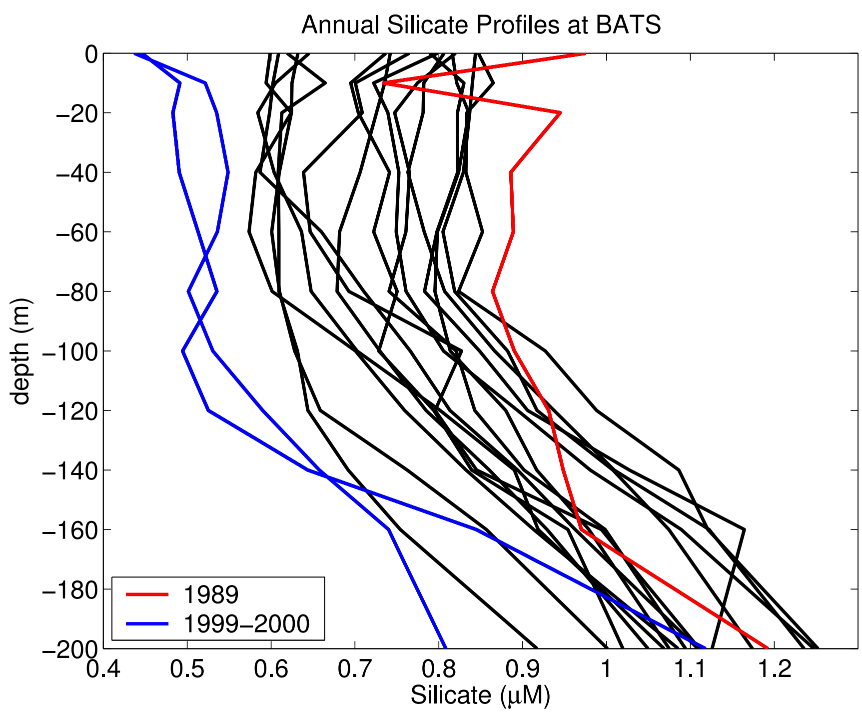


Fig. 9. BATS data.

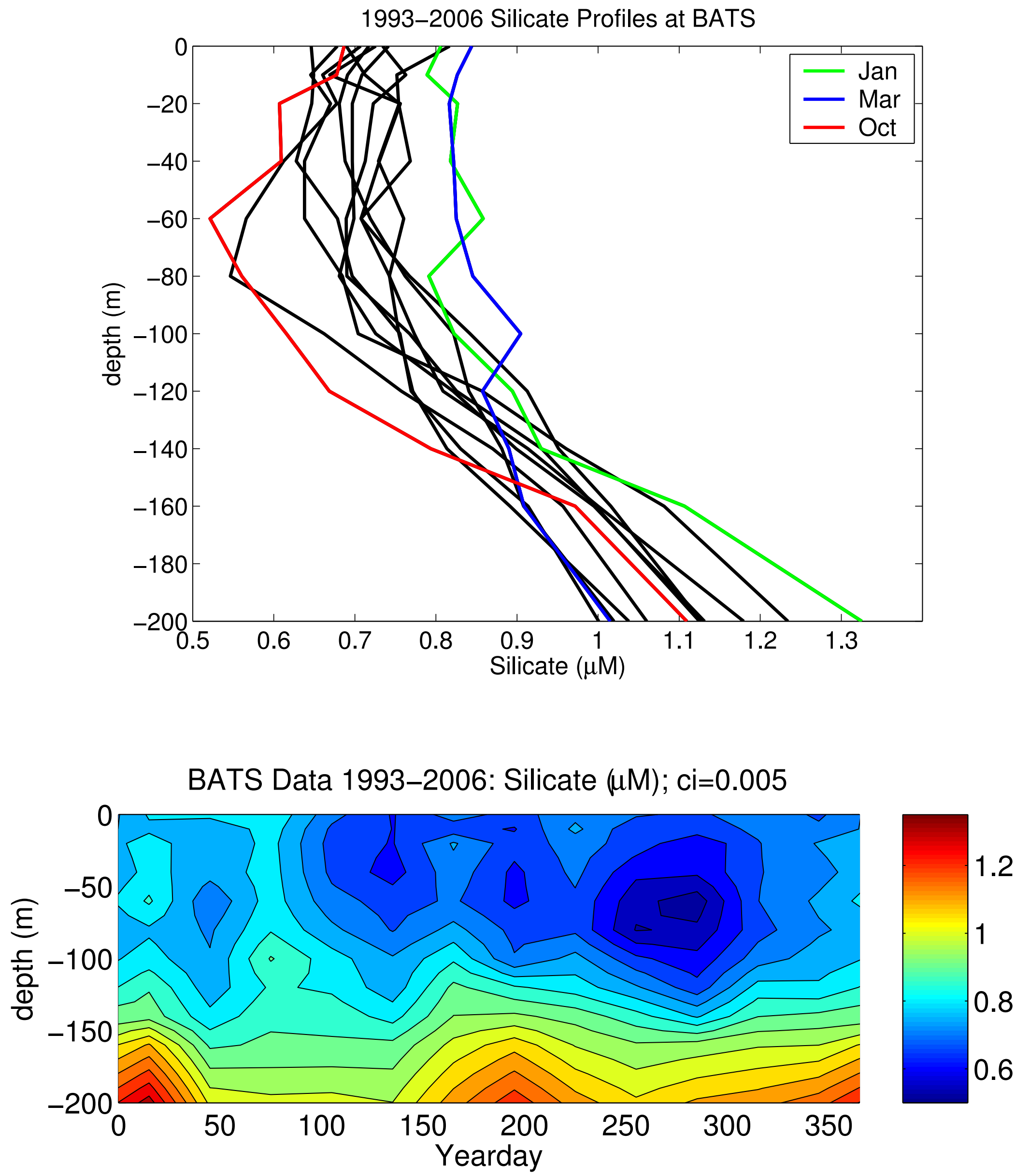


Fig. 10. BATS data.

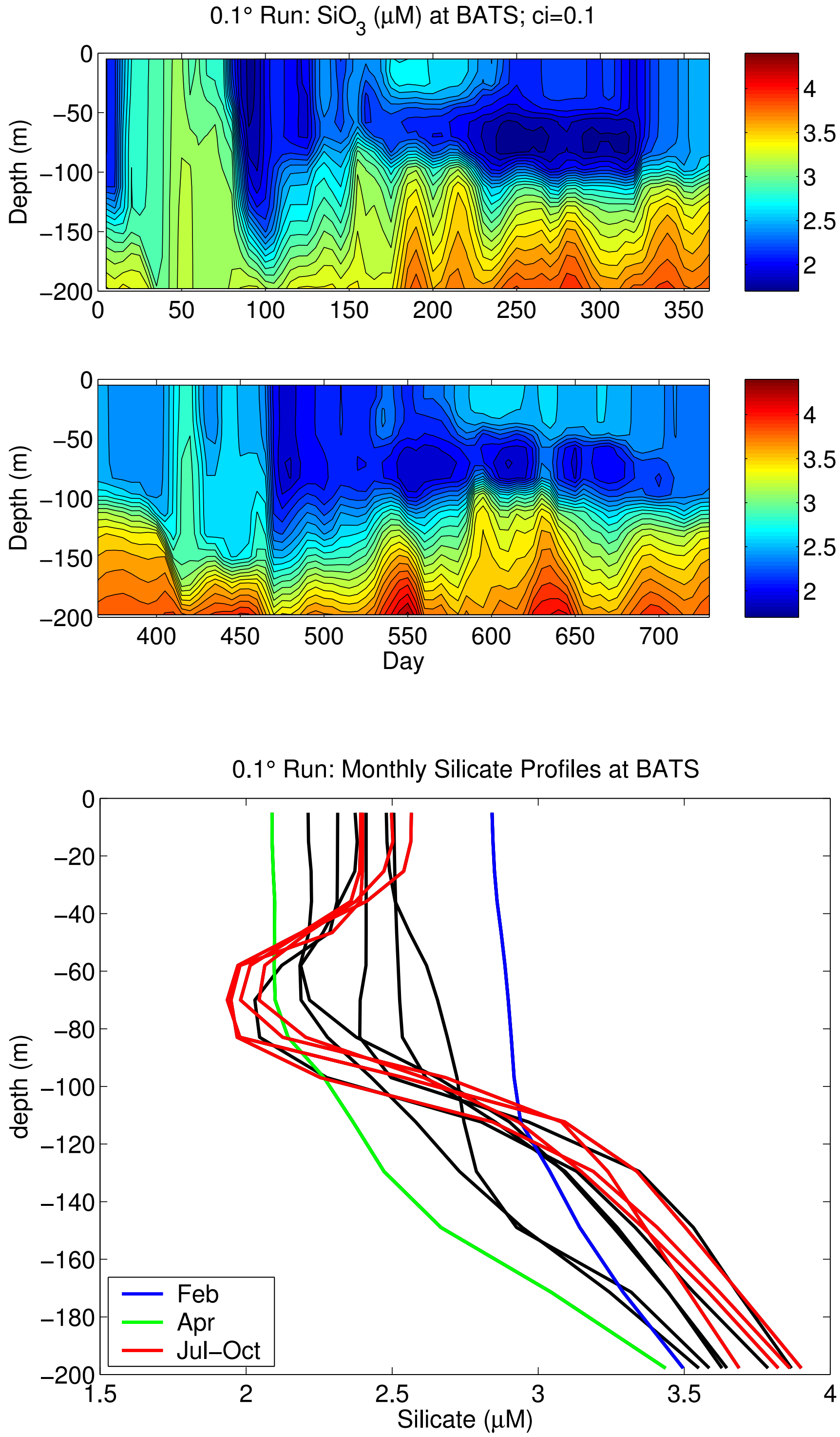

0.1° Run: SiO$_3$ (μM) at BATS; ci=0.1
Depth (m)
Day
0.1° Run: Monthly Silicate Profiles at BATS
depth (m)
Silicate (μM)
Feb
Apr
Jul–Oct

Fig. 11. 0.1° run.

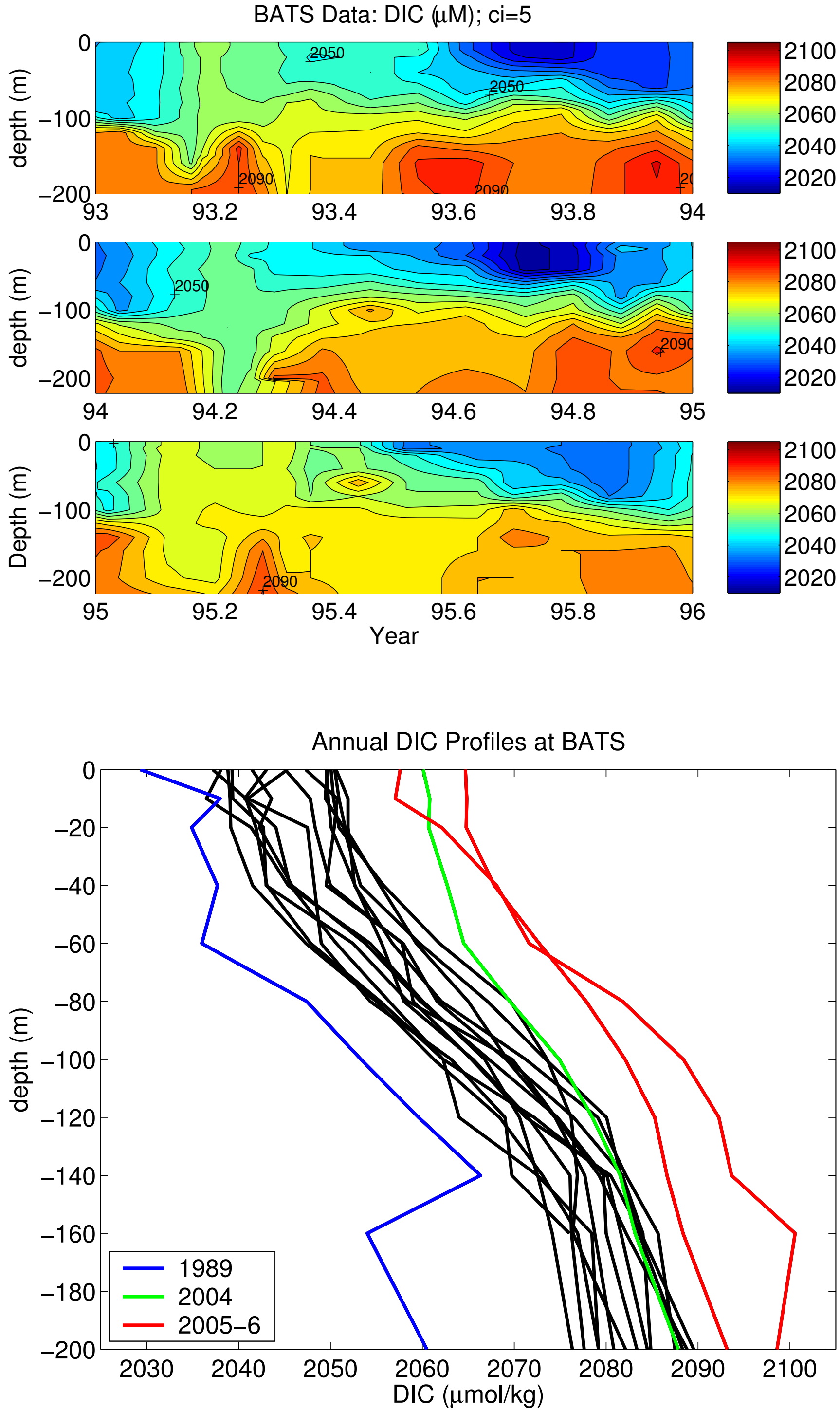


Fig. 12. BATS data.

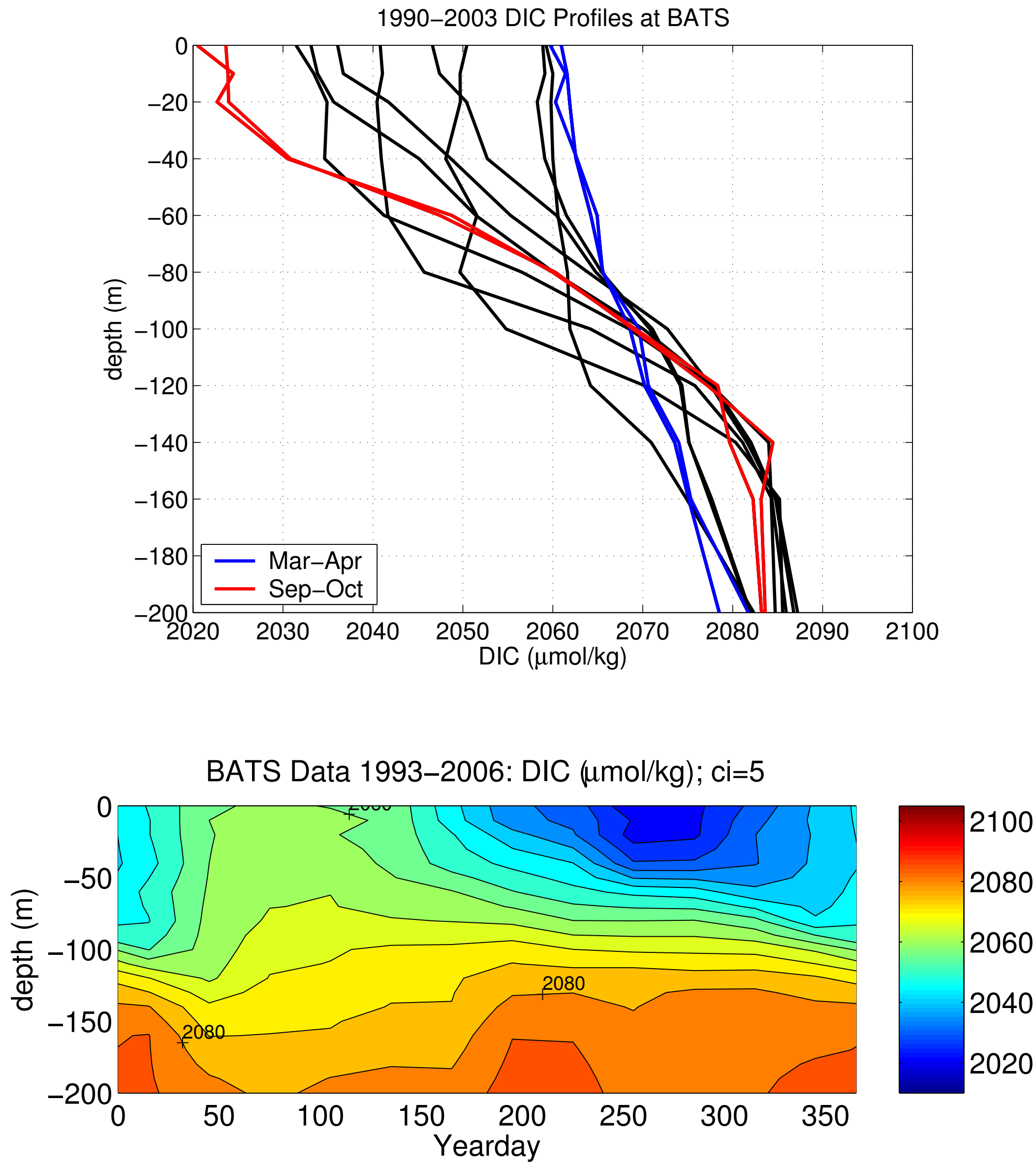


Fig. 13. BATS data.

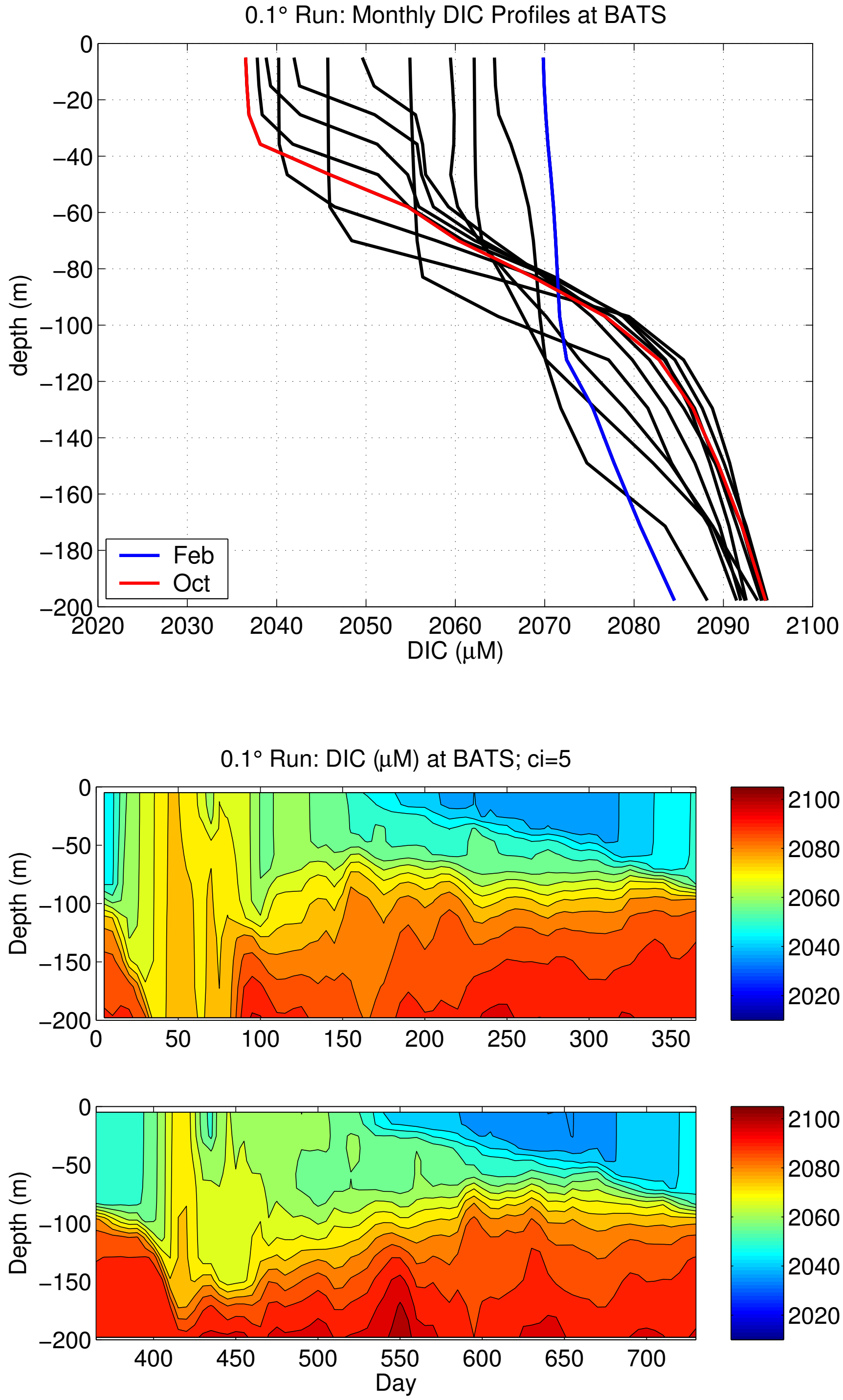

0.1° Run: Monthly DIC Profiles at BATS
depth (m)
DIC (μM)
Feb
Oct
0.1° Run: DIC (μM) at BATS; ci=5
Depth (m)
Day

Fig. 14. 0.1° run.