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**Biogeosciences Discussions**

# *Interactive comment on* "Increased ocean carbon export in the Sargasso Sea is countered by its enhanced mesopelagic attenuation" *by* M. W. Lomas et al.

**Anonymous Referee #1**

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General comments

This is a well-written and worthy of publication piece of work that describes the analysis of the temporal variability in the winter/spring biological carbon pump at the Sargasso Sea. Coinciding with a shift in the winter NAO, this study reveals a very interesting patter of increasing in the carbon pump parameters of the euphotic layer that is countered by the attenuation in the mesopelagic POC flux. This results in constant carbon sequestration below 300 m.

I have an only major concern about the manuscript referring to the fact that the authors do not consider the effect of mesoscale activity in their analysis. Most of the time BATS



site is under the influence of different types of mesoscale activity that are known for being an important source of variability in the biogeochemical parameters. Previous work has also shown that eddies can modify typical spring bloom conditions. As an example, the retrospective analysis (1993-1995) carried out by Sweeny et al (2003) described as the 1994 spring bloom at BATS was suppressed by the passage of an anticyclone. I have identified two main parts of the manuscript where ignoring the effect of mesoscale influence the author's interpretation of the observed trends:

1. Based on the bacterial carbon demand (BCD) data plotted in figure 4 the authors interpret that mesopelagic BCD have decreased significantly due to decreases in bacterial productivity after ca. 1996. According with the authors this reveals an opposite trends to the one observed in AOU and POC attenuation. First, in order to compare BCD with AOU and POC attenuation trends the authors should compare mean values for the periods before and after 1996 (instead of the trend for the 1996-2006 period). The analyses of eddy activity carried out by Mourino-Carballido (2009) for the 1993-2001 period indicated that the highest anomaly in BCD (in the upper 100 m) was recorded in late April 1993, when BATS was under the influence of a mode water eddy (MWE). The large value of mesopelagic BCD shown by the authors in figure 4 (also associated with a large error) is probably influenced by the stimulation in bacterial activity associated with the MWE that influenced the BATS site in late April 1993. Excluding this data, then the pattern in BCD, AOU and POC attenuation would be consistent or al least, due to the small data set for BCD before 1996, not completely inconsistent.

2. The second point refers to the hypothesis that the authors propose to explain the shift observed in the carbon pump parameters based on an increase in the frequency of mixing events. Main justification for this hypothesis is the reduction in the variability (CV) of the MLD. The authors interpret that a reduction in variability involves an increase in the frequency of mixing events. However, an important source of short-term variability in mixing conditions at this site is sub and mesoscale activity. The authors show in figure 4 that the highest variability in MLD was recorded in the winter-

spring bloom 1994, probably due to the strong mixing introduced by the anticyclone that affected this site between mid February and mid March (Mouriño-Carballido, 2009; Sweeney et al., 2003). Therefore, the interpretation of the variability in MLD should also consider differences in the activity of eddy features affecting the BATS site.

Minor/technical comments:

-Page 9548, lines 16-21 “The increased mesopelagic POC attenuation appears mediated by changes in plankton community composition and metabolic activity in both the euphotic and mesopelagic zones which are counter to extant hypotheses regarding inter-relationships between phytoplankton community composition, productivity and carbon export, and have significant impacts on how the Sargasso Sea ecosystem, at least, is modeled.”

This sentence is too long, I recommend short it. Also, modify “. . .changes in plankton community composition and metabolic activity in both the euphotic and mesopelagic zones. . .” to “. . .changes in plankton community composition and metabolic activity in the euphotic and mesopelagic zones, respectively. . .”

-Page 9551, line 5 “Sampling scheme and biogeochemical rate and stock measurements” modified to “Sampling scheme, biogeochemical rates and stock measurements”

-Pages 9551-9555 (2.1 Sampling scheme and biogeochemical rate and stock measurements section)

Indicate in the first paragraph the time period used for this analysis. Include the description of oxygen measurements. Reorganize methods description following the next structure: PAR, nutrients, oxygen, pigments, primary production, bacterial production, zooplankton, POC flux.

-Page 9551, line 17, Van Heukelem (2001) is Van Heukelem and Thomas (2001) in the reference list



-Page 9554, line 11, Knap et al. (1997) is not in the reference list

-Page 9554-9555 “Underwater irradiance data indicates that there have been only subtle changes in the average winter/spring 1% PAR (photosynthetically active radiation) depth between 1992 and 2007; 86.6$\pm$10.4m from 1992 to 1999 and 84.8$\pm$11.6m from 2000 to 2007, suggesting light has not become less limiting over time.” Move to the results section.

-Page 9555, lines 25-26 “The depth horizon on which nutrient concentrations were estimated for this calculation was the =26.28–26.32 kgm$-$3.” Specify how nutrient concentrations were estimated on the isopycnal band. If nutrient values were linearly interpolated on the density range 26.28–26.32 kgm$-$3, should not be the result a nutrient range?

-Page 9556, lines 8-12 “At 200, 250 and 300m dissolved oxygen concentrations were determined using an automated Winkler titration (Williams and Jenkinson, 1982). . .” Move to the previous section

-Page 9556, line 25 “Over the entire 17-year data record presented here. . .” At least in the figures, the number of years used for this analysis is not the same for all the variables. Clarify. The number of years in figures and tables should be consistent.

-Page 9556-9557 “Over the entire 17-year data record presented here, euphotic zone (0–140 m) integrated stocks of (T Chl-a), suspended particulate organic carbon (POC), rates of primary production and shallow (150 m) POC export all display significant (least squares Model 1 linear regression, P <0.05) increases in winter/spring values of >50% (Fig. 1, Table 1).”

According to table 1, increases in POC and PP for the 1990-2007 are ca. 44%

-Page 9557, lines 14-18 “As also observed by Corno et al. (2007) for the subtropical North Pacific, biomass normalized primary production (i.e. the assimilation number) remained virtually constant suggesting the increase in primary production was due

almost exclusively to the increase in biomass and not a change in physiological condition."

Indicate that these data are not shown. -Page 9558, lines 3-5 "Absolute pigment biomass of Synechococcus has increased ïA¿40% over the past decade (Fig. 3c, Table 2)..."

This number is not consistent with that reflected in table 2

-Page 9558, lines 22-26 "The coherence of increased primary production, POC flux at 150m and attenuation of this flux (Teff) with depth suggests that ecosystem pathways in the mesopelagic respond on similar timescales and proportionately with euphotic zone 25 pathways (Spearman Rank Cross correlation, P <0.05 for all pairwise comparisons; Table 3)."

According to table 3 p=0.07 for correlation between Teff and POCflux

-Page 9559, lines 10-14 "Mesopelagic bacterial carbon demand (BCD) has decreased significantly (least squares Model 1 linear regression, P <0.01, Fig. 4d) due to decreases in bacterial productivity. This decrease in BCD is substantial as estimates have decreased from roughly twice the POC attenuation to one-half these values."

I understand that the described increases in AOU and POC attenuation after 1996 refers to the comparison of the mean values for both periods (after and before 1996), whereas the described decrease in BCD refer to a trend observed in the last decade (this last is not specify in the text). In other to compare trends in POC, AOU and BCD the authors should conduct the same kind of comparison. BCD value for 1993 is the highest record for the period and is associated with a large error. If we exclude this data, then the pattern in BCD, AOU and POC attenuation could be consistent or al least not inconsistent (due to the small data set for BCD before 1996). Do the authors have an explanation for the high BCD value recorded in 1993?. The analyses of eddy activity carried out by Mourino-Carballido (2009) in BATS for the 1993-2002 period indicated



that the highest anomaly in BCD was recorded in late April 1993, when BATS was under the influence of a MWE. In this region eddies are known for being an important source of variability in the biogeochemical parameters that can modify typical spring bloom conditions (Sweeny et al (2003) also described as the 1994 spring bloom at BATS was suppressed by the passage of an anticyclone). The authors should include the effect of eddies when discussing the observed trends in their data set. Also related with this figure, why is AOU computed between 200-300 instead of 150-300 (consistent with POC attenuation and BCD)? Why oxygen data before 1992 are not included?

-Page 9561, lines 3-6 "No significant changes in wintertime stratification were apparent between the near surface and 200m (Fig. 7a) in contrast to changes in summer time stratification which were large enough to drive an annual increase in stratification from 1989 to 2003 (Krause et al., 2009)."

Does it make sense to compute a stratification index for the winter-spring bloom period when the water column is well mixed?

-Page 9561, lines 9-12 "Underwater irradiance data indicates that there has only been a slight decrease in the depth of the winter/spring 1% isolume; 86.6$\pm$10.4m from 1992 to 1999 and 84.8$\pm$11.6m from 2000 to 2007, suggesting light has not become less limiting (Fig. 5)."

In order to be consistent with the other parameters it would be better to show the trend in the 1% isolume for the full period.

-Page 9561, lines 19-23 "While the depth of mixing has not changed, the frequency of mixing in this region may have increased, suggested by the reduction in month-to-month variability of estimated MLD (based upon calculated CV of n=4 monthly average MLDs) taken from cruise data during the duration of the winter/ spring period (Fig. 7d)."

An important source of short-term variability in mixing conditions at this site is sub and mesoscale activity. The authors show in figure 4 that the highest variability in

MLD was recorded in the winter-spring bloom 1994, probably due to the strong mixing introduced by the anticyclone that affected this site between mid February and mid March (Mouriño-Carballido, 2009; Sweeney et al., 2003). Therefore, the interpretation of the variability in MLD should also consider differences in the number and type of eddy features affecting the BATS site.

-Page 9561, lines 25-29 “In support of this there are significant statistical correlations between the NAO index and all euphotic zone carbon pump parameters (Table 3), the strongest of which is a negative correlation (Spearman’s Correlation, r=−0.58, P <0.02; Fig. 8) between euphotic zone integrated primary production and the wintertime NAO index (Fig. 8).”

Indicate which carbon parameters the text refers to. According with table 3 correlations are only statistically significant between NAO index and chlorophyll, and for PP p=0.05

-Page 9562, lines 2-3 “In addition, the MLD coefficient of variation is negatively correlated with the biological carbon pump parameters (Table 3).”

Indicate which carbon parameters the text refers to. Correlation between MLD-CV and PP is 0.05 or <0.05

-Page 9564, lines 13-16 “However, there is a difference in that stratification was not shown to increase in the Sargasso Sea as it did in the North Pacific along with the increase in primary production, and therefore the exact physical mechanism may differ between the two oligotrophic gyres.”

But changes in summer time stratification evidence an annual increase in stratification from 1989 to 2003 at BATS (Krause et al., 2009). Do Karl et al (2001) compare a similar winter-spring period?

-Table 1 Include in the legend that data in the “Period Change” are also given in %. Is 1996 included in both periods? (Modify to 1990-1995 and 1996-2006). Remove the empty rows spaces.



-Table 2 The table will be easier to read if just p<0.01 or p<0.05 are indicated

-Table 3 The table will be easier to read if just p<0.01 or p<0.05 are indicated

-Figure 1. Legend “All linear regressions are significant, P <0.05” According with table 1 P-value=0.05 for POC flux.

-Figure 2 Why the number of filled and open circles is not the same in figure 2A?
-Figure 4 “Teff(300 m/150 m flux)” should be “Teff(300 m/150 m flux x 100)”

-Figure 6 Legend, Indicate what the line represents

References Mouriño-Carballido, B., 2009. Eddy-driven pulses of respiration in the Sargasso Sea. Deep Sea Research Part I: Oceanographic Research Papers 56 (8), 1242-1250. Sweeney, E.N., McGillicuddy, D.J., Buesseler, K.O., 2003. Biogeochemical impacts due to mesoscale eddy activity in the Sargasso Sea as measured at the Bermuda Atlantic Time-series Study (BATS). Deep-Sea Research Part Ii-Topical Studies in Oceanography 50 (22-26), 3017-3039.

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