

Author comment to Anonymous Referee #3

We thank anonymous Referee #3 for his/her constructive criticism and valuable comments. In the following we address the points raised, with referee comments in boldface and author responses in normal typeface.

#### **General comments**

**This study provides a decade long time series data set on hydrography, biogeochemistry and sediment traps for the PAP site in the North Atlantic. Results are valuable for understanding the present and future functioning of the biological pump in the PAP site. They also suggest that there might be changes in export as the PAP site transitions into subpolar conditions. However there is little discussion on the actual implications of the results in that context. Although I just have some minor comments on the ms, I recommend the authors to further develop the implications of their study.**

We thank the reviewer for the positive comment, and have expanded on the potential changes in export regime at the PAP site in the revised manuscript.

#### **Abstract**

**Line 10 please specify that a Redfield ratio of 12 is higher than the expected value of 6.6.**

The text has been revised accordingly: "The C:N ratio was high (12) compared to the Redfield ratio (6.6), ..."

#### **Introduction**

**I am surely not well informed on the dynamics of the PAP site but I have trouble with the sentence "It is at or near the boundary between the sub-polar and sub-tropical gyres of the North Atlantic". Is it or is it not? And if both are true how is it explained? This is important for data interpretation.**

The text has been changed to: "The PAP observatory is near the boundary between the sub-polar and sub-tropical gyres of the North Atlantic". Please also see figure 8 of Henson et al. (2009).

**Slide 5171 line 1 (and throughout the text) please include the correct formula of nitrate (NO<sub>3</sub><sup>-</sup>).**

The formula has been corrected to NO<sub>3</sub><sup>-</sup> throughout the manuscript.

**Lines 10 to 15: These are valuable motivations for the study but I though you already named those before. Please regroup your arguments at the end of the introduction section for clarity.**

We agree with the reviewer, and have deleted the sentence in the revised manuscript, as this argument is already given at the end of the introduction section. The revised text now reads: "global carbon cycle (Falkowski et al. 1998). These factors are currently not fully understood, so it is therefore difficult to predict how they will respond to climate change (e.g. Passow & Carlson 2012)."

**Line 23: "multitude" is vague and you cite only one reference. Please detail or rephrase.**

This sentence has been revised in response to a comment made by reviewer#2, and now reads: "It can be challenging to compare between these techniques, and there is ...".

**Slide 5172: consider giving acronyms to concepts such as transfer efficiency, new production, sequestration flux and export flux.**

We considered doing this in the preparation of the manuscript, however we believe that not using too many acronyms in the text makes it easier to follow for the reader.

#### **Materials and Methods**

**Section 2.1: I think details are missing here. For instance, what sensors for nitrate were**

**used during the last 10 years? What is the detection limit? I understand that this information can be found in a variety of papers but it is best not to force the reader to look for sparse information. A Table summarising limits of detection, techniques and periods of use can be useful here.**

We feel that adding a table containing this information would take up a lot of space, however agree that more information could be beneficial, especially on  $\text{NO}_3^-$  measurements (for which the instruments changed over time). We have added the text below to the manuscript.

Regarding detection limits, both the methods below claim to measure zero  $\text{NO}_3^-$ . However, PAP is not an oligotrophic site, so this should not be an issue in our data.

Text added to the revised manuscript: “NAS nutrient analysers (Envirotech LLC) were used in the period from 2002 until 2012, which measures  $\text{NO}_3^-$  plus  $\text{NO}_2^-$  (hereafter referred to as  $\text{NO}_3^-$ ) with a precision of  $\pm 0.05 \mu\text{mol l}^{-1}$ . The NAS was used alongside an optical nitrate sensor from 2009 to 2012, after that time all  $\text{NO}_3^-$  measurements were made with optical sensors (Satlantic ISUS), with a precision of  $2 \mu\text{mol l}^{-1}$ . For the remaining variables a Seabird MicroCAT was used for temperature and salinity ...”.

**Slide 5176 line 9 “an explanation for December to be followed shortly”. Delete. One supposes you are going to explain this later.**

This parenthesis has been deleted from the revised text.

**Slide 5177: Please justify your assumption of negligible mixing.**

This issue was raised by the other reviewers, and we have expanded on the contribution from mixing in the manuscript.

It is stated in Sect. 2.3 that the monthly changes in DIC and  $\text{NO}_3^-$  can be attributed to changes caused by air-sea gas exchange (for DIC), physical mixing processes and biological drawdown. The physical mixing processes, such as vertical entrainment, diffusion and advection are difficult to account for without proper measurements. In Kortzinger et al. (2008) they also assume that the contribution from these three mixing processes are small and negligible in the calculation of NCP, but acknowledges that a “full mixed layer budget cannot be constructed”. Only a simplified budget is possible, under certain limitations and for restricted periods. We have followed the same rationale, calculating NCP and new production for the period when the MLD is stable and where biological drawdown is believed to play a dominating role in monthly changes in DIC and  $\text{NO}_3^-$ . We do, however, acknowledge the limitations in this approach and will elaborate on the uncertainties associated with mixing in the manuscript.

The manuscript has been revised as follows:

Physical mixing processes, such as vertical entrainment, diffusion and advection, will to some degree contribute to monthly DIC changes, however are difficult to quantify without information on vertical and horizontal gradients. Following the approach by Kortzinger et al. (2008) we have performed a simplified budget calculation for the summer period when the mixed layer is relatively stable and the biological drawdown in DIC (and  $\text{NO}_3^-$ ) is strong. Therefore the contribution of  $\Delta \text{DIC}_{mix}$  was assumed negligible, and  $\Delta \text{DIC}_{BP}$  was assumed to be largely determined by NCP (excluding the effect of calcification).

**Slide 5178 line 11: Why did you use 100 m d-1 for all particles?**

This same issue was raised by reviewer#1. Observations at the PAP site have estimated the particle sinking speed as between 60 and 180  $\text{m day}^{-1}$  (Riley et al., 2012; Villa-Alfageme et al., 2014). The value we choose of 100  $\text{m day}^{-1}$  falls squarely in the middle of this range. Faster particle sinking speeds would result in a smaller source region and vice versa for slower sinking particles. The manuscript has been revised: "... , which is chosen because it

falls in the middle of the range observed for particle sinking speeds at the PAP observatory of between 60 and 180 m day<sup>-1</sup> (Riley et al., 2012; Villa-Alfageme et al., 2014)...”

**Results. Slide 5180 line 14. Particle tracking shows considerable interannual variability. You don't mentioned mesoscale variability as a cause of this variability. Please comment.**

This is a valid comment, and mesoscale variability could contribute to the variability in source location of material arriving at the sediment trap, both between and within years. This has been added to the discussion, in Sect. 4.2

Revised text at p. 5185, 19: "... reflecting the seasonal cycle. Mesoscale variability will also contribute to the variability in source location of particles, both between and within years.”

#### **Discussion**

**Slide 5182 lines 20-23. Maybe a table compiling previous N:C estimate would help here.** We believe a table giving these values would take up too much space, especially since comparing with previous C:N estimates is not a central part of this study.

**Line 23: N<sub>2</sub> fixation could be (and references will show you that it is) important in the North Atlantic. Assuming the opposite can be misleading. Please discuss its possible effect on your observed C:N. Also discuss your choice of assuming negligible N<sub>2</sub> fixation.**

Although N<sub>2</sub> fixation is known to be significant, especially in the subtropical North Atlantic gyres, many studies show that it is not likely to be so at the latitude of the PAP observatory. Figure 2a of Moore et al. (2009) has a transect over the PAP observatory (unfortunately, the plot is cut off at 40N), and shows that N<sub>2</sub> fixation is close to zero from 30-40N, a pattern that is likely to continue at higher latitudes. Reynolds et al. (2007) suggest that N<sub>2</sub> fixation plays a minor role in supplying N to the "northern subtropical gyre", the northern boundary of which they call 40N.

The text has been revised as follows: "Studies have found N<sub>2</sub> fixation to be low or zero at latitudes >40°N (PAP observatory is at 49°N) in the North Atlantic (Moore et al. 2009, Reynolds et al. 2007), therefore N<sub>2</sub> fixation is not thought to be an important factor for C overconsumption. Therefore ... ”.

**Slide 5185 line 20. Transfer efficiency is already defined in the text. Also, please discuss a little bit more the implications of the 4% you report here.**

We have deleted the definition of transfer efficiency in this sentence.

We have also added more description of what the relatively low transfer efficiency found at the PAP observatory implies in the revised text: "region by Henson et al. (2012), indicative of regions where the available nitrate is not fully consumed and with strong seasonal mixing.”

**Slide 5186 last paragraph of discussion. This is a speculative statement and I don't think it's a good way to finish your paper. Either you discuss this point in more detail or you replace it with a more conclusive statement that is actually supported by the data.**

We believe it is relevant to mention that the export regime at the PAP observatory (with high export ratio and low transfer efficiency) could alter as a result of climate change. We have elaborated on the causes of the changes and potential effects.

The final paragraph of the discussion now reads: "The PAP observatory currently sits near the boundary between the sub-polar and sub-tropical gyres of the North Atlantic. Seasonably variable areas, like the sub-polar region, are thought to export a higher fraction of labile material than sub-tropical regions (Lutz et al. 2007). As climate change is predicted to result in the oligotrophic gyres expanding over the next century (Sarmiento et al. 2004), the

PAP observatory will likely transition into more sub-tropical conditions. This could result in more refractory material being exported at the PAP observatory, potentially reversing the pattern we report here with a high export ratio and low transfer efficiency. In addition, a more strongly positive NAO index is predicted due to climate change (Gillett 2003), which is expected to increase diatom abundance at the PAP observatory, and result in reduced organic carbon flux to the deep ocean (Henson et al., 2012a). Although the precise response of the biological carbon pump to climate change is as yet unclear, transition-zone regions between gyres (such as the PAP observatory), could be among the systems that are most strongly affected by climate change (Henson et al. 2013).”

**Slide 5186, Line 10: Change how?**

Into a sub-tropical export regime with more refractory material exported out of the euphotic zone, see above.

**Figure 5: Please clarify what the axes are.**

The caption to Fig. 5 has been revised as follows: “Cross-correlations between sediment trap data (top: volume flux, middle: dry weight, bottom: POC) and NPP in the source regions defined by particle tracking (left) or in a 100 km box around the PAP observatory (right). See Sect. 2.4 for calculations.”