

Interactive comment on “A geographical and seasonal comparison of nitrogen uptake by phytoplankton in the Southern Ocean” by R. Philibert et al.

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Reviewer comment:

This paper by Philibert et al., focuses on controls on N uptake in the Southern Ocean using in-situ methods. The authors use measurements of ^{15}N marked nitrate and ammonium performed in both summer and winter to estimate the seasonal cycle of nitrate and ammonium uptake. For obvious reasons, the Southern Ocean is a challenging area to sample in wintertime; this dataset is therefore valuable in order to better understand the mechanisms that control N uptake and its seasonal variation. Measurements are simple but the manuscript finds its strength is the statistical analyses performed in

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order to assess to which extent environmental N uptake. While I am not an expert in the “ ^{15}N technique”, my feeling is that the methods employed to derive estimates N uptake rate are well developed and sound. Also, the statistics used are appropriate. The authors infer that the both day length and the ammonium concentration explain most of the variability observed in N uptake. Although the influence of important factors like Fe concentration could not be tested, the authors fully acknowledge this omission and discuss it in the manuscript. The data are well presented and the article is well written. I have no major concerns with this manuscript and only technical corrections should be addressed before publication. These are listed below:

Response: We would like to thank the reviewer for these very encouraging comments.

Reviewer comment:

Specific comments - The first section of the introduction would benefit of a more thorough referencing on HNLC regions, and factors limiting primary production in the Southern Ocean. Also, the authors could have done a better job in explaining why having winter N uptake data may ease our understanding of winter production in the Southern Ocean.

Response: The first part of the introduction has been reviewed

Changes to the manuscript: Introduction:

In the Southern Ocean, low temperature, low light, strong vertical mixing and iron limitation restrict the uptake of nitrogen and ultimately phytoplankton growth. The concentrations of iron in the Southern Ocean are low due to the lack of terrestrial inputs. The role of these low iron concentrations in limiting nitrogen uptake is well-established (Martin et al., 1990; Moore et al., 2007; Falkowski et al., 1998; Cochlan,

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2008; Boyd et al., 2010; Boyd, 2002). Furthermore, phytoplankton in a strongly mixed environment, such as the Southern Ocean, are not exposed to light sufficiently long for efficient nutrient uptake and growth. (Mitchell et al., 1991; Venables and Moore, 2010). This is compounded by the low incident light. The combination of these “bottom-up” controls and “top-down” controls such as grazing (Behrenfeld, 2010) results in the High Nutrients Low chlorophyll (HNLC) conditions for which the Southern Ocean is well-known. Despite this, the Southern Ocean plays an important role in the global marine carbon cycle. Carbon fluxes in this region accounts for about 4% of global carbon fluxes (Takahashi et al., 2009) and 300 Tg C y^{-1} of export production (Henson et al., 2011; Gruber et al., 2009). This is achieved through a combination of the solubility pump and the biological pump. The solubility pump encompasses the physical processes, such as mixing of surface water masses to the deeper layer, which remove carbon dioxide from the surface. The biological pump is driven by the sinking and subsequent sequestration of organic matter produced by phytoplankton through photosynthesis. In this process, phytoplankton convert inorganic nutrients (carbon, nitrogen and others) into organic matter (Volk and Hoffert, 1985). Given the cellular demands (Hedges et al., 2002), the elements are generally assimilated in a fixed ratio, which was first observed by Redfield (1934). This ratio is very useful in linking the various biogeochemical cycles. For instance, by knowing the rates at which nitrogen is assimilated, carbon assimilation rates can also be estimated. Only part of the organic carbon formed by phytoplankton is exported and sequestered below the permanent thermocline (Falkowski et al., 2003). This fraction can be estimated by distinguishing the sources of inorganic nitrogen nutrients (Dugdale and Goering, 1967; Eppley and Peterson, 1979). Nitrate was considered to be a “new” nutrient which is only formed outside of the euphotic zone and brought to the surface through physical processes. Ammonium and urea were considered to be “regenerated” nutrients formed only within the euphotic zone. Nitrate being used by phytoplankton has to be in balance with the rate of organic nitrogen export for the phytoplankton to maintain itself. Therefore, the fraction of primary production fuelled by nitrate over total primary production would

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correspond to the amount of exported organic matter.

Reviewer comment: The authors measured N uptake at 55% light level according to the method section. However, they often refer to a 50% light level in the text, tables and figures. Please correct -

Response: This has been corrected

Reviewer comment: P1835, L4: Please provide equations or provide more details on how specific and absolute N rate were calculated.

Response: This has been added

Changes to the manuscript:

Specific uptake rates for NO_3^- and NH_4^+ were calculated as described by Dugdale and Goering (1967):

$$v = \frac{a_p - a_{nat}}{t \times (a_{enr} - a_{nat})}$$

, where a_p is the final atom enrichment percent (AE%) in the particulate matter, a_{nat} is the natural abundance of ^{15}N and a_{enr} is the AE% of the water sample (initially labelled fraction) and t is the incubation time. Absolute uptake rates were obtained by multiplying the specific uptake rate by the concentration of nitrogen in the particulate matter.

Reviewer comment: P1835, L22: Please add “RDA” after “redundancy analysis”.

Response: This has been added.

Reviewer comment: P1836, L20: The mixed layer depth increased not decreased -

Response: this has been corrected

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Reviewer comment: P1836, L22: The “biological activity” cannot be inferred from a Chl-a concentration only. Is the decrease in mean Chl-a concentration due to the “dilution” induced by the deepening of the MLD or by an actual decrease in photosynthesis rate? -

Response Integrated chlorophyll concentrations actually increased from CTD 4 (25.9 mg m⁻²) to CTD 15 (31.92 mg m⁻²). Dissolved oxygen concentrations (data not shown) also increased. This confirms that in fact “biological activity” had not decreased. This has been rephrased.

Changes to manuscript: “ A decrease in mean chlorophyll concentrations within the euphotic zone (0.70 mg m⁻³ at CTD 4 to 0.42 mg m⁻³ at CTD 15) was observed.”

Reviewer comment: 3.2.1: Why are the winter N uptake rate not shown in a figure like Figure 3? -

Response For the winter uptake rates, only two depths were available per stations. A straight line between those two points would not be representative of the changes through the water column.

Reviewer comment: P1840, L8: Please provide a list of all the environmental variables you test -

Response: This has been added

Reviewer comment: P1840,L20. Could an eddy from the SAF, “escaping” northward, be responsible of the rather sub-Antarctic characteristic of 15-N-2? -

Response - There are reports of an Agulhas ring in the STZ during the winter cruise Smart (2014). As station 15N-1 was closer to this warm eddy, the differences between stations 15N-1 and 15N-2, the differences between the two might have been

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emphasized.

Reviewer comment: P1840,L26: Please specify whether of wide angle represent a good or bad correlation for non specialist.

Response: This has been added.

Changes to the manuscript: Acute angles represent positive correlations whereas obtuse angles represent negative correlations. Stronger positive correlations are shown by smaller angles while a 180 angle represents a correlation of -1. A 90 angle indicates no correlation.

Reviewer comment: P1848, L13. How were the C:N ratio measured. The method section makes no mention of POC:PON measurements

Response: This has been added to the text.

Changes to the manuscript: Particulate organic carbon (POC) and particulate organic nitrogen (PON) were determined by filtering a fixed volume of seawater onto a GFF. The DIC collected onto the GFF was fumed off with HCl. The POC and PON content were determined using an isotope ratio mass spectrometer (IRMS).

Reviewer comment: . -P1849,L13: Please provide reference

Response: This statement has been removed based on other suggestions by Reviewer number 1. However, a reference discussing the fact that nitrate uptake was more strongly dependent on iron than ammonium uptake would be ?

Reviewer comment:-P1850,L13: Lower case at silicic -P1851,L5: Silicic acid is a product of BSi recycling not a subtract being recycled. Please rephrase. Was an accumulation of BSi in the upper 300m present in the PFZ and south of the PFZ? - The section of silicic acid has been removed from the manuscript according to

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suggestions by Reviewer number 1. There was no measurements of BSi.

Reviewer comment:P1855, L6: Please remove “j” after “Southern Ocean”

Response: removed

Reviewer comment: Figure 1: Were the fronts located at the same positions around Marion Island?

Response: The temperature and salinity profiles obtained from the CTDs, XBT and uCTD were used to establish the position of the fronts on Leg 1 of the winter cruise (west side). These data indicated where the fronts were crossed on this particular transect. However, for the eastern stations, only CTDs were taken and the spatial resolution was not fine enough to establish the position of the fronts.

Reviewer comment: Figure 3: The figure would be clearer if the x axis for Nitrate uptake (a, c, e) were plotted on the same scale (0-0.8). Ditto for the Ammonium uptake rate (b, d, f), (0-12)

Response: This has been changed

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