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Interactive comment on "The sensitivity of primary productivity to intra-seasonal mixed layer variability in the sub-Antarctic Zone of the Atlantic Ocean" *by* W. R. Joubert et al.

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Response to Reviewer2 on the manuscript "The sensitivity of primary productivity to intra-seasonal mixed layer variability in the Sub-Antarctic Zone of the Atlantic Ocean" – Joubert et al., Biogeosciences Discuss., 11, 1–24, 2014.

The article is devoted to the study of very important issue related to the deepening of representations about balance of environmental factors influencing Southern Ocean primary production such as light and nutrition. Article advantage is the consideration of primary production and hydrological processes in synoptic scale. Authors try to propose the appropriate hydrological mechanism to explain transport Fe to the upper

layer and possibility to utilize this micronutrient by phytoplankton. However, I believe that conclusions of the article should be based on more extensive data.

Author response: The authors would like to thank the reviewer for the useful comments and the time taken to review the manuscript. Your comments have helped us to improve the manuscript. Our major results were based around documenting the synoptic scale variations seen in O2/Ar ratios and NCP measured during three Southern Ocean research cruises. We then sought to expand the paradigm for seasonal Fe supply to highlight how synoptic scale input of Fe may be a large term in the seasonal budget. It is then suggested that future process studies would be necessary to more fully test this mechanism. This mechanism should be appraised using a dedicated seasonal cycle process study. In line with the reviewers comments we have modified the conclusions to reflect this. We further address the reviewer's comments below to improve the manuscript as required.

General comments:

reviewer comment1. I believe that investigation of balance between light availability and nutrient limitation via MLD variability impossible without consideration of underwater irradiance, the main nutrients distribution (N, P, Si), "critical depth", euphotic or photosynthetic depth. So, resolution of important and complex problem was not supported by sufficient data.

Author Response1: We agree with the difficulty to assess the balance between light and nutrient limitation in the absence of the suggested parameters. However, in the context that the Southern Ocean is a HNLC region, macronutrients are not considered as a primary driver of phytoplankton production rates. We refer to previously published work on the nutrient concentrations along the transect (Giddy et al., 2012; LeMoigne et al., 2013). Furthermore, the current study is focussed in the summer when high rates of phytoplankton net community production are sustained throughout the season (Swart et al., 2014) when light availability is plentiful. We include the mean water column irradiance and compare this with results from Alderkamp et al., (2010) along the same transect (see author response 5 below). Although the authors were unable to calculate critical depth from the available data, euphotic depth was calculated as the 1% light depth (where light is sufficient to support primary production). According to Falkowski and Raven, 1997, the average compensation depth (where the daily rate of oxygen consumption by respiration equals that produced by photosynthesis) frequently corresponds to the euphotic depth. While the critical depth (daily water column integrated gross primary production equals respiration) is generally substantially deeper than the compensation depth. As such, one is able to infer that when MLD's are in the range of the euphotic depth net community production is positive and not significantly light limited. In summer the mean MLD was (45.7 m $\pm$ 18.9m) and the mean euphotic depth was (88.7 m $\pm$13.5 m). A shallower MLD than euphotic depth over the summer implies that light was not the primary driver accounting for low NCP's. However, the authors do suggest that a deepening MLD would reduce the average light field of the phytoplankton and as such reduce net community production rates but that a deepening MLD entrains Fe, which followed by rapid shoaling would favours growth in a transient iron replete, high light environment.

reviewer comment2. Assumption of the absence of vertical NCP changes seems wrong to me. Apparently, in the present article depth-integrated NCP calculations within MLD based on this assumption. Actually, NCP decrease with depth and in the SAZ 45 m horizon is close to the bottom of euphotic zone where NCP is near zero.

Author Response2: The reviewer is correct that instantaneous NCP is affected by vertical changes in production. NCP calculated from O2/Ar ratios is a time integrated product which is highly dependent on the piston velocity through the wind speed which also influences the depth of the surface mixed layer. As such the NCP calculated here represents the time and mixed layer averaged NCP. In other words, this method accounts for the phytoplankton cells being mixed through a variable light water column over time and calculates the average water column NCP over the time period which

does not change with depth.

reviewer comment3. The authors denote non-linear link between NCP and MLD but did not provide the statistical parameters of this dependence. That's unfortunate due to in general this type of relation between production parameters and MLD previously was registered (Mitchell et al., 1991; Mitchell and Holm-Hansen, 1991; Nelson and Smith, 1991) and it would be interesting to see the new data in synoptic scale.

Author Response3: As the reviewer notes, the abovementioned literature report similar productivity vs mld relationships. Where previous reported data use chl-a as a proxy for productivity, a contribution of the current manuscript is that net community productivity shows a similar relationship. The statistical correlation were $r = -0.52$ and $r = -0.47$ for O2/Ar-ratios ($n = 285$, $p<0.001$) and NCP ($n = 205$, $p<0.001$) respectively. This linear correlation coefficient and statistical significance levels are included in the text. We remove the reference in the manuscript relating to non-linear relationship.

reviewer comment4. The authors define phytoplankton community summer condition in the Sub Antarctic Zone (SAZ) as a "bloom". As shown in Fig. 2c average chl a values were approximately 0.3 – 0.4 mg m-3 along transects and maximum was close to 0.7 mg m-3. These low chl a concentrations are not the characteristics of bloom conditions (Sullivan et al., 1993). Following the classic works, SAZ is the typical HNLC region (e. g. Banse, 1996).

Author Response4: The word 'bloom' is removed and replaced with 'increased NCP'. The SAZ is indeed within the HNLC region, particularly in the open ocean regions, but does show elevated chl a on synoptic scales (Swart et al., 2014).

reviever comment5. The statement that small thickness of MLD promotes the best light conditions for phytoplankton growth in Southern Ocean should be applied with cautions. As revealed in the recent works relatively long time exposition in MLD may cause to photoinhibition and decreasing of production characteristics (Alderkamp et al., 2010; 2011).

Author Response5: The reviewer raises an interesting point that if light increases to very high levels then photoinhibition may occur. Over the length of the transect, mean MLD irradiances are 16.89 $\pm$9.8 mol photons m-2 d-1, which is higher than the 4 – 10 mol photons m-2 d-1 reported by Alderkamp et al. (2010). Although we are concerned with synoptic scale fluctuations in MLD, where phytoplankton are not exposed to the highest light levels for a long period of time it is possible that photo-inhibition could suppress NCP in shallow MLD's. As such the authors have revised the manuscript to be been careful not to promote the shallowest MLD's as the best MLDs for high NCP. However, even with photoinhibition, high NCP is observed in MLD shallower than 45 m which has the highest mean light conditions. One would therefore expect that were photo inhibition not playing a role, the relationship observed in Figure 2 would potentially be even more exaggerated.

reviewer comment6. Overall, I think that complexity of the task which authors try to resolve contradicts with approaches and database used in the present article.

Author Response6: As mentioned in the response to reviewer 1, our goal was to highlight how synoptic scale variations in the MLD have the potential to induce additional Fe fluxes that can sustain productivity in the sub Antarctic Zone of the Southern Ocean. The role of synoptic scale variations in NCP and Fe fluxes is absent from the current paradigm of Southern Ocean seasonal iron supply and utilization (Tagliabue et al. 2014). Our specific contribution is a) to note the synoptic scale variations in O2/Ar ratios and NCP and b) to explore whether synoptic scale Fe input has the potential to explain them. These issues need to be investigated further with a dedicated process study. The data presented here adequately supports our proposed hypothesis that changes in MLD around 45m are able to support the observed high and variable NCP through synoptic scale Fe addition.

Specific comments:

1. To avoid uncertainty in the use of terms net community production (NCP) and net

primary production (NPP) we advise to change in future “primary productivity” on “net community production (NCP)” in the title of the article. 2. NPP values should be presented not only in O2 but also in C units.

Author Response: 1) Title is modified accordingly. 2) NPP is not used in this paper.

Technical comments.

On the Fig. 2c chl a distribution is presented, but in the comments we can read “NCP vs. MLD”. So, drawing content and caption do not match.

Technical comments are corrected in the manuscript.

References added: 1. Alderkamp, A.-C., de Baar, H.J.W., Visser, R.J.W., Arrigo, K.R., 2010. Can photoinhibition control phytoplankton abundance in deeply mixed water columns of the Southern Ocean? Limnology and Oceanography 55, 1248–1264. 2. Alderkamp, A.-C., Garcon, V., de Baar, H.J.W., Arrigo, K.R., 2011. Short-term photoacclimation effects on photoinhibition of phytoplankton in the Drake Passage (Southern Ocean). Deep-Sea Research II 58, 943–955. 3. Banse, K., 1996. Low seasonality of low concentrations of surface chlorophyll in the Subantarctic water ring: underwater irradiance, iron or grazing? Progress in Oceanography 37, 241–291. 4. Mitchell, B.G., Holm-Hansen, O., 1991. Observations and modelling of the Antarctic phytoplankton crop in the relation to mixing depth. Deep-Sea Research 38, 981–1007. 5. Nelson, D.M., Smith, W.O.Jr., 1991. Sverdrup revisited: Critical depths, maximum chlorophyll levels, and the control of Southern Ocean productivity by the irradiance–mixing regime. Limnology and Oceanography 36, 1650–1661. 6. Sullivan, C.W., Arrigo, K.R., McClain, C.R., Comiso, J.C., Firestone, J., 1993. Distribution of phytoplankton blooms in theSouthern Ocean. Science 262, 1832ÂËĞnÂËĞn–1837.

Author response: References 1, 3 – 5 are included in the revised manuscript.

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