Reviewer No. 2

Based on your constructive comments, we have completely redesigned our project with new methodology and additional analyses. A brief description of the new methodology and results is provided below, followed by our detailed response to the reviewer's questions. Reviewer's original questions/comments are in blue, and our answers are in black. Owing to the extensive changes made to the original manuscript, some comments on specific wording and styles may no longer be applicable. We will response to them accordingly.

Synopsis of the new methodology and results

This study aims to examine whether icebergs have a significant impact on the ocean net primary productivity (NPP) at the scale of the entire Southern Ocean (SO). We examine both large and small icebergs based on two separate datasets and determine if similar impacts can be observed. We first divided the SO into four ecological zones based on their different nutrient source and profile: the continental shelf zone (CSZ), the seasonal ice zone (SIZ), the permanent open ocean zone (POOZ), and the polar front zone (PFZ). Within each zone we compared NPP for grids with and without iceberg presence. For small icebergs, we found that grids with iceberg presence in general have higher NPP than those without icebergs. However, the impact is not uniform. In the CSZ where high level of iron is supplied through glacial meltwater and sediment input from the continent and continental shelf, and phytoplankton growth is largely limited by macronutrients, the presence of icebergs does not seem to have any impact on the ocean NPP. On the other hand, Iceberg presence could significantly increase NPP in the high-nutrient low-chlorophyll (HNLC) regions. The NPP of grids with icebergs is 21% higher than those without in the SIZ, and 16% higher in the POOZ. The difference is slightly less (12%) for the PFZ where upwelling and eddy mixing could provide additional iron to the surface water, hence iron limitation is not as severe. Direct correlation between iceberg frequency and NPP is weak although statistically significant. The strongest correlation is found at the SIZ which contains over 70% of the icebergs by volume. For large icebergs, we found that the mean NPP for iceberg grids and their immediately adjacent grids are on average 10% higher than NPP of the nearby grids further away. However, the zonal response is different. The enhancement of NPP is the greatest in the high latitude zone of the CSZ and SIZ, which contains the majority of the large iceberg occurrences. Finally, we examined the secular trend of iceberg occurrence in the SO under the current climate change. For the entire period of the iceberg data, 1992-2014, both iceberg volume and frequency have shown significant increasing trends. The increasing trend is most significant for the Pacific and Indian sections of the SO, whereas the Atlantic section of the SO shows no statistically significant trend. This could be related to the greater mass loss of the West Antarctica Ice Shelf, and the relative stability of the East Antarctica Ice Shelf under present climate change. As the climate continues to warm, the Antarctic Ice Sheet is expected to experience increased mass loss as a whole, which could lead to more icebergs in the region. Based on our study, this could result in higher level of NPP in the SO as a whole, providing a negative feedback for global warming.

Wu & Hou use net primary production (NPP; estimated from satellite observations), temperature, and iceberg occurrence frequency data to investigate the variation of NPP with temperature and/or iceberg frequency in the Southern Ocean. They apply multi-linear regression (MLR) where the logarithm of NPP is considered as response to temperature and iceberg frequency; the logarithm of NPP is used to obtain residuals that better fulfil requirements for linear regression. The MLR and calculation of various coefficients of determination (R2) is described in more detail than usual in the current literature showing the carefulness in application of these powerful methods. The authors claim that they found a small, however, statistically significant influence of icebergs.

The correlation coefficients (r) between the relative frequency of icebergs and (logarithm of) NPP and the corresponding coefficients of determination (R2) based on MLR are small and would speak against an influence of icebergs on NPP. However, this negative result may be, at least in part, due to an inappropriate approach.

We agree that the MLR used in the original paper is not an appropriate approach. We significantly revised our study. First of all, multiple sources of iron exist in the SO. In the revised paper, in order to separate the impact of icebergs from some known sources, we divide our study area into four distinct ecological zones, each with different sources of nutrient supply (Fig. 1). These zones were adapted and modified from previous studies (Treguer and Jacques 1992, Moore and Abbott 2000, Ito et al. 2005), and within each zone the nutrient profile should be relatively similar. They are listed as follows:

- Continental shelf zone (CSZ): area less than 500 m in depth around the Antarctica continent and permanent ice shelves.
- Seasonal Ice Zone (SIZ): area north of the CSZ and within the mean maximum ice extent, defined by area with mean sea ice concentration greater than 70% in February. This region is delineated using the mean monthly sea ice 1979-2013 obtained from the National Snow and Ice Data Centre (ftp://sidads.colorado.edu/pub/DATASETS/nsidc0192_seaice_ trends_climo/monthly-climatology/).
- Permanent Open Ocean Zone (POOZ): area north of the SIZ and south of the Polar front zone (defined below). This zone is largely ice free throughout the year.
- Polar Front Zone (PFZ): area within 1 degree (~110km) of the polar front defined by Dong et al (2006). This is an area characterized by strong upwelling and eddy mixing.

The Subtropical Front, northern boundary of the Antarctica Circumpolar Circulation, usually defines the border of the SO. However, since few icebergs drift past the PFZ, areas of the SO north of the PFZ is not considered in this study.

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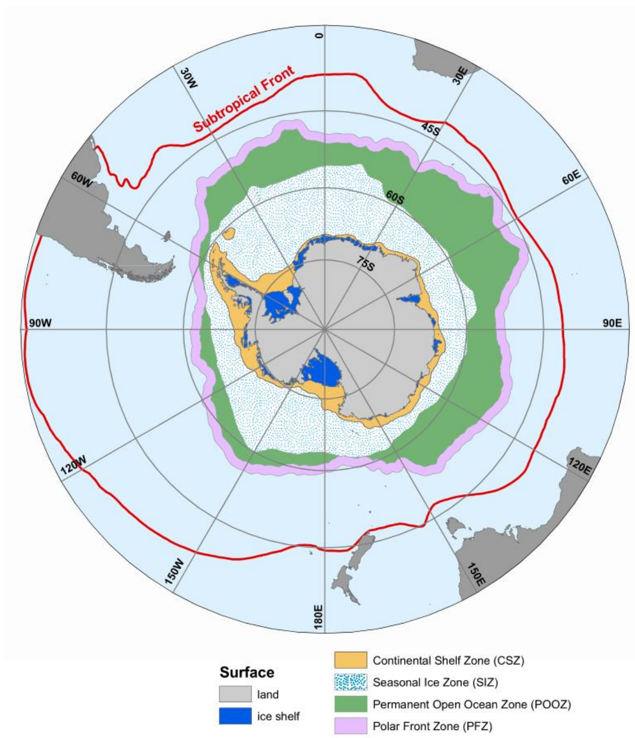

Fig. 1: Ecological zones of the Southern Ocean.

<u>Impact of small icebergs on NPP</u>

Most previous studies focus on large icebergs (> 18.5 km long) (Duprat et al. 2016, Helly et al. 2011). Although these large icebergs may have a big impact on productivity of surrounding area, they are relatively rare compared to much more abundant small icebergs. Tournadre et al. (2008) estimated over 8000 small icebergs (< 1km) alone in one year. Moreover, small icebergs have a much larger surface to volume ratio, providing relatively more substrate for organisms (Smith 2011). So when considered in total, they can have a big impact over much larger area in the SO. The majority of small icebergs come from the dislocation and breaking of large icebergs, and therefore serve as an important diffuse process for transport of freshwater and nutrients including iron (Tounadre et al. 2016). Therefore, in this study, we examine both large and small icebergs to determine if similar impacts on the ocean net primary productivity (NPP) could be observed at the SO scale. Our results show that small icebergs indeed have a quite significant impact on the SO NPP.

Unlike large icebergs which are routinely tracked and monitored through satellite scatterometer instruments, small icebergs could not easily be identified until recently. The monthly dataset of small iceberg (<3km) is obtained from Iceberg Database of the Merged Altimeter for Altiberg project for 1992-2014 (ftp://ftp.ifremer.fr/ifremer/cersat/projects/altiberg/). This is the first and only dataset on small icebergs. The data is generated based on the analysis of high resolution altimeter waveforms from images of 9 satellite-based altimeters (Tournadre et al., 2016). The data contains three variables: iceberg presence probability, surface area and volume. Iceberg probability of presence is defined in Tournadre et al. (2012) as “the ratio of the number of icebergs detected within a grid cell by the total number of valid satellite data samples within the same grid cell”. It is essentially normalized iceberg frequency. In the revised paper, we refer to this variable as such to make it more explanatory. Details of how iceberg surface area and volume are estimated can be found in Tournadre et al. (2012).

Figure 2a shows the spatial distribution of mean NPP (Fig. 2a) in the SO in relation to the defined ecological zones. Figure 2b shows the spatial distribution of normalized frequency for small icebergs in the SO in relation to the defined ecological zones.

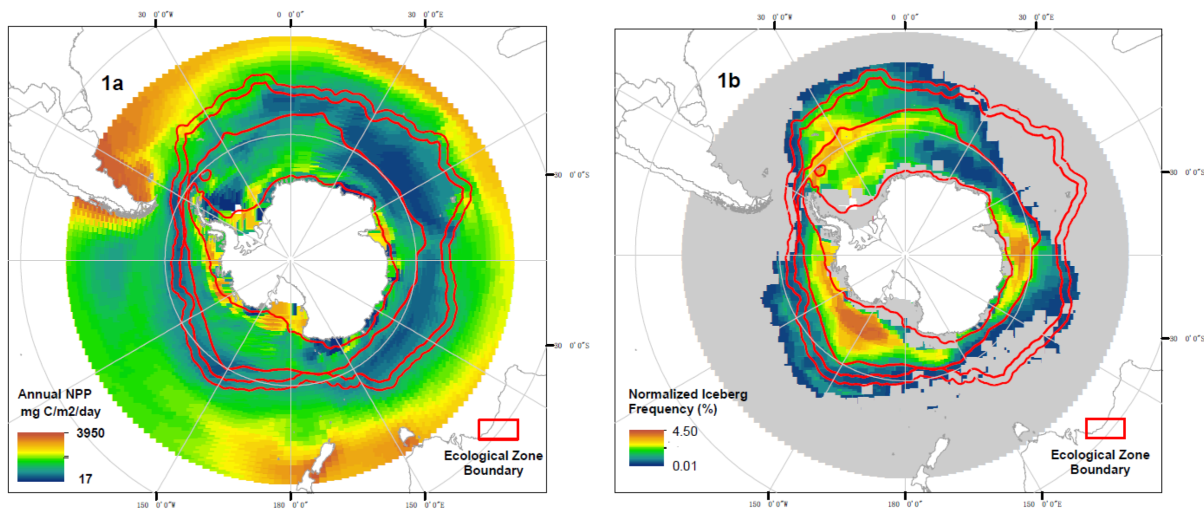

Fig. 2. Spatial distribution of annual mean NPP (a) and normalized iceberg frequency (b) in relation to ecological zones.

For small icebergs, within each zone, we compared the mean NPP for grids with icebergs and those without. Our results suggest that the presence of icebergs is associated with elevated level of productivity in most part of the SO, although their impact varies in different ecological zones. With the exception of CSZ, where there is little difference between the two, NPP in grid cells with iceberg presence is significantly higher than that in cells without icebergs. The difference is most significant for the SIZ with iceberg cell NPP 21% higher than those without. It is 16% higher for the POOZ and 12% higher for the PFZ. All differences are statistically significant based on the two-sample Student’s t test.

Zones	Total area of grids with icebergs (million km^2)	Area of Productive grids with icebergs (million km^2)	Annual iceberg volume (Gt)	Annual iceberg volumes over productive water (Gt)	NPP over productive waters with icebergs (gC m^{-2} yr^{-1})	NPP over productive waters without icebergs (gC m^{-2} yr^{-1})
CSZ	0.20	0.17	103.72	88.88	112.57	113.72
SIZ	2.66	2.34	1351.11	1257.72	70.27	58.04
POOZ	1.33	1.10	370.94	315.16	65.65	56.50
PFZ	0.26	0.23	63.69	54.83	83.40	74.59

Table 1: Mean annual NPP for grids with and without icebergs 2002-2014.

Possible explanations for such differences lie in the different nutrient sources and settings in these zones. Although short in duration, the productive season of the CSZ has the highest values of primary productivity (with an annual NPP of 112.86 gC m^2 yr^{-1}). In this zone, nutrients are largely supplied by shelf sediments derived from the continent. Elevated iron concentration has also been recorded near the coast (Johnson et al. 1997, Moore and Braucher 2008). High levels of nutrients often lead to plankton bloom observed near the coast as well as downstream of islands (Blain et al 2007, Pollard et al. 2009). In addition, Treguer and Jacques (1992) noted high levels of macronutrients at the beginning spring, but during summer these macronutrients become depleted in the coastal waters. This seems to suggest that primary production is limited by macronutrients instead of micronutrients such as iron. As a result, the presence of icebergs does not seem to have any significant impact on productivity near the coast.

In both the CSZ and the SIZ, sea ice can supply additional iron. Lannuzel et al. (2010) suggest that iron is incorporated from the ocean into the ice during sea-ice formation, and hence the iron concentration within the sea ice can be an order of magnitude higher than in the underlying water (Lannuzel et al. 2007). However, some model studies show that the amount of iron released from sea-ice is minor compared to the sediment source (Lancelot et al. 2009, Wadley et al. 2014). This can partly explain the generally much lower productivity in the SIZ (with an annual NPP of 62.08 gC m^2 yr^{-1}), despite similarly high levels of macronutrients in the water during the productive season (Treguer and Jacques 1992). In the SIZ, icebergs seem to have the largest impacts. The productivity in the grid cells with iceberg presence in general is 21% higher than those without icebergs. This large impact can also be attributed to the fact that the majority of icebergs occur in this zone: 65% of all iceberg grids and 73% of total iceberg volume occur in this zone, occupying 36% of the productive waters of this zone.

In contrast to the CSZ and the SIZ, where seasonal ice retreat often leads to stratified system (Sullivan et al. 1988), the POOZ is typically well-mixed and ice free. Mixing brings nutrient-rich water towards the surface, resulting in high supply of macronutrients in the surface water (Pollard et al. 2002). However, although nutrient rich, the POOZ is characterized by low levels of productivity. The annual mean productivity of the POOZ is the lowest among all four zones (with an annual NPP of 56.54 gC m^2 yr^{-1}). It has been recognized that such production in this region is likely to be limited by the micronutrient iron, which plays an important role in chlorophyll synthesis and hence phytoplankton growth (Geider and La Roche 1994, Martin et al. 1988, Martin et al. 1990). In this area, iron released from icebergs can be particularly important. About 30% of iceberg grids (19% by volume) occur in the POOZ, occupying about 9% of its productive waters. On average, they increased the productivity of these grids by 16%.

The Antarctic Polar Front is one of several strong fronts within the Antarctic Circumpolar Current. It is characterized by a strong gradient in the sea surface temperature within the PFZ, and marks the surface transition between cold Antarctic surface water to the south and warmer sub-Antarctic surface waters to the north (Orsi et al. 1995, Moore et al. 1999, Dong et al. 2006). Meander-induced upwelling or increased eddy mixing may lead to increased fluxes of nutrients, including micronutrients such as iron, in the surface layer, particularly where the ACC interacts with large topographic features (Moore et al. 1999, Moore and Abbott 2002). Several studies have suggested that higher levels of dissolved iron in surface waters at the PF led to elevated phytoplankton production (de Baar et al. 1995, Measures and Vink, 2001). The PFZ has a mean productivity of 74.95 gC m^2 yr^{-1}. Although only about 6% of the iceberg grids (3% by volume) are found in the PFZ, occupying 4% of its productive grids, iceberg presence still has an observable impact, increasing the average productivity by 12%. This increase is lower than that observed in the SIZ and the POOZ, partly because the relative low frequency of the icebergs and partly due to the fact that the iron limitation is not as severe in the PFZ as the other two zones.

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Impact of large icebergs on NPP

Large icebergs are routinely tracked and monitored. The Brigham Young University (BYU) Centre for Remote Sensing produces and maintains an Antarctica Iceberg Tracking Database (http://www.scp.byu.edu/data/iceberg/database1.html) for icebergs with length larger than 6 km (Stuart and Long 2011) since 1992, using six different satellite scatterometer instruments. Icebergs are identified using enhanced resolution scatterometer backscatter images. The dataset contains the daily location for all identified icebergs. We summarize the track data into monthly 1x1 degree gridded format to facility the analysis with NPP data. Large icebergs are relatively rare. For the period 2002-2014, 393 icebergs were identified in the BYU data set. Among them, 154 are icebergs larger than 18.5 km in length. They are named icebergs monitored by the National Ice Centre. The other 239 are smaller icebergs between 6 and 18.5 km. Their tracks are presented in Fig. 3a, and the summarized gridded count data in Fig. 3b. The majority of large icebergs concentrate near the coastal region of Antarctica, where they are calved from the major ice shelves, such as the Ross, Filchner, Ronne, Larsen, and Amery. Large number of icebergs are also present in the south Atlantic section of the SO, originated mostly from the ice shelves in the Weddell Sea.

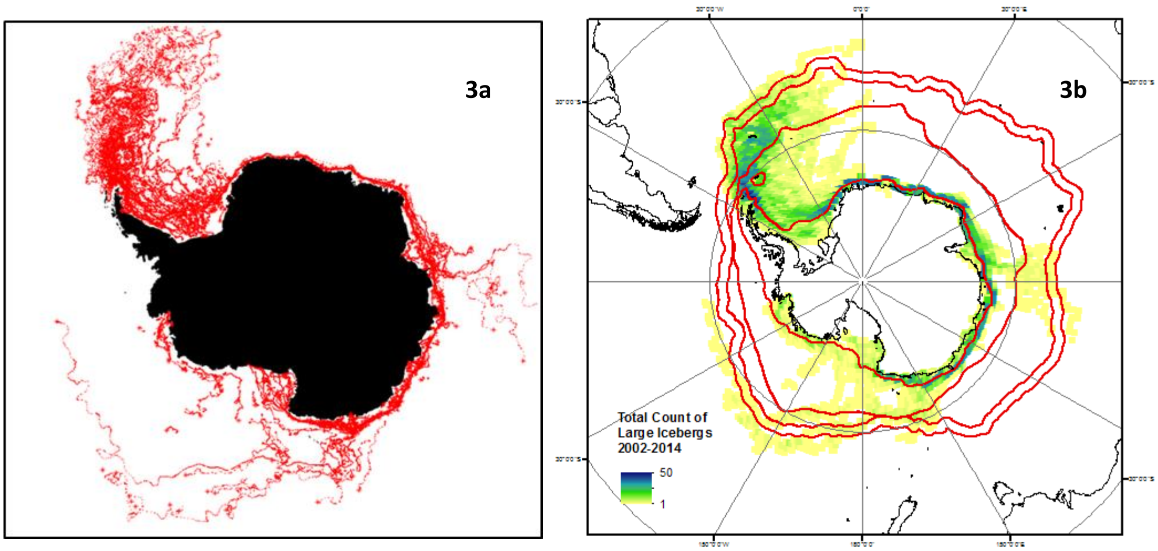

Fig. 3: Spatial distribution of large icebergs. (a) all iceberg tracks between 2002 and 2014. (b) the gridded count of iceberg occurrences between 2002 and 2014.

Since large icebergs are relatively rare, at certain point in time, they cover very small portion of the ocean surface. It is therefore not appropriate to adopt the same approach used in studying small icebergs. We use a different approach instead. We first summarize the track data into monthly snapshots of 1x1 degree grid of iceberg counts. The great majority of the grids only gets 1 large iceberg. Very rarely were more than one large iceberg present in a grid at a given month. For each iceberg occupied grid, we select a 7x7 degree (49 grids) window around it. Within the window, we identify all grids with icebergs (iceberg grids), grids immediately adjacent to iceberg grids (adjacent), and the rest of the grid within the window (nearby grids). We calculate the mean NPP for each group for a single iceberg grid, and repeat the same operation for all iceberg grids at monthly timescale. We then compare the mean NPP of these three groups to see if they are significantly different. Pair-wise t test is used to establish the statistical significance of the difference between groups. The difference is summarized by ecological zones, and their seasonal variations examined.

Based on this methodology, we calculated the mean NPP each of the three groups at monthly timescale. Results are summarized by ecological zones (Table 2). Most of the iceberg grids are located in the CSZ and the SIZ, but their frequency is still relatively low, at 73 and 60 grids per year respectively. In general, the difference in mean NPP between iceberg grids and adjacent grids are fairly small, but the mean NPP of combined iceberg and adjacent grids are significantly (about 10%) higher than the nearby grids. This pattern is fairly consistent in most of the ecological zones with the only exception of the POOZ, where iceberg/adjacent grids have similar NPP as the nearby grids. Seasonally, the most significant increase of NPP from surrounding grids occurs in the most productive months in the austral summer (December, January and February). The general enhancement of NPP near icebergs is consistently found with both small and large icebergs, although the zonal response is different. With small icebergs, the largest enhancement is seen in zones relatively poor in iron such as the POOZ and the

SIZ, whereas the effect in the CSZ is not significant. The large icebergs, on the other hand, seem to increase NPP more in the higher latitudes such as the CSZ and the SIZ. However, the low frequency of large icebergs makes it difficult to establish reliable statistical relationship. Moreover, the coarse spatial resolution (getting even coarser at lower latitudes of the POOZ and PFZ) could make it harder to detect enhancement of NPP near large icebergs.

Zone	Mean NPP of iceberg grids (mgC m^{-2} d^{-1})	Mean NPP of adjacent grids (mgC m^{-2} d^{-1})	Mean Diff.	p value	Mean NPP of iceberg and adjacent Grids (mgC m^{-2} d^{-1})	Mean NPP of nearby grids (mgC m^{-2} d^{-1})	Mean diff.	p value	No. of Iceberg grids per year
CSZ	241.41	240.79	0.62	0.84	241.54	214.62	27.17	0.00	73.08
SIZ	206.05	210.66	-4.61	0.05	208.74	188.72	20.03	0.00	60.92
POOZ	151.13	148.93	2.19	0.25	149.27	149.14	0.13	0.94	14.23
PFZ	248.78	257.69	-8.91	0.02	255.72	242.66	13.06	0.02	3.77
Total	219.15	220.87	-1.72	0.33	220.39	199.17	21.31	0.00	152

Table 2: Mean NPP of iceberg grids, adjacent grids and nearby grids.

By considering the whole region south of 40 S, the authors include large areas that never see an iceberg and where thus icebergs cannot really influence NPP.

In the revised paper, we limited our study to the area of the SO south of the polar front zone, as very few icebergs drift past this zone. See above for more details.

On the other hand, temperature correlates with almost everything and is, at least on the large scales considered here, also a proxy for latitude, light and maybe other quantities. I'm convinced that large icebergs can have an influence on NPP, however, the question is which mechanisms are at work here (iron supply, upwelling of freshwater, increased mixing) and, depending on the mechanism, how large is the area of influence.

We no longer use regression model in the revised study, and temperature is hence not examined as a factor for NPP and iceberg variation. Our revised study seems to suggest that icebergs are associated with elevated levels of NPP in the SO. See above for more details.

I suggest that the authors look at their results with open mind and discuss limitations of their approach in the light of known as well as speculative mechanisms.

Thank you for your suggestions. We have redesigned our study with new methodology and many new analyses, based on which possible mechanism and limitations are discussed. See above for details.

General comments:

The terms 'iceberg probability of presence' and 'iceberg presence probability' should be avoided. I would prefer 'relative frequency of icebergs'.

Iceberg probability of presence is defined in Tournadre et al. (2012) as "the ratio of the number of icebergs detected within a grid cell by the total number of valid satellite data samples within the same grid cell". It is essentially normalized iceberg frequency, and we shall refer to this variable as such to make it more explanatory.

Reference:

Tournadre, J., Girard-Ardhuin, F., and Legrésy, B.: Antarctic icebergs distributions, 2002–2010, J. Geophys. Res., 117, C05004, doi:10.1029/2011JC007441, 2012.

The interpretation of correlation coefficients depends very much on the context (for example, high-quality measurements in branches of physics versus ecological observations with small sample sizes). A rule of thumb might be 'no or weak correlation' for $-0.3 < r < +0.3$, 'positive correlation' for $r > 0.3$. What's your interpretation of correlation coefficients? What is meant by 'significant' in this context?

Regarding your question, in our original paper, "significance" is established based on statistical tests. A correlation is deemed significant if the probability of it being a result of random variation is low (i.e. small p value). A correlation can be statistically "significant" even when the coefficient is low, if it is derived from large number of data points with relatively low variance.

That being said, we agree that the direct correlation between NPP and iceberg frequency is low. Therefore, we designed new ways other than correlation to examine the impact of icebergs on NPP (see above). However, in the revised paper, we did include a section on the correlation between NPP and small iceberg frequency, and discussed possible reasons for low correlation. The frequency of large icebergs is too low for a robust correlation analysis.

Correlation between NPP and small iceberg frequency.

In order to further examine the quantitative relationship between NPP and icebergs, we conduct the correlation analysis between the two factors. Normalized iceberg frequency is chosen over iceberg volume because it seems to better correlate with NPP. The possible reason is that for large icebergs basal melting is small compared to their breaking into smaller icebergs (Tournadre et al. 2015). These smaller icebergs act as an important diffuse process for nutrient transport. Therefore, iceberg frequency may have a more direct impact on NPP than total iceberg volume. We calculate Pearson's correlation coefficient (r) for annual total net production and the annual mean iceberg frequency. The use of annual data eliminates the seasonal cycles that exist in both variables, which can artificially inflate the significance of correlation. Given that both variables are positively skewed, we also tried non-parametric rank correlation Spearman's rho. Both methods yielded similar results, with Spearman's rho giving slightly higher correlation than Pearson's r, indicating the existence of non-linear correlation. We perform the correlation analysis in two ways. First, we calculate the correlation coefficient between annual production and iceberg frequency at each grid point (local correlation), so that we can control it for spatially varied factors such as solar radiation, length of day, and ocean circulations. We then summarize the correlation coefficients by ecological zones. Second, we calculate a single correlation coefficient for annual productivity and iceberg frequency of all grid points within a zone (zonal correlation), and compare the strength of correlation between zones.

Results of local correlation between annual NPP and iceberg frequency at each grid points are presented in Fig. 4 and summarized in Table 3. Only Pearson’s r is reported, as Spearman’s rho gives similar results.

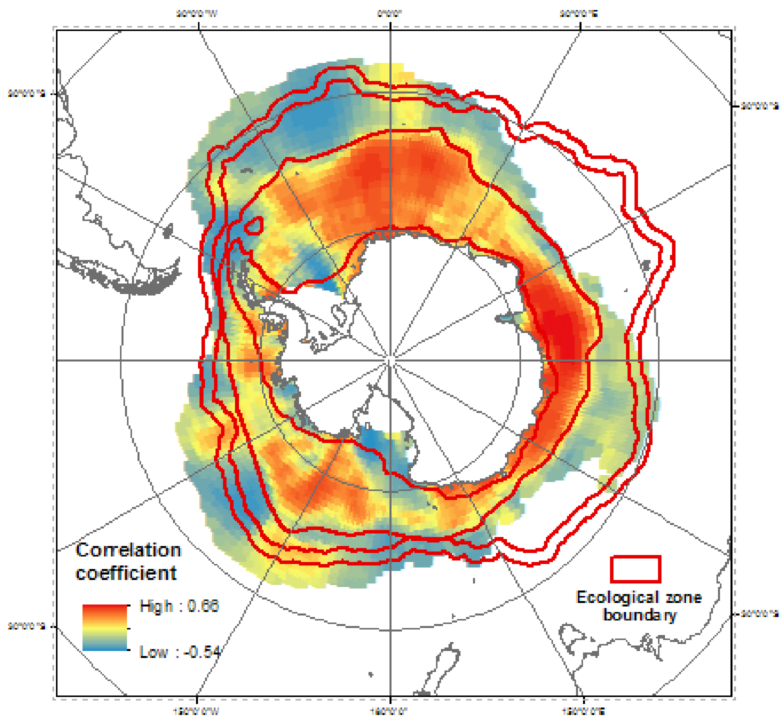

Fig. 4. Temporal correlation between annual NPP and normalized iceberg frequency.

	Local correlation (Pearson’s r)							Global correlation	
Zone	Min.	1st Quarter	Median	Mean	3rd Quarter	Max.	**% of grids Significant	Pearson's r	Spearman's rho
CSZ	-0.40	-0.06	0.10	0.07	0.20	0.66	16.30	0.16*	0.23*
SIZ	-0.55	0.04	0.15	0.14	0.25	0.57	33.49	0.18*	0.22*
POOZ	-0.36	-0.04	0.06	0.04	0.13	0.43	21.54	0.13*	0.16*
PFZ	-0.27	-0.10	0.00	-0.01	0.09	0.23	14.50	0.12*	0.14*

Table 3: Correlation between annual total primary production and iceberg frequency.

Note: * Correlation significant at 0.01 level.

** % of grids with iceberg presence for which correlation is significant at 0.05 level.

Most significant positive correlations occur in the SIZ, with the median coefficient r at 0.15. The correlation is statistically significant at 0.05 level for 33% of the grids in this zone. The correlation is much weaker for other zones (Tab. 3). Within each zone, there is a wide range of coefficient values, both positive and negative. Only a small portion of the correlations are statistically significant. This is largely because when summarized at annual timescale, the size of the data is largely reduced. With the data coverage of only 13 years, at each grid point, the number of data is 13 or less, making it difficult to establish a reliable correlation with statistical significance. When data are pooled together, zonal correlation shows much higher statistical strength, indicated by very low p values for the correlation in all zones. Correlation coefficients, however, are still relatively low (Tab.3). In general, it seems that correlation is more positive and stronger in the high latitude zones of the SIZ and the CSZ, and weaker in the POOZ and the PFZ.

The general low level of correlation is not surprising for several reasons. First of all, the correlation is only calculated between NPP and small iceberg frequency. The occasional presence of large icebergs could sometimes skew the relationship. However, the relatively low frequency of large icebergs makes it difficult to incorporate them into the same correlation analysis. The direct correlation between NPP and iceberg frequency could also be weakened by other sources of Fe (such as meltwater, sedimentary, and upwelling sources), variable phytoplankton Fe:C quotas, light and silicate limitations, the atmospheric Fe dissolution kinetics, aeolian Fe sources and transport pathways. In addition, the statistical relationship between the SO NPP and icebergs also depends on the forms of Fe in icebergs. Most previous studies focus on direct measurement of soluble iron. However, Hassler and Schoemann (2009) found no direction link between soluble and bioavailable Fe because organic ligands have the differential effects on the solubility and the bioavailability. Several studies seem to suggest that organic colloidal Fe provides an important pool to sustain Fe bioavailability to phytoplankton (e.g. Nodwell and Price, 2001; Chen et al., 2003; Wang and Dei, 2003). Finally, icebergs themselves could have other effects on NPP. For example, Arrigo and van Dijken (2004) observed that icebergs could have negative effects on the polar marine ecosystems in some occasions. Many of these icebergs have long residence times, and hence are likely to have been located in highly productive coastal waters during the peak growing seasons of austral spring and summer. Their presence can alter normal advection patterns of annual sea-ice, and hence the fraction of open water available for phytoplankton growth. All these factors could have contributed to a relatively weak correlation between the SO NPP and iceberg occurrences. For more detailed studies on the impact of icebergs relative to some of the factors listed above, we need to develop quantifiable indicators for these factors and incorporate them into statistical modelling. Such indicators could include distance to the coast, distance to aeolian dust sources alone transport pathways based on atmospheric circulation patterns, proportions of bioavailable iron to total soluble iron from iceberg case studies, ocean circulation patterns etc.

References:

Arrigo, K. R., and van Dijken, G. L.: Annual cycles of sea ice and phytoplankton in Cape Bathurst polynya, southeastern Beaufort Sea, Canadian Arctic. *Geophysical Research Letters* 31, no. 8 doi:10.1029/2003GL018978, 2004.

Chen, M., Dei R. C. H., Wang W. X., and Guo, L.: Marine diatom uptake of iron bound with natural colloids of different origins. *Marine Chemistry* 81 (3), 177-189, doi:10.1016/S0304-4203(03)00032-X, 2003.

Hassler, C., and Schoemann, V.: Bioavailability of organically bound Fe to model phytoplankton of the Southern Ocean. *Biogeosciences* 6 (10), 2281-2296, doi:10.5194/bg-6-2281-2009, 2009.

Nodwell, L. M., and Price, N. M.: Direct use of inorganic colloidal iron by marine mixotrophic phytoplankton. *Limnology and Oceanography* 46 (4): 765-777, doi:10.4319/lo.2001.46.4.0765, 2001.

Tournadre, J., Bouhier, N., Girard-Ardhuin, F., and Rémy, F.: Large icebergs characteristics from altimeter waveforms analysis. Journal of Geophysical Research: Oceans 120 (3): 1954-1974, doi:10.1002/2014JC010502, 2015.

Wang, W.X., and Dei, R. C. H.: Bioavailability of iron complexed with organic colloids to the cyanobacteria Synechococcus and Trichodesmium. *Aquatic Microbial Ecology* 33 (3): 247-259, doi:10.3354/ame033247, 2003.

‘Correlation analysis shows that for all grid cells, NPP is significantly correlated with temperature ($r = 0.66$), but not with iceberg probability ($r = -0.03$). However, if only the cells with iceberg presence are considered, NPP becomes significantly correlated with iceberg probability ($r = 0.12$), whereas the correlation between NPP and temperature greatly weakens ($r = 0.27$) albeit still significant. When temperature is controlled, the correlation between NPP and iceberg probability increases significantly both in case of all grid cells and for cells with iceberg presence. In all cases, NPP is positively correlated with iceberg probability, suggesting that the presence of iceberg tends to increase NPP in those places.’

When considering the whole oceanic area south of 40 S, many 1 x 1 cells have very low relative frequencies of icebergs and any variation of NPP in these ‘low frequency’ cell cannot be ‘explained’ by icebergs. Thus it is not surprising that correlation with iceberg frequency is low ($r = -0.03$). If restricting the area to cells where the relative frequency of icebergs is larger than zero (is zero really the threshold value), it is not surprising that the value of the correlation coefficient changes, however, $r = 0.12$ is still very small (-> r^2 = 0.01!!!). I don’t understand what is meant by ‘when temperature is controlled’. A correlation coefficient of 0.27 is in my opinion a borderline case.

We agree that the approach adopted in the original manuscript is not appropriate. In the revised paper, we completely redesigned the study (see above).

p.6 ‘However, the effect of the iceberg probability on NPP increases as measured by both R2 (0.02) and standardized coefficient (0.15). This effect is statistically significant at critical level of 0.01.’ I don’t understand what the authors would like to convey here. R2 = 0.02 is small and thus iceberg frequency is not a good quantity for predicting or explaining variations in NPP. I do not know how the authors calculated a p-value below 0.01 and what it means in the current context. The conclusion is mainly based on these numbers ($R2 = 0.02$, $p < 0.01$):

“… our analyses show that iceberg presence has a small, yet statistically significant, positive impact on the SO NPP. … in places with iceberg presence, iceberg probability could independently explain 2% of the NPP’.

We agree that the approach adopted in the original manuscript is not appropriate. In the revised paper, we completely redesigned the study (see above).

Fig.2: I doubt that comparison of zonally averaged NPP & relative frequency of icebergs yields much insight (please drop figure).

This figure is deleted.

The text needs a bit polishing by a native English speaker (examples: ‘planktons’, ‘which is much contrasted in the three ocean basins’)

The revised paper will be polished by a native English speaker, if we are given the opportunity to resubmit. The above mentioned grammatical mistakes have been corrected.

Specific comments:

- Southern Ocean is defined in the manuscript as the oceanic region south of 40S (which is fine with me): you don’t have to repeat this definition several times

We have paid attention to exclude such repetitions in our revised paper.

- abstract: ‘NPP in the SO is largely influenced by temperature’ I suggest reformulation because MLR only shows variation of NPP with temperature and not (direct) ‘influence’. Temperature is co-varying with many other quantities in the SO and thus it is not clear by what mechanism NPP is ‘influenced’ by temperature.

Owing to the extensive revision of the paper, the abstract is now completely different. This sentence is no longer in the abstract.

- page1, line 27: planktons -> plankton

Corrected.

- page1, line 30: “in either natural or artificial settings” you might cite here: Blain, S., Quéguiner, B., Armand, L., Belviso, S., Bombled, B., Bopp, L., ... & Christaki, U. (2007). Effect of natural iron fertilization on carbon sequestration in the Southern Ocean. Nature, 446(7139), 1070-1074.

- Smetacek, V., C. Klaas, V.H. Strass, P. Assmy, M. Montresor, B. Cisewski, N. Savoye, A. Webb, J.M. Arrieta, U. Bathmann, R. Bellerby, G.M. Berg, P. Croot, F. d’Ovidio, S. Gonzalez, J. Henjes, G.J. Herndl, L.J. Hoffmann, H. Leach, M. Losch, M.M. Mills, C. Neill, I. Peeken, R. Röttgers, O. Sachs, E. Sauter, M.M. Schmidt, J. Schwarz, A. Terbrüggen, & D. Wolf-Gladrow, Deep carbon export from a Southern Ocean iron-fertilized plankton bloom, Nature, 487, 313-319, 2012. doi:10.1038/nature11229

These new citations are included in the revised manuscript.

p.2 total dissolved Fe in SO: you cite more recent work: Klunder, M. B., Laan, P., Middag, R., De Baar, H. J. W., & Van Ooijen, J. C. (2011). Dissolved iron in the Southern Ocean (Atlantic sector). Deep Sea Research Part II: Topical Studies in Oceanography, 58(25), 2678-2694.

Klunder, M. B., Laan, P., De Baar, H. J. W., Middag, R., Neven, I., & Van Ooijen, J. (2014). Dissolved Fe across the Weddell Sea and Drake Passage: impact of DFe on nutrient uptake. Biogeosciences, 11(3), 651-669.

These new citations are included in the revised manuscript.

p.2, lines 9-11: Fe from sediments has to be mixed up or upwelled; Fe source from hydrothermal vents is missing.

German, C. R., Legendre, L. L., Sander, S. G., Niquil, N., Luther, G. W., Bharati, L., ... & Le Bris, N. (2015). Hydrothermal Fe cycling and deep ocean organic carbon scavenging: Model-based evidence for significant POC supply to seafloor sediments. Earth and Planetary Science Letters, 419, 143-153.

This has been added to the revised manuscript.

p.2, line 16: drop 'Thus'

Deleted.

p.2 'Raiswell and Canfield (2012) recently even suggested that icebergs could supply more than 90% of total colloidal and filterable Fe in the SO.' Raiswell and Canfield (2012) write: 'The model indicates that the rate of delivery of bioavailable Fe from icebergs to the Southern Ocean is at least as large as that by wind-blown dust. However estimates of all the main aqueous, nanoparticulate and colloidal (and potentially bioavailable) Fe inputs to the ocean are poorly-constrained.'

We have incorporated this in our Introduction section in the revised paper.

p.4, lines 8-9 'is the mean of the variable and is the standard deviation of the variable' -> 'm is the mean and s is the standard deviation of the sample' & change eq. accordingly, i.e. $z = (x - m)/s$

This section has been deleted from the revised paper.

p. 4, lines 26-27 'NPP is relatively high near the coast of Antarctica, largely because of nutrient input from the continent.' I suggest replacing 'nutrient' by 'iron'.

It has been changed accordingly.

p.4 -60S -> 60S [drop minus sign: S already indicates 'negative' latitudes; no space between degree symbol and S]; please change everywhere in manuscript

This has been corrected throughout the revised manuscript.