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Interactive comment on "Nutrient regimes control phytoplankton ecophysiology in the South Atlantic" *by* T. J. Browning et al.

T. J. Browning et al.

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Responses to reviewer comments

Interactive comment on "Nutrient regimes control phytoplankton ecophysiology in the South Atlantic" by T. J. Browning et al.

Anonymous Referee #1

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General comments The paper describes Frrf results of phytoplankton communities over an environmental gradient from the South Atlantic gyre to the ACC, with particular emphasis on regions around the SSTC. The Frrf results are supplemented by pigment

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concentrations to assess phytoplankton biomass and define groups of phytoplankton based on pigment composition and flow cytometer data to enumerate cyanobacteria. This makes for a nice dataset that is discussed with respect to effects of phytoplankton community composition, light availability, and nutrient availability, with the focus on NO3 and Fe. The main conclusions are that to the south of the SSTC the phytoplankton are limited by Fe availability, whereas to the north of the SSTC phytoplankton communities are in a steady state controlled by macronutrient availability with Fe-replete conditions. In my opinion, these findings are not particularly new, but the paper is a nice description of which factors are likely to influence Frrf data in what regions and highlights some important nuances, the most important of which is that there is a spatial correlation between Fv/Fm and Fe : nitrate ratios, rather than just Fe concentrations.

Response: We appreciate the reviewers comments. We too feel that whilst many of the ideas in the manuscript are not strictly new, the clear division of regimes is to our knowledge one of the clearest examples of the two systems and adds substantial weight to similar former interpretations (i.e. Fe limitation versus steady state nitrate limitation).

Comment 1: My main criticism is the descriptive nature of the paper and the lack of statistical evidence backing the conclusions. Most importantly, the analysis to back the spatial relations mentioned above is missing. Doing some proper statistical analysis of the correlations will improve the paper, which is now solely descriptive, and may also help to come to some clearer conclusions.

Response: We acknowledge this criticism. We have gone through the manuscript thoroughly to address this point and assess where appropriate statistical analysis could be carried out to reinforce points being made. Note that a number of the specific comments from Reviewer #2 were also related to incorporation of a more quantitative description. As such they are not repeated here, but dealt with specifically in the next section.

Firstly we attributed major changes in Fv/Fm and ΔFv/Fm to relative Fe and macronutrient availability, which involved eliminating potentially important community structure controls. In the original manuscript these relationships were mainly qualitative, using trends in Figs 4-6, and we will now include statistical relationships to back these up. We have constructed a table of simple linear regression statistics (Table 1, see pdf file uploaded alongside comment) which we plan to include in a revised manuscript. Our analysis confirms that use of simple quantitative analysis supports our original conclusions (see response to Reviewer comment #5 for more details on calculation of total accessory pigments (AC)).

Using these statistics (Table 1), we will revise the manuscript such that Section 4.1 second paragraph will read:

"... The taxonomic composition of the phytoplankton community can potentially influence Fv/Fm signatures, with a general trend of decreasing Fv/Fm observed with decreasing cell size when grown under the same environmental conditions (Suggett et al., 2009). However, we performed correlation analysis between Fv/Fm and indices of community structure for the upper 50 m water column depth which showed trends opposite to that expected from this control (Table 1). Significant negative correlations were found between Fv/Fm and the contribution of 19′-Hex to total accessory pigments, whilst a positive correlation was found between Fv/Fm and the contribution of zeaxanthin to total accessory pigments. This is indicative of lower Fv/Fm being found in phytoplankton communities with higher haptophyte to cyanobacteria ratios, which is inconsistent with that expected under nutrient replete conditions (Suggett et al., 2009). Furthermore, in terms of the significant Fv/Fm responses from the Fe-addition experiments in the ACC waters south of the SSTC (Fig. 7), net differential growth sufficient to generate taxonomic shifts in the bottles is unlikely over the short 24-hour timescale (Moore et al., 2008; Ryan-Keogh et al., 2013), as evidenced by the generally insignificant changes in total chlorophyll-a."

We will also use the results in this table to backup our claim that Fv/Fm and responses of phytoplankton to Fe replenishment are well correlated with DFe:nitrate. Section 4.1 seventh paragraph will therefore be modified to:

"... Accordingly, across-transect values of the surface DFe:nitrate ratio suggested a good spatial correlation with both Fv/Fm, and the proximal response of the phytoplankton community to Fe replenishment as indicated by ΔFv/Fm, in our study region (Fig. 8). Moreover the degree of Fe stress showed a stronger spatial relationship with both DFe:nitrate and even nitrate than with DFe, with these relationships appearing non-linear (shown visually in Figure 8, and by simple linear regression in Table 1). ..."

Again, see responses to Reviewer #2 specific comments for a number of additional changes regarding making the manuscript more quantitative.

Comment 2: In the discussion, the authors do a good job of integrating effects of nutrient limitation and light effects on the Fv/Fm of the different phytoplankton communities dominated by cyanobacteria vs haptophytes and chlorophytes. They show that the community composition is unlikely to explain the spatial Fv/Fm patterns, and claim that the light levels are too. However, I would like to see this claim backed up by data. The light climate in the upper mixed layer is determined by the in situ irradiance, MLD, and attenuation determined mainly by the phytoplankton biomass. None of these factors is discussed, and neither is the difference in NPQ strategies between cyanobacteria and Eukaryote nano- and picoplankton. With a dark acclimation time of 30 min, there may still be some NPQ active.

Response: We will add the following additional paragraph to the results Section 3.1 in a revised manuscript:

"Mixed-layer depths show consistent values of between ∼40-60 m throughout the central basin (40°W to 15°E), reducing to <25 m nearer South African and South American coasts (Fig. 1b). The light climate experienced by phytoplankton in the upper mixed layer is a function of the attenuation coefficient (Kd) (which in open ocean waters is mainly a function of phytoplankton biomass), the MLD, and above surface incident irradiance levels. Consequently, the lower Kd values, the similar-to-shallower MLD's, and similar incident above surface irradiances would result in higher light levels in sub-tropical gyre mixed layers than sub-Antarctic ones. For example, using two representative stations where rosette deployments included a PAR sensor in addition to the CTD package (Stations 5, representing sub-Antarctic waters, and 18, representing sub-tropical gyre waters) we calculated mean MLD irradiances using the method described in Venables and Moore (2010). For a fixed integrated daytime irradiance for both, calculated values showed the gyre-type mixed layer irradiance to be around double that for the station in sub-Antarctic waters."

We also note that evidence for the elevated irradiance in subtropical gyre type waters comes from the RLC parameters: Ek and ETRmax are higher for surface waters in these regions, likely indicating photoacclimation to higher irradiances.

The second point made by the reviewer is that there may be differences in NPQ between the different phytoplankton types (eukaryotes versus cyanobacteria, picoeukaryotes versus nanoeukaryotes). As such, spatial variability in Fv/Fm could be influenced by changes in species-specific NPQ relaxation times. This is a good point – there might well be differences and these have not been studied in any great detail for the majority of phytoplankton types encountered on our cruise. Current literature suggests most rapid NPQ (energy dependant quenching, qE, and state-transition quenching, qT) would relax in the 30 minute dark acclimation period (e.g. Falkowski and Raven, 1997; Demmig-Adams, 1990; Morrison, 2003, although little data exists on community specific responses). Furthermore, 30 minutes represents the upper end of typical dark acclimation times allocated by most field and laboratory studies. However, some literature suggests this not to be the case for some phytoplankton types, for example Milligan et al. (2012) found 30 minutes was not sufficient to relax NPQ in diatom cultures.

However, a subtlety with regards to our sample collection in the field adds confidence to our claim that rapid NPQ mechanisms would indeed have been fully relaxed: virtually all samples making up the dataset were collected in Niskin bottles on a deployed

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rosette. As such the time taken for the rosette to be retrieved on-ship, sampled for a full suite of GEOTRACES-related samples (gases, isotopes, nutrients etc.) before collecting sample water into bottles for the standard 30 minutes dark acclimation before FRRf measurements meant that the dark acclimation period was actually greater than 1 hour (note in our methods section (Section 2.4) we describe the dark acclimation period as "at least 30 minutes").

Longer lived quenching (qI) as a result of photodamage (Raven, 2011) or PSII down regulation (Milligan et al., 2012) would be expected to persist for several hours, and therefore could be contributing to some of the variability in Fv/Fm for surface waters. However, regardless of this possibility, the Fv/Fm responses to Fe amendment would not be influenced, as the experiments were setup and taken down at night to mitigate against this (i.e. the Fv/Fm response to Fe amendment is still unambiguous).

Some minor comments:

What was the shading of bottle incubations? Please add a % in addition to the statement "simulate the light field at âLij 5 m water depth."

Response: The blue screening decreased incident irradiance to 35% of above surface irradiance. We will add this into a revised manuscript.

The estimates of HPLC derived Chl a are quite a bit lower than those of ocean color. In general, the Chl a concentrations for this region seem rather low for January, could you please comment?

Response: Firstly it should be noted that the in situ and remotely sensed chlorophyll-a concentrations are on a different scale. We will clarify this in the Figure 3 caption: "MODIS monthly composite images (a-f) of chlorophyll-a concentrations for September 2011 – February 2012 around the Atlantic SSTC. Sampling locations are labelled for the January 2012 image which was the month of in situ sampling. (g) Cross-basin section of HPLC-derived chlorophyll-a concentrations. Note the different scales for (a-f)

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and (g).” Comparing the January 2012 image (Fig. 3e) with the in situ concentrations reveals that the two are somewhat different, and this is particularly apparent in the western side of the transect. The reason for this is that Figure 3e is a monthly composite for the whole of January 2012 (i.e. a satellite composite image is averaged for all concentrations throughout that month), whereas the in situ concentrations are a snapshot at various time points though January 2012. As can be seen in the time-progression of satellite images in (Fig 3a-f), the band of elevated chlorophyll shifts progressively south. Therefore as the stations in the western basin were occupied in mid-late January, the concentrations encountered in situ were lower than that of the entire January 2012 average. Reducing the composite time period for the images improves matchups, but images have a much higher percentage of “no data” values (as a result of cloud cover/gaps in satellite coverage etc.).

P11894, line 26: please show an analysis of "a general trend of inverse co-variability with Fv/Fm”

Response: For all data from the cruise Fv/Fm and σPSII show a weak inverse correlation (R2=0.17). However, when the data is split up into three depth intervals correlations are stronger: 0-15m, R2=0.38; 15-25m, R2=0.47; 25-50m, R2=0.26 (also, 0-50m, R2=0.3). We will amended the revised manuscript to reflect this:

“Values of σPSII showed a less clear trend than Fv/Fm (Fig. 6b), although a general trend of inverse co-variability with Fv/Fm can be discerned (e.g. for 0 to 50 m, R2=0.3, p<0.001), with higher values generally seen in sub-Antarctic waters.”

Interactive comment on “Nutrient regimes control phytoplankton ecophysiology in the South Atlantic” by T. J. Browning et al.

Anonymous Referee #2

Received and published: 19 November 2013

General comments The study by Browning et al. focuses on the photophysiology of phytoplankton in the complex environment surrounding the SSTC (South of the South Subtropical Convergence) in the South Atlantic Ocean. The photophysiological response of phytoplankton is estimated via Fast Repetition Rate fluorometry measurements as well as a series of shipboard incubation experiments with Fe addition. Several factors suspected to influence the algal photophysiological response are analyzed, including the composition of phytoplankton communities and the macro- and micronutrient regime. This is a good paper that presents a nice dataset and interesting outcomes. Nevertheless the paper has weaknesses that need to be addressed to make the conclusions clearer and more robust. I found the analysis of the relationships between the photophysiological and the biogeochemical measurements essentially qualitative. The conclusions could be significantly strengthened by a more quantitative analysis, for example using simple linear regression or multiple regression. There should be clearer connections between the authors' results and their hypotheses and conclusions. On some occasions the conclusions are quite speculative and need to be supported by data (examples below).

Response: We appreciate the reviewer's comments. We have added results from statistical tests and a more quantitative description of results (see responses to Reviewer #1 Comment 1, 2 and Minor comments, alongside the additional responses below).

Specific comments:

Comment 1: There are nice features that are totally omitted from the description of the results, even with certain inaccuracies. I understand, and support, the authors' wish to focus the analysis and interpretation on some specific features relevant to Fe-fertilization etc. However I feel it is important that they describe with accuracy the field data as they may be of great interest to some readers (as in a sense would be a "cruise report"). This is also needed to derive robust conclusions.

Response: In the manuscript we tried to present the large dataset whilst also keeping a focus on the main findings and overall topic of the manuscript. However, addressing the specific comments of Referee #2 we will add a more detailed and quantitative description of all results presented. See responses below.

Comment 2: - For example there is no mention of the most striking feature in the distribution of macronutrients, i.e. a maximum of nitrates and phosphate at depth at -45E (Figs. 2a and b). This maximum appears to coincide with an increase in the concentration of silicate (Fig. 2c). Theses conditions could to some extend explain the SCM offucoxanthin (Fig. 5e)?

Response: The reviewer has identified an interesting feature in the macronutrient concentrations. We suspect this is a cyclonic eddy driving upwelling. Indeed for the time periods of sampling, maps of sea surface height showed depressed values over the two stations (18 and 19).

URL for eddy image: http://eddy.colorado.edu/ccar/ssh/grid_output?year=2012&month=0&day=20&west=-
70&east=-10&south=-50&north=-30&width=36&gridInt=0&defined_region=&zmin=-
30&zmax=30&meanOpt=False&dataOpt=Historical&bathOpt=False&bathDepth=0&overlayOpt=None&sstZmin=0&sstZma
5&chlZmax=5&comp_days=1&compOrAveOpt=average&compWindowOpt=centered&resOpt=4km&satOpt=Aqua&levOpt

In a revised manuscript we will briefly mention this feature in the results section (Section 3.2.1) of a revised manuscript:

"... A notable feature in the sections of nitrate and phosphate, and to a lesser extent silicate, were elevated concentrations at depths greater than ∼50 m for Stations 18 - 19 around 45°W. This feature also coincided with relatively colder waters (see Fig. 1b), and lower dissolved oxygen (not shown). This region of the transect was identified as being in a zone of depressed sea surface height (http://eddy.colorado.edu/ccar/data_viewer/index) for the time period of station sampling, suggestive of a cyclonic mesoscale eddy driving upwelling of deeper, colder, elevated nutrient waters."

This elevated nutrient feature reaches the euphotic depth and coincides with the weak

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SCM observed here (Fig. 3a). However, the majority of this feature (i.e. at greater depths) coincides with very low chlorophyll concentrations (<0.1 mg chl m-3) – presumably because light levels are too low (see euphotic depth in Fig 3a) for phytoplankton growth. The shallow mixed layer (∼35 m) in this region (see Fig 3a) is likely also preventing upward vertical mixing of these nutrients and therefore elevated chlorophyll above the SCM. The coinciding elevated fucoxanthin contributions is interesting, and may suggest an increase in prevalence of diatoms, however as mentioned previously, the absolute chlorophyll concentration is very low and therefore actual diatom biomass may be relatively insignificant? Nevertheless, we will amend the manuscript as follows (Section 3.4, second paragraph):

"... The highest fucoxanthin contributions (Fig. 5e) were observed in the stations furthest west along the cruise track within close proximity to the Plata River (up to 77% contribution at 40m depth in Station 24), suggestive of diatoms dominating these waters. Elevated fucoxanthin contributions are also observed in the cyclonic eddy-induced high macronutrient feature identified in Section 3.2.1 (reaching 50% contribution at 100 m depth at Station 18), which is suggestive of an increased contribution of diatoms to total chlorophyll biomass. However, the total chlorophyll-a biomass was very low in this zone (<0.1 mg m-3, Fig. 3b), suggesting the actual biomass of diatoms was also low."

Comment 3: - p. 11982 l. 10-13 "Concentrations of silicate were uniformly low in surface waters [...] apart from near the South African and American coasts": I do not fully agree with this. The concentration of silicate increases dramatically near the South American coast (reaching max values of 12 uM and probably higher?). In contrast, near the South African coast, the concentration remains relatively low at surface but increases significantly at a depth >50 m (5-6 uM?).

Response: We agree the description is not clear. We will amend this such that the manuscript will read (Section 3.2.1):

"Concentrations of silicate were uniformly low (<1 μmol L-1) in surface waters (0-50 m depth) apart from near the South American coast where concentrations increased markedly (Fig. 2c). For example, silicate concentrations reached 10 μmol L-1 at 5 m depth at Station 22, and 22 μmol L-1 at Station 24 (2 m depth) in close proximity to the Plata River outflow. Silicate concentrations remained low in surface waters (0-50 m depth) near the South African coast, yet increased significantly at depths of greater than ~50 m (reaching 7 μmol L-1 at 60 m depth)."

Comment 4: - Fig. 2d shows a clear increase in the concentration of DFe just north of the ACC (with values probably close to those observed near the South American coast). Why is not that mention in section "3.2.2 Micronutrients"?

Response: We have noted that this should be mentioned – we will amend the manuscript as follows (Section 3.2.2):

"Surface dissolved Fe concentrations (DFe) showed low but variable surface concentrations throughout the cruise track (0.083 to 0.535 nmol L-1, Fig. 2d). Consistently low concentrations (<0.16 nmol L-1) were seen east of 10.5°E in the surface AC waters of the Eastern Atlantic. Sub-Antarctic ACC surface waters showed more variable concentrations, reaching a maximum of 0.348 nmol L-1 in Station 9 (proximal to Gough Island). On crossing the SSTC between Stations 13 and 14 (See Fig. 1a), a significant increase in DFe concentrations occurs, reaching a value of 0.501 nmol L-1 which is comparable to those in surface waters in close proximity to the South American coast. To the west of 33°W concentrations showed an increase towards the South American coast, with values reaching a maximum of 0.535 nmol L-1 in close proximity to the Plata River."

Comment 5: -P. 11984 section 3.4 "Phytoplankton community structure": It is not clear what the authors mean by "19'-Hex also dominated diagnostic pigments". I am assuming they calculated the fraction contribution of each pigment to the sum of several diagnostic pigments. Which diagnostic pigments are the authors referring to? Is this sum used as a proxy for the total algal biomass? It is important to clarify this point otherwise the fraction contributions shown in Fig. 5 are quite difficult to interpret.

Response: We appreciate that we did not include these in the original manuscript – we calculated the contribution of each pigment to total accessory pigments (Trees et al., 2000), and will make this addition to Section 2.3.1:

"... Total accessory pigments was defined in this study as the sum of: chlorophyll-c3, chlorophyll-c2, peridinin, 19′-butanoyloxyfucoxanthin, fucoxanthin, 19′-hexanoyloxyfucoxanthin, prasinoxanthin, violoxanthin, diadinoxanthin, alloxanthin, zeaxanthin, lutein, gyroxanthin, chlorophyll-b, divinyl chlorophyll-a, and β-carotene. We found resultant concentrations to closely resemble chlorophyll-a biomass (= chla +0.038, R2=0.8). Fractional contributions of individual diagnostic pigments to total accessory pigments were subsequently calculated."

Comment 6: In addition, I suggest introducing more details regarding the distribution of the pigments. It would be informative to provide the fraction contributions of the major pigments in the study area. The current description is relatively qualitative. For example, 19'Hex contributes up to 50% to the diagnostic pigment pool in the western basin and 10-30% in the eastern basin. As written the algal community in the eastern basin sounds dominated by small cells. However Fig. 5 shows that zeaxanthin and divinyl chlorophyll a contribute a significant yet not dominant portion of diagnostic pigments (e.g. up to 15% only for divinyl chlorophyll a and 20% for zeaxanthin). The contribution of fucoxanthin reaches maximal values that cannot be guessed from Fig. 5e at the very end of the transect (close to the South American coast: 100%?) and large values at -45E, especially at depth: : : 19'But, a biomarker pigment of chrysophyceae and pelagophyceae, is also an important pigment in the eastern part of the transect (contribution up to 45%?).

Firstly we have noticed that the colour bar for Fig. 5 was incorrect. The scale read from 0 to 1 fraction contribution, and should read 0 to 0.6 fraction contribution. This correction will be made in the revised manuscript. The contour values within the sections of Fig. 6 were correct in the original manuscript. Taking the reviewers comments into account we will add a much more quantitative description of Fig. 5. The second paragraph of Section 3.4 will read:

"HPLC samples showed elevated 19′-hexanoyloxyfucoxanthin (19′-Hex) contributions (Fig. 5g) in the eastern basin between 13°E to 10°W (generally >40% contribution to total accessory pigment biomass) suggestive of haptophytes dominating phytoplankton communities in this region. However, 19′-Hex also contributed significantly to accessory pigments in the western basin and closer to the South African coast (e.g. >30% contribution in SCM waters in AC waters of Stations 1 and 2, and generally greater than 20% in waters shallower than 80 m depth west of 10°W), although the photoprotective pigment zeaxanthin (Fig. 5d), a diagnostic pigment of cyanobacteria, was also found to contribute significantly to the total pigment complement (up to 36% in surface waters of Station 1). Elevated contributions of divinyl chlorophyll-a (Fig. 5h) in some of these samples were indicative of Prochlorococcus, matching with elevated Prochlorococcus abundances measured by AFC (Figs 4e and 5h). Elevated contributions of peridinin (Fig. 5a), the unambiguous marker pigment for dinoflagellates, were found in the eastern basin, yet its contribution to total accessory pigments generally remained only around 10% in this region.

High contributions of the photoprotective pigment diadinoxanthin (reaching 17% contribution, Fig. 5b) were found in surface waters (<50 m depth) across the whole transect, as has been observed in previous studies of haptophyte-dominated waters (e.g. Gibb et al., 2000; Gibb et al., 2001). The highest fucoxanthin contributions (Fig. 5e) were observed in the stations furthest west along the cruise track within close proximity to the Plata River (up to 77% contribution at 40m depth in Station 24), suggestive of diatoms dominating these waters. Elevated fucoxanthin contributions are also observed in the high macronutrient feature identified in Section 3.2.1 (reaching 50% at 100 m depth at Station 18), which is suggestive of an increased contribution of diatoms to total chlorophyll biomass. However, as total chlorophyll-a biomass is very low in this region (<0.1 mg m-3, Fig. 3b), the actual biomass of diatoms would also be low. Similarly, elevated contributions of 19′-butanoyloxyfucoxanthin (19′-But) at depths below ~60 m were observed across large parts of the transect however, the low chlorophyll concentrations at these depths indicated the total biomass of phytoplankton types containing this pigment (e.g. Chrysophyceae, Pelagophyceae) were relatively low."

Comment 7: - P. 11984 l. 19-20 "Apart from the station sampled close to Gough Island, low values of Fv/Fm (Fv/Fm < 0.3) are seen throughout the mixed layer in the sub-Antarctic ACC waters of the eastern basin, with increases at greater depth (Fv/Fm > 0.3)": Again the description of the results is relatively convoluted. I cannot see any special feature in Fv/Fm around Gough Island from Fig. 6a. I would rather say that, in the eastern basin, Fv/Fm values are low within the mixed layer (0.3 and lower) and increase with depth (e.g. >0.4 below 80 m), except nearby the South African coast where Fv/Fm show high values throughout the entire water column.

Response: We are confident that mixed layer waters next to Gough Island station stand out as a region of high Fv/Fm on Fig. 6a – see the colouring within the mixed layer above the triangle at ~10°W: the depth profile has warmer colours (higher Fv/Fm) than stations to the east or west? However we will try to make the description of this a little clearer – the revised manuscript will read (Section 3.5):

"Low values of Fv/Fm (Fv/Fm <0.3) are seen throughout the mixed layer in the sub-Antarctic ACC waters of the eastern basin with increases at greater depths. An exception to this is the station occupied next to Gough Island (Station 9), where elevated Fv/Fm (Fv/Fm >0.3) can be discerned throughout the mixed layer. Higher Fv/Fm is seen at all depths in subtropical gyre-type waters in the western basin (west of 35°W) and in AC waters (>13°E)."

Comment 8: - P. 11984 l. 26-27 "higher values in the eastern basin than in the western basin and coastal waters are seen": This is true and I would even add that the lowest values of PSII are observed at the coastal stations.

Response: This is true, particularly for the coastal stations on the S. American side. We will add this in such that the manuscript will read:

“Values of σPSII showed a less clear trend than Fv/Fm (Fig. 6b), although a general trend of inverse co-variability with Fv/Fm can be discerned (e.g. for 0 to 50 m, R2=0.3, p<0.001), with higher values generally seen in sub-Antarctic waters. Lowest σPSII values were observed next to the South American coast.”

Comment 9: - P. 11986 l. 6-9: The authors do not mention the surface sample located in the eastern basin with very high Ek value (350 umol photons m-2 s-1). Why?

Response: We have implied that the reader interprets this station as part of the sub-tropical gyre-type waters i.e. where stratification is observed. However, as this is not clear we will amend the manuscript (Section 3.5):

“Surface samples from thermally-stratified subtropical gyre-type waters (west of 25°W and east of 10°E) show higher ETRmax and Ek values than SCM samples. Particularly large differences, with highest recorded ETRmax and Ek surface values, are observed for Stations 1 (nearest the South African coast), 19 and 20 (near the South American coast).”

Comment 10: - P. 11986 section “3.6 Fe addition experiment”: This section is extremely short whereas Fe-fertilization is one of the main focuses of the paper. I think a detailed description of Figs. 7a and b would be most appropriate.

Response: We will include a more thorough description. The manuscript will read (Section 3.6):

“The Fe addition experiments showed clear (t-test $p < 0.01$) Fv/Fm responses from Fe-amended bottles over that of the control bottles for surface waters in the eastern basin between 10°E and 20°W (IF3 to IF8 in Figs 7a-b). Within these experiments, a notable east-to-west reduction in response was observed in surface water amendments between IF3 and IF8 (e.g. ΔFv/Fm values of 0.155 for IF3, decreasing to 0.063

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for IF8). No significant Fv/Fm response to Fe amendment was seen either side of this zone. Furthermore no statistically significant Fv/Fm responses to Fe amendment were seen for the five SCM experiments conducted (Fig 7b), although it should be noted that no SCM Fe-amendment experiments were conducted where the largest surface water responses were seen (IF3 to IF6). Significant changes in chlorophyll-a concentrations were also not observed in the majority of experiments."

Comment 11: - P. 11986 l. 23-24 "Several factors are thought to control values of Fv/Fm, including light climate [: : :] Using accessory pigment, AFC, irradiance: : :": Where are the irradiance data? Where are they discussed and how do you come to the conclusion that they cannot explain the spatial variations in Fv/Fm?

Response: See response to Comment 2 from Reviewer #1.

Comment 12: - P. 11989 l. 28-29 and p. 11990 l. 1-8 "RLC parameters showed [: : :] instead being dominated by vertical gradients within the gyre-type waters, likely related to photoacclimation: : :": This is quite speculative considering that RCL parameters were measured in the mixed layer exclusively, except for a few gyre-type stations where measurements below the MLD were also performed.

Response: All gyre-type stations (10-11 stations) had below-mixed layer SCM RLC's performed (Fig. 6b and c) and these showed marked differences to surface samples from these same waters. This correlates with the difference in light climates phytoplankton are experiencing (i.e. being kept at >40-60m depth continuously in comparison to being entrained in the surface mixed layer) and is consistent with expectations of photoacclimation for these parameters (Moore et al., 2006). If we had performed RLCs below the mixed layer in ACC-type waters we would have expected greater differences between these depths and the mixed layer, as a result of the different light climates phytoplankton are experiencing. We will try to clear up this statement such that the revised manuscript will read (last paragraph of Section 4.1):

"RLC parameters showed a less clear across-transect trend than Fv/Fm, instead being

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dominated by vertical gradients within the gyre-type waters (see differences in parameters between surface water samples and below mixed layer depth samples in Figs 6c and d). This difference is likely related to photoacclimation, as the light environment phytoplankton are experiencing above and below the mixed layer is expected to be quite different. Specifically, elevated ETRmax and Ek of surface samples compared to SCM samples (below the mixed layer) likely reflect acclimation to the increased irradiance encountered here. In contrast, RLC parameters displayed less vertical variability between surface waters and those at the base of the mixed layer in ACC waters of the eastern basin: deep (∼40 m) and shallow (∼5 m) values of ETRmax and Ek were in between that of surface and SCM samples from the subtropical gyre-type regions to the east and west. Such a pattern likely resulted from these phytoplankton communities acclimating to mean mixed layer depth irradiances."

Comment 13: - P. 11990 section "4.2 Controls of the development of the SSTC bloom" – Hypothesis related to the narrowing of the SSTC chlorophyll band: First, the "narrowing" is difficult to observe from the chlorophyll images (Fig. 3). To me the most striking feature is a sort of filament of enhanced chlorophyll concentration (> 1 mg m-3) along the South American coast that expands in the western basin in November and December. I suggest displaying a region that is larger than just the study area so the increased chlorophyll band is obvious. Second, I do not understand how the authors conclude that the "narrowing of the chlorophyll band [is : : :] caused by the bloom-induced depletion of macronutrients to the north of the SSTC and Fe to the south". Wouldn't you need seasonal data to come to this conclusion? I may have missed something here, but then how the results lead the authors to this conclusion should be clarified. I suggest adding to the chlorophyll map the currents and additional geographic features as shown on the temperature map (Fig. 1a).

Response: We will revise Fig. 3a-f such that the region we show extends southwards to -60°N. We have experimented with adding all the features on Fig. 1, however this lead to a relatively cluttered figure. In the revised figure we propose a compromise by

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adding on the 16 °C (SSTC) contour in purple colouring (as for Fig. 1a) which acts as a reference for the expected location of currents in Fig 1a.

We appreciate that the description was lacking clarity and interpretation relatively speculative. We can identify a number of interesting features in the maps of chlorophyll in Figs 3a-f. The first is the marked increase in chlorophyll that occurs downstream (northward) of the Falkland Islands between September and October, which is presumably a result of the increased irradiance that is occurring (alongside the Fe/nutrient enrichment from the Falkland Islands that is expected to be occurring in both of these months). Similarly the same explanation could be applied to the enhanced chlorophyll downstream of South Georgia and the Northern Scotia ridge between October and December. This natural Fe enrichment appears important for waters across the Atlantic sector of the ACC. Eastward moving ACC waters entrain Fe supplied from the Scotia Ridge (including islands) and have been suggested to result in the enhanced chlorophyll band at around 45-50°S (e.g. Sokolov and Rintoul, 2007; Moore and Abbott, 2002). Separate to this Scotia Ridge-fertilized band, and what we were intending to focus on in our original discussion, is the band of chlorophyll at the SSTC further north. These two separate bands can also be clearly identified downstream of other Southern Ocean islands at similar latitudes (e.g. Kerguelen). The SSTC band itself intensifies (i.e. chlorophyll concentrations increase) throughout the time series shown in Fig 3a-f. A definitive explanation for this cannot be stated using our field data – as the reviewer says, seasonal data would be needed. What we can say is that there is an expected increase in light availability, however Fe levels, at least in January, are limiting phytoplankton growth in this region. The first paragraph of Section 4.2 will hence be altered:

“Satellite images suggest a band of elevated chlorophyll concentrations around the SSTC in austral summer (Fig. 3a-f). Note that the SSTC chlorophyll band can be distinguished from the Fe-fertilized band downstream of South Georgia and the Scotia Ridge further to the south (e.g. Sokolov and Rintoul, 2007; Moore and Abbott, 2002).

Increasing chlorophyll concentrations are observed at the SSTC between September 2011 and February 2012 which could be a result of increased light availability through a combination of increased irradiance and reduced mixed-layer depths (de Boyer Montégut et al., 2004). However, as we have demonstrated, phytoplankton in these waters are limited by Fe availability in January 2012. Consequently the sustained and even increased chlorophyll into February 2012 may be indicative of a maintained Fe supply to this region.

The expected response of phytoplankton to natural Fe supply in these waters is particularly well demonstrated by Fe enrichment from Gough Island, which sits centrally in the Atlantic Basin at 40°S within the region of Fe-stress (Fig. 8). ...”

Comment 14: - P. 11989-11990 section “4.2 Controls of the development of the SSTC bloom” – Fe fertilization around Gough Island: It would be interesting to know the % difference in DFe, Chl and Fe/Fm between the station located at Gough Island relative to the stations located nearby in the Fe-limited area. For example, Fig. 8 shows an important increase in DFe (0.35 nM at Gough Island as compared to 0.1 nM in surrounding waters). The corresponding increase in chlorophyll, which would support the hypothesis of natural Fe-enrichment from the island, does not seem as elevated (0.9 to 1 mg m-3?). Also it would be interesting to look at the composition of the algal community around the island as small diatoms often dominate the community in Fe-fertilized waters.

Response: We think this is a valuable suggestion and have calculated % changes and looked at the community composition for these stations in more detail. The revised manuscript will read (Section 4.2, second paragraph):

“... Indeed, both elevated chlorophyll-a concentrations and a recovery of Fv/Fm to higher values were observed for the single station occupied in the vicinity of Gough Island (Station 9), as might be expected upon relief of Fe limitation. DFe was around 3-fold higher proximal to Gough Island than with the waters just to the north. Increases in

Fv/Fm and chlorophyll were more modest (34% and 46% respectively), potentially reflecting the time required for phytoplankton entrained in the eastward flowing current to respond to Fe supply from Gough Island. For instance, the increase in Fv/Fm between the two stations (8 and 9) was comparable to the increase observed for the 24 hour duration Fe-amendment experiment using water collected at Station 8 (26% increase for IF7, Fig. 7b). Moreover, there is no reason to suspect a linear correlation between Fe concentration and Fv/Fm or chlorophyll (e.g. Cullen et al., 1992, also see Table 1 and Fig. 8). Similarly, there was relatively little indication of any significant species shifts accompanying the natural Fe-fertilization, with contributions of major diagnostic pigments remaining relatively constant (e.g. mixed layer fucoxanthin remained at ∼10% contribution for both stations). Although our data from Station 8 suggest Fe-fertilization from Gough Island is spatially limited to the north, the downstream (longitudinal) Fe-fertilization distance from Gough Island remains to be tested."

Technical corrections:

Comment 15: - Although it may seem obvious I suggest adding the unit of longitudes on the figures where applicable.

Response: Units added for all relevant figures.

Comment 16: - Fig. 1a: y-axis has no label.

Response: Label has been added

Comment 17: - Fig. 4a title: Units should be m2 (mg Chl)-1 instead of m2 mg-1 Chl.

Response: Done

Comment 18: - Fig. 8: I recommend drawing both x- and yaxes as the current figure is extremely difficult to read. This figure is important as it summarizes the results and help with the conclusions. I recommend make it a little nicer (axes easier to read, larger etc.).

Response: We are not quite sure what the reviewer intends us to do for this. In our copy of the manuscript Fig. 8 has clear x and y axes, labels and units. Perhaps there is a problem with reviews copy of the figure? Making axis labels larger would clutter the figure as y-axis labels would impinge on each other too much?

Additional references

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Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/10/C7309/2013/bgd-10-C7309-2013-supplement.pdf

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