Dear associate editor,

We followed your recommendations and give detailed responses to all referee's comments. The clarity of writing throughout the manuscript has been improved (by us in red in the Moutin_Copernicus_Word_template_NV_with_COR file) and by a native English speaker (correction in blue in the Moutin_Copernicus_Word_template_NV_with_COR file).

A sentence about sediment trap biases was added. Moreover, we decided to remove most of the discussion about the role of zooplankton vertical migration. It was not the main scope of our paper and we decided, mainly following the comment of Referee 1 to postpone the study about zooplankton migrations. It is now clearly explained that vertical migrations of zooplankton are one of the three hypotheses that can, at least partially, explain the seasonal unbalances in DIC estimated. The two additional hypotheses are high temporal variations in POC export and a methodological underestimation of POC export.

We clarify the assumptions and limitations regarding the nutrient budgets. We are looking for first order biogeochemical budgets (simple budgets) in an area where only few data are available. We added a paragraph in the discussion explaining why transient nutrient input (cyclone, mesoscale activity) may not drastically change our simple nutrient budgets.

We discussed Fe concentration data and give answers to the comments of Referee 2. We added the Fe 0-70 m averaged concentration measured during OUTPACE in each area, as requested by Referee 2. We cannot enter more in detail because the paper by Guieu et al. is under revision in Nature Scientific Report.

Yours sincerely

Thierry Moutin

Anonymous Referee #1

On the one hand, this ms. deals with an impressive dataset, but in the end, the main conclusions (importance of iron, importance of zooplankton vertical migration for export) are conjectured from indirect evidence, not from processes/data studied by the authors on the cruise.
There are several grave deficiencies in the data treatment and interpretations.

We thank Referee #1 for remarking on the 'impressive dataset' the ms deals with, and for taking the time to read it and providing his/her thoughts and comments. In the following paragraphs, the original review comments from Referee #1 are in bold and our own responses are interspersed in normal characters. Our main conclusion in the paper is that the discrepancies between the depth of the nitracline and phosphacline, together with evidence of deep mixing at 70 m, allow excess P to annually reach the upper surface, support nitrogen fixation, and induce a significant biological soft tissue pump in the MA. Based on the available iron data in the area, we can consider that the WMA is replete in iron, while the gyre is iron depleted. The importance of phosphate in the WTSP and iron in the gyre is not a main conclusion of this paper. It was the conclusion of a previously published study (Moutin et al., 2008). This conclusion is extended in the present paper. Because this was the starting point of the narrative of this study, it was necessary to recall the critical role of iron and phosphate in the Abstract, and to discuss specifically recent advances on this subject (section 4.4). Again, our main conclusion concerns the local origin of the excess-P at an annual time scale and subsequent processes, such as the role of N_2 fixation in nutrient availability and the biological carbon pump. The importance of zooplankton vertical migration is suggested by our data, but not for export (as stipulated by Referee #1). It is suggested to explain part of the missing DIC in the upper surface carbon budgets. Nevertheless, we recognize that some sentences may prove confusing and apologize for the lack of precision in the section 'Settling particulate matter mass, C, N and P flux measurements'. A detailed protocol is added at the end of this response. As requested by Referees #2 and # 3, we will provide figures of the ADCP data showing vertical migrations. Because it seems to be a point of contention and because it is for us a secondary subject that will distract from our main conclusion, this part will be has been considerably shortened in the new version of the ms. Please note that we only needed to delete one sentence in the Abstract [the following: "We also suggest that mesozooplankton diel vertical migration plays a dominant role in the transfer of carbon from the upper surface to deeper water in the MA. ": 27/422 words] to answer Referee #1’s main arguments in favour of rejection (point 5). The Discussion will be considerably shortened.

Moutin, T., Karl, D. M., Duhamel, S., Rimmelin, P., Raimbault, P., Van Mooy, B. A. S., and H. Claustre. 2008. Phosphate availability and the ultimate control of new nitrogen input by nitrogen fixation in the tropical Pacific Ocean, Biogeosciences, 5, 95-109.

1. Why should it be justified to obtain "winter values" of properties by taking the 70m values as representative?

"Winter values" of properties are essential to draw to establish simple budgets. We understand the question as: "..will it be possible to consider 70 m values (70 m being the maximum mixed layer depths (MLD) calculated for the whole area) as representative of homogenized 0-70 m winter conditions?"

We only have satellite and some climatological data to estimate winter conditions in this largely under-sampled ocean. Therefore, we firstly validated satellite measurements during our survey in March (SST as an example below)

	WMA	EMA	EGY	
SST(°C) March 2015	28,8 ± 0,3	28,3 ± 0,7	29,1 ± 0,4	
CT(°C) March 2015	28,9 ± 0,3	29,3 ± 0,3	29,5 ± 0,4	

and showed that 70 m depth values measured during our survey corresponded well with satellite winter data (SST as an example below)

	WMA	EMA	EGY	
SST(°C) July 2014	24,9 ± 0,2	24,2 ± 0,7	26,5 ± 0,2	
$CT_{70\,m}$(°C) March 2015	25,3 ± 0,3	24,8 ± 0,9	26,1 ± 0,9	

Of course, this is an extrapolation, but we also showed a good agreement between chlorophyll a (Chl a and SSChl a), and for carbonate variables (DIC, Alk, pCO_2) measured during OUTPACE at 70 m depth and the same variables provided at the ocean surface in winter by the climatology study of Takahashi et al. (2014): see paper for details. Considering that 5 different available winter variables gave a good agreement, we consider that we can use the proposed extrapolation for all other variables to obtain our 'first order' budgets. Of course, this is the simplest 'model' to obtain seasonal variations in the absence of seasonal data, but highlighting the importance of seasonal variations in areas where they are generally considered as unimportant, or even non-existent, is an important issue in our opinion.

These are minimum estimates at best given that in almost all profiles the chl-a maximum is below 70m.

Yes, but the DCM depth in oligotrophic areas is essentially related to a maximum of pigments (chlorophyll a) by carbon unit and did not correspond to a maximum in biomass (see figure 5g) or in production (see figure 6a). Almost all C-biomass and C-production were measured in the upper 0-70 m, even if the DCM depths were below 70 m.

2. How can matter, recovered from sediment traps, be taken at face value and trap biases be not considered? Or, even better, corrected for! This issue has been extensively discussed: Gardener 2000 in The changing ocean carbon cycle, Hanson, Ducklow, Field, eds., Cambridge Univ. Press, p 240-281; Buesseler et al. 2007, J.Mar.Res. 65, 345-416).

We apologize for the lack of precision in the description of our sediment trap data methodology. We followed most of the major recommendations proposed by Gardner (2000) and Buesseler et al (2007) but not the ^{234}Th calibration. Nevertheless, we recognize that our protocol was not detailed enough, and we propose some modifications (see below). Gardner (2000) explain that ^{234}Th calibration was not done around HOT because the scavenging of ^{234}Th is so low in oligotrophic regions that this calculation is subject to major errors. We therefore assume that Referee #1 does not want us to explain why we did not use the ^{234}Th calibration in our oligotrophic study area. Concerning the 3 major biases in Buesseler et al. (2007):

i) Hydrodynamics: please note that for our quasi-Lagrangian study, we sampled in low horizontal advection areas and chose regions with low surface currents on purpose (de Verneil et al., this issue). Buesseler et al. (2007) concluded from several experiments in Bermuda that at low velocities, there may not be a strong hydrodynamic effect on the mass flux measured with surface-tethered drifting traps. We have no isotope measurements to quantify this effect, but we can argue that our sample conditions should minimize this bias.

ii) Zooplankton swimmers: according to Buesseler (2007), the term 'swimmer' refers to metazoan zooplankton (and occasionally small fish) that are thought to actively enter sediment traps. Their "uninvited presence in the sediment trap" means that swimmers may be seen as a problem, and solutions are proposed to avoid it. Although Buesseler et al. (2007) encourages the continual development of swimmer avoidance traps in order to improve estimates of in situ particle flux, they explain that screening is often used for deep sediment traps as many of the swimmers are large and can be readily removed using screens. Since swimmers caught in oligotrophic environments tend to be smaller, however, traps used there will require sorting and manual removing. As the method for swimmer removal varies widely (Buesseler et al., 2007), we understand the need to describe it precisely and we propose to do so. Please note that for French cruises, the same person is in charge for the whole analysis and protocol development. Particularly for the removing of swimmers, and even if the method is subjective, it allows for a direct comparison of all measurements.

Iii) Solubilization: This point is discussed below.

Solubilization into collection cup supernatants is (almost) not considered at all but this is important especially in shallow traps, see Kähler and Bauerfeind (2001), Limnol. Oceanogr. 46, 719-723; Antia (2005) Biogeosci. Discussions 275-302. In the case of phosphorus, supernatants have been measured but assigned 100% to swimmers! What about P in the passive flux?

According to Antia (2005, introduction, paragraph 4) cited by Referee #1, they worked with traps below 500 m depth: "..shallow deployments for merely hours to days in high-swimmer environments would require a different approach, since swimmers are a major source of dissolved elements in such trap samples, and there is no reliable way to separate swimmers contribution of different elements from that originating from the passive flux". We do indeed consider that swimmers are probably the major source of dissolved P, and we agree that there is no reliable way to separate swimmers' contribution of different elements from that originating from the passive flux. Furthermore, using formaldehyde precluded DOC measurements. Therefore, it will not be possible to correct for this bias. This bias will be mentioned in the new version of the ms.

DOC could obviously not be measured (formalin) and DON was not, or is not reported. Hence almost all P and much N and C "export" by particles is missed in the trap data.

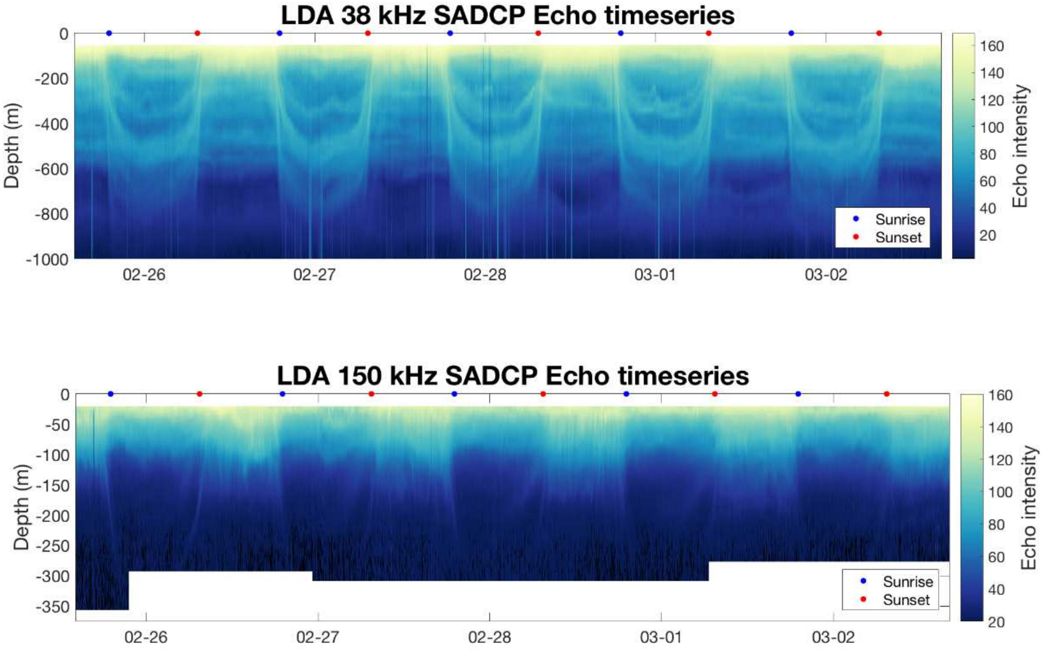
Yes, the only dissolved contribution measured, because it was supposed to be the largest (as shown by Antia (2005)), was the P contribution. Because we prefer not to enter into the details considering this controversial point, which is outside the main focus of our paper, we will add this methodological issue as another hypothesis to possibly explain part of the unbalanced carbon budgets.

Also one of the traps is used in the balances of two regions (Fig. 7).
Yes, the trap deployed at LD A for several days was considered for the Melanesian archipelago (WMA and EMA) and the trap deployed at LD C for several days was considered for WGY. We understand Referee #1's remark, but this point was clearly explained in the ms and without specific trap data, we considered that it would be worse to withdraw the EMA budget.

3. **Zooplankton vertical migration is conjectured to be the one important export mechanism with only implied evidence (ADCP data not shown).**

Zooplankton and micronekton diel vertical migrations have already been observed and considered to play a significant role in the WTSP (Smeti et al., 2015), a reference that we missed in our ms and propose to add in the revised version. The ADCP data (figures below) show the vertical migrations at LDA.

Smeti H., Pagano M., Menkès C., Lebourges Dhaussy A., Hunt B. P. V., Allain V., Rodier M., de Boissieu F., Kestenare E., Sammari C.: Spatial and temporal variability of zooplankton off New Caledonia (Southwestern Pacific) from acoustics and net measurements. J. of Geophys. Res. Oceans, 120 (4), 2676-2700. ISSN 2169-9275, 2015.



Raw SADCP Echo time series data at LDA station 38 KHz (above) and 150 KHz (below) showing diel vertical migrations of zooplankton-micronecton during the 5 days of the station occupation.

But to present swimmers attracted to the sediment trap as evidence of vertical migration ("Zoo/Particulate mass flux ratio" in Tab.4) or "mean carbon export by swimmers" (p.13 line 23) is downright nonsense. Swimmers killed in the trap cannot move upward again. And of what should swimmers be representative? Certainly not of a vertical flux.

We understand the problem. "mean carbon export by swimmers" (p.13 line 23) is definitely not the best term because it implies that this carbon is definitely exported from the upper layer, while most vertical migrators also ascend to the surface waters as part of the diel cycle (this explains why they should be removed (Buesseler et al., 2007)). This sentence and the entire paragraph will be removed. Moreover, and because swimmers may be attracted to the sediment trap, we will only speak about zooplankton content and not fluxes.

4. New production and primary production are not neatly distinguished in the text (e.g. p.13 line37; p13 line 19). Most PP is recycled in these environments thus PP cannot explain the drawdown of DIC.

New production is the production associated with new N (Nitrate from below and from nitrogen fixation), as clearly mentioned by Dugdale and Goering (1967), even if most people forget nitrogen fixation as a significant new N source. Rates of nitrogen fixation are found to be high or higher than nitrate uptake, in some cases suggesting an important role for nitrogen-fixing phytoplankton (Dugdale and Goering, 1967). As mentioned by Referee #1, it is clearly a fraction of the whole primary production. Even if most of the PP is recycled, the e-ratio is higher than in other oligotrophic areas less influenced by N_2 fixation (see paper).

p. 13 line 19 : The sentence is : « Considering that half of this loss (12.5,%) happens at 500 m depth following ingestion of the water column's whole PP(new biomass) in the upper layer, … »

This sentence will be removed in the new version of the ms.

p.13 line37 : The really high N_2 fixation rates in the MA, compared to other areas in the world (Bonnet et al., 2017), may provide the nitrogen required for primary production, creating the necessary decrease in p_{CO2}^{oc} to stimulate CO_2 invasion.

This sentence will be replaced by: The really high N_2 fixation rates in the MA, compared to other areas in the world (Bonnet et al., 2017), may provide the new nitrogen required for new production, creating the necessary decrease in p_{CO2}^{oc} to stimulate CO_2 invasion.

5. The ms. was to me difficult to read because of abounding abreviations and numbers in the text, repeated checks were necessary whether the authors refer to their own data or speculate. No story is told convincingly. But my rejection of the ms. is mainly based on points 2 and 3 above.

We recognize that the ms is not easy to read, but as mentioned by Referee #1, the ms deals with an extensive dataset, and we think that it is the main reason for this difficulty. Referee #1 recommended rejecting the ms mainly on the basis of points 2 and 3 above. We hope he will reconsider his decision in view of the detailed responses given here and the near-deletion of this part, which is of secondary importance in terms of the main focus of our ms. The role of zooplankton and vertical migrations in this region will be the subject of a new paper by C. Menkes and collaborators in the near future. We now only suggest, in a section of the Discussion and among 2 other hypotheses, a possible role of diel vertical migrations of zooplankton in the transfer of carbon.

* Protocol in the new version

Settling particulate matter mass and C, N, and P flux measurements

The settling of particles in the water column outside of the upper layer was measured using 2 PPS5 sediment traps (1 m^2 surface collection, Technicap, France) deployed for 4 days at 150 and 330 m at LD A (MA) and LD C (WGY) stations (Fig. 1). The PPS5 traps are covered with baffled lids (mesh 1 cm^2) to reduce current shear at the mouth of the trap, but also to prevent large zooplankton and fish from entering the traps. Particle export was recovered in polyethylene flasks screwed on a rotary disk which automatically changed the flask every 24-h to obtain daily material recovery. The flasks were previously filled with a 2% (v/v) buffered solution of formaldehyde (final pH≈8) prepared with in situ deep seawater. A sample of this water is kept to measure dissolved nutrients (phosphate and silicate). Immediately after trap retrieval, samples were stored at 4 °C in the dark until they were processed. Back in the laboratory, one part of the sample's supernatant was kept and stored at 4°C to measure dissolved nutrients (phosphate and silicate), and pH was checked on every trap sample. Swimmers (all organisms deemed to have actively entered the trap) were identified under a stereomicroscope and carefully removed with plastic fine-tipped forceps and placed into small vials with some of the reserved trap preservative. The main species removed were copepods, crustaceans (ostracods, euphausiids, amphipods) and pteropods. Microphotographs of each sample were taken. After the swimmers were removed, the whole sample was then rinsed 3 times with ultrapure (MilliQ) water in order to remove the salt and then freeze-dried. Mass particle fluxes were obtained by weighing the freeze-dried sample 5 times. The accuracy of the weighing (and thus of the flux) was 1 % over the whole data series. In this study, swimmers were rinsed and freeze-dried and their dry weight was also determined. Settling particulate matter and swimmers were analyzed separately on an Elemental Analyzer coupled to an Isotope Ratio Mass Spectrometer EA-IRMS (Integra2, Sercon

Ltd) to quantify total C and N. Total P was analyzed as described in Sect. 2.2. The total element measurements for the settling particulate matter were considered to represent the settling particulate organic C, N, P. The results are presented Sect. 2.2 (Table 4).

Anonymous Referee #2

This manuscript reports upper water column biogeochemical observations from a cruise in the western tropical South Pacific. The cruise programme had a particularly novel finding: elevated rates of nitrogen fixation throughout the Melanesian Archipelago. These results have already been reported: briefly in Bonnet et al. (2017), and in detail in a companion manuscript as part of the cruise special issue in Biogeosciences Discussions (Bonnet et al., in review). The novel contribution of the present manuscript is that an upper water column carbon budget for the region, built from observations on the cruise and longer time series datasets, appears to require an additional fixed nitrogen source other than seasonal entrainment of waters below the mixed layer.
They interpret this deficit as originating from the enhanced nitrogen fixation observed (Bonnet et al., 2017; Bonnet et al., in review). Provided all carbon system calculations are correct which is not my area of expertise I think the manuscript is of significant interest to the scientific community. I do however have a number of comments that should be addressed.

We thank Referee #2 for remarking on the novel findings of the cruise program and the significant interest for the scientific community of our ms. In the following paragraphs, the original review comments from Referee #2 are in bold and our responses are interspersed in normal characters. The main conclusion of our paper is that the discrepancies between the depth of the nitracline and phosphacline together with evidence of deeper mixing at 70 m allows excess P to annually reach the upper surface, support nitrogen fixation, and induce a significant biological soft tissue pump in the MA. Calculations of the carbon system have been done with the seacarb R package following all instructions provided by the authors of the package and the manuscript has been read by a carbon chemistry specialist (Nicolas Metzl, as mentioned in the Acknowledgements).

Main comments:
Clarity of writing. The manuscript requires a large number of corrections for English, sentence structure, and correct terminology. This will much improve the readability of the paper and make it more readily understandable. There were a number of instances where I had to read a paragraph more than once to work out what message the author was trying to convey (and not always with 100% success!). Therefore, I would recommend going through the paper in detail with a native English scientist in order to check sentence structure and terminology for simplicity and clarity. I have made some suggestions in the specific comments section, but these are only examples; there are more throughout the manuscript.

We will follow the recommendations provided and we will send the revised ms to a native English speaker for proof-reading.

The role of Fe. The manuscript argues for a primary role of Fe in enabling nitrogen fixers to become established in the Melanesian Archipelago, but then invoke phosphorus availability as the primary factor controlling the activity of nitrogen fixers. Accordingly, Fe is frequently stated as 'high' (or 'Fe-replete') in Melanesian Archipelago area.
Where are the Fe data? The authors do give some values from a paper in review that appear high, however, since this is central to the manuscripts conclusions, some more details are needed to describe how Fe concentrations varied though surface waters of the three regions discussed. Surface Fe supply from shallow hydrothermal vents is also mentioned, which is very interesting, however as I understand it none of these data are yet published. Regardless, whilst this could significantly influence the overall Fe budget and capacity of the Melanesian Archipelago system for nitrogen fixation, this does not preclude periodically or seasonally low levels of Fe in surface waters of the Melanesian Archipelago. In other words, what evidence is there that Fe is at high, steady state value in this biogeochemical province? Supplied Fe has a short lifetime in seawater because of rapid scavenging and concentrations following a point source supply diminish rapidly

and require continuous inputs to lead to sustained high surface concentrations (such as under the Saharan dust plume in the tropical North Atlantic). Other Fe values reported by Moisander et al. (2011) in the vicinity of the region appear lower than the two values stated.

After re-stating our main conclusion regarding the role of iron in this area, several important questions were raised by Referee #2 that need individual responses.

Where are the Fe data? We understand this to mean 'Where are the OUTPACE Fe data?', because other values are given clearly indicating the large difference between the gyre (~0.1 nM measured in the upper 350 m water column of the SP gyre (Blain et al., 2008)) and the MA (0.57 nM reported by Campbell (reference in the ms) as an example). We reported only the average concentrations in the photic layer measured during OUTPACE (Guieu et al., in revision), which confirmed this difference in iron availability and was sufficient for our purpose: 1.7 nM in the MA compared to 0.3 nM in the WGY. As requested by Referee #2, we will add the averaged 0-70 m integrated concentration corresponding to our 3 areas in the revised ms: 0.57±0.14 nM (WMA); 1.18±1.02 nM (EMA); 0.28±0.03 nM (EGY), but we cannot present detailed data that will be published in Guieu et al. paper. elsewhere!

We appreciate Referee #2's interest in the role of hydrothermal Fe sources, which is really an important point. The paper by Guieu et al. is currently under revision (Nature Scientific Report) and will we hope be accepted soon. We previously highlighted the importance of shallow hydrothermal sources in providing iron to the MA: following the South Equatorial Current from east to west (see our figure in Bonnet et al., PNAS, 2017), water flows across the most active volcanic area of the world ocean (the low bathymetry area in Figure 1) and becomes enriched in iron, as reported by several authors.

Referee #2 indicates that this does not preclude periodically or seasonally low levels of Fe in surface waters of the Melanesian Archipelago, and Referee #2 is right. Nevertheless, if we consider iron as a nutrient-type trace element that undergoes seasonal variations, the lowest surface concentrations should be during summer stratification (especially if the source of iron is from below). The OUTPACE measurements are from the summer, and we still measured high Fe concentrations. Therefore, even if we have no evidence that Fe is at a high, steady-state value in this biogeochemical province, we can reasonably hypothesize that high concentrations are expected all year long. Because data will always be better than a long explanation, we contacted Martine Rodier (cited in the ms). To the best of our knowledge, she is the only person who has measured seasonal iron data in the WTSP. She kindly agreed to send us these data to answer Referee #2's comment. Surface (0-60 m) average iron concentrations measured during the DIAPALIS cruises (http://www.obs-vlfr.fr/proof/vt/op/ec/diapazon/dia.htm) in the open ocean east of New Caledonia using the method detailed in Blain et al. (2007) were [May 2002 : 1.00 ± 0.35 nM (n=10) ; Feb. 2003 : 1.57 ± 0.63 nM (n=6) ; June 2003 : 1.75 ± 0.53 nM (n=6) ; Oct. 2003 : 1.65 ± 0.86 nM (n=5)], indicating higher concentrations than in the gyre and no clear seasonal variations. During the same period, DIP turnover times varied from months to several hours (Van den Broeck et al., 2004; Moutin et al., 2005: references in the ms).

The last part concerns the lifetime of iron in seawater. How can iron concentrations be considerably above the iron hydroxide solubility in seawater considered to be < 0.1 nM (Liu and Millero, 2002)? Even if we had no direct measurements during OUTPACE, it is now accepted that organic ligands, some of them probably also originating from hydrothermal sources, allow higher solubility (and also longer lifetime) of iron than initially expected. All this will be discussed in the Guieu et al. paper, but please note that Fitzimmons et al. (2014) already explained that "dFe must have been transported thousands of kilometers away from its vent site to reach our sampling station", a reference that will be added in the revised version.

The DFe concentrations reported by Moisander et al. (2011), while lower than the average concentrations reported for the photic zone by Guieu et al. (in revision), were at least twice higher than the ~0.1 nmol L-1 measured in the upper 350 m water column of the SP gyre (Blain et al., 2008). Thus, these data still indicate higher concentrations closer to the MA. Furthermore, phosphate concentration (SRP), except at their station 17, was largely above our measurements and specific conditions, different from those observed during the OUTPACE cruise, may have been observed. Again, a detailed, seasonal survey would be of great interest in this region, which is one of the perspectives suggested in the present paper.

Fitzsimmons, J.N., Boyle, E.A., and Jenkins, W.J.: Distal transport of dissolved hydrothermal iron in the deep South Pacific Ocean. Proc Natl Acad Sci U S A. 2014 Nov 25;111(47):16654-61. doi: 10.1073/pnas.1418778111, 2014.
Liu, X., and Millero, F.J.: The solubility of iron in seawater. Mar. Chem. 77, 43-54, 2002.

Sources of fixed nitrogen. Currently the authors use profiles of nitrate concentrations measured during their cruise and climatology of MLD to estimate nitrate entrainment during deeper wintertime mixing. From this they conclude that nitrate input to the surface mixed layer by this process is minimal. Indeed, looking at the depth profiles of nitrate (nitracline _70m depth) and MLD climatology (maximum mixed layer of _75m) this would appear to be sound. However, in using climatological average mixed layer depths, the authors do not consider periodic entrainment of much deeper waters with much higher nitrate concentrations by transient storms (see, for example, general cyclone passages at: https://en.wikipedia.org/wiki/Tropical_cyclogenesis#/media/File:Global_tropical_cyclone_tracksedit2.jpg). What is the role of periodic nitrate entrainment by these deep mixing events that are not characterised by average MLD climatology? It is worth noting that such storms would also entrain DIC into the mixed layer, as well as nitrate, and the net effect on carbon budgets might be low.

Referee #2 asked about the effect of cyclones on nitrate entrainment. We thank Referee #2 for this comment, and the paper by Law et al. (2011) in the North Tasman Sea shows precisely the effect of such a cyclone. There was in fact no nitrate entrainment but a phosphate entrainment due to explicit differences in nitracline and phosphacline depths, and this allowed nitrogen fixation to be enhanced in a process close to the one we describe in our ms, but for physical forcing acting at a much finer horizontal spatial scale than the winter vertical mixing. Yes, a cyclone may entrain nitrate from below or enhance nitrogen fixation through introduction of phosphate, and therefore enhance the biological soft tissue pump. Incidentally, during OUTPACE, there was a strong wind forcing event within the study region. Cyclone Pam entered the Southwest Pacific in early March, and a drop in SST and increase in Chl followed in its wake (see figures provided by the response to Referees for another article in this special issue, de Verneil et al., 2017, page 8: https://www.biogeosciences-discuss.net/bg-2017-84/bg-2017-84-AC2-supplement.pdf). The storm did indeed have a fertilizing effect but at relatively short spatial (around Vanuatu islands) and time (around 2 weeks) scales, compared to the larger-scale processes highlighted in the present study. In any case, this additional effect and the paper by Law et al. (2011) will be added in the revised version of the ms, mainly to explain that while episodic storms such as Cyclone Pam can induce deep mixing, which in turn brings phosphate (but no nitrate, i.e. excess P) to the surface and enhances nitrogen fixation, this mechanism may concern limited spatial and temporal scales compared to winter mixing.

Law, C. S., Woodward, E. M. S., Ellwood, M. J., Marriner, A., Bury, S. J., and Safi, K. A.: Response of surface nutrient inventories and nitrogen fixation to a tropical cyclone in the southwest Pacific. Limnology and Oceanography 56, 1372–1385, 2011.

What is the mesoscale eddy activity in this region? These have been shown to supply significant N to other oligotrophic waters. Could eddies be supplying additional nitrate? See, for example, Falkowski et al. 1991; Oschlies and Garcon, 1998.

According to de Verneil et al. (this issue; see again the supplemental .pdf referred to above, pgs. 4-5), mesoscale vertical fluxes due to quasi-geostrophic forcing calculated from satellite data were weak and would act on a layer displaced from the relevant nutrient reservoirs. The mesoscale activity was considered outside the scope of this large-scale study, and is studied in other papers in this special issue, such as Rousselet et al., (in revision). The idea was not to ignore mesoscale activity but rather to demonstrate that interesting results can be obtained from considering larger spatial and temporal scales.

Additional sediment trap sample details. Some details with regards to the type of material found in the sediment traps could be valuable to support the 'mechanistic' discussion with respect to nitrogen fixation-fuelled carbon export. Were significant Trichodesmium colonies found in the sediment traps? Or diazotrophic diatoms? Or zoo-plankton? Partly related to this, are there any details about phytoplankton community structure determined from HPLC pigment analyses, flow cytometry, or microscopy? I appreciate that all these details could be in another article in the special issue, but I cannot see it mentioned. More generally the manuscript should be very clear/explicit as to what the new data in this manuscript are, and what is has been published/is in review elsewhere. XX

As requested by Referee #2, we have added sediment trap sample details in the new version of the ms. The protocol has been rewritten, as follows:

Settling particulate matter mass and C, N, and P flux measurements

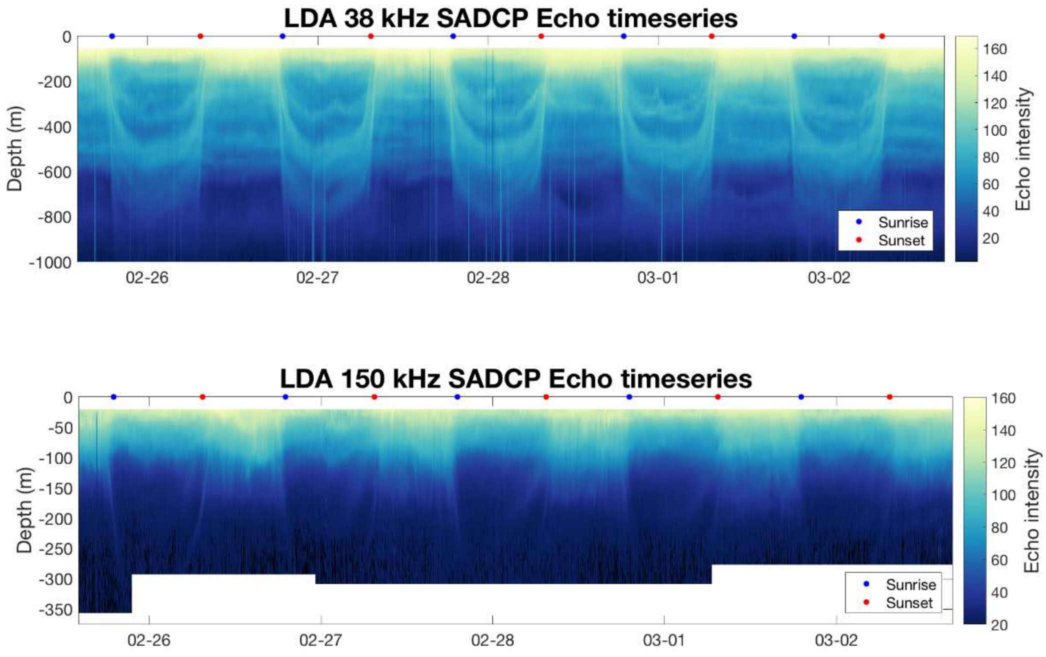
The settling of particles in the water column outside of the upper layer was measured using 2 PPS5 sediment traps (1 m^2 surface collection, Technicap, France) deployed for 4 days at 150 and 330 m at LD A (MA) and LD C (WGY) stations (Fig. 1). The PPS5 traps are covered with baffled lids (mesh 1cm^2) to reduce current shear at the mouth of the trap, but also to prevent large zooplankton and fish from entering the traps. Particle export was recovered in polyethylene flasks screwed on a rotary disk which automatically changed the flask every 24-h to obtain daily material recovery. The flasks were previously filled with a 2% (v/v) buffered solution of formaldehyde (final pH≈8) prepared with in situ deep seawater. A sample of this water is kept to measure dissolved nutrients (phosphate and silicate). Immediately after trap retrieval, samples were stored at 4 °C in the dark until they were processed. Back in the laboratory, one part of the sample's supernatant was kept and stored at 4°C to measure dissolved nutrients (phosphate and silicate), and pH was checked on every trap sample. Swimmers (all organisms deemed to have actively entered the trap) were identified under a stereomicroscope and carefully removed with plastic fine-tipped forceps and placed into small vials with some of the reserved trap preservative. The main species removed were copepods, crustaceans (ostracods, euphausiids, amphipods) and pteropods. Microphotographs of each sample were taken. After the swimmers were removed, the whole sample was then rinsed 3 times with ultrapure (MilliQ) water in order to remove the salt and then freeze-dried. Mass particle fluxes were obtained by weighing the freeze-dried sample 5 times. The accuracy of the weighing (and thus of the flux) was 1 % over the whole data series. In this study, swimmers were rinsed and freeze-dried and their dry weight was also determined. Settling particulate matter and swimmers were analyzed separately on an Elemental Analyzer coupled to an Isotope Ratio Mass Spectrometer EA-IRMS (Integra2, Sercon Ltd) to quantify total C and N. Total P was analyzed as described in Sect. 2.2. The total element measurements for the settling particulate matter were considered to represent the settling particulate organic C, N, P. The results are presented Sect. 2.2 (Table 4).

Papers specifically dealing with trap material and nitrogen budgets are cited (Caffin et al., this issue, Knapp et al., this issue) to confirm the preponderant role of nitrogen fixation in the MA. Zooplankton (swimmers) C, N, P contents in the traps were already presented in the ms but not the species, although this information is available on our website upon request. The title of the special issue is: "Interactions between planktonic organisms and biogeochemical cycles across trophic and N_2 fixation gradients in the western tropical South Pacific Ocean: a multidisciplinary approach (OUTPACE experiment)", and therefore most of the papers deal with biology and biogeochemical cycles. The aim of this paper was to focus on large scale and biogeochemical budgets only. Our attempt to demonstrate the influence of zooplankton migration as a mechanism within our biogeochemical budgets had its own limitations (in addition to Referee #2’s comments, see Referee #1). As a result, our subsequent decision has been to focus on the main, biogeochemical budget message and to shorten the Discussion.

The objective of the OUTPACE special issue is to provide an original opportunity for a group of researchers to focus on the “Interactions between planktonic organisms and biogeochemical cycles across trophic and N_2 fixation gradients in the western tropical South Pacific Ocean”. The results will be published in a single book at the end. It is a multidisciplinary approach with a tight time schedule, and the major objective is to share data between project collaborators to give the better analysis of the dense datasets. Data may be used several times in different papers of the special issue focusing on different scientific questions. In this case, the method is described in full detail only in one paper that is clearly referenced as the prevalent one for the method. In our paper, we focus on the C, N, P inventories and fluxes in the upper 0-200 m layer, but as an example the N_2 fixation rates were also presented in a more specific paper presenting the methodology in detail.

More specific comments

ADCP data. These data are mentioned with regards to the zooplankton migration, with implications for sub-mixed layer carbon export. Can we see plots of the data?



Raw SADCP Echo time series data at LDA station 38 KHz (above) and 150 KHz (below) showing diel vertical migrations of zooplankton-micronecton during the 5 days of the station occupation.

Please note that the diel vertical migration of zooplankton-micronecton will now be detailed in another paper by Menkes et al. (in prep) who have already worked and published data on this subject (Smeti et al., 2014), a reference that we will add in our Discussion.

Smeti H., Pagano M., Menkès C., Lebourges Dhaussy A., Hunt B. P. V., Allain V., Rodier M., de Boissieu F., Kestenare E., Sammari C.: Spatial and temporal variability of zooplankton off New Caledonia (Southwestern Pacific) from acoustics and net measurements. J. of Geophys. Res. Oceans, 120 (4), 2676-2700. ISSN 2169-9275, 2015.

How were the reported zooplankton respiratory carbon losses to the sub-mixed layer calculated?

We used the quota of primary production (PP) proposed by Pagano and Ikeda (cited reference) to estimate carbon losses by respiration considering that all daily PP was grazed by zooplankton. In any case, note that this part has been removed following the remarks by Referee #1.

DOP and alkaline phosphatase activity. Figure 5 shows significant phosphate available as DOP, even in DIP-depleted Melanesian Archipelago waters. Could the P demand of nitrogen fixers be sustained by DOP access?

Yes, in theory, but it is still not clear if it is a direct uptake of DOP molecules or rather a DOP to DIP transformation outside of the cells (ecto-enzyme activity) followed by DIP assimilation. In any case, the turnover times of DIP are really short in the MA, suggesting both rapid recycling and really low DIP concentrations. One of the interesting results we provided is a seasonal increase in DOP, suggesting a relatively low utilization of the major part at this time scale.

Was alkaline phosphatase activity measured? Recent findings show that Fe/Zn is required for some dominant forms of alkaline phosphatase and so Fe/Zn availability could also control P access, in addition to N access via nitrogen fixation (Mahaffey et al., 2014; Browning et al., 2017i; Landolfi et al., 2015).

Yes, alkaline phosphatase activity was measured by F. Van Wambeke. Data show higher Vmax in the MA compared to the GY. Referee #2 indicates an interesting point concerning Fe/Zn availability and a possible control of alkaline phosphatase activity. Unfortunately, we do not have Zn measurements at the present time.

Relative influence of iron and nitrogen in the WGY region. Biologically accessible nitrogen is inferred to be the limiting resource to the overall phytoplankton community in the WGY (western gyre region) (with Fe being the limiting nutrient for diazotrophs). What is the evidence that nitrogen and iron are not directly co-liming to the overall phytoplankton community in this region (Saito et al., 2014; Browning et al., 2017) both studies through the edge of gyre boundaries)? In the study of Moisander et al. (2011), which was in proximity to the OUTPACE cruise region, a bottle enrichment experiment displayed Fe was serially limiting (following nitrogen) to the overall phytoplankton community, supporting this possibility.
Co-limitation. Co-limitation is not mentioned once in the manuscript but it seems central to the discussion. For instance, iron and phosphorus could co-limit nitrogen fixation (Mills et al., 2004), but iron could also co-limit phosphorus acquisition by the microbial community from the DOP pool, and iron and nitrogen could co-limit the overall phytoplankton community. These interactions and potential for feedbacks are pertinent when hypothesising a role of 'ultimate' limiting nutrients and potential for future change (both topics of this manuscript). To quote Moore et al. (2013; referenced in the manuscript): "Establishing the identity of a single ultimate limiting nutrient may thus be less relevant than understanding the controls on, and feedbacks pertaining to, any given process".
Personally I would avoid conclusions/discussion that heavily refer to 'ultimate' limiting nutrients (e.g. Moore et al., 2013; Tyrrell, 1999) as this is more relevant to larger spatial-temporal scales than this dataset can be used for.

It is a very important point that needs to be discussed because as Referee #2 said, it is central to our discussion and even part of the title.
The introduction of Moutin et al. (2005) was as follows: "In a nitrogen- limited ocean, the input of ‘new’ nitrogen (i.e. not related to organic matter recycling) into the photic zone controls primary production (Codispoti, 1989). Nitrogen fixation in the ocean is a source of ‘new’ nitrogen. Thus, a fundamental question arises as to: ‘What factors control nitrogen fixation in the ocean?’ What are the factors that control N2 fixation over annual or longer time-scales (Falkowski 1997, Tyrell 1999, Letelier & Karl 1998, Tyrell 1999) and are these distinct from ‘physiological’ factors that may temporarily control the process of nitrogen fixation? Light, temperature (Carpenter et al. 2004) and nutrient availability, particularly that of phosphate (Sañudo-Wilhelmy et al. 2001, Mulholland et al. 2002, Fu & Bell 2003) and iron (Behrenfeld & Kobler 1999, Kustka 2002), could physiologically control the kinetics of nitrogen fixation. These factors could be different from the ‘systemic’ factor (Paasche & Erga 1988) that controls the cumulative biomass over time within a particular oceanic area, and ultimately, when considering all the oceanic provinces, the amount of nitrogen introduced via di-nitrogen fixation in the world’s oceans.
Physiological factors can be investigated using short-term experiments such as selective enrichment experiments showing that there may be co-limitation of diazotrophs by both iron and dissolved inorganic phosphate (DIP) in certain situations (Mills et al. 2004). However, such short-term limitation may not control accumulation of diazotroph biomass over time. For example, if the ‘systemic’ limiting factor is DIP availability in a particular area, a more or less high iron availability will only drive the system to a more or less rapid consumption of DIP. The cumulative biomass of Trichodesmium spp., which depends essentially on the DIP consumption, will not be affected in the long term by iron availability. Considering the cumulative biomass as the end product of the nitrogen fixation process, ‘physiological’ factors act as catalytic factors only. Thus, knowing the systemic controlling factor is of prime necessity and can only be assessed using annual or longer- term studies on nutrient availability and uptake kinetics parameters of the species studied."

Yes, nitrogen is the first limiting nutrient, rapidly followed by others in the WTSP using short term experiments (Van Wambeke et al., this issue), but 5-10 days were necessary to obtain an increase in PP, chl a and export production after a DIP enrichment in a minicosm experiment, suggesting that classical methods (short-term microcosm experiments) used to quantify nutrient limitations of PP may not be relevant (Gimenez et al., 2016), at least in the WTSP.

As high nutrient concentrations in High Nutrient Low Chlorophyll (HNLC) areas (Minas et al. 1986) may be considered as the result of an inefficient biological carbon pump (Sarmiento and Grüber, 2006), high or relatively high phosphate concentrations (and high DIP turnover time) in the south Pacific gyre (Moutin et al., 2008; Moutin et al., this issue) may be the result of inefficient N_2 fixation. Conversely, the low P availability (low concentration and DIP turnover time) in the upper surface of the WTSP is the result of intense N_2 fixation.

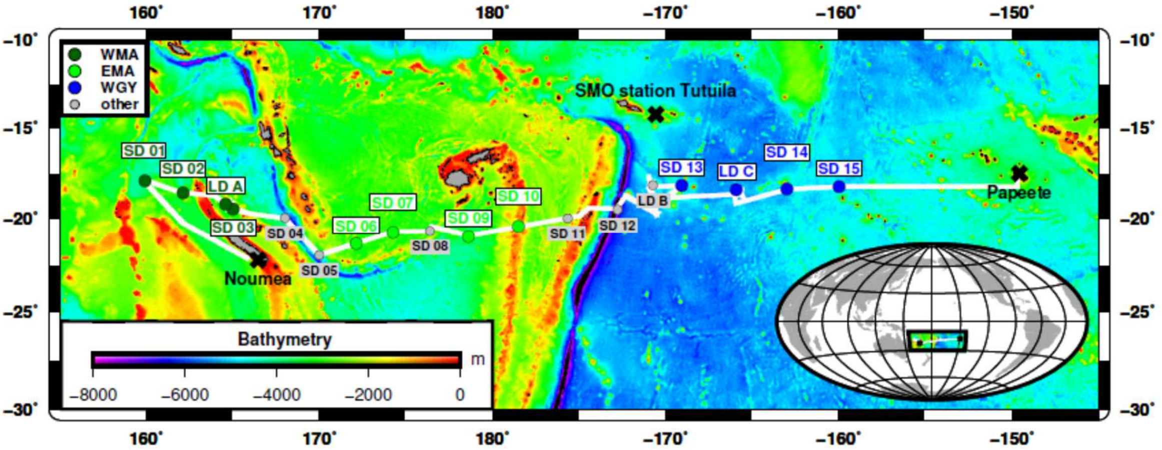
Because iron concentrations are really low in the gyre and high in the MA (even during the strongest stratified period), and because of the specific iron needs of diazotrophs, iron availability is the best candidate for preventing nitrogen fixation in the gyre and allowing nitrogen fixation in the MA. Therefore, DFe may appear as the ultimate (systemic) nutrient control in the gyre and DIP may appear as the ultimate (systemic) nutrient control in the MA.

We hope we have managed to convince Referee #2 that we cannot avoid mentioning the term 'ultimate' in our large-scale study, and also that we cannot enter into a debate about co-limitation without specific data. We are only interested in the large scale nutrient limitation.

Gimenez, A., Baklouti, M., Bonnet, S., and Moutin, T.: Biogeochemical fluxes and fate of diazotroph-derived nitrogen in the food web after a phosphate enrichment: modeling of the VAHINE mesocosms experiment, Biogeosciences, 13, 5103-5120, https://doi.org/10.5194/bg-13-5103-2016, 2016.
Minas, H.J., Minas, M., and Packard, T.T.: Productivity in upwelling areas deduced from hydrographic and chemical fields. Limnol. Oceanogr., 31(6), 1182-1206, 1986.
Moutin, T., Van Den Broeck, N., Beker, B., Dupouy, C., Rimmelin, P., and LeBouteiller, A.: Phosphate availability controls Trichodesmium spp. biomass in the SW Pacific Ocean, Mar. Ecol. Prog. Ser., 297, 15-21, 2005.
Moutin, T., Karl, D. M., Duhamel, S., Rimmelin, P., Raimbault, P., Van Mooy, B. A. S., and Claustre, H.: Phosphate availability and the ultimate control of new nitrogen input by nitrogen fixation in the tropical Pacific Ocean, Biogeosciences, 5, 95-109, 2008.
Sarmiento, J. L., and Gruber, N.: Ocean Biogeochemical Dynamics, Princeton University Press, Princeton. 503 pp, 2006.

Figures. Figures are generally clear but some details to captions need to be added.
For example, check that all vertical/horizontal lines in Figs 3–6 are defined in the figure caption (even if defined in the text). Figure 1 (map) is good for detail but not very good for placing the cruise in its wider geographic position. Could an inset map or similar with continents for geographic context be included in addition to the current map? See Bonnet et al. (in review in this special issue Fig 1).

We thank Referee #2 for describing our figures as mostly clear. We have added the text corresponding to all vertical/horizontal lines in Figs 3–6 in the figure captions. We also add an inset map in Fig. 1: see below.



All comments indicated below have been taken into account in the revised version of the ms, unless a specific response is included within the Referee's comments. We thank Referee #2 for his/her careful reading of the ms.

Tables. Currently commas rather than decimal points are used in tables. This could be confusing for some readers. Please change.
Spelling/sentence structure/grammar: see first main point, below are some examples:
Pg 2 Line 3: 'deep Sea' ! 'deep sea'
Pg 5 Line 41: allowing to draw first-order winter to summer seasonal variations ! 'allowing us to draw first-order winter to summer seasonal variations'
Pg 6 Line 10: 'and 2, 3, and 3' ! 'and 2, 3, and 4'?

No, it is 'and 2, 3, and 3'

Pg 8 line 23: 'Rapidly, seawater was collected in triplicates from the Niskin bottles in 2.3 L polycarbonates bottles at 6 depths (75 %, 54 %, 19 %, 10 %, 1 %, and 0.1 % surface irradiance levels), like for PP measurements' ! 'As for PP measurements, seawater was rapidly collected in triplicate from the Niskin bottles in 2.3 L polycarbonates bottles at 6 depths (75 %, 54 %, 19 %, 10 %, 1 %, and 0.1 % surface irradiance levels).'
Pg 11, line 12: 'Otherwise, very low and improbable P contents were found in the swimmers' ! Please be more specific with regards to 'very low' and 'improbable'

We have added (see the previous column in Table 4) to the end of the sentence in order to be clearer. Please keep in mind that loss of P is known from living organisms after poisoning (Talarmin et al., 2011)

Talarmin, A., F. Van Wambeke, S. Duhamel, P. Catala, T. Moutin, and P. Lebaron. 2011. Improved methodology to measure taxon-specific phosphate uptake in live and unfiltered samples. Limnol. Oceanogr. Methods 9:443-453 (2011) | DOI: 10.4319/lom.2011.9.443.

Pg. 11 line 37: 'large precipitation' ! do you mean rainfall?
Pg 12 line 41: 'Else we need. . .' ! 'Otherwise we need..'
Pg 18 Line 17: 'from an iron limitation in the east' ! 'from probable iron limitation in the east'; currently no iron data is given to rule out other potential controls.
Pg. 18 Line 28: 'Furthermore, both diazotrophy and denitrification are known to undergo drastic alterations due to climate change.' ! References needed to back up this statement?

We have replaced 'known' by 'expected' and added 2 recent references (including other references), as requested:
McMahon, K. W., McCarthy, M. D., Sherwood, O. A., Larsen, T., and Guilderson, T. P.: Millennial-scale plankton regime shifts in the subtropical North Pacific Ocean, Science, 350, 1530-1533, 2015.
Lachkar, Z., Lévy, M., and Smith, S.: Intensification and deepening of the Arabian Sea oxygen minimum zone in response to increase in Indian monsoon wind intensity, Biogeosciences, 15, 159-186, https://doi.org/10.5194/bg-15-159-2018, 2018.

References

Browning, T.J., Achterberg, E.P., Yong, J.C., Rapp, I., Utermann, C., Engel, A. and Moore, C.M., 2017i. Iron limitation of microbial phosphorus acquisition in the tropical North Atlantic. Nature Communications, 8.
Browning, T.J., Achterberg, E.P., Rapp, I., Engel, A., Bertrand, E.M., Tagliabue, A. and Moore, C.M., 2017ii. Nutrient co-limitation at the boundary of an oceanic gyre. Nature, 551(7679), p.242.
Falkowski, P.G., Ziemann, D., Kolber, Z. and Bienfang, P.K., 1991. Role of eddy pumping in enhancing primary production in the ocean. Nature, 352(6330), p.55.
Landolfi, A., Koeve,W., Dietze, H., Kähler, P. and Oschlies, A., 2015. A new perspective on environmental controls of marine nitrogen fixation. Geophysical Research Letters, 42(11), pp.4482-4489.
Mahaffey, C., Reynolds, S., Davis, C.E. and Lohan, M.C., 2014. Alkaline phosphatase activity in the subtropical ocean: insights from nutrient, dust and trace metal addition experiments. Frontiers in Marine Science, 1, p.73.
Mills, M.M., Ridame, C., Davey, M., La Roche, J. and Geider, R.J., 2004. Iron and phosphorus co-limit nitrogen fixation in the eastern tropical North Atlantic. Nature, 429(6989), pp.292-294.
Moisander, P.H., Zhang, R., Boyle, E.A., Hewson, I., Montoya, J.P. and Zehr, J.P., 2012. Analogous nutrient limitations in unicellular diazotrophs and Prochlorococcus in the South Pacific Ocean. The ISME journal, 6(4), pp.733-744.

Moore, C.M., Mills, M.M., Achterberg, E.P., Geider, R.J., LaRoche, J., Lucas, M.I., McDonagh, E.L., Pan, X., Poulton, A.J., Rijkenberg, M.J. and Suggett, D.J., 2009. Large-scale distribution of Atlantic nitrogen fixation controlled by iron availability. Nature Geoscience, 2(12), pp.867-871.
Moore, J.K. and Doney, S.C., 2007. Iron availability limits the ocean nitrogen inventory stabilizing feedbacks between marine denitrification and nitrogen fixation. Global Biogeochemical Cycles, 21(2).
Saito, M.A., McIlvin, M.R., Moran, D.M., Goepfert, T.J., DiTullio, G.R., Post, A.F. and Lamborg, C.H., 2014. Multiple nutrient stresses at intersecting Pacific Ocean biomes detected by protein biomarkers. Science, 345(6201), pp.1173-1177.
Oschlies, A. and Garcon, V., 1998. Eddy-induced enhancement of primary production in a model of the North Atlantic Ocean. Nature, 394(6690), pp.266-269.

Anonymous Referee #3

Moutin et al.'s study investigates the regulation of the ocean C, N and P fluxes in the western tropical South Pacific Ocean, a key oligotrophic oceanic region for nitrogen fixation. They combine a large new dataset collected during the OUTPACE campaign (February-April 2015) with climatologies of upper water properties. The OUTPACE cruise followed a 4000 km longitudinal transect going from the Melanesian Archipelago (MA) to Papeete (French Polynesia). Comparing seasonal trends of C, N, and P mass balances for 3 main areas of the WTSP, they find that (1) the MA is a net sink of atmospheric CO2, mainly caused by the soft-tissue biological pump; (2) the MA biological pump results from both high rate of N2 fixation fuelling export production and mesozooplankton diel vertical migration; and (3) MA N2 fixation is essentially controlled by phosphate availability.

I think the tackled questions and presented results of this study are really interesting and important and deserve publication. There are lots of uncertainties on the role of nitrogen fixers in fuelling ocean production and export in oligotrophic area especially of the Pacific Ocean due to lack of observations. This region is particular important as covering a large area and presenting high rates of N2 fixation. I thus strongly recommend this work for publication. I have however the following main comments that need to be taken into consideration.

We thank Referee #3 for remarking on the new large dataset obtained and his conclusion that the tackled questions and presented results are interesting, important and deserve publication. We really appreciate the detailed expression of our main conclusions, showing that the diel vertical migrations of zooplankton are only a part of one of the three main conclusions.
In the following paragraphs, the original review comments from Referee #3 are in bold and our responses are interspersed in normal characters.

Main comments

Paper presentation - At the moment the results and the argument for the role of nitrogen fixation and mesozooplankton vertical migration for the atmospheric CO2 sink of the Melanesian Archipelago region are a bit convoluted. While it is nice to follow the steps of thought of the authors on how they come about to find these links, this is done a step too far: for instance, the second half of section 4.3 more or less repeats what is said in section 4.2. I recommend the authors to reorganise the results and discussion to be a lot more concise. This will help following the argument and strengthening the case of the paper.

Following all the comments from the other Referees regarding zooplankton vertical migrations (which, as previously mentioned, was not the primary focus of this paper), and also the recommendation by Referee #3 regarding repetition in the Discussion, we have considerably shortened this part, deleting all sentences in the Abstract and Conclusion concerning this topic, and limiting the Discussion to what we consider to be our main focus. The diel vertical migrations of zooplankton-micronecton during OUTPACE will be the focus of a new paper by C. Menkes and collaborators in the near future. With these changes, we hope to focus the reader's attention on what we consider to be the main message in this paper, the biogeochemical budgets.

To help make a stronger case for the paper, I wonder also if it would be possible to add a diagram that visualises the main processes occurring in the region (N2 fixation, vertical migration of zooplankton, CO2 uptake . . .).

We agree with Referee #3, but the diagram below has already been published in the OUTPACE preface paper (Moutin et al., 2017: https://www.biogeosciences.net/14/3207/2017/). Therefore, we proposed to add (see Moutin et al., 2017; their figure 1) after: The "soft tissue" pump in the new version of the ms. Please note that the vertical migrations of zooplankton were not specifically shown.

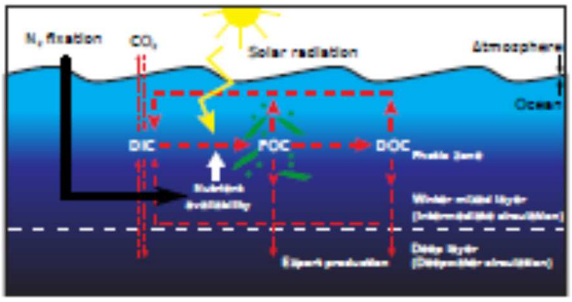


Figure 1. Major C fluxes for a biological pump budget and the main role of N_2 fixation. Biological pump is the C transfer into the ocean interior by biological processes. DIC is dissolved inorganic C, POC is particulate organic C, and DOC is dissolved inorganic C. See Moutin et al. (2012) for a detailed description.

Moutin, T., Doglioli, A. M., de Verneil, A., and Bonnet, S.: Preface: The Oligotrophy to the UlTra-oligotrophy PACific Experiment (OUTPACE cruise, 18 February to 3 April 2015), Biogeosciences, 14, 3207-3220, https://doi.org/10.5194/bg-14-3207-2017, 2017.

Effect of zooplankton vertical migration - The current manuscript presents the vertical migration of mesozooplankton as an explanation for the missing sink in the upper C budget at WMA. It would be nice to quantify this process either based on other technique or by simply doing a mass balance (which the authors are shying away). MA net sink of atmospheric CO2 - It would be good to quantify the net sink in pCO2 and compare it with other estimates and with other regions.

We now only suggest, in a section of the Discussion and among 2 other hypotheses, a probable role of diel vertical migrations of zooplankton in the transfer of carbon.

Minor comments

P2, L3: Confusing sentence. In my mind mineral refers to carbonate and silicate which is at odd in association with the soft-tissue pump which refers to organic carbon.

We have replaced 'mineral' by 'dissolved inorganic', to avoid confusion.

P3, L35: Can you give slightly more information of the climatology of de Boyer- Montegut et al. (2004)? Mainly the type of collected data and coverage.

The 2° resolution global climatology of the mixed layer depth (MLD) of de Boyer Montegut et al (2004) is constructed from nearly 5 million individual temperature profiles from the following databases: NODC WOD09 from 1941 to 2008, WOCE 3.0 from 1990 to 2002 and ARGO PFL from 1995 to sept. 2008. Profiles with any spurious data in the mixed layer have been removed (about 8% of the total profiles). For each selected profile, a MLD was estimated following the chosen criterion. In our study the MLD_DT02 data were used where the MLD is defined as the depth where the temperatures on the profiles differed from a fixed threshold of 0.2°C compared to the temperature at 10m. The MLD defined on individual profiles were gathered into monthly boxes of 2° latitude by 2° longitude.

For our study, pixels corresponding to each station of the different groups were extracted from the global climatology. Even if the number of existing profiles in the South Pacific Ocean is low, the MLD in the selected pixels were estimated from at least 5 and up to 80 profiles, depending on the pixel and month.

P6, L39: Say in the Figure 2 caption, what the red lines refer to.

We have added: "The vertical red lines indicate the period of the OUTPACE cruise:18 Feb. to 3 Apr. 2015." in the new version of the ms.

P9, L27: Need to specify that shallow nitracline indicates oligotrophic waters.

We have added: "with shallower nitracline depths » at the end of the sentence.

P12, L35: Can you add the sum of the MA regions so that we can see that the MA area is a net sink of atmospheric CO2?

We have rewritten this and added the mean atmospheric CO_2 input for the MA.

P12, L40: Little bit misleading as the Table 6 and main text do not use the same unit. Can you add in the text the numbers in mol m-2 d-1 as well?

We have modified the ms to use the same unit.

P18, L40: Can you stipulate here if the source of P changes with climate change, how this might affect N2 fixation, zooplankton migration and CO2 sink?

We did not think that the sources of P would change with climate change, but more precisely that the main expected alteration following climate change would strengthen the P limitation. This was developed in Moutin et al., (2008). In other words, the P-limited areas such as the MA, the Sargasso Sea or the Mediterranean Sea, might be extended.

Moutin, T., Karl, D. M., Duhamel, S., Rimmelin, P., Raimbault, P., Van Mooy, B. A. S., and Claustre, H.: Phosphate availability and the ultimate control of new nitrogen input by nitrogen fixation in the tropical Pacific Ocean, Biogeosciences, 5, 95-109, 2008.

Nutrient availability and the ultimate control of the biological carbon pump in the Western Tropical South Pacific Ocean

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Abstract

Surface waters (0-200 m) of the western tropical South Pacific (WTSP) were sampled along a longitudinal 4000 km transect (OUTPACE cruise, 18 Feb., 3 Apr. 2015) during the stratified period between the Melanesian Archipelago (MA) and the western part of the SP gyre (WGY). Two distinct areas were considered for the MA, the western MA (WMA) and the eastern MA (EMA). The main carbon (C), nitrogen (N), phosphorus (P) pools and fluxes ~~allow for~~ provide a basis for the characterization of the expected trend from oligotrophy to ultra-oligotrophy, and ~~to~~ the building of first-order budgets at the daily and seasonal scales (using climatology). Sea surface chlorophyll a reflected well the expected oligotrophic gradient with higher values obtained at WMA, lower values at WGY and intermediate values at EMA. As expected, the euphotic zone depth, the deep chlorophyll maximum and nitracline depth deepen from west to east. Nevertheless, phosphaclines and nitraclines did not match. The decoupling between phosphacline and nitracline depths in the MA allows excess P to be locally provided in the upper water by winter mixing. We found a significant biological "soft tissue" carbon pump in the MA sustained almost exclusively by N_2 fixation and essentially controlled by phosphate availability in this iron-replete environment. The MA appears to be a net sink for atmospheric CO_2 while the WGY is in quasi-steady state. We suggest that the necessary excess P, allowing the success of nitrogen fixers and subsequent carbon production and export, is mainly brought to the upper surface by local deep winter convection at an annual scale rather than by surface circulation. ~~We also suggest that mesozooplankton diel vertical migration plays a dominant role in the transfer of carbon from the upper surface to deeper water in the MA.~~ While the origin of the decoupling between phosphacline and nitracline remains uncertain, the direct link between local P upper waters enrichment, N_2 fixation, organic carbon production and export, offers a possible shorter time scale than previously thought between N input by N_2 fixation and carbon export. The low iron availability in the SP gyre and P availability in the MA during the stratified period may appear as the ultimate control of N input by N_2 fixation. Because of the huge volume of water to consider, and because the SP Ocean is the place of intense denitrification in the east (N sink) and N_2 fixation in the west (N source), precise seasonal C, N, P, Fe budgets would be of prime interest to understand the efficiency, at the present time, and in the future, of the oceanic biological carbon pump.

1 Introduction

The oceanic biological carbon pump corresponds to the transfer of carbon from the upper surface to the ocean interior by biological processes, greatly influencing atmospheric CO_2 concentration and therefore the earth's climate. It is a highly ranked priority ~~of contemporaneous~~ in current research in oceanography (Burd et al., 2016). Two biological pumps have been defined (Volk and Hoffert, 1985), the "soft tissue" and "carbonate" pumps associated with organic matter or calcium carbonate processes (e.g. production, export, remineralization or dissolution). The "soft tissue" pump (see Moutin et al., 2017; their figure 1), considering both its intensity and shorter time scales, is by far the larger contributor to the ~~mineral~~ dissolved ~~–~~inoganic carbon gradient between the upper surface and the deep ~~Sea~~sea. Following climate alteration, the biological "soft tissue" pump begins to deviate from its equilibrium condition, meaning that its influence on atmospheric CO_2 change may occur at time scales shorter than previously thought (Sarmiento and Grüber, 2006). Because the strength of the biological carbon pump depends on nutrient availability in the upper ocean, and more particularly on nitrogen availability (Falkowski et al., 1998, Tyrell, 1999, Moore et al., 2013), which is at long term regulated by external input by dinitrogen (N_2) fixation and internal denitrification (Grüber and Sarmiento, 1997; Codispoti et al., 2001; Deutsch et al., 2001; Brandes and Devol, 2002; Grüber, 2004; Mahaffey et al., 2005; Deutsch et al., 2007; Codispoti et al., 2007; Capone and Knapp, 2007; Moutin et al., 2008; Deutsch and Weber, 2012; Landolfi et al., 2013, Jickells et al., 2017), quantitative evaluation of the regulation, interdependence~~,~~ and ~~evolution~~ patterns of change of these two processes require~~s~~ ~~intense (?)~~ attention at the present time. It has been suggested earlier that N_2 fixation may play a large part in changing atmospheric CO_2 inventories (McElroy et al., 1983), but at long time scales and ~~considering~~ taking into account ~~large~~ major differences in Aeolian iron input (Falkowski, 1997, Broecker and Henderson, 1998). Because N_2 fixation may ultimately be controlled by iron availability, and because dust delivery to the ocean is climate sensitive, there may be inextricably linked feedback mechanisms that regulate N_2 fixation, atmospheric CO_2 concentrations~~,~~ and dust deposition over relatively long periods (Michaels et al., 2001; Karl, 2014). Although fundamental, the time scales by which N sources and sinks are coupled in the ocean remain uncertain (Falkowski et al., 1998; Brandes and Devol, 2002; Straub et al., 2013). Excess P emerges as a master variable to link them in the modern ocean (Deutsch et al., 2007), as well as from a paleobiogeochemical point of view (Straub et al., 2013). ~~T~~It has been suggested that the recent (since the beginning of the industrial era) increase in production by N_2-fixing cyanobacteria ~~was suggested to provide~~may have provided a negative feedback response to rising atmospheric carbon dioxide concentrations (McMahon et al., 2015), although an inverse trend was also proposed (Kim et al., 2017). While the observed changes in N_2 fixation and biogeochemical cycling reflect either natural oceanic variability or climate change (Karl et al., 1997; Karl, 2014), the most probable changes for the near future in both N_2 fixation and denitrification processes following climate forcing are ~~suggested (?~~ predicted~~)~~ to be a strengthening control of the carbon cycle by P availability (Moutin et al., 2008).

The western tropical South Pacific (WTSP) is a poorly studied area where large blooms of diazotrophs were previously observed by satellite (Dupouy et al., 2000; 2011), and which has been recently qualified as a hot~~-~~spot of N_2 fixation (Bonnet et al., 2017). It is hypothesized that following the South Equatorial Current (SEC), the N-depleted, P-enriched waters from areas of denitrification located in the East Pacific reach waters with sufficient iron in the west to allow N_2 fixation to occur (Moutin et al., 2008; Bonnet et al., 2017). While horizontal advection of waters from the east through the SEC probably supports an active biological pump in the WTSP, local vertical convection may also play a central role.

In addition to the main objective of following the same water mass for several days (de Verneil et al., 2017) by a quasi-Lagrangian experiment (Moutin et al., 2017) in order to propose daily budgets (Caffin et al., this issue; Knapp et al., this issue), or short term biological trends (Van Wambeke et al., this issue), we proposed here to work at larger space and time scales, in complement to the work by Fumenia et al. (this issue) showing that N_2 fixation in the WTSP may influence the whole SP Ocean. While many recent works focus on ~~important (?)~~ small spatial scales influencing the biological carbon pump (Lévy et al., 2012; Stukel et al., 2017), we found it important to also show results from a larger scale study in the OUTPACE (Oligotrophy to UlTra-oligotrophy PACific Experiment) special issue (https://www.biogeosciences.net/special_issue894.html), showing that they are complementary rather than mutually exclusive. ~~T~~Another interest of this study ~~was also motivated because~~is that we are far from resolving seasonal variations of the main biogeochemical variables in the WTSP, still largely under-sampled compared to the ~~northern~~ North Pacific and

Atlantic. The ~~objective~~ aim of this study is therefore to provide a large spatial (hundreds of km) and temporal (annual) scale study of the main biogeochemical C, N, P stocks and fluxes in the upper 200 m of the WTSP Ocean from measurements gathered during the stratified period, and to evaluate the main seasonal trends ~~from~~ on the basis of estimations of previous winter conditions and climatological analysis.

2 Material and methods

2.1 General method and strategy

Station locations, chronology, CTD measurements, sample collection

The OUTPACE cruise was carried out between 18 February and 3 April 2015 from Nouméa (New Caledonia) to Papeete (French Polynesia) in the WTSP (Fig. 1). We sampled water along a 4000 km transect from the oligotrophic water of the MA to the clearest ocean waters of the South Pacific (SP) gyre (Moutin et al., 2017) from a SBE 911+ CTD-Rosette. Euphotic zone depth (EZD) was immediately determined on-board from the photosynthetic available radiation (PAR) ~~in~~ at depth compared to the sea surface PAR(0^+), and used to determine the upper waters sampling depths corresponding to 75, 54, 36, 19, 10, 3, 1 (EZD), 0.3, and 0.1 % of PAR(0^+). CTD sensors were calibrated and data processed post-cruise using Sea-Bird Electronics software in~~to~~ 1~~-~~m bins. Conservative temperature, absolute salinity and potential density were computed using TEOS-10 (McDougall and Barker, 2011). Chlorophyll a (chl a) in mg m^{-3} were measured with an Aqua Trak III fluorimeter (Chelsea Technologies Group Ltd). All samples were collected from ~~the~~ 24~~,~~ 12-L Niskin bottles equipped with silicone rubber closures and tubing for measurements (see section 2.2. Analytical method) of stock variables (dissolved oxygen, dissolved inorganic carbon (DIC), total alkalinity (TA), nutrients, chl a, particulate and dissolved organic C, N, P) and fluxes (primary and bacterial production rates, N_2 fixation rates, and dissolved inorganic phosphate (DIP) turnover times, i.e. the ratio of DIP concentration to DIP uptake).

Group of stations

For our large-scale study, we considered 3 areas: the western MA (WMA), the eastern MA (EMA) and the western gyre (WGY) waters. Four 0-200 m CTD casts, mainly devoted to nutrient pool analyses, were considered for each area and correspond to the following stations: SD 1, SD 2, SD 3 and LD A for WMA, SD 6, SD 7, SD 9 and SD 10 for EMA and SD 13, SD 14, SD 15 and LD C for WGY (Fig. 1, Tables 1 & 2). Therefore, the same number of CTD casts was used to characterize each area. The choice of the stations for each area was essentially geographical, but justified *a posteriori* by the results. SD 8 was discarded because no nutrient measurements were available. SD 11, SD 12 and LD B were also discarded because a bloom was sampled at LD B, meaning these measurements are outside ~~of~~ the scope of this paper, which deals with large-scale spatial and temporal variations. The ~~specificity~~ specificities of the transition area between the MA and GY waters are presented in another paper of the OUTPACE special issue (de Verneil et al., 2017). WMA, EMA and WGY will be presented in dark green, light green and blue, respectively, in close relationship with the expected oligotrophic gradient.

Mixed layer depths

Mixed layer depth (MLD) was calculated using a threshold temperature of 0.2 °C deviation from the reference value at 10~~-~~m depth (de Boyer-Montegut et al., 2004) from OUTPACE CTD profiles (Table 1). For climatological MLD data (Fig. 2a, 2d, 2g), values at each station were extracted from the global climatology at 2° resolution proposed by de Boyer-Montegut et al. (2004) (downloaded from http://www.ifremer.fr/cerweb/deboyer/mld/Surface_Mixed_Layer_Depth.php on Jan 12, 2017). The same criterion (threshold temperature deviation of 0.2 °C) was used.

Vertical eddy diffusivity measurement

The mean eddy vertical diffusivity between 40-200 m was determined for each station from one to several casts undertaken using a VMP1000 (Bouruet-Aubertot et al., this issue). Briefly, Kz is inferred from the dissipation rate of turbulent kinetic energy, ε, mixing efficiency, γ, and buoyancy frequency, N, according to the Osborn relationship: $K_z = (\gamma \varepsilon) / N^2$. ε is computed from the microstructure shear measurements (e.g. Xie et al, 2013) and mixing efficiency is inferred from the Bouffard and Boegman parameterization as a function of turbulence intensity (Bouffard and Boegman, 2013).

Satellite data

Sea surface temperature (SST) (Fig. 2b, 2e, 2h) and sea surface chl a (SSchl a) (Fig. 2c, 2f, 2i) from July 2014 to July 2015 were obtained using processed satellite data provided by the MODIS Aqua mission (downloaded from https://oceandata.sci.gsfc.nasa.gov/ on Jan 3, 2017). The mapped level 3 re-analysis has a 4 km spatial resolution produced at a monthly time scale. For each station, pixels within a rectangle with sides +/- 1/8° longitude and latitude away from the station position were averaged together to produce a single value.

Depth profiles of all discrete variables

All measurements are presented together with their estimated mean concentrations profile (thick line) ~~on~~ in Figs. 3, 4, 5, 6. In order to determine the mean concentrations, the profiles of the variable in question (concentration vs depth) for all stations included in the group were interpolated between 5 and 200 m with a piecewise cubic hermite interpolating scheme (pchip function in the pracma R package). In case of missing values close to 200 m, the interpolation was stopped at the deepest (~~before~~above 200 m) point available. The mean profile was estimated from the mean value of the interpolated profiles ~~on~~ at every ~~one meter~~one-meter depth horizon. For inorganic nutrient concentrations < quantification limit (QL) (see section 2.2), a zero was indicated ~~in order to~~to show that a measurement was taken.

Normalization

Concentrations normalized by salinity are used to study biological processes independent of variations related to evaporation/precipitation. At global scales, it is common to apply S_P=35 (Millero, 2007). In order to estimate seasonal trends in our specific areas, we normalized to the mean absolute salinity measured at 70 m depth in each area, S_A = 35.65 ± 0.04, 35.83 ± 0.04 and 35.91 ± 0.02 $g.kg^{-1}$ for the WMA, EMA and WGY, respectively. This choice will be further justified hereafter. Important differences in the carbonate system require ~~to take into account~~ this normalization to be taken into account, which justifies its use for the other variables, even if changes are relatively small (e.g., for nutrients).

Inventories

Inventories were calculated from the depth profiles of the discrete variables of inorganic and organic C, N, P dissolved and particulate pools (see section 2.2), measured during the OUTPACE cruise (Table 3) between 0 and 70 m depth. The latter depth corresponded to the average deeper annual MLD obtained using climatology, as explained above and shown in Fig. 2 (a, d, g). The integrated fluxes were calculated considering the same depths.

Settling particulate matter mass and C, N, and P flux measurements

The settling of particles in the water column outside ~~of~~ the upper layer was measured using 2 PPS5 sediment traps (1 m^2 surface collection, Technicap, France), deployed for 4 days at 150 and 330 m at LD A (MA) and LD C (WGY) stations (Fig. 1). The PPS5 traps are covered with baffled lids (sieve $1 cm^2$) to reduce current shear at the mouth of the trap, but also to prevent large zooplankton and fish from entering the traps. Particle export was recovered in polyethylene flasks screwed on a rotary disk, which automatically changed the flask every 24-h to obtain ~~a~~ daily material recovery. The flasks were previously filled with a 2% (v/v) buffered solution of formaldehyde (final pH≈8) prepared with in situ deep seawater. A sample of this water is kept to measure dissolved nutrients (phosphate and silicate). Immediately after trap retrieval, samples were stored at 4 °C in the dark until they were processed. Back in the laboratory, ~~a~~one part of the sample's supernatant was kept and stored at 4°C to measure dissolved nutrients (phosphate and silicate), and pH was checked on every trap sample. Swimmers (all organisms deemed to have actively entered the trap) were identified under a stereomicroscope and carefully removed with plastic fine-tipped forceps and placed ~~into~~in small vials with some of the reserved trap preservative. The ~~greatest~~ main species removed were copepods, crustaceans (ostracods, euphausiids, amphipods) and pteropods. Microphotographs of each sample were taken. After the swimmers were removed, the whole sample was then rinsed 3 times with ultrapure (MilliQ) water in order to remove salt and then freeze-dried. Mass particle fluxes were obtained by weighing the freeze-dried sample 5 times. The accuracy of the weighing (and thus of the flux) was 1 % over the whole data series. In this study, swimmers were rinsed and freeze-dried and their dry weight was also determined. Settling particulate matter and swimmers were analyzed separately on an Elemental Analyzer coupled to an Isotope Ratio Mass Spectrometer EA-IRMS (Integra2, Sercon Ltd) to quantify total C and N. Total P was analyzed as described in Sect. 2.2. The total element measurements for the settling particulate matter were considered to represent the settling particulate organic C, N, P. The results are presented in Sect. 2.2 (Table 4).

~~*Settling particulate matter and swimmers mass, C, N and P flux measurements*~~

~~The settling of particles in the water column outside of the upper layer was measured using 2 PPS5 sediment traps (1 m^2 surface collection, Technicap, France) deployed for 4 days at 150 and 330 m at LD A (MA) and LD C (WGY) stations (Fig. 1). Particle export was recovered in polyethylene flasks screwed on a rotary disk which allowed automatically changing the flask every 24 h to obtain a daily material recovery. The flasks were previously filled with a buffered solution of formaldehyde (final conc. 2 %) and were stored at 4 °C after collection until analysis to prevent degradation of the collected material. Onshore, swimmers were handpicked from each sample. Settling particulate matter and swimmers were both weighted and analyzed separately on Elemental Analyzer coupled to an Isotope Ratio Mass Spectrometer EA-IRMS (Integra2, Sercon Ltd) to quantify total C and N. Total P was analyzed as described in section 2.2. The total element measurements for the settling particulate matter were considered to represent the settling particulate organic C, N, P. The results are presented Table 4.~~

Ocean-atmosphere CO$_2$ fluxes

Ocean-atmosphere CO$_2$ fluxes $\Phi_{CO2} = -k_g * (p_{CO2}{}^{atm} - p_{CO2}{}^{oc})$ were calculated considering 1) a mean k_g of 0.031 ± 0.005 mol m^{-2} y^{-1} µatm^{-1} (i.e. 85 µmol m^{-2} d^{-1} µatm^{-1}) for gas transfer velocity, estimated from the Liss and Melivat (1986) relationship and sea winds derived from satellite measurements (1999-2009). Data came from Boutin et al. (downloaded from http://cersat.ifremer.fr/ on March 3 , 2017 and extracted on a geographical grid (Latitude : -17 to -23° N, Longitude: +159 to +211° E) - one grid was used because no significant differences were obtained in k_g for the 3 areas WMA, EMA and WGY), 2) a mean oceanic p_{CO2} ($p_{CO2}{}^{oc}$) determined for each area during the OUTPACE cruise, and 3) a mean atmospheric p_{CO2} ($p_{CO2}{}^{atm}$) estimated from the molar fraction of CO$_2$ (X_{CO2}) in dry air measured at SMO station Tutuila (American Samoa, Lat 14.247° S, Lon 170.564° W, north of LD B (Fig. 1), NOAA/ESRL - data downloaded from http://dx.doi.org/10.7289/V51834DB on February 7 , 2017). A monthly averaged X_{CO2} = 398.4 ppm for March 2015 was used, whereas X_{CO2} varied from 396.0 to 398.4 ppm from July 2014 to July 2015 at Tutuila with an annual mean of 397.3 ppm. The X_{CO2} data were converted in $p_{CO2}{}^{atm}$ considering 100% humidity and a total pressure of 1 atm (101325 Pa), following Weiss and Price (1980), with surface seawater temperature and salinity of each area (Table 5). A total pressure of 101260 ± 180 Pa was determined considering NCEP-NCAR Reanalysis 1 on the OUTPACE area from July 2014 to July 2015, with no longitudinal trend, justifying ~~to~~ considering 1 atm as total pressure for the conversion (downloaded from https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html on December 19, 2017).

Upper layer (0-70 m) daily C, N, P, budgets

Comparative daily C, N, and P budgets of the upper 70 m layer were established for each area (Table 6). Inputs from below associated with vertical turbulent diffusion were calculated using the mean vertical eddy diffusivity, and slopes of nutriclines (Table 2) and DIC gradients calculated between 70-200 m using linear regressions (data not shown). The ocean-atmosphere CO_2 fluxes were detailed in the previous paragraph. The input of nitrogen by N_2 fixation was calculated for each area (Table 6) using depth profile sampling and on-deck 24-h $^{15}N_2$ incubations (section 2.2). Both C, N, P particulate and dissolved organic export were estimated. The way ~~to~~ of obtaining particulate export by settling material (Table 4) was described above. Output of dissolved and particulate organic matter by turbulent diffusion was calculated from the mean vertical eddy diffusivity (Table 1) and from gradients estimated with linear regressions (data not shown) between the surface and 70 m depth of DOC-POC (Fig. 5d-5g), DON-PON (Fig. 5e-5h) and DOP-POP (Fig. 5f-5i). When non-significant gradients were obtained, fluxes were nil.

Seasonal variations and upper layer (0-70 m) annual C, N, P budgets

We sampled for OUTPACE during the stratified period characterized by minimum MLDs close to 20-40 m (Fig. 2a, 2d, 2g), where the largest part of biological fluxes (Fig. 6) occurred. Because the only mechanism able to disrupt this stratification at a large spatial scale is deep water mixing occurring during winter, and more specifically in July in this area (Fig. 2a, 2d, 2g), we postulated that conditions at 70 m depth (average depth of wintertime MLD) remained unchanged, or did not significantly change, ~~all over~~throughout the year. Considering no large inter-annual differences in winter MLDs, we considered that the mean measurements at 70 m depth during OUTPACE well represented the homogeneous upper water column (0-70 m) variables and initial winter conditions (i.e. conditions in July 2014), allowing us to ~~draw~~ determine first-order winter to summer seasonal variations (Table 7) and 8-month C, N, P budgets (Table 8). The dashed lines in ~~all~~ Figs. 3, 4 and 5 indicate the upper surface expected values for all variables during the 2014 austral winter, and allow ~~for~~ evaluation of the temporal variation toward the austral summer season (full lines) in each area.

Surface waters carbonate system climatology

The climatological gridded values proposed in Takahashi et al. (2014), hereafter referred as NDP-094 climatology, were used to validate our estimated values for the carbonate system in the upper surface previous winter conditions (July 2014). The dataset is based on interpolated $p_{CO2}{}^{OC}$ and calculated TA data (based on regional linear potential alkalinity-salinity relationships) on a 4° Latitude by 5° Longitude monthly grid in the reference year 2005. The variable DIC (among others) is calculated from $p_{CO2}{}^{OC}$ and TA. Data were downloaded from http://cdiac.ess-dive.lbl.gov/ftp/oceans/NDP_094/ on December 19, 2017. Climatological July data centred on 20°S were extracted along the cruise transect and 2, 3 and 3 pixels were averaged for comparison in the WMA, EMA and WGY areas, respectively (Table 5). In order to account for the p_{CO2} increase at the earth's surface between 2005 and 2015, a constant offset of 1.5 µatm.y^{-1} was applied to p_{CO2} and a corresponding constant offset of 1 µmol kg^{-1} y^{-1} was also applied to DIC.

2.2 Analytical chemical methods

Oxygen and apparent oxygen utilization (AOU)

Oxygen concentration in the water column was measured with a Seabird SBE43 electrochemical sensor interfaced with the CTD unit. The raw signal was converted to an oxygen concentration with 13 calibration coefficients. The method is based on the Owens and Millard (1985) algorithm that has been slightly adapted by Seabird in the data treatment software using a hysteresis correction. A new set of calibration coefficients has been determined after the cruise to post-process the whole dataset. Only three coefficients (the oxygen signal slope, the voltage at zero oxygen signal, the pressure correction factor) among the 13 determined by the pre-cruise factory calibration of the sensor were adjusted with the following procedure: ~~T~~the oxygen concentrations measured by Winkler were matched with the signal measured by the sensor at the closing of the Niskin bottles. The three values were fitted by minimizing the sum of the square of the difference between Winkler oxygen and oxygen derived from the sensor signal. Winkler oxygen concentration was measured following the Winkler method (Winkler, 1888), with potentiometric endpoint detection (Oudot et al., 1988) on discrete samples collected with Niskin bottles. For sampling, reagents preparation and analysis, the recommendations from Langdon (2010) have been carefully followed. The Thiosulfate solution was calibrated by titrating it against a potassium iodate certified standard solution of 0.0100N (WAKO). AOU was computed with oxygen concentration at saturation estimated following the algorithm proposed by Garcia and Gordon (1992), considering Benson and Krause values.

TA, DIC and p_{CO2}^{oc}

Samples for total alkalinity (TA) and dissolved inorganic carbon (DIC) were collected from Niskin bottles in one 500 mL glass flask (Schott Duran) and poisoned directly after collection with $HgCl_2$ (final concentration 20 mg.L^{-1}). Samples were stored at 4°C during transport and analyzed 5 months after the end of the cruise at the SNAPO-CO_2 (Service National d'Analyse des paramètres Océaniques du CO_2- LOCEAN – Paris). TA and DIC were measured on the same sample based on one potentiometric titration in a closed-cell (Edmond, 1970). A non-linear curve fitting approach was used to estimate TA and DIC (Dickson 1981, DOE 1994). Measurements were calibrated with reference materials (CRM) for oceanic CO_2 m easurements purchased by the SNAPO-CO_2 ~~to~~ from Prof. A. Dickson (Oceanic Carbon Dioxide Quality Control, USA). The reproducibility expressed as the standard deviation of the CRM analysis was 4.6 µmol kg^{-1} for TA and 4.7 µmol kg^{-1} for DIC. Moreover, the standard deviation on the analysis of 12 replicates collected at the same depth (25 m) at station LD C was 3.6 µmol kg^{-1} for TA and 3.7 µmol kg^{-1} for DIC. The Estimation of p_{CO2}^{oc} was made with the SEACARB R package [Gattuso and Lavigne, 2009]. The dissociation constants K_1 and K_2 (for carbonates in seawater) from Lueker et al. (2000) were used. When available, phosphate and silicate concentrations were used in the calculation.

-Nutrient, dissolved and particulate C, N, P pools

Total C, N, P (TC,TN,TP) in seawater samples may be separated in three pools: the dissolved inorganic C, N, P pools (DIC, DIN, DIP), the dissolved organic C, N, P pools (DOC, DON, DOP) and the particulate organic C, N, P pools (POC, PON, POP). No significant particulate inorganic pools are generally considered in open ocean waters.

Two samples for dissolved inorganic nutrient pool~~s~~ measurements were collected from Niskin bottles in 20-mL Polyethylene bottles, and one sample was directly analyzed on-board and the other poisoned with 50µl $HgCl_2$ (20 g.L^{-1}) and stored for analysis after the cruise in the laboratory. DIN = $[NO_3^-] + [NO_2^-] + [NH_4^+]$, sum of nitrate, nitrite and ammonium, respectively. Because $[NO_2^-]$ and $[NH_4^+]$ were negligible compared to $[NO_3^-]$, DIN = $[NO_3^-]$. DIP = $[HPO_4^{2-}] + [PO_4^{3-}]$ = orthophosphates also symbolized as PO_4. Nitrate, nitrite and orthophosphates concentrations were determined on a segmented flow analyzer (AAIII HR SEAL ANALYTICAL) according to Aminot and Kérouel (2007), with a QL of 0.05 µmol L^{-1}. Ammonium was measured by fluorometry (Holmes et al., 1999; Taylor et al., 2007) on a fluorimeter Jasco FP-2020 with a QL of 0.01 µmol L^{-1}.

The dissolved organic pools, DON and DOP, were measured using high-temperature (120 °C) persulfate wet-oxidation mineralization (Pujo-Pay and Raimbault, 1994). Samples were collected from Niskin bottles in 100 mL combusted glass bottles and immediately filtered through 2 pre-combusted (24h, 450 °C) glass fiber filters (Whatman GF/F, 25mm). Filtered samples were then collected in Teflon vials adjusted at 20 mL for wet oxidation. Nitrate and phosphate formed, corresponding to total dissolved pool (TDN and TDP), were then determined as previously described for the dissolved inorganic pools. DON and DOP were obtained by the difference between TDN and DIN, and TDP and DIP, respectively.

The precision and accuracy of the estimates decreased with increasing depth, as inorganic concentrations became the dominant component in the total dissolved nutrient pools. The limits of quantification were 0.5 and 0.05 µmol L^{-1} for DON and DOP, respectively. The same pre-filtration was used for dissolved organic carbon (DOC) measurements. Filtered samples were collected into glass pre-combusted ampoules that were sealed immediately after samples were acidified with orthophosphoric acid (H_3PO_4) and analyzed by high temperature catalytic oxidation (HTCO) (Sugimura and Suzuki, 1988; Cauwet, 1994, 1999) on a Shimadzu TOC-L analyzer. Typical analytical precision is ± 0.1–0.5 (SD). Consensus reference materials (http://www.rsmas.miami.edu/groups/biogeochem/CRM.html) ~~was~~ were injected every 12 to 17 samples to insure stable operating conditions.

The particulate pools (PON, POP) were determined using the same wet oxidation method (Pujo-Pay and Raimbault; 1994). 1.2-L samples were collected from Niskin bottles in polycarbonate bottles and directly filtered onto a pre-combusted (450 °C, 4 h) glass fiber filter (Whatman 47 mm GF/F). Filters were then ~~introduced~~ placed in teflon vials with 20 mL of ultrapure water (Milli-Q grade) and 2.5 mL of wet oxidation reagent for mineralization. Nitrate and orthophosphates produced were analyzed as described ~~before~~previously. QLs are 0.02 µmol L^{-1} and 0.001 µmol L^{-1} for PON and POP, respectively. Particulate organic carbon (POC) was measured using a CHN analyzer and the improved analysis proposed by Sharp (1974).

Primary production rates and DIP turnover times

Vertical profiles of DIC uptake (V_{DIC}) and phosphate turnover time (T_{DIP}) ~~have been~~were measured once at each station using a dual-labeling method (^{14}C and ^{33}P) considering a ^{33}P period $T_{1/2} = 25.55 \pm 0.05$ days (Duhamel et al., 2006). Each sample (150~~-~~mL polycarbonate bottle) was inoculated with 10 µCi of ^{14}C-Carbon (Sodium bicarbonate, Perkin Elmer NEC086H005MC) and 4 µCi of ^{33}P-Phosphate (H_3PO_4 in dilute hydrochloric acid, Perkin Elmer NEZ080001MC). The bottles were then placed in blue-screen-on-deck incubators representing 75, 54, 36, 19, 10, 2.7, 1, 0.3 and 0.1 % incident PAR (https://outpace.mio.univ-amu.fr/spip.php?article135) and maintained at constant temperature using a continuous circulation of surface seawater. The same protocol was used for duplicate 150 mL samples, where 150 µL $HgCl_2$ (20 g L^{-1}) had been added as a control for non-biological uptake. After 3 to 24 h (the optimal incubation time was determined from a prior time-series experiment), incubations were stopped by the addition of 150 µL of non-radioactive KH_2PO_4 (10 mmol L^{-1}) and dark conditions. Filtrations of 50 mL triplicate subsamples were carried out on 25 mm polycarbonate filters (0.2 µm), placed on DIP-saturated support GF/F filters, using a low-vacuum pressure < 0.2 bars. Filters were not washed with filtered seawater at the end of the filtration, but pressure was briefly increased to 0.6 bars, to remove non-cellular ^{33}P radioactivity from the filter. Filters were then placed in low-potassium 6 mL glass scintillation vials (Wheaton) with 500 µL of 0.5 M HCl for 12 hours in order to drive off any unincorporated ^{14}C. Then, 6 mL of scintillation liquid (Ultima gold MV, Packard) was added and the radioactivity of the filters measured using a scintillation counter Packard Tri-Carb® 2100TR on-board (first count). Initial radioactivity was also measured on 5 replicates for each profile. Samples were then stored until the second count in the laboratory after ^{33}P emission became not measurable (12 months). DIC uptake and DIP turnover time were then deduced from the following equations (details in Thingstad et al., 1993; Moutin et al., 2002): $T_{DIP} = -Ti/(\ln(1-(dpm^{33}P-dpm_{b33P})/dpm_{t33P})$, where T_{DIP} is DIP turnover time (in days), Ti is the incubation time, $dpm^{33}P$ is the dpm attributable to the ^{33}P activity, dpm_{b33P} is the dpm attributable to the blank and dpm_{t33P} is the initial (total) activity of ^{33}P. $V_{DIC} = [(dpm^{14}C-dpm_{b14C})/dpm_{t14C}] * [DIC] / Ti$ where: V_{DIC} is the C uptake rate (nmol L^{-1} h^{-1}), $dpm^{14}C$ is the dpm attributable to the ^{14}C activity of the filtered sample, dpm_{b14C} is the dpm attributable to the blank, dpm_{t14C} is the initial (total) activity of ^{14}C added to the sample, [DIC] is the dissolved inorganic carbon concentration of the sample, and Ti is the incubation time. The daily surface photosynthetic available radiation (SPAR) data were used to estimate the daily primary production (PP) values from the PP rates obtained with short time incubation durations using a conversion model (Moutin et al., 1999).

N_2 fixation rates

N_2 fixation rates were measured using the $^{15}N_2$ tracer method (Montoya et al., 1996), adapted and precisely described in Bonnet et al. (this issue). As for PP measurements~~Rapidly~~, seawater was rapidly collected in triplicates from the Niskin bottles in 2.3 L polycarbonates bottles at 6 depths (75 %, 54 %, 19 %, 10 %, 1 %, and 0.1 % surface irradiance levels)~~, like for PP measurements~~. 2.5 mL of $^{15}N_2$ gas (99 atom% ^{15}N, Eurisotop) were injected in each bottle through the septum cap using a gas-tight syringe. All bottles were shaken 20 times to facilitate the $^{15}N_2$ dissolution and incubated for 24 h from sunrise to sunrise. To avoid any possible rate underestimation due to equilibration of the $^{15}N_2$ gas with surrounding seawater, final ™^{15}N enrichment in the N_2 pool was quantified for each profile in triplicates at 5 m and at the deep chl a maximum (DCM). After incubation, 12 mL of each 4.5L bottle were subsampled in Exetainers, fixed with $HgCl_2$ and stored upside down at 4°C in the dark and analyzed onshore within 6 months after the cruise, according to Kana et al. (1994), using a~~n~~ Membrane Inlet Mass Spectrometer. Incubation was stopped by gentle filtration of the samples onto pre-combusted (450 °C, 4 h) Whatman GF/F filters (25 mm diameter, 0.7 µm nominal porosity). Filters were stored in pre-combusted glass tubes at -20 °C during the cruise, then dried at 60 °C for 24 h before analysis onshore by EA-IRMS on an Integra2 (Sercon Ltd). The detection limit associated with the measurement was 0.14 nmol L^{-1} d^{-1}. The accuracy of the EA-IRMS system was systematically controlled using International Atomic Energy Agency (IAEA) reference materials, AIEA-N-1 and IAEA-310A. In addition, the natural δ^{15}N of particulate organic N needed for N_2 fixation rate calculations was measured on each profile at two depths (surface and DCM).

3 Results

3.1 General annual trends of MLD, SST and SSchl a for the 3 selected areas

MLD against month in the climatology (Fig. 2a, 2d, 2g) varied annually from around 70 m depth in July during the austral winter to between 20-40 m during the austral summer for the 3 areas. The OUTPACE cruise from 18 Feb. to 3 Apr. 2015 (red lines) sampled during the stratified period characterized by ~~minimal~~ minimum MLD and ~~maximal~~ maximum SST (Fig. 2b, 2e, 2h). SST varied from 24.2 ± 0.2 to 28.8 ± 0.3 °C, 23.8 ± 0.5 to 28.3 ± 0.7 °C, 25.9 ± 0.4 to 29.0 ± 0.4 °C between July 2014 and July 2015 for WMA, EMA and WGY, respectively. Mean March 2015, SST of 28.8 ± 0.3 °C, 28.3 ± 0.7 °C and 29.1 ± 0.4 °C are close to the mean conservative temperature measurements measured in the MLD during the OUTPACE cruise of 28.9 ± 0.3 °C, 29.3 ± 0.3 °C and 29.5 ± 0.4 °C for WMA, EMA and WGY, respectively. The mean conservative ~~-~~temperature measurements at 70 m depth were 25.3 ± 0.3 °C, 24.8 ± 0.9 °C, 26.1 ± 0.9 °C for WMA, EMA and WGY, respectively (Fig. 3a). These values are comparable with the SST measured during the deeper winter mixing in July 2014 of 24.9 ± 0.2, 24.2 ± 0.7 and 26.5 ± 0.2 for WMA, EMA and WGY, respectively (Table 5). Our hypothesis to consider limited exchanges allowing properties to be conservative at 70 m depth seems reasonable for temperature. Expected seasonal upper surface temperature variations calculated from the differences between temperature at the surface and at 70 m depth of 3.6 ± 0.6, 4.5 ± 1.2 and 3.4 ± 1.3 °C for WMA, EMA and WGY, respectively, agreed relatively well with SST variations observed between July 2014 and March 2015 of 3.9 ± 0.5, 4.2 ± 1.4 and 2.6 ± 0.6 °C ~~observed~~ (Fig. 2b, 2e, 2h). Following a similar reasoning, we established a relatively good comparison between chl a measured at 70 m depth during OUTPACE of 0.217 ± 0.092, 0.091 ± 0.012 and 0.046 ± 0.010 mg m^{-3} for WMA, EMA and WGY, respectively (Fig. 3f), and SSchl a obtained during the deeper mixing of 0.173 ± 0.005, 0.121 ± 0.023 and 0.042 ± 0.002 mg m^{-3} for WMA, EMA and WGY, respectively (Fig. 2c, 2f, 2i). SSchl a reflected well the expected oligotrophic gradient with higher values obtained at WMA, lower values at WGY and intermediate values at EMA. The increase of SSchl a observed in July seems to be related to the deep mixing during winter. The comparison between measurements at 70 m depth and in the upper mixed layer during OUTPACE may be used as a first approach to characterize surface seasonal changes of physical and biogeochemical properties of upper surface waters (section 4.3).

3.2 General hydrological and biogeochemical conditions allowing for characterization of oligotrophic states of the different upper water masses sampled during OUTPACE

The general hydrological and biogeochemical conditions during OUTPACE provide the means to characterize the oligotrophic states of the different water masses sampled (Table 1). The shallow austral summer MLD varied between 11 and 34 m with a mean of 16.7 m (SD = 6.4 m). The low variation is in agreement with the relatively similar weather conditions and SST along the zonal transect near 20° S (Moutin et al., 2017). The euphotic zone depth (EZD) and the DCM depth (DCMD) deepen from west to east, from around 70 m to ~~largely~~ considerably deeper than 100 m, indicating the higher oligotrophy of the SP gyre water compared to the MA water with shallower nitracline depths. The DCM concentration decreases from west to east, but only slightly, from a maximum of 0.40 to a minimum of 0.25 mg m^{-3}. A better indicator of oligotrophic conditions is the depth of the nitracline (D_{NO3}) which varied between 46 and 141 m, typical of oligotrophic to ultraoligotrophic areas of the world ocean (Moutin et al., 2012, their Fig. 9). A relative homogeneity of the slopes (S_{NO3} = 47.0 ± 11.5 µmol m^{-4}) was observed (Table 1). Phosphaclines and nitraclines did not match, as shown by the lower D_{PO4} observed everywhere. No phosphaclines linked with upper water biological processes were determined in the SP gyre because phosphate concentrations above the QL were measured up to the surface. S_{PO4}, when measurable, was 2.8 ± 1.0 µmol m^{-4} (Table 1).

The same characteristics are presented for the 3 areas considered (WMA, EMA and WGY) in Table 2 by their means and SD. The DCMD (about 10-20 m below the EZD in all areas) increased from 78 ± 10 m in the WMA to 134 ± 14 m in the WGY, with an intermediate value of 104 ± 15 m in EMA. D_{NO3} follows the same pattern, with values of 76 ± 10 m, 100 ± 18 m, and 116 ± 18 m, respectively, showing a clear relationship between DCMD and D_{NO3} (Table 2).

The 3 areas considered are characterized by similar trends of conservative temperature, absolute salinity and potential density vs depth between 0-200 m (Fig. 3a, 3b, 3c), i.e., a~~n~~ homogeneity in the mixed layer followed by a drastic change at the ~~basis~~ base of the mixed layer and a break in slopes around 70 m depth. Temperature increased from the deeper layer to the surface where higher temperature characterized the austral summer heating, while lower salinity above 70 m depth indicate significant fresh water input from rainfall~~precipitation~~. The deepening of the DCMD from WMA (dark green) to WGY (blue), with an intermediate value for EMA (light green), demonstrates the westward-eastward gradient of increased oligotrophy (Fig. 3f), reflected as well as by corresponding D_{NO3} ($D_{NO3} = D_{DIN}$, see section 2.2) at similar depths (Fig. 5b). 0-70 m integrated chl a decreased ~~largely~~ considerably from west to east along the transect, from 7.2 ± 2.1 mg m^{-2} for WMA to 2.0 ± 0.6 mg m^{-2} for WGY, with an intermediate value of 4.6 ± 0.7 mg m^{-2} for EMA (Table 2). When integrated over the top 200 m, no difference between chl a stocks were noticeable with a mean value for the whole dataset of 19.9 ± 2.4 mg m^{-2}.

AOU showed similar patterns in all areas, with a slight decrease from the surface to a minimum between 50-70 m, and an increase below 70 m (Fig. 3e). The values close to zero for the first depths indicated saturation or a light super-saturation following classical rapid exchanges with atmospheric oxygen. The AOU values below, and up to, 70 m at both WMA and EMA, and to 100 m depth at WGY, indicated oversaturation. Between 70 and 200 m, almost linear relationships between AOU and depth were observed for all areas.

3.3 C, N, P pools

The dissolved inorganic (upper), dissolved organic (middle) and particulate organic (below) C, N and P (left to right) pools are represented in Fig. 5. For N and P graphs, a Redfield ratio (RR) of 16:1 was systematically applied between N and P axes, allowing for a more direct comparison. DIC in µmol kg^{-1} (Fig. 4a), nDIC (normalized DIC) in µmol kg^{-1} (Fig. 4c) and in µmol L^{-1} (Fig. 5a) showed linear increasing trends with depth in all areas between 70 and 200 m. The specific variations of nDIC close to the surface will be discussed later. Total alkalinity increased rapidly with depth between 0 and 70 m and was more or less constant below ~~until~~ down to 200 m (Fig. 4b). Normalized total alkalinity indicated no change in concentration with depth (Fig. 4d), showing that total alkalinity variations were related to fresh water input. Surface p_{CO2}^{oc}

was everywhere close to or below the average atmospheric p_{CO2} of 383 µatm (Table 5). Nitrate (DIN) was under the QL everywhere in the upper surface ~~until~~ down to 70 m (Fig. 5b). Then the increase with depth (nitracline) was almost the same in each area (similar slopes, S_{NO3}) but did not begin at the same depth (D_{NO3}), as ~~was~~ previously described. Phosphate (DIP) concentrations were ~~largely~~ considerably higher than nitrate concentrations (considering RR) everywhere except close to the surface at WMA and EMA, where they reached QL. High DIP concentrations around 0.2 µmol L^{-1} in the upper 70 m were observed at WGY (Fig. 5c). The depletion in DIP was higher in EMA than in WMA (Fig. 5c). DOC, DON and DOP concentrations were higher close to the surface (Fig. 5d, 5e, 5f) and decreased almost linearly with depth ~~until~~ down to 200 m with only slight differences between the different areas, particularly for the deeper depth measurements where ~50, 4, and 0.07 µmol L^{-1} of DOC, DON and DOP were measured, respectively. The concentration increases ~~in~~ at the surface compared to the values at 200 m depth corresponded roughly to around 25, 1.5, and 0.1 µmol L^{-1} of DOC, DON and DOP, respectively (in similar proportions to the RR for N and P, but more than 2-fold higher for C). The particulate organic C, N, and P pools showed similar patterns with depth between 70 and 200 ~~m, but~~m but diverged in the upper layer between the different areas (Fig. 5g, 5h, 5i). No to ~~little~~ few changes were observed at WGY while significant increases in concentration close to the surface were observed both in WMA and EMA. The increases in surface water concentrations compared to the value at 200 m depth corresponded roughly to changes around 5, 0.5 and 0.03 µmol L^{-1} of POC, PON and POP, respectively (in relatively similar proportions to the RR for C, N and P).

The 0-70 m depth inventories are presented in Table 3. Interestingly, there were ~~really~~ very similar C stocks in the 3 areas, both for the dissolved inorganic and dissolved organic pools. The particulate organic C pool was ~~2 times lower~~ twice lower in WGY than in the MA. Very similar observations ~~are~~ were obtained for all N pools. Nevertheless, DIN stocks were negligible in all areas. DIP stocks were different, and higher in the gyre. The other P pools follow the same pattern as C and N pools, i.e. almost identical in the 3 areas concerning the dissolved organic pool and ~~2 times~~ twice lower in the gyre for the particulate pool.

3.4 C, N, P fluxes

Some major fluxes, PP and N_2 fixation rates, together with DIP turnover times, are shown Fig. 6. All rates are ~~largely~~ considerably higher for WMA and EMA than for WGY, where values indicated only slight differences with depth. Conversely, higher PP (Fig. 6a) and N_2 fixation (Fig. 6b) rates were measured close to the surface, and rapidly decreased with depth reaching negligible values below 50 m and beyond for WMA and EMA. T_{DIP} values of around 100 days for WGY contrast with lower values for WMA and EMA upper waters close to or even below 2 days (Fig. 6c).

Particulate matter mass flux and swimmers contents ~~mass fluxes~~ collected with sediment traps are presented in Table 4 with C, N, and P partitioning. ~~Large~~ Wide variability ~~exists~~ occurs between measurements as shown by the minimum and maximum values obtained. Nevertheless, a mean particulate matter mass flux of 48 mg d^{-1}, three times higher in the MA compared to WGY, was obtained, in good agreement with the higher PP rates and biomass in the MA compared to the gyre. Swimmer ~~s mass fluxe~~contents were also highly variable and represent, as a mean, 9.7 (min: 0.7, max: 26.0) times more mass (dry weight) per day than the settling particles in the MA, and 4.4 (min: 1.4, max: 7.1) times for WGY. The mean proportion of C, N, and P in the settling organic matter of 106/12.7/1.2 for MA and 106/16.6/0.5 for WGY are in relatively good agreement with the theoretical 106/16/1 RR. Note that ~~it~~ this is also the case for C, N, and P proportions in swimmers both for MA (106/15.8/0.7) and WGY (106/19.9/0.7), particularly when P measured in the supernatant was added to the swimmers (see * in Table 4). Otherwise, very low and improbable P contents were found in the swimmers (see the previous column in Table 4).

4 Discussion

4.1 A significant biological carbon pump in the WTSP fuelled by N_2 fixation

We use the surface p_{CO2}^{oc} expected seasonal changes between austral winter and summer in order to draw a first picture of the role of the biological pump in the WTSP. Surface p_{CO2}^{oc} is determined by temperature and salinity changes, and by processes affecting the DIC and alkalinity concentrations, which includes gas exchange, the biological pump, lateral and vertical advection, and mixing (Sarmiento and Grüber, 2006). We will consider that the horizontal spatial scale is large enough to avoid considering lateral advection. Numerical horizontal particle experiments integrating several months of satellite data using Ariane (Rousselet et al., this issue), together with the relative homogeneity of SST along the 4000 km water transect (Moutin et al., 2017), provides support for this first assumption. Furthermore, we will consider that the influence of salinity changes on the "soft tissue" pump is negligible, as generally considered (Sarmiento and Grüber, 2006).

Upper surface temperature variations between the 2014 austral winter and the 2015 austral summer period were estimated to be 3.6 ± 0.6, 4.5 ± 1.2 and 3.4 ± 1.3 °C for WMA, EMA and WGY, respectively. Estimated winter p_{CO2}^{oc} were 372, 355 and 364 µatm (Table 5). Following the Takahashi (1993) calculation ($\Delta p_{CO2}^{oc}|_{Thermal} \approx p_{CO2}^{oc} * 0.0423 * \Delta T$), considering a closed system with constant DIC and Alk, we estimate an increase in p_{CO2}^{oc} of +57, +68 and +52 µatm following summer warming for WMA, EMA and WGY, respectively. The seasonal warming should result in an ~60 µatm increase of p_{CO2}^{oc}~~-~~, which is not observed for any group of stations;~~,~~ indeed, the differences in p_{CO2}^{oc} were ~~of~~ 366 – 372 = -6, 376 – 355 = +21 and 390 – 364 = +26 µatm between winter and summer for WMA, EMA and WGY, respectively (Table 5). The differences were obtained from normalized DIC and Alk measured during the OUTPACE cruise in the MLD~~,~~ and estimated from the expected normalized winter DIC and Alk. The lower than expected p_{CO2}^{oc} changes suggest that the seasonal variations of p_{CO2}^{oc} due to SST changes are counterbalanced by a seasonal reduction due to DIC and/or Alk changes. We can estimate this term by removing p_{CO2} changes due to thermal variation from the observations ($\Delta p_{C02}^{oc}|_{DIC,Alk} = \Delta p_{C02}^{oc}|_{observed} - \Delta p_{C02}^{oc}|_{thermal}$), resulting in -63, -47 and -26 µatm for WMA, EMA and WGY, respectively. The negative signs imply a decrease in DIC or an increase in Alk between winter and summer. When normalized, we do not observe any difference in Alk with depth (Fig. 4d), suggesting that seasonal salinity changes due to ~~large precipitation~~ high rainfall may explain the small change in Alk observed (Fig. 4b). Therefore, the carbonate pump does not seem to play a significant role in the WTSP, and consequently, we expect a major role of the "soft tissue" pump and thus DIC variations. Considering a Revelle factor γ_{DIC} of 9.5, we calculate DIC changes of -35.8, -28.0 and -15.0 µmol kg^{-1} ($\Delta DIC = DIC/p_{CO2}^{oc}\gamma_{DIC} * \Delta p_{C02}^{oc}|_{DIC,Alk}$) necessary to explain the changes in p_{CO2}^{oc} observed. We did indeed observe ~~indeed~~ a decrease in nDIC concentration of 32.9, 25.7 and 15.3 µmol kg^{-1} (Table 5) for WMA, EMA and WGY, respectively (37.0, 30.0 and 18.7 µmol L^{-1}, Table 7, Fig. 5a) between the estimated winter concentration and the mean value measured during the OUTPACE cruise, that may explain the negative sign, and the order of magnitude of the DIC changes. This result based on estimated winter values is reinforced by the fact that winter DIC from NDP-094 climatology of 2006.4 ± 0.7, 2000.9 ± 3.0 and 2004.7 ± 9.9 µmol kg^{-1}, are ~~really~~ close to our estimates for winter conditions, 2007.5 ± 3.0; 2009.6 ± 9.6 and 2008.9 ± 3.7 µmol kg^{-1}, for WMA, EMA and WGY, respectively (Table 5). TA also showed good agreement, 2335.4 ± 0.2, 2333.6 ± 1.7 and 2343.4 ± 8.6 µmol kg^{-1} from NDP-094 climatology, and 2332.4 ± 5.0, 2344.1 ± 6.5 and 2350.8 ± 2.7 µmol kg^{-1} with our estimates for winter conditions. The differences between climatological p_{C02}^{oc} and our estimates for winter conditions are ~~higher~~ wider (Table 5) and can be related to differences in temperature (SST from NDP-094 climatology, SST from MODIS Aqua, T from our estimates). If p_{C02}^{oc} are calculated from DIC and Alk (NDP-094 climatology) with SST from MODIS Aqua (361, 344 and 371 µatm) or our estimated temperatures (366, 353 and 368 µatm), the values are ~~really~~ close to our estimated winter upper surface p_{C02}^{oc} (372, 355 and 364 µatm for WMA, EMA and WGY, respectively) (Table 5). Upper surface estimated DIC seasonal changes may explain why counterintuitive low seasonal p_{C02}^{oc} changes were obtained despite significant increases in temperature. What ~~is~~ therefore controls~~ling~~ the decrease in nDIC? Is it gas exchange at the air-sea interface, mixing, and/or the biological pump?

Gas exchange may be excluded because surface water p_{CO2}^{oc} ranged from 355-390 µatm while the p_{CO2}^{atm} is 383 µatm, with almost no seasonal variations (Table 5). Therefore, surface waters are close to saturation at WGY or under-saturated in the MA all year round and will uptake CO_2 from the atmosphere, and as a result DIC should then increase, which ~~is~~ was not observed. Thus, our observations are more biological in origin, but ~~we have~~there is an inconsistency. The significant decrease in nDIC (Fig. 5a and Table 7), indicating a significant biological soft tissue pump, coincided with no significant changes in nitrate concentration, which were ≤0.03 µmol L^{-1} in all areas (Fig. 5b, Table 7), indicating no or almost no nitrate input by deep winter mixing. Considering the low nitrogen input by upward nitrate turbulent diffusion (see later), we have to consider another nitrogen source, N_2 fixation (Fig. 6b), which is really high in the upper water of the WTSP, recently identified as a hot~~-~~spot for N_2 fixation (Bonnet et al., 2017).

The estimated seasonal nDIC (ΔDIC) variations for the MA waters of 32.9 and 25.7 µmol kg^{-1} for WMA and EMA, respectively, can be compared to those measured in oceanic gyre time-series sites. They are higher than the ΔDIC~15 µmol kg^{-1} observed at the HOT station in the North Pacific subtropical gyre near Hawaii (Dore et al., 2003), and close to the ΔDIC~30 µmol kg^{-1} observed at BATS in the subtropical North Atlantic gyre near Bermuda (Bates et al., 2012), where ΔDIC is at least partially attributable to nitrate from below (Sarmiento and Grüber, 2006). Interestingly, the estimated amplitude of surface DIC seasonal change for the MA is only ~~2 times~~twice lower than the around 50 µmol kg^{-1} DIC decrease measured between March and April in the ~~northern~~ North Atlantic (Merlivat et al., 2009), in an area known to experience a large bloom of phytoplankton. The biological "soft tissue" carbon pump, fuelled almost exclusively by N_2 fixation (see section 4.2), therefore plays a significant role in the WTSP.

4.2 A net sink of atmospheric CO_2 ~~mainly driven by zooplankton migration in the MA~~

Quantification of the major biogeochemical fluxes on a daily basis allows ~~for the establishment of some~~certain conclusions to be drawn concerning the upper biogeochemical cycles of C, N, and P (Table 6). C-budgets of the 0-70 m upper layer showed that the MA area appears as a net sink of atmospheric CO_2~~.~~ with a mean a~~A~~tmospheric carbon input in the ocean of 1250 µmol m^{-2} d^{-1} ~~was the major flux~~ in the ~~W~~MA. Sediment trap POC export was one order of magnitude higher than POC or DOC export by turbulent diffusion, which represented only 7-12 % of the total organic export. Without considering any additional flux, the budget resulted in a surprising~~ly~~ daily net accumulation of carbon of ~~0.~~859 µ~~m~~mol m^{-2} d^{-1} for WMA, and a quasi-equilibrium for EMA and WGY. Note that the accumulation at WMA resulting in an increase of only several nmol L^{-1} d^{-1}, is ~~largely~~ considerably below what we are able to measure at the present time, and longer time scales are thus needed to observe and study the changes (section 4.3). ~~Else we need to explain the estimated net seasonal decreases of DIC in the upper surface waters and of the total carbon pool between all areas (section 4.1, Table 7)) which implies that we probably missed an export flux, particularly for WMA.~~

Averaged integrated PP (IPP) rates were 33.3 ± 12.1, 26.4 ± 16.2 and 6.5 ± 2.4 mmol m^{-2} d^{-1}~~.~~, and export by settling and turbulent diffusion (Table 6, in µmol m^{-2} d^{-1}) represented only 1.2, 1.2 or 0.3 mmol m^{-2} d^{-1}, for WMA, EMA and WGY, respectively. The organic matter exported daily compared to IPP represented 3.6, 4.5 and 4.6 %, respectively, in good agreement with previous measurements in oligotrophic areas (Moutin and Raimbault, 2002, Karl et al., 2012), with a high proportion relative to particles settling, 3.3, 4.1 and 4.1 %, rather than turbulent diffusion. Swimmer~~s~~ contents are really high in the sediment traps, ~~largely~~considerably above fluxes by settling material (Table 4, last column) and diel vertical migrations of mesozooplankton-micronekton, already observed in the MA (Smeti et al., 2015), followed by respiration ~~in~~at depth half of the day time might play a significant role in the transfer of carbon from the upper surface to deeper layers. ~~Furthermore, no large increase in phytoplankton biomass (chl a) was observed during the whole year in the upper surface (Fig. 2c, 2f, 2i). Chl a varied only between 0.05 and 0.20 mg m^-3 in the MA, suggesting a strong top-down control by~~

~~zooplankton able to maintain pigment concentration in a quasi-steady state for many months (Banse et al., 2012). Therefore, as has already been observed in the equatorial Pacific (Landry et al., 2011), it is not unconceivable to consider an equilibrium between phytoplankton production and grazing by mesozooplankton. Both sediment trap data (Table 4, last column) and ADCP measurements (not shown) indeed indicate large zooplankton diel vertical migration, the latter being widespread in the ocean and forming a fundamental component of the biological pump generally overlooked in global models (Bianchi et al., 2013). The ADCP data clearly shows vertical migration from the upper level depths down to around 500 m when light increases at the 2 stations LD A & LD C, with the reverse migration back to the upper levels when light decreases. The objective for mesozooplankton is to feed at night in order to avoid predators. Additionally, while mesozooplankton spend half of the time at around 500 m depth, they respire and lose carbon. Around 25% of their biomass in term of carbon is considered to be lost through respiration each day (Ikeda, 2014; Pagano, pers. com). Considering that half of this loss (12.5 %) happens at 500 m depth following ingestion of the water column's whole PP(new biomass) in the upper surface, it may explain fluxes of 4.2, 3.3 and 0.8 mmol m^{-2} d^{-1}, largely able to significantly influence the daily budgets (Table 6 in µmol m^{-2} d^{-1}). The estimated downward flux of carbon from the euphotic zone due to mesozooplankton diel vertical migrators was at least one order of magnitude higher than the 0.6-1.1 mmol C m^{-2} d^{-1} reported for the equatorial Pacific (Zhang and Dam, 1998). But the mean C export by swimmers of 632 % (MA) and 876 % (WGY) relative to the passive flux measured (Table 4) was also largely higher than the 15-30 % reported at ALOHA station (Al-Mutairi and Landry, 2001). Furthermore, the numerous species of mesozooplankton observed during OUTPACE were not all known to migrate (Carlotti et al., this issue) and temperature dependence on metabolic rates (Ikeda, 2014) needs also to be taken into account (i.e. a slower respiration at depth in colder temperature). Even if considerable uncertainty remains, a predominant role of mesozooplankton in the transfer of carbon (biological pump) is suggested by these data in the WTSP, and particularly in the MA waters.~~

Except for the WMA area, there were no DIN gradients around 70 m depth and therefore no nitrate input from below by turbulent diffusion (Table 6). Nitrogen input by N_2 fixation was by far the largest input of new nitrogen (at least 83%), and reached values among the ~~largest~~ highest ~~values~~ measured ~~everywhere~~ anywhere in the open ocean (Bonnet et al., 2017; Caffin et al., this issue, Knapp et al., this issue). A net daily accumulation of nitrogen is estimated for MA and equilibrium for WGY. Zooplankton diel migrations may also play a significant role in daily N budgets through defecation, excretion or mortality ~~in~~ at depth (Caffin et al., this issue; Valdes et al., this issue). Averaged integrated N_2 fixation rates were 0.64 ± 0.21, 0.45 ± 0.27 and 0.04 ± 0.04 mmol m^{-2} d^{-1} for WMA, EMA and WGY, respectively. The ~~really~~ very high N_2 fixation rates in the MA, compared to other areas in the world (Bonnet et al., 2017), may provide the new nitrogen required for new ~~primary production~~PP, creating the necessary decrease in p_{CO2}^{oc} to stimulate CO_2 invasion.

The daily P-budgets of the 0-70 m upper layer showed losses greater than inputs, in complete ~~opposition with~~contrast to daily C and N budgets showing accumulation in the WMA (Table 6). This ~~main~~ observation indicates why this element, compared to carbon and nitrogen, may rapidly become a limiting factor for biological production and specifically of the input of nitrogen by N_2 fixation in the MA (Moutin et al., 2008). Nevertheless, the mean particulate P export seemed relatively high (Table 6) and should be considered with caution, considering the huge range of variation, from 0.6 to 68.9 µmol m^{-2} d^{-1}, for only 8 measurements in the MA.

4.3 Estimated seasonal trends of the major biogeochemical stocks and fluxes

As already ~~written~~stated, the dashed lines in ~~all~~ Figs. 3, 4 and 5 indicate the upper surface expected values for all variables during the 2014 austral winter, and allow ~~for~~ evaluation of the temporal variation toward the 2015 austral summer season (full lines) in each area corresponding to the OUTPACE dataset. The ~~strong~~ hypothesis allowing this first-order estimation of seasonal variation was presented in section 2.1, validated for SST and chl a variations in section 3.1, and shown to give good agreement with upper surface DIC expected seasonal changes (section 4.2).

Conservative temperature (Fig. 3a) increased everywhere, but more for WMA and EMA than for WGY, while absolute salinity decreased everywhere. Potential density values were similar in each area at 70 m depth. Similar mean depths of convection were estimated for the three areas (min of 68 m at LD A and max of 73 m at LD C), and justified the mean value of 70 m taken into account for the whole OUTPACE area. The rapid exchanges of oxygen between ocean and atmosphere pre-empted significant seasonal changes in the upper surface (Fig. 3d, 3e). The vertical homogeneous chl a concentration expected in winter (Fig. 3f) was shown to be in good agreement with climatological SSchl a (section 3.1). Part of the relatively high chl a concentration estimated in July 2014, specifically in WMA, is ~~likely~~ probably linked to enhanced vertical winter mixing from the DCM.

The seasonal C, N, and P pool changes may be followed in concentration in Fig. 5 but are easier to discuss as 0-70 m water column inventories (Table 8). As previously indicated, DIC decreased in all areas but more in the west than in the east (Fig. 5a), following the already described oligotrophic gradient clearly shown both in biomass (Fig. 3f) and in PP (Fig. 6a). The DIC decrease was partially compensated by the increase in organic concentrations, with the increase of the dissolved concentrations (Fig. 5d) being larger than those of the particulates (Fig. 5g). No increase in the particulate carbon concentration was found for WGY. The decrease of TC (representing the sum of all pools) between winter and summer indicated that 68.1, 61.9 and 68.3 % of ΔDIC were lost from the upper layer, i.e only 31.9, 38.1 and 31.7 % accumulated in the organic C pools for WMA, EMA and WGY, respectively (Table 8). Therefore, organic matter accumulation may partly explain why the large input of atmospheric carbon did not result in DIC accumulation in the MA waters. It may partly explain why the total carbon pool decreased so much seasonally. Following the RR, DIN decreases of 236, 198 and 109 mmol m^{-2} might be expected from the DIC decreases. ~~Indeed, the~~The DIN decreases were indeed around 0-2 mmol m^{-2}, which is in concordance with very poor DIN replenishment of the upper water column. Conversely, increases of the PON stocks ~~on~~ of the same order of magnitude as the RR predicts from POC stocks for WMA and EMA were observed (12.0 and 7.3, compared to RR = 6.6), with a small PON decrease for WGY. The largest increases for the organic pools were for the dissolved phase in all areas (Table 8). DOC accumulation was 3.8 and 8.1 times higher than POC accumulation for WMA and EMA, respectively. Only DOC accumulated at WGY, but with a change ~~two times~~twice lower in magnitude than in the MA waters (Table 8). A relative stronger dissolved organic carbon production compared to particulate production may be ~~reached~~ observed in oligotrophic areas, depending largely on light and nutrient availabilities (Carlson, 2002). In oligotrophic areas, characterized by low export of particulate organic matter, relatively large dissolved organic matter production, and heterotrophic bacteria often limited by nutrients (Van Wambeke et al., 2002), DOC may accumulate (Copin-Montégut and Avril, 1993; Marañón et al., 2005, Pujo-Pay et al., 2011), which is indeed observed (Fig. 5d). Dissolved organic carbon accumulation reached 391, 445 and 220 mmol m^{-2} over 8 months (Table 8), which dispersed over 70 m gives a mean 8-month accumulation of 7.0, 7.1 and 3.0 µmol L^{-1} for the 0-70 m water column. These values, while lower, are of the same order of magnitude of DOC concentration changes observed in the upper mixed layers of 10.1, 9.3 and 5.0 µmol L^{-1} for WMA, EMA and WGY, respectively (Fig. 5d, Table 7). Interestingly, the western SP was recently shown as a localized refractory dissolved organic carbon sink (Hansell and Carlson, 2013).

No significant DIN inventory changes were observed while ~~large~~ strong increases in the DON stocks and similar but relatively lower increases were observed for the PON stocks for WMA and EMA (Table 8, Fig. 5e, 5h). The TN evolution was a net increase of inventories between winter and summer, of 49 and 34 mmol m^{-2} for WMA and EMA, respectively. No significant changes of the N pools were observed at WGY (Table 8, Fig. 5b, 5e, 5h). A decrease of DIP stocks was observed in the MA waters between the winter and summer, with no significant change for WGY (Table 8). Following the RR, DIP decreases of 14.7, 12.3 and 6.8 mmol m^{-2} might be expected from the DIC decreases. ~~Indeed, t~~The DIP decreases were indeed less, 5.9 and 3.1 mmol m^{-2} for WMA and EMA, and no decrease was observed at WGY. The DIC decreases are probably only partially related to the DIP decreases in the MA. As for C and N, the ~~largest~~ highest organic P inventory increases were for the dissolved phase (Fig. 5f, Table 8). Nevertheless, the changes were close to the SD calculated for the mean concentrations and should be considered with caution. As an example, the 1.8 mmol m^{-2} increase in DOP concentrations for EMA (Table 8) corresponds to the difference between 11.6 ± 1.1 mmol m^{-2} during winter and 9.8 ± 2.0 mmol m^{-2} during summer. Note that the SD reported is the maximum SD calculated at each season (Table 8). Small or no decreases in the organic P pools were observed for WGY. Finally, it is clear that seasonal C losses were not compensated by organic carbon accumulation in the 0-70 m layer. Therefore, organic carbon production, which represents by far the largest flux in each area, should be linked with an efficient export from the upper layer, not directly related to RR.

We shall now try to connect the seasonal variations of C, N, and P stocks with the estimated C, N, and P fluxes in order to ~~draw~~ determine first-order budgets and characterize the main seasonal trends in the WTSP. Our very simple model considers an instantaneous winter mixing followed by 8 months (240 days) of C, N, and P fluxes at the same rates as the mean rates measured during the OUTPACE cruise. All fluxes expressed in mmol m^{-2} and corresponding to the 8-month period defined (July 2014-March 2015) are ~~synthesized~~ summarized in Fig. 7. Accumulation rates are presented inside the boxes and input and output fluxes outside the boxes, with arrows for direction (+ for input, - for output). The X value corresponds to the flux necessary to reach equilibrium in each box. The main question is ~~still~~ how can we explain the large DIC losses in all areas, whereas we ~~got~~ obtained a significant DIC input by winter convection and turbulent diffusion, low export of organic matter by settling or turbulent diffusion during the summer period, and a p_{CO2}^{oc} lower than or equal to the p_{CO2}^{atm} meaning a DIC enrichment by atmospheric exchanges, and furthermore no significant input of DIN from below in the 0-70 m upper layer?

The source of new N required to sustain new PP is clearly N_2 fixation (Fig. 7b, 7e, 7h). Converted in C using the RR of 6.6, new production may represent 12.8, 11.3 and 4.2 % of IPP of 7.94, 6.34 and 1.56 mol m^{-2} for the 8-month period in the WMA, EMA and WGY, respectively. ~~A n~~New production ≤ 5% is typical of strong oligotrophic conditions (Moutin and Raimbault, 2002), while above 5% is related to more productive areas or areas with high N_2 fixation rates (Karl et al., 2012). Taking into account the fact that the previous values are for 8 months only, we can estimate annual production ~~s~~rates of 145, 116 and 28 gC m^{-2} y^{-1} for WMA, EMA and WGY, respectively, close to the average rate of 170 gC m^{-2} y^{-1} reported for the ALOHA station in the North Pacific central gyre (Karl et al., 1996), and to the 86-232 gC m^{-2} y^{-1} range reported for the Mediterranean Sea at the DYFAMED site (Marty and Chiavérini, 2002), known as oligotrophic areas.

Having found the source of new N, in order to answer the question regarding DIC losses, several ~~a first~~ hypothese~~i~~s may be ~~to~~ considered. A first hypothesis is an episodic or seasonal high export of matter ~~largely~~considerably different from ~~the one~~that measured during the end of the summer season (OUTPACE cruise)~~, in complete contradiction with our initial postulate~~. We cannot ~~completely~~ discard this hypothesis specifically because no seasonal data are available at the present time, and also because episodic yet large export fluxes have already been reported in other oligotrophic areas (Böttjer et al., 2017). Nevertheless, the relative constant chl a concentration during the entire period considered in the upper water column (Fig. 2c, 2f, 2i), where most of the production is likely to occur (Fig. 6a), preferentially suggests relatively constant production and therefore export. Furthermore, the C, N, and P proportions of the X fluxes (Fig. 7) in all areas are completely different from RR, even in an opposite sense for P (Fig. 7c, 7f, 7i), suggesting that such C fluxes were not directly related to organic matter settling.

A second hypothesis ~~considers~~ might be in relation with ~~a major role of~~diel vertical migrations of zooplankton-micronekton already described in the MA (Smeti et al., 2015), ~~migration in the transfer of carbon. It seems that it is the only way to~~ which may explain significant C losses with proportionally lower N losses and no P losses (Fig. 7). Indeed, mesozooplankton-micronekton feed at night in order to avoid predators and migrate to spend half of the time at around 500 m depth where they respire and lose carbon. Chl a varied only between 0.05 and 0.20 mg m^{-3} in the MA upper surface, suggesting a strong top-down control by zooplankton able to maintain pigment concentration in a quasi-steady state for many months (Banse et al., 2012). Zooplankton-micronekton diel vertical migrations, the latter being widespread in the ocean and forming a fundamental component of the biological pump generally overlooked in global models (Bianchi et al., 2013), and well known in the Pacific Ocean (Zhang and Dam, 1998, Al-Mutairi and Landry, 2001; Landry et al., 2011), might explain part of the unexplained ΔDIC observed in the upper surface waters. ~~If, as already suggested, a quasi-steady state between phytoplankton and zooplankton productions is considered, which means that IPP is totally grazed by zooplankton, and that 12.5% of the carbon was lost by zooplankton respiration during its stay in depth, then we found C losses of 993, 793 and 195 mmol m^{-2} for that period. These numbers are of the same magnitude order than the X values of 1274, 821 and 426 mmol m^{-2} determined from seasonal C budgets (Fig. 7a, 7d, 7g). Because the C lost in that case, by respiration, is independent from N or P losses, it may explain the discrepancies observed between the C, N and P fluxes. This, together with the observed zooplankton migration through ADCP data, definitely suggests that zooplankton may be a preponderant actor in the transfer of carbon from the upper layer to the interior of the ocean in the WTSP.~~ A third hypothesis might be an underestimation of the settling carbon through methodological issues, mainly concerning the performance of traps (Buesseler et al., 2007) or solubilization (Antia, 2005), which is impossible to take into account without specific measurements. ~~Indeed, t~~There is in fact no reliable way to separate swimmers' contribution of different elements from that originating from the passive flux (Antia, 2005), and ~~particularly~~in particular, using formalin, we cannot measure the DOC in the trap supernatant.

Tropical storms, ~~like~~such as Cyclone PAM observed during the OUTPACE cruise (de Verneil et al., 2017), might have an influence on seasonal budgets. Law et al., (2011) reported the effect of such a cyclone in the North Tasman Sea. ~~Indeed, t~~There was no nitrate entrainment but rather phosphate entrainment due to explicit differences in nitracline and phosphacline depths. This allowed nitrogen fixation to be enhanced in a process close to ~~the one~~that we described in our study, albeit in response to physical forcing acting at a smaller spatial than winter mixing. During OUTPACE, the strong wind forcing event PAM entered the Southwest Pacific in early March, and a drop in SST and increase in Chl followed in its wake. The storm did indeed have a fertilizing effect but at relatively short spatial (around Vanuatu islands) and time (around 2 weeks) scales, compared to the larger-scale processes highlighted in the present study.

Mesoscale structures have been previously shown to influence primary production (Falkowski et al., 1991; Oschlies and Garçon, 1998; Moutin and Prieur, 2012; Levy et al., 2015). Nevertheless, the mesoscale vertical fluxes due to quasi-geostrophic forcing calculated from satellite data during OUTPACE were weak and acted on a layer displaced from the relevant nutrient reservoirs (de Verneil et al., 2017). The seasonal vertical nutrient input into the photic layer, mainly driven by deep vertical mixing, will be the main influence on annual biological production, whereas summertime mesoscale activity will primarily influence the horizontal spatial distribution of phytoplankton (Rousselet et al., this issue).

4.4 Iron and phosphate availabilities as key factors controlling the N input by N_2 fixation and the biological carbon pump in the WTSP

The western SP is known as an iron-~~–~~rich area (Wells et al., 1999). Iron concentrations measured during the DIAPALIS cruises (http://www.obs-vlfr.fr/proof/vt/op/ec/diapazon/dia.htm) near New Caledonia (M. Rodier unpubl. data in Van den Broeck et al., 2004) were higher than concentrations reported in the sub-tropical North Pacific (Landing and Bruland, 1987), and ~~indicating~~indicated no clear seasonal variations. Average iron concentrations of 0.57 nmol L^{-1} were reported in the upper surface waters of the WTSP (Campbell et al., 2005), higher than the ~0.1 nmol L^{-1} measured in the upper 350 m water column of the SP gyre (Blain et al., 2008) where ferricline depths were located well below nitracline depths (Blain et al., 2008). The Equatorial Undercurrent, which originates near Papua New Guinea, close to New Caledonia, is known to be a source of iron in the SP Ocean (Wells et al., 1999; Ganachaud et al., 2017). Nevertheless, atmospheric deposition fluxes of iron are very low (Duce and Tindale 1991, Wagener et al., 2008). During OUTPACE, the apparent contradiction between low atmospheric deposition of iron and high surface water iron concentration was resolved. The high iron average concentration within the photic layer in the MA (1.7 nmol L^{-1}) compared to WGY (0.3 nmol L^{-1}) was shown to be related to ~~an~~ the influence of hydrothermal sources at shallower depths than commonly associated with volcanic activities (Guieu et al., in revision), confirming the importance of hydrothermal contribution to the oceanic iron inventory (Tagliabue et al., 2010; Fitzsimmons et al., 2014; Tagliabue et al., 2017). The averaged 0-70 m integrated concentrations were 0.57 ± 0.14 nM; 1.18 ± 1.02 nM; 0.28 ± 0.03 nM for WMA, EMA and WGY, respectively. Iron is a major component of the nitrogenase enzyme that catalyzes N_2 fixation (Raven, 1988). The high iron concentration likely alleviates the iron limitation of N_2 fixation in the WTSP, again considered as a hot~~-~~spot of N_2 fixation (Bonnet et al., 2017).

Phosphate turnover time (T_{DIP}) represents the ratio between natural concentration and uptake by planktonic species (Thingstad et al., 1993) and is considered the most reliable measurement of phosphate availability in the upper ocean waters (Moutin et al., 2008). Phosphate availability in the MA, characterized by DIP < 50 nmol L^{-1} and T_{DIP} reaching below 2 days, is ~~largely~~ considerably lower than in the SP gyre, with DIP concentrations above 100 nmol L^{-1} and T_{DIP} in the order of magnitude of months (Fig. 6c), as already reported (Moutin et al., 2008). Phosphate availability, as well as primary production, were shown to follow the same seasonal patterns close to New Caledonia in the MA, suggesting that in this iron-rich area known to sustain high N_2 fixation rates, phosphate may appear as a key factor controlling carbon production (Van den Broeck et al., 2004). ~~Indeed, a~~It was suggested that a seasonal pattern of phosphate availability with higher values (Low DIP, High T_{DIP}) related to winter mixing and lower value (Higher DIP, Lower T_{DIP}) during the stratified period ~~was suggested to~~ might control *Trichodesmium* spp. growth and decay in the SP near New Caledonia (Moutin et al., 2005). A T_{DIP} below 2 days was shown to be critical for *Trichodesmium* spp. growth (Moutin et al., 2005). T_{DIP} below or close to 2 days was measured in the MA upper waters during the OUTPACE cruise (Fig. 6c), and T_{DIP} as low as several hours was measured at LD B station and has been related with the strong biomass and specifically *Trichodesmium* spp. decline observed at this station (de Verneil et al., 2017). With T_{DIP} around or even below 2 days, the MA appears as a low P area during the stratified period, indicating a probable role of phosphate availability in the control of nitrogen input by the nitrogen fixers. The higher iron availability in the MA is probably the main factor allowing N_2 fixation to occur, and phosphate availability the main factor controlling the annual input of N by N_2 fixation~~its rate~~. A T_{DIP} of 2 days corresponds to the lowest value reported at ALOHA station in the NP (Table 2 in Moutin et al., 2008), where phosphate availability is considered to play a dominant role in the control of nitrogen fixers (Karl et al., 1997; Karl, 2014). T_{DIP} reached several hours, which is ~~closest~~ close to the phosphate availability of the Mediterranean Sea or the Sargasso Sea, known for a long time for their phosphate deficiency (Wu et al., 2000; Moutin et al., 2002). While phytoplankton and heterotrophic bacterioplankton may appear N-limited (Van Wambeke et al., this issue; Gimenez et al., this issue), the low availability of phosphate in the upper waters of the WTSP during the stratified period ~~likely~~ probably controls the biomass of nitrogen fixers and ultimately the input of nitrogen by this process. In a recent mesocosm~~s~~ experiment, ~~large~~ high increases in N_2 fixation rates, PP rates and carbon export were obtained after a DIP enrichment of WTSP waters (Berthelot et al., 2015). Nevertheless, several days were necessary to measure significant increases, indicating that regular short~~-~~term experiments to establish nutrient limitation as usually operated (Dekaezemacker et al., 2013; Moisander et al., 2012; Moore et al., 2013), may not be relevant in WTSP conditions (Gimenez et al., 2016).

The high DIP low DIN (excess P or high P*) content of water was suggested ~~to be~~as a preliminary condition allowing N_2 fixation to occur (Redfield, 1934; Capone and Knapp, 2007; Deutsch et al., 2007), and is a characteristic of surface waters of the South Equatorial current flowing from the east to the west in the SP, due to intense denitrification related to one of the main OMZ (Oxygen Minimum Zone) areas in the East Pacific (Codispoti et al., 2001). The alleviation of iron limitation when waters originating from the east reach the WTSP was considered as the main factor explaining the hot~~-~~spot of N_2 fixation observed in the OUTPACE area (Bonnet et al., 2017). The strong nitracline and phosphacline depth differences (Table 1), associated with winter mixing down to around 70 m, allows us to estimate a replenishment of DIP ~~on~~ of the order of magnitude of ΔDIP (5.9 mmol m^{-2} for WMA and 3.0 mmol m^{-2} for EMA; Fig. 7c, 7f), ~~largely~~ far above the vertical input by turbulent diffusion (around 0.7 mmol m^{-2}), together with no DIN replenishment. Alone, these DIP fluxes may support N_2 fixation of 94.4 and 48.0 mmol m^{-2} during this period (following RR), ~~on~~ of the order of magnitude of the fluxes of 154 and

108 mmol m^{-2} calculated for WMA and EMA (Fig. 7b, 7e), respectively. While horizontal advection of high DIP low DIN waters from the SP gyre toward the iron-rich WTSP was suggested to create the environmental conditions favourable for diazotroph growth (Moutin et al., 2008; Bonnet et al., 2017), we here suggest that local seasonal winter mixing may also play a significant role in providing excess P to the upper waters, and therefore in controlling nitrogen input by N_2 fixation and therefore the associated carbon cycle. Phosphate availability appears, in the high iron MA, as the ultimate control of the biological carbon pump. The simulations of the main C, N, and P fluxes at LD A and LD C, using a 1DV model with similar physical forcing, strengthen the idea of strong seasonal variations being able to explain the control of N_2 fixation and carbon fluxes by the availability of phosphate in the MA and iron at WGY (Gimenez et al., this issue). Iron was hypothesised to prevent N_2 fixation at LD C and this allows to obtain the high DIP concentration observed at LD C.

4.5 Toward reconciliation between simulations and observations?

During the past 10 years, global biogeochemical model simulations suggested relatively high N_2 fixation in the SP gyre and low fixation in the western part of the Pacific Ocean (Deutsch et al., 2007; Grüber 2016), in contradiction with the little data then available. While the decrease in P* toward the centre of the gyre observed during the BIOSOPE cruise (ETSP toward the central gyre 10-30°S in latitude) corresponds to the trend observed by Deutsch et al. (2007), N_2 fixation in the simulation, with minimum values found on the edge and maximum values found in the centre of the gyre, was contrary to our observations (Moutin et al., 2008). The high N_2 fixation expected in the ETSP, because “downstream of OMZs, surface waters that initially carry a surplus of phosphorus (because of subsurface denitrification) lose this excess gradually through N_2 fixation” (Deutsch et al., 2007), was not confirmed by isotopic budgets (Knapp et al., 2016), suggesting an elusive marine N_2 fixation (Grüber, 2016). The discovery of a hot~~-~~spot of N_2 fixation in the whole WTSP covered by the OUTPACE transect and other cruises in the Coral Sea (Bonnet et al., 2017), ~~allows us to consider~~ justifies considering a larger spatial coupling between denitrification and N_2 fixation than previously thought (Deutsch et al., 2007). Taking into account the role of iron to allow (or not) N_2 fixation to occur~~,~~ ~~seems indispensable for the reconciliation between simulations and observations~~seems a necessary basis to reconcile simulations and observations (Dutkiewicz et al., 2012; Monteiro et al., 2011; Weber and Deutsch, 2014). ~~Indeed, these~~These new modelling ~~efforts~~studies have identified the WTSP as a unique region with conditions seemingly favourable for significant N_2 fixation fluxes (Knapp et al., this issue). Interestingly, the opposite trends between expected N_2 fixation and P* observed during the BIOSOPE cruise and possibly attributed to non-Redfieldian processes (Moutin et al., 2008) may be rather due to horizontal advection and isopycnal mixing of water masses originating from the WTSP, and therefore marked by a strong signature of intense N_2 fixation (High N* corresponding to Low P*) (Fumenia et al., this issue), in an opposite sense than the ~~more well-known~~better-known and more widely studied influence of water masses marked by a strong signature of intense denitrification originating from the OMZ (Yoshikawa et al., 2015). Furthermore, the deepening of isopycnals from the eastern to the western SP (Yoshikawa et al., 2015; Fumenia et al., this issue) suggests a deeper (~200 m) influence of excess P waters from the SEC in the MA, deeper than previously hypothesised (Moutin et al., 2008; Bonnet et al., 2017). Because the influence of isopycnal mixing ~~influence~~ is below the maximum mixing depth estimated in the WTSP (~70 m), the link between N sink in the east and N source in the west ~~imply~~ implies longer time scales than ~~the one~~that associated only ~~to~~ with surface circulation. The N budget of the SP Ocean is of prime interest to understand the efficiency, at the present time, and in the future, of the oceanic biological carbon pump. ~~Getting~~ Determining the budget requires a precise understanding of the general water mass circulation, which ~~suffers~~ at the present time suffers from a lack of data, specifically during water mass formation (Fumenia et al., this issue).

5 Conclusion

We found a significant biological soft tissue carbon pump in the WTSP despite no winter replenishment of surface waters by DIN. N_2 fixation is the major process introducing the necessary N to sustain the biological soft tissue carbon pump allowing oceanic $p_{CO2}^{oc} < p_{CO2}^{atm}$ in the MA, and therefore significant atmospheric C input. ~~Thanks to~~Because of N_2 fixation, the WTSP is a significant atmospheric carbon sink. ~~We suggest that zooplankton diel vertical migration at around 500 m depth, and their respiration at depth, may significantly contribute to the transfer of carbon from the upper surface to the ocean interior.~~

The upper surface waters of the MA sampled during the stratified period were characterized by a DIP availability close to or below the level required for phosphate sufficiency, which contrasts with observations in the central Pacific gyre at the same latitude. We confirmed the geographical trend of limitation of N_2 fixation in the SP, from a probable~~n~~ iron limitation in the east and central SP Ocean, to a P limitation in the west. The limit was clearly shown to be associated with the lower depths of the MA, where sufficient iron was provided to upper surface waters to alleviate iron limitation of N_2 fixation, probably by hydrothermal sources at anomalously shallow depths. Extrapolating these data in order to obtain seasonal trends ~~allows~~ enables us to show that winter vertical mixing, although limited to 70 m depth, may bring sufficient excess P to allow most of N_2 fixation to occur. ~~Additionally~~In addition, more excess P may be locally provided in the upper surface (where N_2 fixation was shown to occur predominantly) by winter mixing than by horizontal transport from areas of excess P formation (OMZ). As previously hypothesized (Moutin et al., 2008), the low availability of phosphate in the high iron upper waters of the WTSP during the stratified period ~~likely~~ probably controls the biomass of nitrogen fixers and ultimately the input of nitrogen by this process, and the biological pump. As ~~–~~high nutrient concentrations in High Nutrient Low Chlorophyll (HNLC) areas (Minas et al. 1986) may be considered as the result of an inefficient biological carbon pump (Sarmiento and Grüber, 2006), ~~-~~high phosphate concentrations (and high DIP turnover time) in the south Pacific gyre (Moutin et al., 2008; this study) may be the result of inefficient or inexistent N_2 fixation. Conversely, the low P availability (low concentration and DIP turnover time) in the upper surface of the WTSP ~~are~~is the result of intense N_2 fixation. Because iron concentrations are low in the gyre and high in the MA (even during the strongest stratified period), and because of the specific iron needs of diazotrophs, iron availability is the best candidate for preventing nitrogen fixation in the gyre and allowing nitrogen fixation in the MA. Therefore, iron availability and DIP availability may appear as the ultimate controls of biological production and export in the gyre and in the MA, respectively.

The SP Ocean deserves special attention because of its huge volume of water where the N budget is likely to be controlled by N lost in the east (denitrification) and N gain in the west (N_2 fixation). Furthermore, both diazotrophy and denitrification are ~~known~~ expected to undergo drastic alterations due to climate change (McMahon et al., 2015; Lachkar et al., 2018). Our data suggest that one had better take into account the role of iron and phosphate in global biogeochemical models, in order to better reconcile simulations and data, which seems to be the prerequisite to understand at the present time the relationship between N sources and sinks in the SP Ocean. Moreover, it will be of great interest to study future scenarios which consider iron coming from below (hydrothermal sources) ~~rather~~ in addition to that ~~than~~ from above (atmospheric source) in the WTSP and in the whole SP Ocean. Changes in N_2 fixation following changes in dust (iron) supply have been suggested to play a central role in explaining past glacial/interglacial changes in CO_2 concentration and earth temperature. It was considered that N_2 fixation on a regional scale would change global nitrogen availability and the biological carbon pump on the time scale of ocean circulation. The direct link between N_2 fixation and carbon export ~~through zooplankton diel migration and respiration~~ proposed here for the WTSP, a hot~~-~~spot of N_2 fixation, allows for a much closer coupling between N_2 fixation and the biological carbon pump, which may in turn require us to consider changes at shorter time scales ~~like~~ such as that ~~the one~~ associated with climate change. ~~The low P availability may appear as the ultimate control of N input by N_2 fixation and therefore on of the efficiency of the biological pump in the MA.~~

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Table 1. General physical and biogeochemical characteristics of the stations investigated along the OUTPACE transect presented ~~by~~ in columns : (1) Short duration (SD) or long duration (LD) station; (2) Station number; (3) CTD-rosette number; (4) MLD: Mixed layer depth (m); (5) EZD: Euphotic zone depth (m); (6) K_z: Mean 40-200 m vertical eddy diffusivity ($m^2 d^{-1}$); (7) K_z error ($m^2 d^{-1}$); (8) DCMD, Deep chl a maximum depth; (9) DCMC, Deep chl a maximum concentration: chl a concentration at the DCMD ($mg m^{-3}$); (10 and 11) Ichl a, integrated (0-70 m) and (0-200 m) total chl a concentration ($mg m^{-2}$); (12-24) D_x, eD_x, S_x, eS_x, N_x and r_x^2: characteristics of nutriclines (depths in m where NO_3 or PO_4 reaches zero and slopes in µmol m^{-4} with associated errors, N: number of samples for the linear relationship, r^2 : correlation coefficient). QL: Quantification limit; nd : no data; nc : not calculated (linear relationship not established); na : nutrient above QL at surface.

							Chl a				Nitracline						Phosphacline					
Station		CTD number	MLD (m)	EZD (m)	K_Z ($m^2 s^{-1}$)	eK_Z ($m^2 s^{-1}$)	DCMD (m)	DCMC ($mg m^{-3}$)	I 0-70m ($mg m^{-2}$)	I 0-200m ($mg m^{-2}$)	D_{NO3} (m)	eD_{NO3} (m)	S_{NO3} (µmol m^{-4})	eS_{NO3} (µmol m^{-4})	N	r^2	D_{PO4} (m)	eD_{PO4} (m)	S_{PO4} (µmol m^{-4})	eS_{PO4} (µmol m^{-4})	N	r^2
SD	1	out_c_006	12	70	9,37E-06	1,10E-05	88	0,40	5,0	18,9	73	8	53	9	3	0,97	25	18	2,8	0,6	5	0,89
SD	2	out_c_010	23	70	7,69E-06	7,28E-06	85	0,33	6,0	20,4	78	4	61	6	3	0,99	27	4	3,2	0,2	5	0,99
SD	3	out_c_019	14	70	5,04E-06	3,79E-06	69	0,28	9,4	20,0	87	8	61	8	4	0,97	17	5	2,7	0,3	4	0,98
LD	A	out_c_066	14	70	1,45E-05	1,83E-04	71	0,32	8,4	21,3	65	11	39	9	3	0,96	11	3	5,3	0,6	3	0,99
SD	4	out_c_070	12	70	7,15E-06	8,26E-06	62	0,49	9,2	19,8	54	15	24	3	5	0,96	22	18	2,0	0,5	3	0,95
SD	5	out_c_074	11	70	1,33E-05	1,33E-05	62	0,49	9,3	27,0	46	25	24	4	5	0,92	nc	nc	nc	nc	nc	nc
SD	6	out_c_078	13	79	7,49E-06	1,39E-05	119	0,29	5,4	22,3	118	6	56	11	3	0,96	40	10	1,9	0,2	5	0,97
SD	7	out_c_082	12	90	4,51E-06	2,79E-06	89	0,30	4,1	16,9	77	7	41	4	4	0,98	33	7	2,4	0,2	4	0,98
SD	8	out_c_086	12	90	5,95E-06	6,75E-06	114	0,28	3,3	17,5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
SD	9	out_t_012	22	90	3,29E-06	2,36E-06	nd	nd	nd	nd	95	10	43	9	3	0,96	60	12	2,4	0,3	5	0,95
SD	10	out_c_094	13	90	4,90E-06	4,30E-06	103	0,28	4,2	18,1	112	1	64	1	3	1,00	nc	nc	nc	nc	nc	nc
SD	11	out_c_098	13	90	7,01E-06	8,37E-06	91	0,36	4,4	18,2	78	18	42	8	5	0,90	41	6	2,8	0,2	4	0,99
SD	12	out_c_102	16	85	5,25E-06	4,80E-06	94	0,33	5,1	18,8	84	2	57	2	3	1,00	na	na	na	na	na	na
LD	B	out_c_150	21	55	4,18E-06	6,66E-06	74	0,35	7,8	22,2	120	1	48	1	3	1,00	nc	nc	nc	nc	nc	nc
SD	13	out_c_152	27	x	nd	nd	122	0,30	1,2	18,1	102	12	41	5	4	0,97	na	na	na	na	na	na
LD	C	out_c_198	34	120	4,25E-06	1,49E-05	129	0,29	1,9	19,6	117	4	51	3	5	0,99	na	na	na	na	na	na
SD	14	out_c_209	13	110	3,49E-06	4,11E-06	155	0,25	2,1	18,2	141	10	50	3	5	0,99	na	na	na	na	na	na
LD	15	out_c_212	19	116	3,06E-06	2,45E-06	131	0,26	2,7	20,3	105	12	45	7	4	0,96	na	na	na	na	na	na

							Chl a				Nitracline						Phosphacline					
Station		CTD number	MLD (m)	EZD (m)	K_Z ($m^2 s^{-1}$)	eK_Z ($m^2 s^{-1}$)	DCMD (m)	DCMC ($mg m^{-3}$)	I 0-70m ($mg m^{-2}$)	I 0-200m ($mg m^{-2}$)	D_{NO3} (m)	eD_{NO3} (m)	S_{NO3} (µmol m^{-4})	eS_{NO3} (µmol m^{-4})	N	r^2	D_{PO4} (m)	eD_{PO4} (m)	S_{PO4} (µmol m^{-4})	eS_{PO4} (µmol m^{-4})	N	r^2
SD	1	out_c_006	12	70	9.37E-06	1.10E-05	88	0.40	5.0	18.9	73	8	53	9	3	0.97	25	18	2.8	0.6	5	0.89
SD	2	out_c_010	23	70	7.69E-06	7.28E-06	85	0.33	6.0	20.4	78	4	61	6	3	0.99	27	4	3.2	0.2	5	0.99
SD	3	out_c_019	14	70	5.04E-06	3.79E-06	69	0.28	9.4	20.0	87	8	61	8	4	0.97	17	5	2.7	0.3	4	0.98
LD	A	out_c_066	14	70	1.45E-05	1.83E-04	71	0.32	8.4	21.3	65	11	39	9	3	0.96	11	3	5.3	0.6	3	0.99
SD	4	out_c_070	12	70	7.15E-06	8.26E-06	62	0.49	9.2	19.8	54	15	24	3	5	0.96	22	18	2.0	0.5	3	0.95
SD	5	out_c_074	11	70	1.33E-05	1.33E-05	62	0.49	9.3	27.0	46	25	24	4	5	0.92	nc	nc	nc	nc	nc	nc
SD	6	out_c_078	13	79	7.49E-06	1.39E-05	119	0.29	5.4	22.3	118	6	56	11	3	0.96	40	10	1.9	0.2	5	0.97
SD	7	out_c_082	12	90	4.51E-06	2.79E-06	89	0.30	4.1	16.9	77	7	41	4	4	0.98	33	7	2.4	0.2	4	0.98
SD	8	out_c_086	12	90	5.95E-06	6.75E-06	114	0.28	3.3	17.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
SD	9	out_t_012	22	90	3.29E-06	2.36E-06	nd	nd	nd	nd	95	10	43	9	3	0.96	60	12	2.4	0.3	5	0.95
SD	10	out_c_094	13	90	4.90E-06	4.30E-06	103	0.28	4.2	18.1	112	1	64	1	3	1.00	nc	nc	nc	nc	nc	nc
SD	11	out_c_098	13	90	7.01E-06	8.37E-06	91	0.36	4.4	18.2	78	18	42	8	5	0.90	41	6	2.8	0.2	4	0.99
SD	12	out_c_102	16	85	5.25E-06	4.80E-06	94	0.33	5.1	18.8	84	2	57	2	3	1.00	na	na	na	na	na	na
LD	B	out_c_150	21	55	4.18E-06	6.66E-06	74	0.35	7.8	22.2	120	1	48	1	3	1.00	nc	nc	nc	nc	nc	nc
SD	13	out_c_152	27	x	nd	nd	122	0.30	1.2	18.1	102	12	41	5	4	0.97	na	na	na	na	na	na
LD	C	out_c_198	34	120	4.25E-06	1.49E-05	129	0.29	1.9	19.6	117	4	51	3	5	0.99	na	na	na	na	na	na
SD	14	out_c_209	13	110	3.49E-06	4.11E-06	155	0.25	2.1	18.2	141	10	50	3	5	0.99	na	na	na	na	na	na
LD	15	out_c_212	19	116	3.06E-06	2.45E-06	131	0.26	2.7	20.3	105	12	45	7	4	0.96	na	na	na	na	na	na

Table 2. General physical and biogeochemical characteristics for the 3 selected areas presented ~~by~~ in columns: (1) western Melanesian Archipelago (WMA), eastern Melanesian Archipelago (EMA), western gyre (WGY) with the corresponding stations chosen; (2) Mean or standard deviation (SD); (3) MLD: Mixed layer depth (m); (4) EZD: Euphotic zone depth (m); (5) K_z: Mean 40-200 m vertical eddy diffusivity (m^2 d^{-1}); (6) DCMD: Deep chl a maximum depth; (7) DCMC: Deep chl a maximum concentration = chl a concentration at the DCMD (mg m^{-3}); (8 and 9) Ichl a, Integrated (0-70 m) and (0-200 m) total chl a concentration (mg m^{-2}); (10-13) D_x, S_x: characteristics of nutriclines (depths in m where NO_3 or PO_4 reaches zero and slopes in µmol m^{-4}). QL: Quantification limit; na: nutrient above QL at surface.

					Chl a				Nitracline		Phosphacline	
		MLD (dbar)	EZD (dbar)	K_Z (m^2 d^{-1})	DCMD (m)	DCMC (mg m^{-3})	I 0-70m (mg m^{-2})	I 0-200m (mg m^{-2})	D_{NO3} (m)	S_{NO3} (µmol m^{-4})	D_{PO4} (m)	S_{PO4} (µmol m^{-4})
WMA (SD 1,2,3 LD A)	Mean	16	70	0,79	78	0,33	7,2	20,2	76	53	20	3,5
	SD	5	0	0,34	10	0,05	2,1	1,0	10	10	7	1,2
EMA (SD 6,7,9,10)	Mean	15	87	0,44	104	0,29	4,6	19,1	100	51	44	2,2
	SD	5	6	0,15	15	0,01	0,7	2,8	18	11	14	0,3
EGY (SD 13,14,15 LD C)	Mean	23	115	0,31	134	0,28	2,0	19,0	116	47	na	na
	SD	9	5	0,05	14	0,03	0,6	1,1	18	5	na	na

					Chl a				Nitracline		Phosphacline	
		MLD (dbar)	EZD (dbar)	K_Z (m^2 d^{-1})	DCMD (m)	DCMC (mg m^{-3})	I 0-70m (mg m^{-2})	I 0-200m (mg m^{-2})	D_{NO3} (m)	S_{NO3} (µmol m^{-4})	D_{PO4} (m)	S_{PO4} (µmol m^{-4})
WMA (SD 1,2,3 LD A)	Mean	16	70	0.79	78	0.33	7.2	20.2	76	53	20	3.5
	SD	5	0	0.34	10	0.05	2.1	1.0	10	10	7	1.2
EMA (SD 6,7,9,10)	Mean	15	87	0.44	104	0.29	4.6	19.1	100	51	44	2.2
	SD	5	6	0.15	15	0.01	0.7	2.8	18	11	14	0.3
WGY (SD 13,14,15 LD C)	Mean	23	115	0.31	134	0.28	2.0	19.0	116	47	na	na
	SD	9	5	0.05	14	0.03	0.6	1.1	18	5	na	na

Table 3. Mean integrated 0-70 m C, N, and P pools (mol m^{-2}) during the OUTPACE cruise (austral summer period) for the 3 selected areas: western Melanesian Archipelago (WMA), eastern Melanesian Archipelago (EMA), and western gyre (WGY). Dissolved inorganic (DI), dissolved organic (DO) and particulate organic (PO), C, N and P, respectively.

			DIC	DOC	POC	DIN	DON	PON	DIP	DOP	POP
Austral summer	WMA	Mean	141,2	5,07	0,21	0,000	0,392	0,035	0,0040	0,0112	0,0019
		SD	0,3	0,12	0,02	0,000	0,036	0,004	0,0020	0,0018	0,0002
	EMA	Mean	141,6	5,22	0,22	0,000	0,370	0,031	0,0011	0,0117	0,0018
		SD	0,6	0,07	0,02	0,001	0,017	0,002	0,0011	0,0010	0,0001
	EGY	Mean	141,9	5,35	0,09	0,000	0,378	0,015	0,0101	0,0136	0,0010
		SD	0,4	0,08	0,01	0,000	0,045	0,001	0,0012	0,0020	0,0001

			DIC	DOC	POC	DIN	DON	PON	DIP	DOP	POP
Austral summer	WMA	Mean	141.2	5.07	0.21	0.000	0.392	0.035	0.0040	0.0112	0.0019
		SD	0.3	0.12	0.02	0.000	0.036	0.004	0.0020	0.0018	0.0002
	EMA	Mean	141.6	5.22	0.22	0.000	0.370	0.031	0.0011	0.0117	0.0018
		SD	0.6	0.07	0.02	0.001	0.017	0.002	0.0011	0.0010	0.0001
	WGY	Mean	141.9	5.35	0.09	0.000	0.378	0.015	0.0101	0.0136	0.0010
		SD	0.4	0.08	0.01	0.000	0.045	0.001	0.0012	0.0020	0.0001

Table 4. Sediment trap data. Minimum, maximum and mean values of particulate matter mass flux and swimmer~~s~~ contents~~mass fluxes~~, C, N, P and Redfield ratio (RR) from particulate matter and swimmers (Zoo). * P calculated from the RR with adding the P measured in the supernatant. Last column: particulate matter mass flux and swimmer~~s~~ content ~~mass flux~~ ratio. MA: Melanesian Archipelago, WGY: western SP gyre.

		Particulate matter	Swimmer	POC	PON	POP	RR 106/N/P proportion			Zoo-C	Zoo-N	Zoo-P	Zoo-P*	RR 106/N/P proportion			*	Zoo/Particulate
		mgDW d^{-1}	mgDW d^{-1}	µmol m^{-2} d^{-1}			C	N	P	µmol m^{-2} d^{-1}				C	N	P	P	mass flux ratio
MA	Min	14	69	241	22	0,6	106	9,8	0,3	2 994	492	4	22	106	12,4	0,0	0,2	0,7
(N=8)	Max	122	403	3 084	395	68,9	106	15,4	2,9	11 742	1 653	26	55	106	20,2	0,6	1,1	26,0
	Mean	48	219	1 092	136	18,5	106	12,7	1,2	6 903	961	14	36	106	15,8	0,2	0,7	9,7
WGY	Min	7	24	138	20	0,4	106	11,2	0,2	609	75	2	5	106	13,1	0,2	0,5	1,4
(N=8)	Max	28	148	385	59	2,1	106	20,4	0,8	4 552	1 067	16	28	106	25,2	0,5	0,9	7,1
	Mean	17	76	266	41	1,1	106	16,6	0,5	2 330	473	8	15	106	19,9	0,3	0,7	4,4

		Particulate matter	Swimmer	POC	PON	POP	RR 106/N/P proportion			Zoo-C	Zoo-N	Zoo-P	Zoo-P*	RR 106/N/P proportion			*	Zoo/Particulate
		mgDW d^{-1}	mgDW d^{-1}	µmol m^{-2} d^{-1}			C	N	P	µmol m^{-2} d^{-1}				C	N	P	P	mass flux ratio
MA	Min	14	69	241	22	0.6	106	9.8	0.3	2 994	492	4	22	106	12.4	0.0	0.2	0.7
(N=8)	Max	122	403	3 084	395	68.9	106	15.4	2.9	11 742	1 653	26	55	106	20.2	0.6	1.1	26.0
	Mean	48	219	1 092	136	18.5	106	12.7	1.2	6 903	961	14	36	106	15.8	0.2	0.7	9.7
WGY	Min	7	24	138	20	0.4	106	11.2	0.2	609	75	2	5	106	13.1	0.2	0.5	1.4
(N=8)	Max	28	148	385	59	2.1	106	20.4	0.8	4 552	1 067	16	28	106	25.2	0.5	0.9	7.1
	Mean	17	76	266	41	1.1	106	16.6	0.5	2 330	473	8	15	106	19.9	0.3	0.7	4.4

Table 5. Molar fraction of CO_2 (X_{CO2}) in dry air measured at SMO station Tutuila (American Samoa, Lat 14.247° S, Lon 170.564° W, see Fig. 1; Source: NOAA/ESRL) and derived atmospheric p_{CO2} (p_{CO2}^{atm}). Mean values for the carbonate system, measured in the mixed layer depth (MLD) during the OUTPACE cruise (summer conditions), measured at 70 m depth (estimated winter conditions) and NDP-094 climatological data (Takahashi et al., 2014). Oceanic climatological p_{CO2} (p_{CO2}^{oc}) are given for different estimations of winter temperature (SST from NDP-094, mean T at 70 m depth from OUTPACE, SST from MODIS Aqua). CT: conservative temperature, S_p: practical salinity, nDIC: normalized dissolved inorganic carbon, nAlk: normalized alkalinity, SST: sea surface temperature; SSS: sea surface salinity). WMA: western Melanesian Archipelago, EMA: eastern Melanesian Archipelago, and WGY: western SP gyre sampled during the OUTPACE cruise.

SMO station TUTUILA	Monthly mean X_{CO2} (March 2015)	ppm	398,4	
	Annual mean X_{CO2} (Jul 2014-Jul 2015)	ppm	397,3 (SD = 0,8)	

			WMA		EMA		WGY	
		Unit	Mean	SD	Mean	SD	Mean	SD
	Monthly mean p_{CO2}^{atm} (March 2015)	µatm	383,0		382,7		382,5	
Mean values measured in the MLD (austral summer conditions, March 2015)	CT	°C	28,9	0,3	29,3	0,3	29,5	0,4
	S_P		35,0	0,1	35,1	0,2	35,1	0,1
	nDIC	µmol kg^{1}	1974,6	9,5	1983,9	8,6	1993,6	3,2
	nAlk	µmol kg^{1}	2333,7	1,9	2343,1	8,0	2347,7	6,1
	nP_{CO2}^{oc}	µatm	366	11	376	8	390	6
Mean values at 70 m (estimated austral winter MLD conditions)	CT	°C	25,3	0,2	24,8	0,8	26,2	0,9
	S_P		35,5	0,0	35,7	0,0	35,7	0,0
	nDIC	µmol kg^{1}	2007,5	3,0	2009,6	9,6	2008,9	3,7
	nAlk	µmol kg^{1}	2332,4	5,0	2344,1	6,5	2350,8	2,7
	nP_{CO2}^{oc}	µatm	372	10	355	15	364	8
Austral winter (July 2014) temperature at surface from MODIS Aqua	SST	°C	24,9	0,2	24,2	0,7	26,5	0,2
Mean climatological austral winter values at surface (from Takahashi et al., 2014)	SST	°C	23,9	0,0	24,4	0,1	25,1	0,1
	SSS		35,5	0,0	35,5	0,0	35,6	0,1
	DIC	µmol kg^{1}	2006,4	0,7	2000,9	3,0	2004,7	9,9
	Alk	µmol kg^{1}	2335,4	0,2	2333,6	1,7	2343,4	8,6
	P_{CO2}^{oc} at surface	µatm	344	1	345	4	349	7
Mean climatological austral winter P_{CO2}^{oc} at surface calculated with different temperatures	T from OUTPACE, mean CT at 70 m depth	µatm	366		353		368	
	SST from MODIS Aqua	µatm	361		344		371	

SMO station TUTUILA	Monthly mean X_{CO2} (March 2015)	ppm	398.4	
	Annual mean X_{CO2} (Jul 2014-Jul 2015)	ppm	397.3 (SD = 0,8)	

			WMA		EMA		WGY	
		Unit	Mean	SD	Mean	SD	Mean	SD
	Monthly mean p_{CO2}^{atm} (March 2015)	µatm	383.0		382.7		382.5	
Mean values measured in the MLD (austral summer conditions, March 2015)	CT	°C	28.9	0.3	29.3	0.3	29.5	0.4
	S_P		35.0	0.1	35.1	0.2	35.1	0.1
	nDIC	µmol kg^{1}	1974.6	9.5	1983.9	8.6	1993.6	3.2
	nAlk	µmol kg^{1}	2333.7	1.9	2343.1	8.0	2347.7	6.1
	nP_{CO2}^{oc}	µatm	366	11	376	8	390	6
Mean values at 70 m (estimated austral winter MLD conditions)	CT	°C	25.3	0.2	24.8	0.8	26.2	0.9
	S_P		35.5	0.0	35.7	0.0	35.7	0.0
	nDIC	µmol kg^{1}	2007.5	3.0	2009.6	9.6	2008.9	3.7
	nAlk	µmol kg^{1}	2332.4	5.0	2344.1	6.5	2350.8	2.7
	nP_{CO2}^{oc}	µatm	372	10	355	15	364	8
Austral winter (July 2014) temperature at surface from MODIS Aqua	SST	°C	24.9	0.2	24.2	0.7	26.5	0.2
Mean climatological austral winter values at surface (from Takahashi et al., 2014)	SST	°C	23.9	0.0	24.4	0.1	25.1	0.1
	SSS		35.5	0.0	35.5	0.0	35.6	0.1
	DIC	µmol kg^{1}	2006.4	0.7	2000.9	3.0	2004.7	9.9
	Alk	µmol kg^{1}	2335.4	0.2	2333.6	1.7	2343.4	8.6
	P_{CO2}^{oc} at surface	µatm	344	1	345	4	349	7
Mean climatological austral winter P_{CO2}^{oc} at surface calculated with different temperatures	T from OUTPACE, mean CT at 70 m depth	µatm	366		353		368	
	SST from MODIS Aqua	µatm	361		344		371	

Table 6. 0-70 m upper layer comparative C, N, P daily budgets in the 3 selected areas (western Melanesian Archipelago (WMA), eastern Melanesian Archipelago (EMA), and western gyre (WGY)) sampled during the OUTPACE cruise (µmol m^{-2} d^{-1}).

		WMA			EMA			EGY		
		C	N	P	C	N	P	C	N	P
INPUT	Dissolved inorganic turbulent diffusion	426	46	2,8	198	0	1,0	200	0	0,0
	Atmospheric CO_2 exchange or N_2 fixation	1675	642	negligible	825	452	negligible	0	41	negligible
OUTPOUT	Particulate organic settling	-1092	-136	-18,5	-1092	-136	-18,5	-266	-41	-1,1
	Particulate organic turbulent diffusion	-29	-4	-0,2	-16	-1	-0,1	2	0	0,0
	Dissolved organic turbulent diffusion	-121	-8	-0,7	-58	-6	-0,3	-21	0	0,0
BUDGETS		859	540	-16,6	-143	309	-17,9	-85	0	-1,1

		WMA			EMA			WGY		
		C	N	P	C	N	P	C	N	P
INPUT	Dissolved inorganic turbulent diffusion	426	46	2.8	198	0	1.0	200	0	0.0
	Atmospheric CO_2 exchange or N_2 fixation	1675	642	negligible	825	452	negligible	0	41	negligible
OUTPOUT	Particulate organic settling	-1092	-136	-18.5	-1092	-136	-18.5	-266	-41	-1.1
	Particulate organic turbulent diffusion	-29	-4	-0.2	-16	-1	-0.1	2	0	0.0
	Dissolved organic turbulent diffusion	-121	-8	-0.7	-58	-6	-0.3	-21	0	0.0
BUDGETS		859	540	-16.6	-143	309	-17.9	-85	0	-1.1

Table 7. Estimated temporal evolution of surface biogeochemical properties between austral winter (up) and summer (below) in µmol L^{-1} presented ~~by~~ in columns: (1) Mean measurements at 70 m depth during OUTPACE were considered to represent the homogeneous upper water column (0-70 m) variables and initial winter conditions (i.e. conditions in July 2014). The summer conditions were those observed during the OUTPACE cruise (March 2015). Δ represents the summer – winter conditions differences. (2) Selected area: western Melanesian Archipelago (WMA), eastern Melanesian Archipelago (EMA) or western gyre (WGY). (3) Mean or standard deviation (SD), (4 to 15) Dissolved inorganic (DI), dissolved organic (DO), particulate organic (PO), and total (T), C and N and P, respectively. All variables were normalized to the mean absolute salinity measured at 70 m depth to discard evolution due to evaporation/precipitation.

			nDIC	nDOC	nPOC	nTC	nDIN	nDON	nPON	nTN	nDIP	nDOP	nPOP	nTP
Austral winter	WMA	Mean	2055,1	67,5	1,6	2124,2	0,00	5,06	0,38	5,44	0,142	0,125	0,022	0,289
		SD	3,0	4,4	0,5		0,00	0,38	0,06		0,030	0,024	0,005	
	EMA	Mean	2057,5	68,9	2,3	2128,7	0,03	4,93	0,34	5,30	0,059	0,140	0,021	0,220
		SD	10,2	2,0	0,4		0,04	0,27	0,05		0,046	0,028	0,004	
	EGY	Mean	2056,2	74,2	1,4	2131,8	0,01	5,52	0,24	5,77	0,142	0,182	0,015	0,339
		SD	4,3	2,3	0,2		0,01	0,74	0,01		0,020	0,037	0,001	
Austral summer	WMA	Mean	2018,1	77,6	4,3	2100,0	0,00	6,05	0,68	6,73	0,000	0,163	0,032	0,195
		SD	10,0	2,2	0,3		0,00	0,58	0,12		0,000	0,029	0,004	
	EMA	Mean	2027,5	78,2	4,5	2110,1	0,00	5,72	0,59	6,31	0,000	0,180	0,031	0,211
		SD	8,8	1,1	1,1		0,00	0,39	0,15		0,000	0,018	0,005	
	EGY	Mean	2037,6	79,2	1,2	2117,9	0,00	5,50	0,21	5,71	0,150	0,190	0,013	0,353
		SD	3,4	1,1	0,2		0,00	0,70	0,04		0,014	0,017	0,002	
Δ	WMA		-37,0	10,1	2,6	-24,2	0,00	1,00	0,29	1,29	-0,142	0,037	0,010	-0,095
	EMA		-30,0	9,3	2,2	-18,6	-0,03	0,79	0,25	1,01	-0,059	0,040	0,010	-0,009
	EGY		-18,7	5,0	-0,2	-13,9	-0,01	-0,02	-0,03	-0,06	0,008	0,008	-0,002	0,014

			nDIC	nDOC	nPOC	nTC	nDIN	nDON	nPON	nTN	nDIP	nDOP	nPOP	nTP
Austral winter	WMA	Mean	2055.1	67.5	1.6	2124.2	0.00	5.06	0.38	5.44	0.142	0.125	0.022	0.289
		SD	3.0	4.4	0.5		0.00	0.38	0.06		0.030	0.024	0.005	
	EMA	Mean	2057.5	68.9	2.3	2128.7	0.03	4.93	0.34	5.30	0.059	0.140	0.021	0.220
		SD	10.2	2.0	0.4		0.04	0.27	0.05		0.046	0.028	0.004	
	WGY	Mean	2056.2	74.2	1.4	2131.8	0.01	5.52	0.24	5.77	0.142	0.182	0.015	0.339
		SD	4.3	2.3	0.2		0.01	0.74	0.01		0.020	0.037	0.001	
Austral summer	WMA	Mean	2018.1	77.6	4.3	2100.0	0.00	6.05	0.68	6.73	0.000	0.163	0.032	0.195
		SD	10.0	2.2	0.3		0.00	0.58	0.12		0.000	0.029	0.004	
	EMA	Mean	2027.5	78.2	4.5	2110.1	0.00	5.72	0.59	6.31	0.000	0.180	0.031	0.211
		SD	8.8	1.1	1.1		0.00	0.39	0.15		0.000	0.018	0.005	
	WGY	Mean	2037.6	79.2	1.2	2117.9	0.00	5.50	0.21	5.71	0.150	0.190	0.013	0.353
		SD	3.4	1.1	0.2		0.00	0.70	0.04		0.014	0.017	0.002	
Δ	WMA		-37.0	10.1	2.6	-24.2	0.00	1.00	0.29	1.29	-0.142	0.037	0.010	-0.095
	EMA		-30.0	9.3	2.2	-18.6	-0.03	0.79	0.25	1.01	-0.059	0.040	0.010	-0.009
	WGY		-18.7	5.0	-0.2	-13.9	-0.01	-0.02	-0.03	-0.06	0.008	0.008	-0.002	0.014

Table 8. Estimated temporal evolution of (0-70 m) biogeochemical inventories between austral winter and summer in mmol m^{-2} presented ~~by~~ in columns: (1) Mean measurements at 70 m depth during OUTPACE were considered to represent the homogeneous upper water column (0-70 m) variables and initial winter conditions (i.e. conditions in July 2014). The summer conditions were those observed during the OUTPACE cruise (March 2015). Δ represents the summer – winter conditions differences. (2) Selected area: western Melanesian Archipelago (WMA), eastern Melanesian Archipelago (EMA) or western gyre (WGY). (3) Mean or standard deviation (SD), (4 to 15) Dissolved inorganic (DI), dissolved organic (DO), particulate organic (PO), and total (T), C and N and P, respectively. All variables were normalized to the mean absolute salinity measured at 70 m depth to discard evolution due to evaporation/precipitation.

			nDIC	nDOC	nPOC	nTC	nDIN	nDON	nPON	nTN	nDIP	nDOP	nPOP	nTP
Δ (summer - winter)	WMA	Mean	-1563	391	102	-1070	0,0	40,8	8,5	49	-5,9	2,4	0,4	-3,1
		SD	209	307	33		0,0	35,6	4,1		2,1	1,8	0,4	
	EMA	Mean	-1355	445	55	-855	-1,7	28,0	7,5	34	-3,0	1,8	0,3	-0,9
		SD	713	139	26		3,1	19,0	3,7		3,2	2,0	0,3	
	EGY	Mean	-659	220	-8	-448	-0,3	-4,6	-1,5	-6	0,1	1,0	-0,1	1,1
		SD	298	162	14		0,9	51,5	1,3		1,4	2,6	0,1	

			nDIC	nDOC	nPOC	nTC	nDIN	nDON	nPON	nTN	nDIP	nDOP	nPOP	nTP
Δ (summer - winter)	WMA	Mean	-1563	391	102	-1070	0.0	40.8	8.5	49	-5.9	2.4	0.4	-3.1
		SD	209	307	33		0.0	35.6	4.1		2.1	1.8	0.4	
	EMA	Mean	-1355	445	55	-855	-1.7	28.0	7.5	34	-3.0	1.8	0.3	-0.9
		SD	713	139	26		3.1	19.0	3.7		3.2	2.0	0.3	
	WGY	Mean	-659	220	-8	-448	-0.3	-4.6	-1.5	-6	0.1	1.0	-0.1	1.1
		SD	298	162	14		0.9	51.5	1.3		1.4	2.6	0.1	

Figures caption

Fig. 1. Transect of the OUTPACE cruise (18 Feb. 3 Apr. 2015) superimposed on a bathymetry map (GEBCO_2014 grid) of the Western Tropical South Pacific Ocean. The two types of stations, short duration and long duration, are indicated together with the stations chosen to represent 3 selected areas: the western Melanesian Archipelago (WMA in dark green), the eastern Melanesian Archipelago (EMA in light green) and the western SP gyre (WGY in blue). SMO station Tutuila (American Samoa, Lat 14.247° S, Lon 170.564° W).

Fig. 2. Monthly mean mixed layer depth (MLD) against month in climatology (a, d, g), sea surface temperature (SST) (b, e, h) and chl a (c, f, i) against months from July 2014 to July 2015, respectively, for (a, b, c) the western Melanesian Archipelago (WMA), (d, e, f) the eastern Melanesian Archipelago (EMA) and (g, h, i) the western SP gyre (WGY). The horizontal dashed lines indicate the mixed layer depth of 70 m. The vertical red lines indicate the period of the OUTPACE cruise:18 Feb. to 3 Apr. 2015.

Fig. 3. Vertical profiles of (a) conservative temperature (CT in °C), (b) absolute salinity (SA in g kg^{-1}), (c) potential density (Sigma in kg m^{-2}), (d) dissolved oxygen (O_2 in µmol kg^{-1}), (e) apparent oxygen utilization (AOU in µmol kg^{-1}) and (f) chl a (mg m^{-3}) versus depth (0-200 m) in the 3 distinct areas sampled during the OUTPACE cruise: the western Melanesian Archipelago (WMA in dark green), the eastern Melanesian Archipelago (EMA in light green) and the western SP gyre (WGY in blue). The horizontal dashed lines indicate the mixed layer depth of 70 m. The vertical dashed lines indicate the upper surface expected values for all variables during the 2014 austral winter.

Fig. 4. Vertical profiles of (a) dissolved inorganic carbon (DIC), (b) total alkalinity (TA), (c) normalized dissolved inorganic carbon (nDIC) and (d) normalized total alkalinity (nTA) against depth (m) for the 3 distinct areas sampled during the OUTPACE cruise: the western Melanesian Archipelago (WMA in dark green), the eastern Melanesian Archipelago (EMA in light green) and the western SP gyre (WGY in blue). The horizontal dashed lines indicate the mixed layer depth of 70 m. The vertical dashed lines indicate the upper surface expected values for all variables during the 2014 austral winter.

Fig. 5. Vertical profiles of normalized (n) C, N, P data against depth (m). Dissolved inorganic (DI), dissolved organic (DO) and particulate organic (PO) C (a, d, g), N (b, e, h) and P (c, f, i), respectively, in µmol L^{-1}, for the 3 distinct areas sampled during the OUTPACE cruise: the western Melanesian Archipelago (WMA in dark green), the eastern Melanesian Archipelago (EMA in light green) and the western SP gyre (WGY in blue). The horizontal dashed lines indicate the mixed layer depth of 70 m. The vertical dashed lines indicate the upper surface expected values for all variables during the 2014 austral winter.

Fig. 6. Vertical profiles of (a) primary production (PP rate in nmolC L^{-1} d^{-1}), (b) N_2 fixation rate (nmolN L^{-1} d^{-1}) and dissolved inorganic phosphate turnover times (T_{DIP} in days on log scale) against depth for the 3 distinct areas sampled during the OUTPACE cruise: the western Melanesian Archipelago (WMA in dark green), the eastern Melanesian Archipelago (EMA in light green) and the western SP gyre (WGY in blue). The vertical red line indicates the critical DIP turnover time of 2 days.

Fig. 7. C, N, and P estimated budgets in the 0-70 m water column during the 8-month period between deep convection in July 2014 (austral winter) and strong stratification in March 2015 (austral summer) for the 3 distinct areas sampled during the OUTPACE cruise: the western Melanesian Archipelago (WMA, top), the eastern Melanesian Archipelago (EMA,

middle) and the western SP gyre (WGY, bottom). C budgets (7a, 7d, 7g), N budgets (7b, 7e, 7h) and P budgets (7c, 7f, 7i). Dissolved inorganic (DI), dissolved organic (DO), and particulate organic (PO) C, N, and P fluxes are considered, respectively. Atmospheric exchanges limited to CO_2 penetration and N_2 fixation are indicated. All fluxes are expressed in mmol m^{-2} (of elemental C, N, and P, respectively) with arrows indicating direction (input or output). The 2 numbers for the particulate fluxes correspond to fluxes by turbulent diffusion (above) and particle settling (below). Estimated accumulation rates for the same period are indicated inside the boxes.