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Interactive comment on "The Oligotrophy to the UlTra-oligotrophy PACific Experiment (OUTPACE cruise, Feb. 18 to Apr. 3, 2015)" *by* Thierry Moutin et al.

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We thank Reviewer 1 for the useful comments provided and address them below.

Rev. 1: Moutin et al. present this overview paper on OUTPACE cruise. It is a well written manuscript and the objectives of the cruise are discussed clearly. But I feel there is a need to list the major findings of this cruise. Results can be discussed in individual manuscripts of the special issue separately, but important findings reported in each manuscript can just be listed (with references) here.

Resp.: Section 7 has been modified according to the suggestions.

The goal of this special issue is to present the knowledge obtained concerning the functioning of WTSP ecosystems and associated biogeochemical cycles based on the datasets acquired during the OUTPACE experiment. The cruise strategy was organized to promote collaboration between physicists, biologists and biogeochemists with expertise including marine physics, chemistry, optics, biogeochemistry, microbiology, molecular ecology, genetics, and modelling. Most of the contributions to this volume have benefited from this collective effort and are presented according to the main objectives of the OUTPACE experiment. The hydrological and dynamical context of biogeochemical sampling are described for the entire cruise route (Fumenia et al., 2017) and specifically at the three long duration stations, where low physical variability validated the quasi-lagrangian sampling strategy employed (de Verneil et al., 2017a). Turbulence measurements revealed an interesting longitudinal gradient with higher turbulence levels in the West, i.e. the Coral Sea, compared to the Eastern part within the gyre, consistent with the increasing oligotrophy (Bouruet-Aubertot et al., 2017). The large scale circulation was dominant even though the mesoscale and submesoscale circulation can have a strong influence (Rousselet et al., 2017), in particular on the bloom observed at station LD-B (de Verneil et al., 2017b) An important focus of OUTPACE was on dinitrogen fixation and its fate in the ecosystem (Caffin et al., 2017b). N2 fixation was detected at all 18 sampled stations and the transect could be divided into two main characteristic sub-areas (Bonnet et al., 2017): i) the MA waters (160°W to 170°E) exhibiting very high N2 fixation rates (631 $\pm$ 286 μmol N m-2 d-1, i.e. among the highest reported for the global ocean, Luo et al., 2012) and dominated by Trichodesmuim (Stenengren et al., 2017), and ii) the GY waters (170°E-160°E) exhibiting low N2 fixation rates (average 85 $\pm$ 79 μmol N m-2 d-1) dominated by UCYN-B (Stenengren et al., 2017). The differing δ15N signature of suspended particles measured over the photic layer of MA (-0.41‰ and GY waters (8.06‰ confirms the presence of two contrasting regions in terms of N2 fixation. Thanks to the lagrangian strategy followed at the LD stations (Moutin et al., 2017a), and the low dispersion measured showing that we sampled the same water masses, N-budgets were established Caffin et al. (2017). N2 fixation was the major external source of N representing more than 90 % of new N input into the photic layer, and the e-ratio quantifying the efficiency of a system to export particulate organic matter was higher in MA waters than in GY waters (Caffin et al., 2017). Caffin et al. (2017b) revealed that the diazotroph-derived nitrogen (DDN) was efficiently transferred from diazotrophs (Trichodesmium and UCYN) to non-diazotrophic phytoplankton, both autotrophs and heterotrophs. Hunt et al., (2017) report an efficient transfer of DDN in zooplankton. The fate of C and N was under the influence of programmed cell death in diazotrophs (Berman-Frank et al., 2017) but diazotrophs were poorly exported directly, and we suspect that this transfer of DDN fueled indirect export associated with N2 fixation. By using nitrogen isotope budgets, Knapp et al., (2017) confirmed that >50% of export production was supported by N2 fixation in MA waters. Stenegren et al. (2017) identified a clear niche separation between a subsurface (UCYN-A1 and A2 with their hosts) and a surface group (Trichodesmium, UCYN-B and the het-group) based on a temperature-depth gradient. They also found discrepancies between the UCYN-A and their hosts in both abundances and distributions which suggest that the UCYN-A could be living freely or with a wider diversity of hosts than previously believed. Finally, the assemblage of epibiotic micro-organisms associated with Trichodesmium were characterized in relation with environmental parameters (Frischkorn et al., 2017). N2 fixation in the ocean does not only occur in tropical sunlit surface waters, but also in less obvious environments such as temperate latitudes and aphotic waters. Here, N2 fixation was measured also in the mesopelagic zone along the OUTPACE transect and the diazotroph community present were identified. Deep N2 fixation rates were low but measurable and recurrently found along the transect with the exception of the easternmost stations located in the ultraoligotrophic subtropical Pacific gyre (Benavides et al., 2017). N2 fixation activity was presumably driven by the dominating Gamma-proteobacterial community, and fueled by the presence of labile organic matter compounds. Benavides et al. (2017) provided further evidence that N2 fixation in the deep ocean is not negligible and likely impacts global nitrogen inputs in a significant manner. The dynamics of phytoplankton (Bock et al., 2017; Leblanc

et al., 2017; Lefevre et al., 2017; Guidi, 2017), heterotrophic bacterioplankton (Van Wambeke et al., 2017), and zooplankton (Carlotti et al., 2017; Hunt et al., 2017) along the zonal gradient of diazotroph diversity and activity are described together with the composition and distribution of dissolved organic carbon (Panagiotopoulos et al., 2017) and the changes in inorganic carbon content along the longitudinal transect (Wagener et al., 2017). Stations sampled during the OUTPACE cruise were characterized by a highly stratified community structure, with significant contributions of Prochlorococcus and picophytoeukaryote populations to biomass (Bock et al., 2017). Size-fractionated results show a non-negligible contribution of the pico-sized fraction (<2-3 μm) to both Si biomass and uptake, which could confirm the previous hypothesis of Si assimilation by Synechoccocus populations or reflect the presence of an overlooked Si group such as Parmales (Leblanc et al., 2017). Surface DOC concentrations varied little (50-75 μM) across the transect with slightly higher values observed at LDB (78 μM), and labile organic matter (sugars were used as a good proxy) closely followed DOC patterns ranging from 1.5 to 3 μM with higher values also recorded at LDB (3.5 μM). Labile organic matter accounted about 3-5% of DOC with glucose being the dominant sugar (> 60% of total sugars). Valdes et al., (2017) suggest that copepods can retain N and P compounds obtained from feeding in the upper layer, preventing the rapid loss of these nutrients. Copepods were able to sustain and modify the composition of microbial communities and could provide P for further development of cyanobacterial blooms. Optical properties of the WTSP waters are presented, with a focus on the cyanobacterial (diazotroph) impact upon bio-optical properties, UV-VIS light attenuation (Dupouy et al., 2017) and chl a algorithms (Frouin et al., 2017). Operational NASA bio-optical algorithms (OC4v6, OCI) substantially underestimated surface chlorophyll-a concentration, but a normalized reflectance difference index, robust to atmospheric correction errors, performed well over the range of chlorophyll-a values encountered across the transect (Frouin et al., 2017). Trichodesmium is considered the main nitrogen-fixing species, especially in the South Pacific region. Due to the paucity of in situ observations, alternative methods for estimating the presence of Trichodesmium must be sought to evaluate the global impact of these species on primary production. Rousset et al. (2017) elaborate a new satellite-based algorithm and use that algorithm to estimate the extent of Trichodesmium surface blooms and their dynamics during the OUTPACE experiment. Finally the main processes controlling the biological carbon pump in the WTSP were investigated using 1DV (Gimenez et al., 2017) and regional (Dutheil et al., 2017) biogeochemical-physical coupled models. The new knowledge gained on the interactions between planktonic organisms and the cycle of biogenic elements are then used to propose a new scheme for the biological carbon pump functioning and its role, at the present time and in the near future, in the oligotrophic Pacific Ocean (Moutin et al., 2017b).

Rev. 1: I have some minor suggestions as follows: Page 2: line 32, oligotrophic itself means low concentration so the 'oligotrophic' word is redundant here.

Resp.: We deleted "in the oligotrophic ocean"

Page 3: line 9, This 60% is only the surface area (not the volume), so 'ocean' could be replaced by 'surface ocean' to make explicitly clear.

Resp.: We did this correction.

Rev. 1: C1 Page 4: lines 3-5: "A d15N budget. . .. .export production". Please check the recent work done in the Arabian Sea by (Gandhi et al. 2011; Kumar et al. 2017), who showed that the contribution of N2 fixation to export production can be up to 92%.

Resp.: We modified the sentence :"A δ15N budget performed in the mesocosms confirmed the high contribution of N2 fixation (56 %, Knapp et al., 2016) to export compared to other tropical and subtropical regions where active N2 fixation contributes 10 to 25 % to export production (e.g. Altabet, 1988; Knapp et al., 2005)" as follows : "A δ15N budget performed in the mesocosms confirmed the high contribution of N2 fixation (56 %, Knapp et al., 2016) to export compared to other tropical and subtropical

regions where active N2 fixation contributes 10 to 25 % to export production (e.g. Altabet, 1988; Knapp et al., 2005) and exceptionally up to 92% in the Arabian Sea (Gandhi et al. 2011; Kumar et al. 2017)."

Rev. 1: Page 4: line 9, 'significant contribution', provide the quantitative estimate. I am not sure though if nanoSIMS could provide that. Since the authors mentioned 'significant', it becomes important to know the quantitative amount.

Resp.: The sentence :" the use of nanoSIMS (nanoscale Secondary Ion Mass Spectrometry) enabled tracking the fate of 15N from both Trichodesmium (Bonnet et al., 2016b) and UCYN blooms (Berthelot et al., 2015; Bonnet et al., 2016c), and demonstrated that a significant fraction of N originating from N2 fixation is quickly transferred to non-diazotrophic plankton, in particular diatoms (i.e. efficient C exporters to depth, (Nelson et al., 1995) during Trichodesmium blooms (Bonnet et al., 2016b)." has been modified as follows : "the use of nanoSIMS (nanoscale Secondary Ion Mass Spectrometry) enabled tracking the fate of 15N from both Trichodesmium (Bonnet et al., 2016b) and UCYN blooms (Berthelot et al., 2015; Bonnet et al., 2016c), and demonstrated that $\sim$8 % of N originating from N2 fixation is quickly transferred to non-diazotrophic plankton, in particular diatoms (i.e. efficient C exporters to depth, (Nelson et al., 1995) during Trichodesmium blooms (Bonnet et al., 2016b)."

Rev. 1: Page 4: line 15, 'this question', which question?

Resp.: We replaced the sentence by "The western tropical south Pacific (WTSP) is an ideal location to study the fate of N fixed by N2 fixation"

Rev. 1: Page 4: line 16-21, "While average. . .. . New Caledonia". Again see (Gandhi et al. 2011; Kumar et al. 2017), who observed the highest ever rates anywhere in the world ocean. Particularly check the table (2) in (Kumar et al. 2017) that has listed all and compared all the rates – updated after (Benavides and Voss 2015).

Resp.: It is written “which is in the upper range of rates reported in the global N2 fixation MAREDAT database and even surpassed its upper rates (100-1000 μmol N m-2 d-1) (Luo et al., 2012)” which is indeed the case. We nevertheless added the sentence. Very high rates have also been recently reported in the Arabian Sea (Gandhi et al. 2011; Kumar et al. 2017).

Rev. 1: Page 5: line 18, satisfactory does not sound proper here. It is subjective – it could be satisfactory to one person but not to others.

Resp.: We deleted “satisfactory”

Rev. 1: Page 6:, lines 5-6, revise the sentence for grammar

Resp.: We deleted “as follows” in the sentence: Following the planned adaptive strategy, the initial transect designed to approximately follow 19° S was modified along-route thanks to the information coming from satellite images.

Rev. 1: Page 7: line 16, Marine Video Profiler does not acronym to UVP. Do the authors mean Underwater Vision Profiler?

Resp.: Yes, thank you.

Rev. 1: Table 1: (deg, min) data are just converted to degrees in the next columns, which is redundant.

Resp.: Right but it is helpful for the other scientists who will publish in the special issue. We prefer to leave it like it is to avoid future conversion error in other ms.

Rev. 1: Fig. 1: N2 fixation is discussed several times in the manuscript. It would be helpful to represent this process in this schematic diagram.

Resp.: We added N2 fixation in Figure 1.

References Benavides, Mar, and Maren Voss 2015 Five Decades of N2 Fixation Research in the North Atlantic Ocean. Frontiers in Marine Science 2: 1–20. Gandhi,

Naveen, Arvind Singh, S Prakash, et al. 2011 First Direct Measurements of N2 Fixation during a Trichodesmium Bloom in the Eastern Arabian Sea. Global Biogeochemical Cycles 25(4). Kumar, PK, A Singh, R Ramesh, and T Nallathambi 2017 N2 Fixation in the Eastern Arabian Sea: Probable Role of Heterotrophic Diazotrophs. Frontiers: Marine Science 4: 80. âĂČ New Fig. 1 in supplement pdf

New Fig. 1. caption: Major C fluxes for a biological pump budget and main role of N2 fixation. Biological pump: C transfer by biological processes into the ocean interior. DIC: Dissolved Inorganic C, POC: Particulate Organic C, DOC: Dissolved Inorganic C. See Moutin et al., (2012) for a detailed description.

Additional references: Benavides, M., Moisander, P.H., Dittmar, T., Berthelot, H., Grosso, O., and Bonnet, S.: Aphotic N2 fixation is related to labile organic matter in the Western Tropical South Pacific. Biogeosciences, this issue. Berman-Frank, I., Spungin, D., Belkin, N., Van-Wambeke, F., Gimenez, A., Caffin, M., Stengren, M., Foster, R., Knapp, A., and Bonnet, S.: Programmed cell death in diazotrophs and the fate of C and N in the Western Tropical South Pacific. Biogeosciences, this issue. Bock, N., Dion, M., Van Wambeke F., and S. Duhamel. Picophytoplankton Community Structure in the Western Tropical South Pacific During Austral Summer. Biogeosciences, this issue. Bonnet S., Caffin, M., Berthelot, H., Grosso, O., Guieu, C., and Moutin, T. Contribution of dissolved and particulate fractions to the Hot Spot of N2 fixation in the Western Tropical South Pacific Ocean (OUTPACE cruise). Biogeosciences, this issue. Bouruet-Aubertot, P., Cuypers, Y., Le Goff, H., Rougier, G., de Verneuil, A., Doglioli, A., Picheral, M., Yohia, C., Caffin, M., Lefèvre, D., Petrenko, A., and T. Moutin.: Longitudinal contrast in small scale turbulence along 20°S in the Pacific Ocean: origin and impact on biogeochemical fluxes. Biogeosciences, this issue. Caffin, M., Foster, R., Berthelot, H., Stenegren, M., Caputo, A., Berntzo, L., and Bonnet, S.: Fate of N2 fixation in the Western Tropical South Pacific Ocean: Transfert of diazotroph-derived nitrogen to non-diazotrophic communities and export of diazotrophs. Biogeosciences, this issue. Caffin, M., Moutin, T., Bouruet-Aubertot, P., Doglioli, A., Berthelot, H., Grosso, O., Helias-Nunige, S., Leblond, N., Gimenez, A., de Verneil, A., and Bonnet, S.: Nitrogen budget in the photic layer of the Western Tropical South Pacific (WTSP) Ocean: evidence of high nitrogen fixation rates. Biogeosciences, this issue. Carlotti,F., Pagano, M., Guilloux, L., Donoso, K., and Valdes, V.: Mesozooplankton structure and functioning across the Western Tropical South Pacific Ocean. Biogeosciences, this issue. De Verneil A., Rousselet L., Doglioli A., Petrenko A.A., Bouruet-Aubertot P., Maes C., Moutin T. OUTPACE Long Duration Stations: Physical variability and context of biogeochemical sampling. Biogeosciences, this issue. De Verneil A., Rousselet L., Doglioli A., Petrenko A., and Moutin T.: The Fate of a Southwest Pacific Bloom: Gauging the impact of submesoscale vs. mesoscale circulation on biological gradients in the subtropics. Biogeosciences, this issue. Dupouy C., Frouin R., Maillard M., Tedetti M., Charriere B., Roettgers R., Martias C., Rodier M., Pujo-Pay, M., Duhamel S., Guidi L., and Sempere R.: Influence of cyanobacteria on Longitudinal and short-term variations in UV-Vis optical properties in the Western Tropical South Pacific Ocean. Biogeosciences, this issue. Dutheil, C., Menkes, C., Aumont O., Lorrain A., Bonnet S., Rodier M., Shiozaki, T., and Dupouy C.: Impact of Trichodesmium sp. on Pacific primary production. Biogeosciences, this issue. Frischkorn, K.R., Krupke A., Dyhrman, S.T., and Van Mooy, B.A.S.: Quorum sensing influences Trichodesmium consortia physiology in the oligotrophic South Pacific. Biogeosciences, this issue. From large to submesoscale circulation influence during the OUTPACE cruise (SouthWest Pacific). Biogeosciences, this issue. Frouin, R., Dupouy, C., and Tan, J.: Chlorophyll-a algorithms for South Pacific oligotrophic waters. Biogeosciences, this issue. Fumenia, A., Moutin, T., Petrenko, A., Doglioli, A., de Verneil, A., and Maes, C.: Optimum multiparameter analysis of the water mass structure in the western Tropical South Pacific Ocean during OUTPACE. Biogeosciences, this issue. Gandhi, N., Singh, A., Prakash, Ramesh, R., Raman, M., Sheshshayee, M. S. and Shetye, S.: First direct measurements of N2 fixation during a Trichodesmium bloom in the eastern Arabian Sea, Global Biogeochem. Cycles, 25, GB4014, doi:10.1029/2010GB003970, 2011. Gimenez, A., Baklouti, M.,

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Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/bg-2017-50/bg-2017-50-AC1-supplement.pdf

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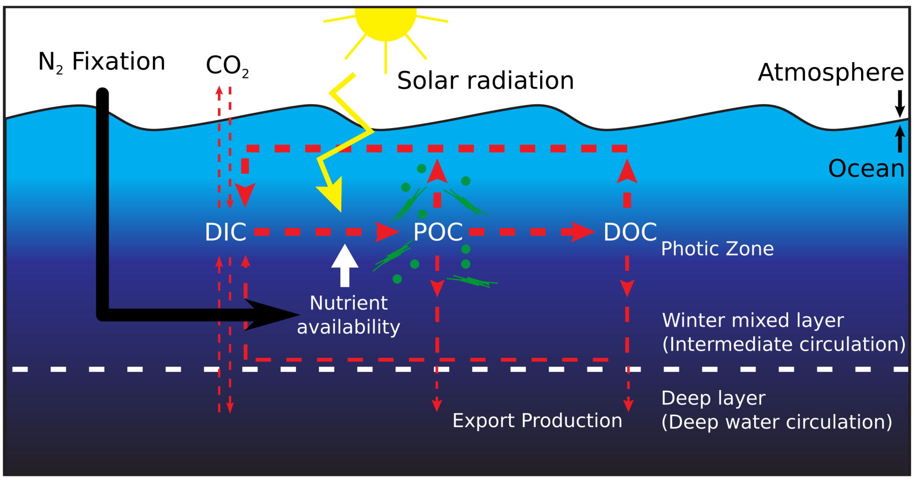

Fig. 1.