Marseille, March 8th 2018

To : Associate Editor, Laurent MÉMERY

Subject : Submission of revised manuscript

Dear Editor,

First, we would like to thank again the reviewers for their valuable comments on our manuscript entitled «Large to submesoscale surface circulation and its implications on biogeochemical/biological horizontal distributions during the OUTPACE cruise (SouthWest Pacific)». We are pleased to submit a revised version of our manuscript. We also provide a version of the manuscript that includes track changes so that you and the reviewers can easily identify changes from the previous version. As reported in both responses to the reviewers, we followed most of their comments because we believe they contributed to improve the quality and robustness of our study.

Considering the major changes required, large portions of the manuscript have been rewritten. Therefore we were unable to provide the correct page and line numbers corresponding to the modifications in our responses to the reviewers. We hope this will not be an inconvenience to the reviewers. Please, also note that in addition to the modifications requested by the reviewers, we have improved figures 7b and 8b. Since we estimated the abundance of other picoplankton groups, we added these data in figures 7b and 8b of the submitted version. For a better visualization we decided to divide the previous figures into two subplots. These new data do not alter the outcome of this study but rather reinforce our results.

Hereinafter, we provide both responses to reviewers and the version of the manuscript including track changes.

We would be grateful if you would consider the new version of our manuscript for publication.

Your sincerely,

Louise Rousselet
on behalf of the coauthors.

Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2017-456-AC1, 2018

Interactive comment on "Large to submesoscale surface circulation and its implications on biogeochemical/biological horizontal distributions during the OUTPACE cruise (SouthWest Pacific)" *by* Louise Rousselet et al.

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We would like to thank the Anonymous Referee 1 for his review. In the following we respond to the reviewer's comments and we follow most of his proposition in order to improve our work and its presentation. For clarity, the reviewer's remarks are copied in bold.

In seeking to explore causes and consequences of spatial gradients in the Western Tropical South Pacific, as part of OUTPACE, this manuscript tackles the role

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of physical advection at different scales. More specifically it investigates how the circulation at large, mesoscale and submesoscale relates to the observed biogeochemical and biological fields. This is important context for the OUTPACE experiment and should be published. There are issues I'd like to see addressed before I can recommend this. The most significant issue is that the authors overstate the robustness of their results. It would always have been a difficult task to interpret the influence of the physical circulation at all scales studied given the linear nature of the cruise.

Indeed, we agree definitely with your point but, if it is very difficult to fully explore the influences of the physical circulation considering only data collected during the cruise combined with satellite data, it remains one important step to explore before using models and build other observational strategy. Here we wanted to give the most complete picture as possible, given the available data from the cruise, of the circulation at scales that are known to play a major role and their potential influence on biogeochemical variabilities. This, of course, leads to make some assumptions that are not verified yet in this paper. We agree to pay attention in separating the observations part and the hypotheses made to explain them as well as the potential influences raised by these observations.

The claim of demonstrating 'the influence of fronts in controlling the distribution of bacteria and phytoplankton' on the basis of 2 transects and a weak (but admittedly significant) correlation is optimistic. An example of this is the interpretation of Fig 6 on page 12 (lines 21-23). The Chl and other fields decrease over a much larger area than the location of the "tip". The "tip" could presumably have occurred anywhere along this section of decreasing biological fields with the authors drawing the same conclusion.

We agree with the reviewer that the focus should not be on the tip of the FSLE as, also considering the resolution of the satellite data, the "real" physical barrier might be offseted by a few kilometers. What is interesting in this studied case is that the FSLE delimit a region of relatively high abundance of organisms and a region of relatively low abundance on each side of it. In section 3.4, we describe and discuss what appears to be the clear influence of fronts in the two case studies. These are two examples of the potential influence of fronts on the horizontal phytoplankton distribution. We are not suggesting that every front will lead to a separation of phytoplankton community, but that some of them can. Here we propose to rename section 3.4 to "Example of physical barriers' influences on phytoplankton community" and to add the following sentences to help the readers to clearly understand the conditional form on such influence: "In this section we present two case studies that highlight the potential influence of fronts on phytoplankton horizontal distribution. To test the hypothesis of Bonnet et al..".

The combination of Results and Discussion risks being misleading as in several places statements based on direct observation are followed by conjecture written in a similar direct way, sometimes with neither data nor further analysis nor reference to support them e.g. discussion of El Nino and winds at end of Section 3.1 ("data not shown"), "eddy-eddy interactions might be responsible for the emergence of complex paths" on page 10 (line 11), lines 13-18 on page 10, talking of microbial growth with no observations of it on p13 line 9, "isolating areas with different biogeochemical characteristics" on line 17 on page 11. The latter in particular is over-played. Figures 6 and 7 are interpreted as showing coincidence of FSLE and organisms or segregating organisms but this might be guided by the eye of the faithful. Interpreting a "relatively better correlation" (page 11, line 27) as evidence for "not randomly distributed" with 75% of cases still not showing a match is another example as the upper threshold of 25% that is possible from satellite altimetry comes with no evidence to support it. I don't have a problem with conjecture as I think it's an important means of directing future research, but I would recommend pushing analysis further to back these thoughts up and either splitting Results and Discussion or else making much clearer where the reporting of observations ends and speculation begins.

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We understand the reviewer's concern about the combination of Results and Discussions together as this question was raised during the article scripting process. In consequence, we decided to describe the circulation from large to submesoscale through a descending approach and it was a difficult task to split the Results and the Discussion into two different sections as the Discussion will refer to different sections of the Results part. To avoid the reader a back and forth exercise between what was described in the Results and what was suggested in the Discussion, we believed (and still do) it is more convenient to directly discuss the results highlighted. So we tried to be extremely rigorous with the tenses: using the direct way to talk about the results and the conditional way (could, may, might...) to talk about the potential influence of the observations. However we understand that some parts, listed by the reviewer, were still suffering from a lack of clarity. To avoid confusion, we propose to clearly split the results and discussions into different paragraph in each existing subsections (3.1, 3.2, 3.3, 3.4) and to add few sentences to clarify the transition between the observations of the circulation and the potential impact on biogeochemical distributions:
- Section 3.1 "Considering the large scale biogeochemical distribution, the meridional transport observed could lead to ..."
- Section 3.2 "Coherent mesoscale features are well-known to participate in the surface biogeochemical variations ..."

The comparison of satellite-based advection proxies with drifter data seems to be a more significant piece of work than acknowledged here and I would like to see it rescued from the Appendix and given a more thorough account in the main body of the paper. As part of this it would be good to see a discussion of the possible bias of comparing trajectories of just a few real floats with many more virtual ones and an acknowledgement of the fact that the streamfunctions only really do a reasonable job compared to drifter trajectories for LDC (Figure A1) and why this might be so.

We agree with the reviewer's suggestion and we propose to add a new subsection in

Material and Methods to detail the comparison between the different satellite-based advection and in situ drifters. The new subsection would be *2.4 Comparison of satellite products with in situ drifters*. It would include the Figure 1 and discussion raised in the third comment of Referee#2.

Minor: Page 3, line 6: I'm not sure I'd describe the surveyed area as 'relatively high kinetic energy' or 'intense' given that it only visits the high value areas intermittently in Fig. 1.

The "relatively high eddy kinetic energy" refers also to the study by Qiu et al., 2009. That's why we propose to change the sentence as follows : " As displayed in Figure 1, the OUTPACE cruise was conducted in the transition area between a zonal band of relatively high eddy kinetic energy south of 19°S (Qiu et al., 2009) and low eddy kinetic energy to the north. "

Page 4, line 21: how was DIP turnover time calculated and why is it of interest?

As describe in Moutin et al. (this issue), Dissolved Inorganic Phosphate (DIP) turnover time represents the ratio between Phosphate natural concentration and Phosphate uptake by planktonic species (Thingstad et al., 1993). It is considered the most reliable measurement of phosphate availability in the upper ocean waters (Moutin et al., 2008). In our region of interest, the phytoplankton growth, and in particular nitrogen fixers, is often limited by Phosphate availability and Phosphate may appear as a key factor controlling carbon production (Van den Broeck et al., 2004). This parameter thus gives an important information on the biological activity. As these clarifications are important, we add them in Material and Methods : "Dissolved inorganic phosphate turnover times (TDIP) were determined using a dual 14C-33P labelling method following Duhamel et al. (2006) and described in Moutin et al. (this issue). As describe in the latter, DIP turnover time represents the ratio between Phosphate natural concentration and Phosphate uptake by planktonic species (Thingstad et al., 1993). It is considered the most reliable measurement of phosphate availability in the upper ocean waters (Moutin et al., 2008). In the WTSP, the phytoplankton growth is often limited by Phosphate availability. This parameter thus gives an important information on the biological activity in relation to resource availibility : a very short DIP turnover time means rapid utilization of the ambient phosphate present in limiting concentration, whereas a long DIP turnover time represents a slow utilization of the ambient phosphate present in higher concentration."

Page 7, line 33: "...and 0.2...as thresholds..." In several places 'west' and 'east' are confused. e.g. page 8, line 27; page 10, line 2; page 10, line 28

We checked and corrected the points highlighted.

Page 8, line 29: explain location/extent of Melanesia

We modify the sentence as follows : " Moreover the path through the Melanesian area, which includes the multiple islands from Papua New Guinea to Fiji (140°E-170°W), may enrich these waters due to the contact with islands whereas... "

Page 11, line 7: I think it is debatable that chlorophyll shows a "reasonable correlation in Fig. 5. Scatter plots and correlation n coefficients would be more convincing.

Correlation coefficients are mentioned in Section 2.2 p5 L34 : 0.8 for both temperature and chlorophyll, which is a reasonable value when comparing in situ data and satellite-derived data. Below we plot the difference between in situ temperature (chlorophyll) and satellite data (Fig. 1 and 2 respectively). In temperature, we get differences between +1.5°C and -1°C which allows us to confidently use satellite temperature. For chlorophyll, the differences are smaller than ±0.1 mg m^{-3} which is also a reasonable deviation between satellite and in situ measurements, besides considering the colorbar scale of Figure 5 with values that vary from 0 to 1 mg m^{-3}. We can also note that the satellite data clearly underestimate chlorophyll concentrations in the Melanesian area. We believe this figure and explanation could help the reader, so we decide to add the figure in the Appendix and to add this text in Section 3.3 : "The differences

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between in situ temperature (chlorophyll) and satellite data are plotted on Figure A4 (top and bottom respectively). In temperature, we get differences between +1.5°C and -1°C which allows us to confidently use satellite temperature. For chlorophyll, the differences are smaller than ±0.1 mg/m^{-3} which is also a reasonable deviation between satellite and in situ measurements, besides considering the colorbar scale of Figure 5b with values that vary from 0 to 1 mg/m^{-3}. We can also note that the satellite data clearly underestimate chlorophyll concentrations in the Melanesian area."

Figure 4: The backward and forward streamfunctions cross, particularly for LDA. This warrants comment.

We agree with the reviewer: this is very interesting that around LDA backward and forward paths cross. This highlights again the complexity of the circulation between New Caledonia and Vanuatu, characterized by meanders and recirculations. We propose to add a comment about this in Section 3.2 as it reinforces the previous observations of complex path in this area (Rousselet et al., 2016) : "Backward and forward streamfunctions cross around station LDA which suggests that the area between New Caledonia and Vanuatu is a region of complex recirculation with waters that stay in this region for a while before exiting the Coral Sea."

Page 22, Fig 5 middle: why are the data points for the TSG so far apart given that it is a flow-through system?

Indeed the TSG provides data every 1min30, however plotting these data on a scatter plot including the whole cruise route requires a large amount of memory to finally obtain a not so clear information. Thus to reduce the size of the figure and provide an useful comparison with the satellite image, we decided to plot a weighted mean over 5 days that is the time interval used to produce the composite satellite images. As a consequence the position of the point depends on the position of the boat every 5 days. We performed the same calculation for underway chlorophyll data (Fig. 5b). In order to avoid misunderstanding, we precise in the caption that TSG and chlorophyll data point correspond to weighted mean data over 5 days as follows : “ Top : . . . superimposed with 5 days weighted mean of sea surface temperature (°C) from TSG... .Center : . . . superimposed with 5 days weighted mean of surface chlorophyll concentration...“.

Figures 6 and 7: it is difficult to relate top and bottom panels with one labelled in degrees and the other in km.

Referee #2 also pointed out this issue. We agree to change both figures and to plot Fig 6b. and Fig 7b. in degrees (Fig.3 and 4).

Figure 7: what are the white squares? Missing data due to cloud ?

Indeed white squares are missing data due to cloud covering as we use satellite data from a specific day. This missing information will be added in the caption for more clarity : “ White squares are missing satellite data due to cloud cover.”

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Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-456, 2017.

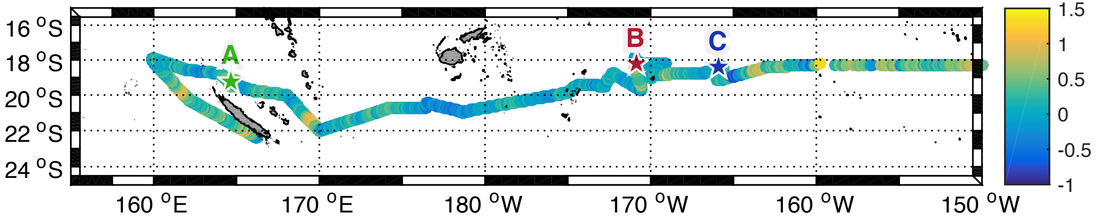

Fig. 1. Difference between in situ surface temperature from TSG and satellite-derived sea surface temperature from CLS (°C)

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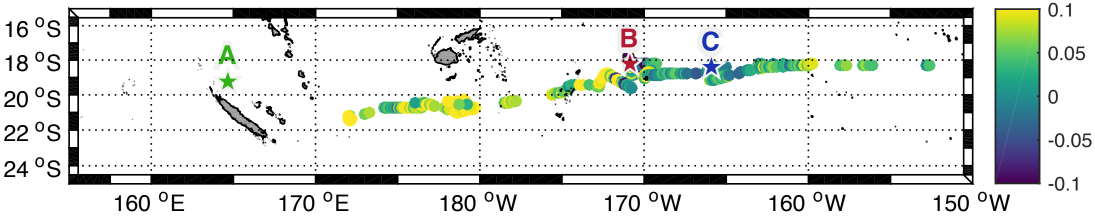

Fig. 2. Difference between in situ surface chlorophyll concentration from the underway survey and satellite-derived sea surface chlorophyll concentration from CLS (mg mËL’^{3})

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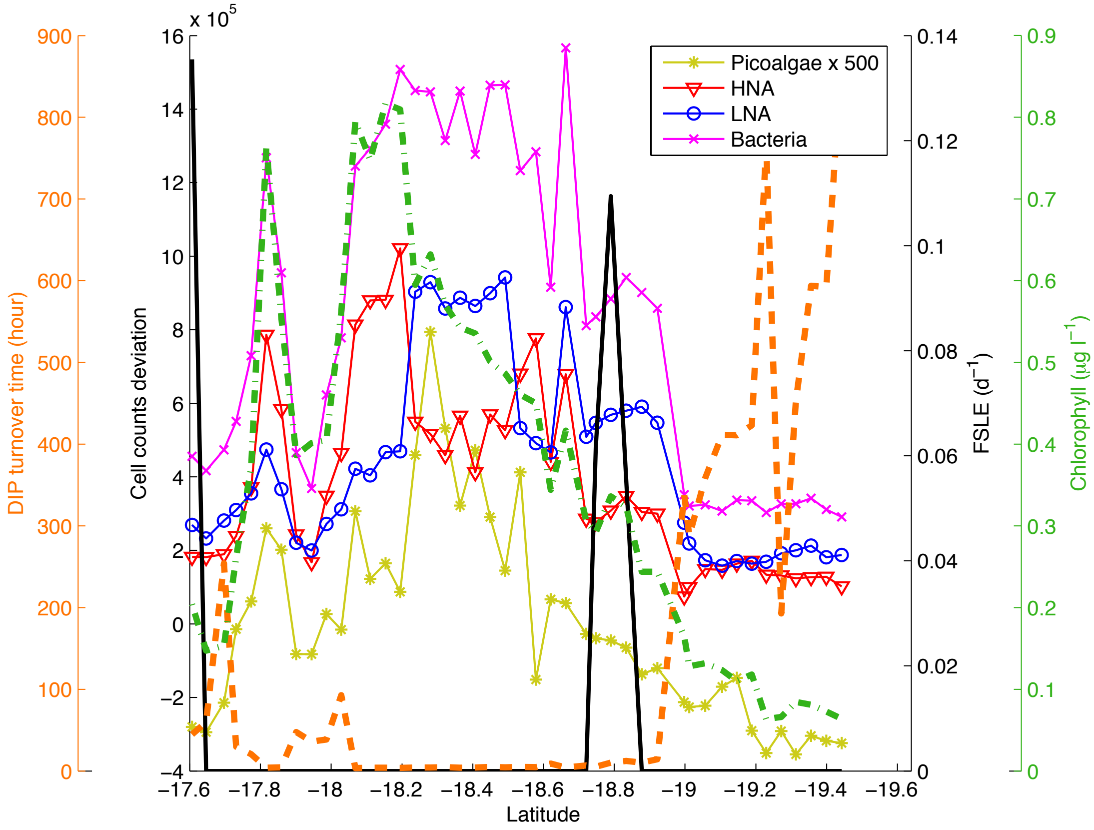

Fig. 3. Modified figures 6b

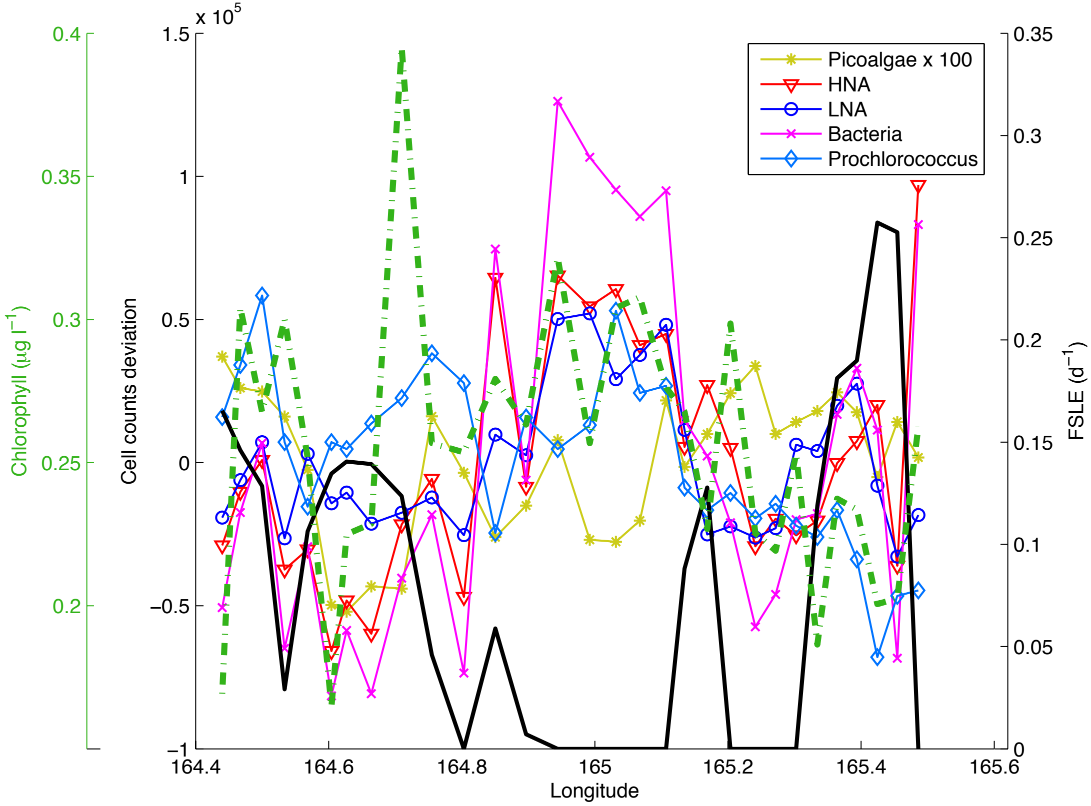

Fig. 4. Modified figures 7b

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Interactive comment on “Large to submesoscale surface circulation and its implications on biogeochemical/biological horizontal distributions during the OUTPACE cruise (SouthWest Pacific)” *by* Louise Rousselet et al.

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First, we would like to thank the Anonymous Referee 2 for his review. In the following we respond to his comments. We followed most of the remarks addressed and we believe the modifications improve our manuscript.For clarity, the reviewer’s remarks are copied in bold.

This paper aims to highlight the role of large to submesoscale surface circulation on biogeochemical/biological horizontal distribution during the OUTPACE

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cruise. This cruise, held in Feb-April 2015, was dedicated to obtain a precise representation of the complex interactions between planktonic organisms and the cycle of biogenic elements along a zonal section in the WTSP ocean crossing contrasting environments . Results from this cruise are being valorized and some papers are already published. Moutin et al. (2017) described the hydrological and dynamical context of biogeochemical sampling. De Verneil et al. (2017) analyse a surface chlorophyll a bloom by combining in situ and remote sensing datasets. They characterize the role of the physical circulation, and in particular the role of surface mesoscale circulation responsible for the bloom's biogeochemical properties. This new paper wants to put the OUTPACE cruise into a more synoptic view by looking at surface satellite data in order to illustrate the role of large scale as well as meso/submesoscale dynamics on the biogeochemial/biological horizontal distributions of OUTPACE data. This is clearly a worthwhile exercise, and the authors have done a substantial work by compiling different satellite data set, and by using original diagnostics. The paper is well written, easy to read. The description of surface conditions by satellite data confirms most of the existing literature. But at first order, the motivation of this study is to do the link between this synoptic approach and the OUTPACE zonal section. It is not an easy task, and as a consequence most of the results are highly speculative. It is not really discuss what is the new contribution of this paper in comparison with the other existing papers dealing with the OUTPACE data. So, at this stage I am not convinced that the materials presented are strong enough to justify a publication. My general comment is to not recommend the paper for publication until an effort was done to better give evidence of the results that motivate this paper.

The first objective of our study was to replace the in situ observations collected during the OUTPACE cruise into a synoptic view. In the framework of the OUTPACE special issue, the idea was also to provide, to everyone working on the same dataset, the most complete picture of the horizontal circulation as possible. We agree on the speculative aspect raised by the reviewer, but we wanted to highlight the significance of each scale (from large to submesoscale) to fully understand the variations that biogeochemists or biologists could identify on their dataset collected during the cruise. Besides the descriptive characteristic of the paper, we feel it is important to give some ideas (speculative by definition) of what could be the effect of the different scales studied in this paper. The originality of this work includes: i) the descending approach in describing both large to meso/submesoscale circulations in the context of an oceanographic cruise; ii) the focus on horizontal submesoscale, as it was indeed already shown that it was difficult to find vertical submesoscale evidences (de Verneil et al., 2017); iii) the example of fine-scale physical influence on horizontal ecological distributions. We consider that these points are appropriate contributions for the community of the OUTPACE cruise and beyond, and we agree to let this appear with more clarity in our manuscript. In particular, we modified the section Introduction to better introduce our objectives at the beginning of the manuscript. We add in Section Introduction:

"In this study we replace the in situ observations collected during the OUTPACE cruise into a synoptic view of the WTSP circulation at different horizontal scale. We investigate through a descending approach the large, meso- and submesoscale patterns using in situ observations obtained during the OUTPACE cruise, coupled with satellite data. Remote sensing provides daily physical and biological information over the entire WTSP for a time period covering the cruise duration and beyond (from June,1 2014 to May,31 2015). The inter-comparison between physical lagrangian diagnostics and available biogeochemical/biological measurements explores the potential influence of each scale on biogeochemical variations. In particular, we propose to focus on the possible impact of horizontal small-scale ocean circulations on horizontal dispersal of tracers such as temperature, salinity or chlorophyll, as well as on biological dynamics. Two original case studies are also presented to illustrate the fine-scale physical influence on horizontal ecological distributions."

l.4: "several studies indicate a strong mesoscale variability due to barotropic instabilities and the interactions of the major currents and jets with the numerous

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islands of the region (Qiu et al., 2009; Hristova et al., 2014)." Barotropic instability doesn't appear as the only source of instability in the WTSP. If barotropic instabilities are related to the NVJ/CSCC/NCJ system (at 16 âŮę S) in most places baroclinic instabilities prevail as in the STCC-SEC system (Qiu and Chen, 2004; Hristova et al., 2014).

We agree with the reviewer and the sentence needs to be modified. We change our text in p3 L4 to: "Superimposed on these large scale patterns, several studies indicate a strong mesoscale variability due to barotropic, baroclinic instabilities and the interactions of the major currents and jets with the numerous islands of the region (Qiu and Chen, 2004; Qiu et al., 2009; Hristova et al., 2014)."

General comment: A great number of satellite data are used. Four different altimetry-derived velocity product are tested: The classic Ssalto/Duacs product that provides maps of absolute geostrophic velocities at 1/4 âŮę of resolution, a similar product at higher resolution (1/8 âŮę) that may include an Ekman component, and a cyclogeostrophy correction. The authors identify the last product as the most accurate in situ surface currents with regards to the trajectories of the SVP floats launched during OUTPACE. It is not surprising than adding the Ekman component improve the comparison with surface drifters. The cyclogeostrophy correction must improve the current associated with eddies by taking account centrifugal acceleration. In my knowledge, it is a really new altimetric product and it could be interesting to illustrate the improvement brought by this correction. On this part, I am reserved because we don't know what are the respective contributions of high resolution, Ekman component, cyclogeostrophy. The result is based by looking at trajectories of numerical particles launched at only the three particular locations where SVP floats were deployed. Besides the relative limited number of locations for the validation, it is difficult to validate such conclusion based only on Fig. A1. If the LDC plot provides a good qualitative agreement, it is not the case for LDA and LDB.

As the choice of the best product relies on a qualitative comparison, we agree that it would be easier for the reader to actually analyze the same figures as we did it. In Fig. 1, we present the 8-days trajectories of in situ floats and numerical particles at each long-duration station and for each satellite-derived products considered (Geostrophy 1/4°; geostrophy 1/8°; geostrophy and Ekman 1/8°; geostrophy, Ekman and cyclo-geostrophy 1/8°). In the case of station LDA, none of the products shows a significant improvement but this can be due to the relative closeness of the station position to the New Caledonia coast. Indeed, we know that satellite measurements are not well resolved close to the coast, and especially near New Caledonia where the topography and bathymetry are very complex. In the cases of LDB and LDC, the increase in resolution does not modify the general pattern of the trajectories, but when adding the Ekman component, we can notice an improvement in the direction of the numerical particles. Even if the particle positions are offseted, their direction are consistent with those of in situ drifters. Cyclogeostrophy seems to accelerate the particles' displacements, which is not surprising. The final positions of the numerical particles are closest to the final position of in situ drifters in the case of LDC. In the context of the OUTPACE cruise, we consider that LDC is a good example of the contribution of each improvement parameter as in the case of LDA and LDB neither improvement or decay are clearly obvious on the trajectories. This analysis and figure appear in a new subsection *2.4 Comparison of satellite products with in situ drifters* as Anonymous Referee #1 also pointed out to the lack of explanations about the comparison with the different satellite datasets. A more quantitative comparison would need a larger dataset of surface floats and a statistic on a greater number of trajectories, but it is clear that such a work is out of the goal of the present study and of the topic of this journal.
Therefore we propose to add the following text into a new subsection 2.4:
"The choice of the satellite product that best represents the surface dynamics relies on a qualitative comparison between the trajectories of in situ floats launched during the OUTPACE cruise (see Section 2.1) and the trajectories of numerical particles computed with each of the satellite-derived velocity field described in Section 2.2. Figure

2 shows the 8-days trajectories of in situ floats and numerical particles at each long-duration station and for each satellite-derived products considered (Geostrophy 1/4°; geostrophy 1/8°; geostrophy and Ekman 1/8°; geostrophy, Ekman and cyclogeostrophy 1/8°). The comparison is restricted to 8 days for a better visualisation and to be consistent with duration of the LD stations. In the case of station LDA, none of the products displays a significant improvement of numerical trajectories. This lack of refinement between the different products may be due to the lack of accuracy of satellite products when getting closer to the coast. Indeed, satellite measurements are not well resolved close to the coast, and especially near New Caledonia where the topography and bathymetry are very complex. In the cases of LDB and LDC, the increase in resolution does not modify the general pattern of the trajectories. However when adding the Ekman component, we can notice an improvement in the direction of the numerical particle trajectories. Even if the particle positions are offseted, their direction are consistent with those of in situ drifters. Cyclogeostrophy seems to accelerate the particles' displacements. The final positions of the numerical particles are closest to the final position of in situ drifters in the case of LDC. This observation is not surprising considering that cyclogeostrophy represents the centrifugal acceleration. In the context of the OUTPACE cruise, we consider that LDB and LDC examples illustrate clear improvements of the new satellite product including geostrophy, the Ekman component and cyclogeostrophy. In the case of LDA and LDB neither clear improvement or decay are obvious on the trajectories. Moreover when considering the surface circulation, it also remains important to take the wind effect, through the Ekman component, into account as it will strongly influence the trajectories of surface waters at large, meso- and submesoscale. As most of the diagnostics used in this study are calculated through particle trajectory computations, the Ekman component is of major significance. As a consequence and to stay consistent all along this study, we decide to chose the product combining geostrophy, the Ekman component and cyclogeostrophy at 1/8° resolution to compute every diagnostics. In the following we will refer to this product as the total surface altimetry-derived velocity field."

Figure A1 have thus disappeared from Appendix.

p.6 l.29: "It is clearly more interesting to use CLS data instead of commonly used AVISO geostrophic surface currents because they include the wind effect and cyclogeostrophy with higher resolution, as well as better represents in situ data." Okay, I agree that the last product should represent in a better way the surface circulation. The authors argue that it is the most interesting data set. I am not against this opinion but it depends on the objective. Is it really interesting to add an Ekman component when you are interested by mesoscale features? The Ekman velocity is a strong component of the surface circulation but it is limited to the thin Ekman layer. So what is the importance of transport in such layer with regard to OUTPACE objectives where processes on the vertical must be crucial and partly related to submesoscale features? In my opinion, it lacks a discussion on the interest of such product for your objective.

In this study, we are interested in the surface circulation, from large to submesoscale, and it is very important to take into account the wind effect on the surface because, as we have seen earlier, it can modify the trajectories of surface waters or buoyant material in the surface layer. We also agree that vertical processes can be crucial but here we decided to focus this paper on the horizontal influence. Hence considering the Ekman component is of major significance as it will strongly influence the large but also the meso/submesoscale circulations. Even if it does not significantly modify the mesoscale structures (defined as eddies), it will affect the trajectories of the water masses/particles. In particular the Lyapunov exponents, that allow for the identification of physical barriers, are calculated through particle trajectory computations. The trajectories bias due to the wind effect addition will increase the more the time scale considered will be large. That is also why it is important to be consistent by using the same product to compute the different diagnostics at the different time/space time scales. One of the main focus of the OUTPACE cruise is to study the dynamics of the diazotrophs in the surface layer (a few dozen meters). The Ekman layer include

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this typical layer on which, of course, vertical biological processes occur. Hence in this study, we consider the surface circulation in an homogeneous layer in which there are some vertical processes. We agree to add this discussion in the additional section (2.4) about satellite product comparison proposed in the previous comment: “When considering the surface circulation, it also remains important to take the wind effect, through the Ekman component, into account as it will strongly influence the trajectories of surface waters at large, meso- and submesoscale. As most of the diagnostics used in this study are calculated through particle trajectory computations, the Ekman component is of major significance.”

p.7 l.1: Figure 4 is cited before Fig. 3

We are sorry about this mistake that would be corrected in a revised manuscript.

Table 1: For me it is mysterious why the statistics of meanders vary so much between backward/forward experiments. Any explanation?

The long-duration stations were positioned within mesoscale structures in real time during the course of the cruise (Moutin et al., this issue), which can explain a high rate of meanders. Indeed, depending on the dynamics of such structures a high number of particles can remain trapped inside or not. The stations were characterized at different stage of the structures’ life. In particular, LDB and LDC were performed in structures that were coherent for a long time but that disappeared (by filamentation and by merging repesctively) quite rapidly after the stations occupation.

General comment: The authors have used Lagrangian approaches based on the recent LAVD method, and the combination of OW and RP parameters used in d’Ovidio (2013). They are very interesting methodologies as they ensure that eddies correspond with trapped waters. It seems more robust that the more classic linear parameter used in Chelton et al. (2011). As it is written both methods are in good agreement so what is the advantage to mix both methods? There is always some subjectivity when defining eddies, also when looking at Fig. C2,

it seems that the RP contours are more in agreement with the velocity field. If one result of this paper is to test different methods to detect and track eddies, it could be interesting to test the methods classically used based on sea level extrema (Chelton, 2011; Chaigneau et al., 2009, Isern Fontanet,).

As highlighted by the reviewer, both methodologies ensure to detect trapping eddies which is the main criteria chosen by the authors in order to focus on structures that may have a biogeochemical/biological influence through mesoscale features' transport. Both methods are compared to check their consistency as, to our knowledge, it was never done before and the LAVD method is rather new. We agree that the eddy detection and tracking is a really interesting question. But we believe that comparing all different methodologies, as in Souza et al. (2011), is a large study that would require to test many different methods, on longer time scale than the cruise and, possibly, in different regions. That is not the objective of this work in the context of the OUTPACE cruise and the special issue, although we think it is a necessary work that should be performed in an other paper. The main objective of our study on mesoscale features is to give an overview of the number of features that may strongly influence the water masses transport and their general circulation in the context of the OUTPACE cruise. However to clarify why we use the three different methodologies (LAVD method, OW parameter and RP parameter), we add the following sentence in Section 3.2: "To ensure that this new detection method is consistent with previous approaches that identify mesoscale features (eulerian Okubo-Weiss parameter) or retention areas (RP), we compare the structures detected with both parameters."

FSLE results are compared with surface gradient measured from the in situ OUTPACE data. Because the OUTPACE section is zonal, the corresponding surface gradient is mainly representative of cross track fronts. This aspect that limits the comparison of the two datasets is not mentioned.

Indeed, this is a good point raised by the reviewer that is mentioned in a revised manuscript in Section 3.3: "The zonal characteristic of the OUTPACE section forces the surface gradient identified with the TSG to be mainly representative of cross track fronts."

p.8 l7: "using altimetric..including the wind effect" and the cyclogeostrophy correction?

Yes, all the diagnostics discussed in section Results and Discussion are computed with the product that include an increase in resolution, geostrophy, the wind effect (Ekman) and cyclogeostrophy. We now give better attention to clarify this point in the manuscript. We believe that adding the new subsection 2.4, about the comparison of satellite products (as previously proposed) will/could help clarifying this aspect with the following sentence: "As a consequence and to stay consistent all along this study, we decide to chose the product combining geostrophy, the Ekman component and cyclogeostrophy at 1/8° resolution to compute every diagnostics."

P.8 l.14: "or an artefact.. due to the short averaging.." It seems in contradiction with the sentence in section 2.3.1: ".. these simulations ensures that the use of a one year time period doesn't significantly modify statistical outputs". Also, with a RT of 15 days max for eddies it would be surprising that mesoscale dynamics have a strong influence on the mean circulation.

We removed this sentence.

p.8 l.15: "The meridional transport does not correspond to any surface current but is mainly due to the south-easterly trade winds. This meridional component appears due to the addition of the Ekman component in altimetry surface velocities (Fig.B1, Supplementary Material). The large scale transport of surface waters in the OUTPACE area is thus a combination of the transport by general well-known surface currents and wind- driven circulations." What are the dynamics which refer to these "surface currents"?? This sentence is a little bit ambiguous. If the "surface current" refers to geostrophic balance, it is normal that it doesn't take account for the well-known poleward Ekman transport. Now

if we look at the circulation inferred from Sverdrup theory, it is not so different of the streamfunction in Fig.2 despite its depth integrated estimation.

Surface currents refer to general geostrophic currents, that can also be depth integrated, identified in the literature (Tomczak and Godfrey, 2013; Kessler and Cravatte, 2013; Ganachaud et al, 2014). Here we try to differentiate between the main currents described in the literature from the actual transport of waters. For example, it is well-known that the South Equatorial Current (SEC) flows westward but it is not obvious for every future reader that the transport induced by the wind is poleward, so that in total the waters would have a southwestward deviation when flowing into the SEC. We were trying to keep in mind that we address a paper to a large community of oceanographers and not only to physicists.
Moreover we have few example of transport calculation in the area. Tomzcak and Godfrey (2013) showed a streamfunction calculated with wind stress (Fig 4.4-4.7) that highlight a global westward transport with very little meridional transport (from the north to the south), apart when they clearly detected a southward flow corresponding to the western boundary current, the East Australian Current (EAC). But this transport occurs very close to the Australian coasts, whereas in our manuscript, we show that we have a southward flow occurring in the entire WTSP. We thus demonstrate that the surface transport can be slightly different from the well-known integrated transport. Kessler and Cravatte (2013) also show the Sverdrup transport stream function (Sv) calculated from Godfrey's Island Rule and the wind stress curl field in the Coral Sea (Figure 4(c)). We find the same southward transport at 10 S due to the South Equatorial Counter Current. However south of 10S, the transport is mainly westward with no southward component. We believe this is an important point for biogeochemists to know that the major part of the waters sampled during the cruise have a northern origin.
Nonetheless we understand the reviewer's concern about this part and the clarifications discussed here should appear in the subsection *3.1 Large scale wind-driven pathways*: "Very few studies got interested in the surface transport inferred by the wind in the WTSP. Indeed Tomczak and Godfrey (2013) calculated a streamfunction from wind-

stress and show a global westward transport with very little meridional transport except in the EAC which is very close to the Australian coasts. Kessler and Cravatte (2013) also computed the Sverdrup transport streamfunction calculated from Godfrey's Island Rule and the wind stress curl field in the Coral Sea. We agree on the southward transport at 10S due to the SECC. However south of 10S, they only identify a westward transport."

P.8 l18: "surface waters travel from northeast to southwest" Fig. C1 shows that most of the waters of importance for OUTPACE comes from the north and the northest as written in l.22.

This point is right: the major part of the waters reaching the OUTPACE area comes from the north. We also want to highlight the eastern origin which is less important but cannot be neglected. The sentence p8ÂăL18 is changed as followsÂă: "Most of the surface waters travel southwest from the northern Ariane section, with a significant part that originates from northeast".

p.8 L27; "west of 170 w" → East of??

Indeed the ultra-oligotrophic waters are located east of 170W. We corrected this mistake.

P.8 28: ".The wind-driven surface transport highlighted here could participate in the biogeochemical variations between western and eastern waters. Indeed the path through the Melanesian area may enrich these waters due to the contact with multiple islands whereas waters that directly recirculate within the gyre keep their ultra-oligotrophic characteristics. " The authors here want to do a link between the wind driven circulation at the surface and biogeochemical variations. It seems very speculative because their argument is the path through the Melanesian area that is also valid for what is named "surface current". Also, what is the role of these surface waters in the biochemical properties against deeper water and vertical processes??

Here we want to highlight that the 170 W longitude limit between waters that recirculate within the gyre (eastward transport at 25S) and waters that flow directly south or southwestward match with the limit between oligotrophic (west of 170W) and ultra-oligotrophic (east of 170W) waters as shown in Moutin et al. (2017, this issue). We believe this may not be a simple coincidence but we agree that this assumption is very speculative. However de Verneil et al. (2017, this issue) showed that the meso/submesoscale horizontal circulation in this area of transition (170W) is a major component to explain the origin of a phytoplanktonic bloom. We thus suggest that this specific surface transport through the islands may create particular conditions in surface biogeochemical concentrations that can influence biological activity.

p.9 l.4: "the OUTPACE cruise took place during an El Niño phase but they determined that climatological effects, upon the results of the cruise, were minimized." The trade winds are very sensitive to ENSO conditions in the WTSP. So the authors argue for little effects of the wind driven circulation upon the results of the cruise. So, it seems to be in contradiction with the fact to use the altimetric product including the wind effect. Also, the authors argue the interest to investigate the mesoscale circulation. I am not sure that the altimetric product they used is well suited for such purpose. At first order, meso and submescale are driven by internal dynamics.

The OUTPACE cruise clearly took place during an El Niño phase as mentioned by Moutin et al. (2017, this issue). If the climatological effects can be minimized for biogeochemical sampling, we show that the circulation/transport is still strongly influenced by the trade winds. It is not surprising that the wind driven circulation plays a key role in this region. That is also why we decided to still take the wind effect in consideration. We added this clarification in p9 L4: " were minimized, for biogeochemical samplings. However we show that the circulation and transport is still strongly influenced by the trade winds." We agree with the reviewer that meso/submesoscale are driven by internal dynamics but the same confusion as raised earlier appears: when we talk about

meso and submesoscale circulation we mean in terms of trajectories at meso and submesoscale not in terms of structures. It is clear that the addition of the wind modifies fine scale trajectories. It is thus important to take this effect into account when considering the backward and forward mesoscale trajectories or the detection of physical barriers. Fig. 2 and 3 are example of the difference between submesoscale features detected with FSLE calculated without and with the wind effect. We can notice that the features detected with geostrophy are still there when adding the wind effect but their shape are somewhat different at fine scale. So it is important to take these variations when considering fine scale distributions of the surface biogeochemical properties.
We believe that the additional subsection 2.4 brings a clarification on this aspect: "When considering the surface circulation, it also remains important to take the wind effect, through the Ekman component, into account as it will strongly influence the trajectories of surface waters at large, meso- and submesoscale. As most of the diagnostics used in this study are calculated through particle trajectory computations, the Ekman component is of major significance."

p.9 l. 20: "If the major part propagates westward, the meridional band between 180W and 170W is identified as a region with mostly eastward propagation of mesoscale structures." Based in Fig.3, it is very hard for me to see propagation. This result is developed in the next sentences to argue for the importance of mesoscale dynamics to transport enriched-fluid into nutrient-poor gyre waters. But this eastern propagation is not really shown and as said by the authors there are no in situ data to illustrate this point. At this stage the discussion is highly speculative.

As raised by the reviewer, this discussion lies on few observations, in particular in de Verneil et al., 2017, that remains to be proved by further in situ observations and analysis. We propose to take this part out to avoid speculations.

P.10 l. 25 " enhanced by the mesoscale transport" Fig.4 shows an eastward transport at LDB but the link with mesoscale is not obvious. Are there particles

trapped into eddies that propagate eastward until LDB? And what their retention time and their distance travelled?

When we talk about mesoscale we refer to the circulation at a scale of the order of 10-100 km which is different than the mesoscale coherent features. A specific experiment was computed around station LDB in de Verneil et al., 2017 to follow the individual trajectories of particles initialized inside the bloom. If the particle trajectories followed the physical boundaries detected with FSLE, no characteristics of eddy trapping has been identified at first sight.

P.11 l. 7 "correlations" It is not really a correlation here

Actually we calculated correlation coefficient between satellite products (SST and Chl) and in situ data from TSG. This comparison resulted in a reasonable correlation of 0.8 between in situ measurements and co-located satellite data as described in Section 2.2.

P.11 l.25; "These latter results also exhibit that an FSLE existence does not necessarily create a gradient but probably needs pre-existing tracer gradients and a lifetime longer than few days." The orientation of the front against the direction of the density gradient could be also an explanation?

This point is correct. The orientation of the front with respect to the direction of the density gradient is also a factor that controls the generation of a strong gradient. A cross-front gradient should be sharper than an along-front gradient. We propose to add this comment in Section 3.4: "Moreover the orientation of the front with respect to the direction of the density gradient is also a factor that controls the generation of a strong gradient."

Fig.6. It should be better if the axis in Fig.6b is in âŮę (as in Fig. 6a) despite than in km. Section 3.4 is the section that best fits with the objective of the paper highlighted in the title. It shows two interesting case studies of interaction

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between fronts and biogeochemical properties. In my opinion, it is the most interesting part of the paper but it is only 1 page. It is regrettable that such results are not discussed with regard to the results of De Verneil et al. (2017). Do strong density gradients correspond with the FSLEs discussed LDB and LDA?

We appreciate the reviewer's interest about this part. As suggested (also by Anonymous Referee #1), the figures 6b and 7b are modified to plot the axis in degree (Fig. 4 and 5). De Verneil et al. (2017) described the fate of the bloom over the period of the station on the vertical and studied the possible origins of this bloom (vertical vs horizontal submesoscale processes). Based on the results of de Verneil et al. (2017), we can conclude that the LDB bloom was generated by horizontal submesoscale processes and bounded by some physical features acting like barriers. In this paper, we support the significance of horizontal submesoscale processes in driving the distribution of phytoplanktonic community. Moreover we add complementary information about the surface community structure of the bloom. Horizontal submesoscale circulation and features, not only help generating the bloom but also drive the species distribution in it. We believe this result is in agreement with what de Verneil et al. (2017) observedÂă: the horizontal submesoscale processes play an important role in the bloom's generation and evolution.

Multiple strong density gradient (as defined in Section 2.3.2) are identified on both High Frequency (HF) sampling transects (Fig. 6 and 7 see red crosses). Most of the strong gradient are localized on an FSLE structure for HFA whereas only few of them match with a FSLE structure in the case of HFB. This observation is in agreement with the discussion p13 l20Âă: the presence of a FSLE does not necessarily imply a density gradient and, vice versa, a density gradient does not necessarily need a FSLE structure to exist. However, it is encouraging that the FSLE highlighted by the comparison with phytoplankton abundances also match with a strong density gradient.

Following the reviewer's comment we add a discussion with de Verneil et al. (2017, this issue) in Section 3.4Âă: “de Verneil et al. (2017) identified the influence of the submesoscale processes in generating the bloom. They also showed that the bloom

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was bounded by some physical features acting like barriers. The results previously presented in this paper support the significance of horizontal submesoscale processes in driving the bloom's dynamic but we also show that the distribution of phytoplanktonic community inside the bloom is conditioned by submesoscale features."

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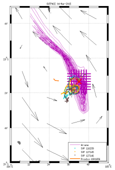
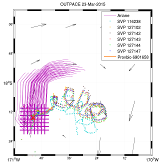
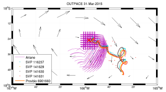
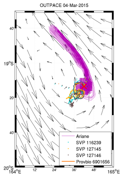
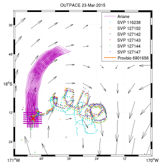
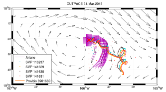
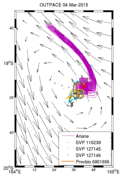
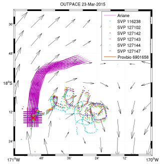
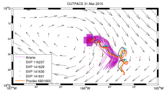
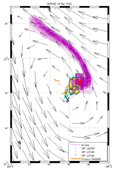
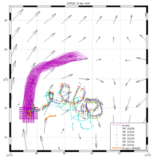
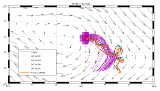
	LDA	LDB	LDC
Geostrophy 1/4º			
Geostrophy 1/8º			
Geostrophy + Ekman 1/8º			
Geostrophy + Ekman + Cyclogeostrophy 1/8º			

Fig. 1. Trajectories of numerical particles computed with Ariane (purple) with each satellite products and in situ floats (colors) for 8 days after the starting date of each long-duration station (LDA, LDB LD

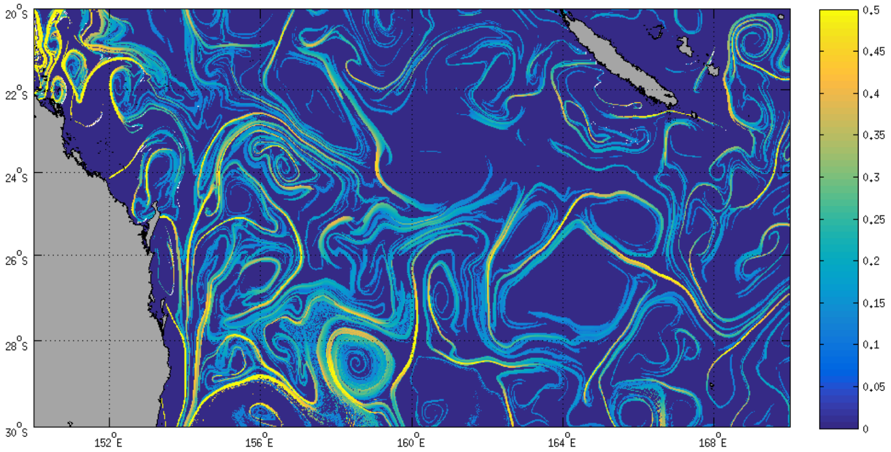


Fig. 2. FSLE features calculated with the high-resolution (only) geostrophy productÂă

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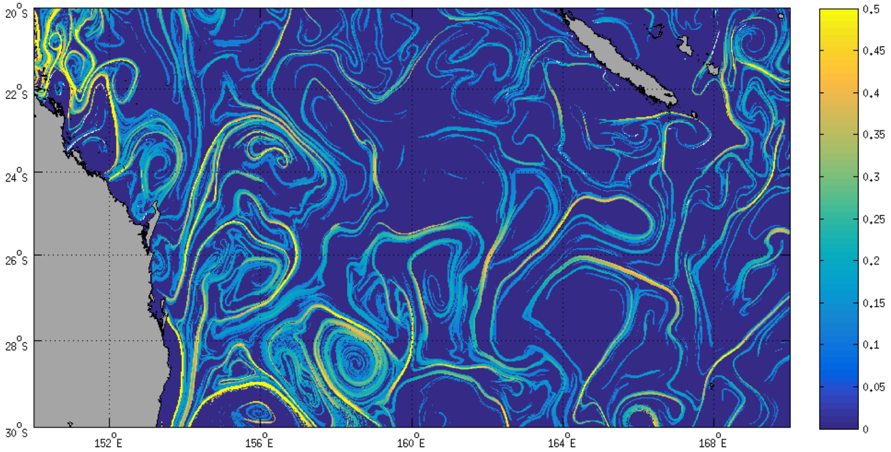

Fig. 3. FSLE features calculated with the high-resolution geostrophy, Ekman and cyclogeostrophy product.

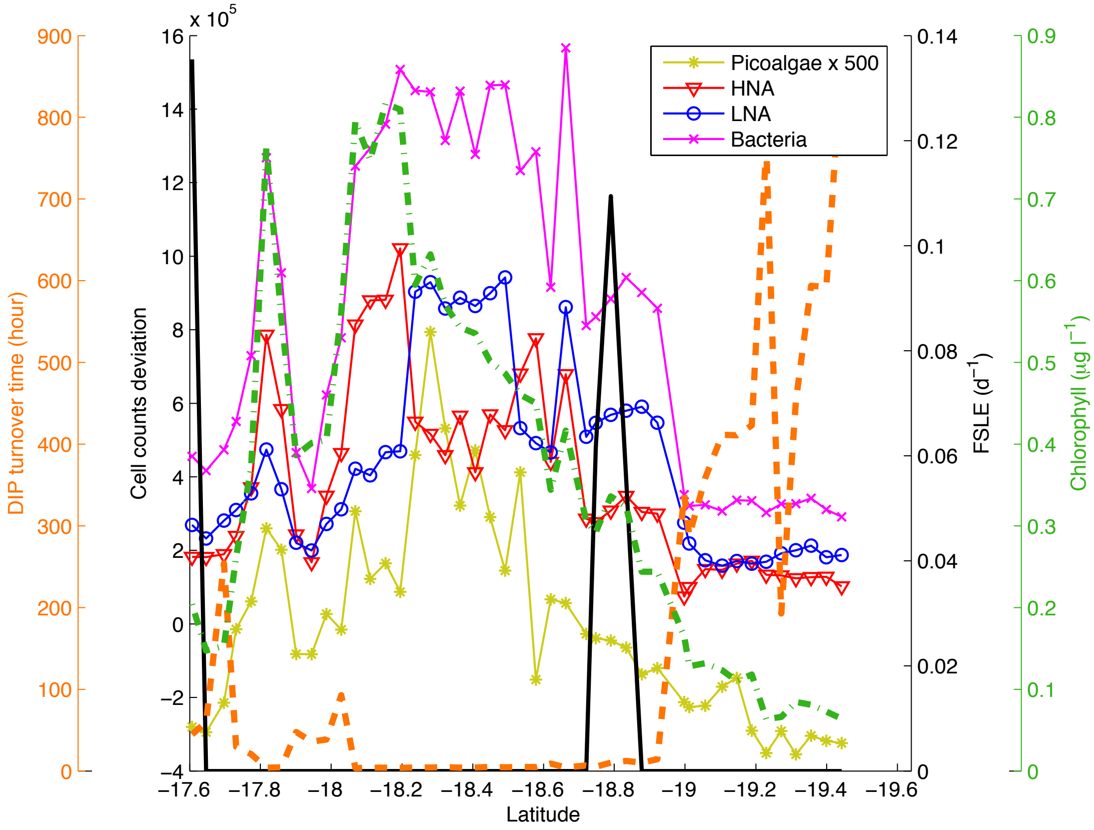

Fig. 4. Modified figures 6b

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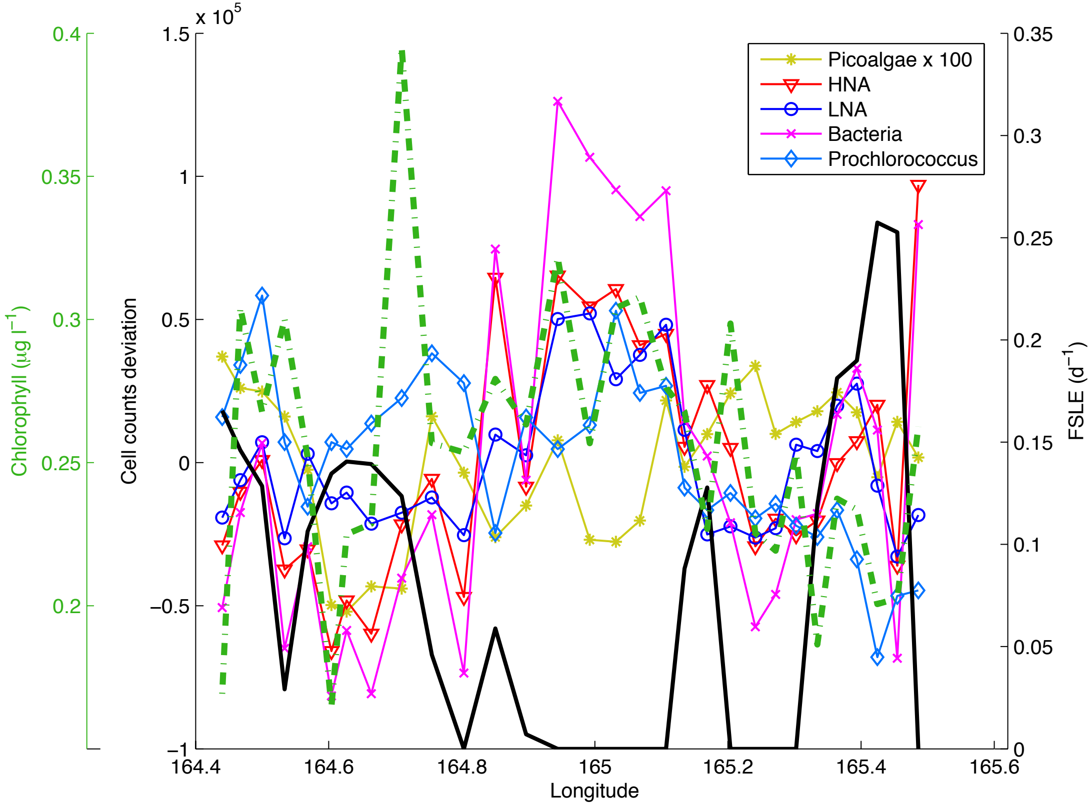

Fig. 5. Modified figures 7b

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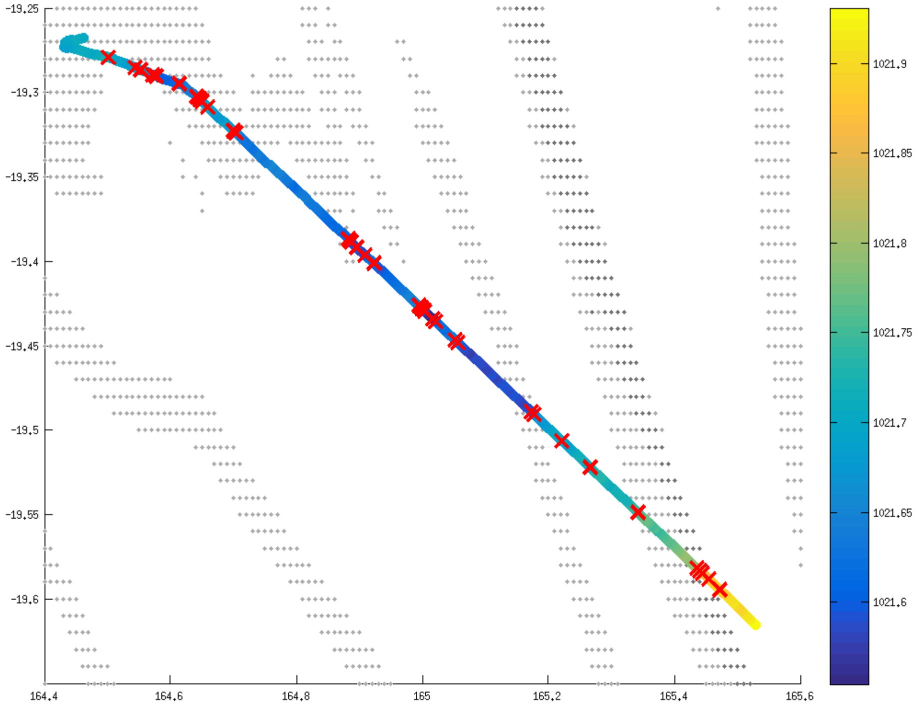

Fig. 6. Sea surface density calculated with TSG temperature and salinity (TEOS-10 standards) at the location of high frequency sampling during LDA (left). Red crosses show the position of stro

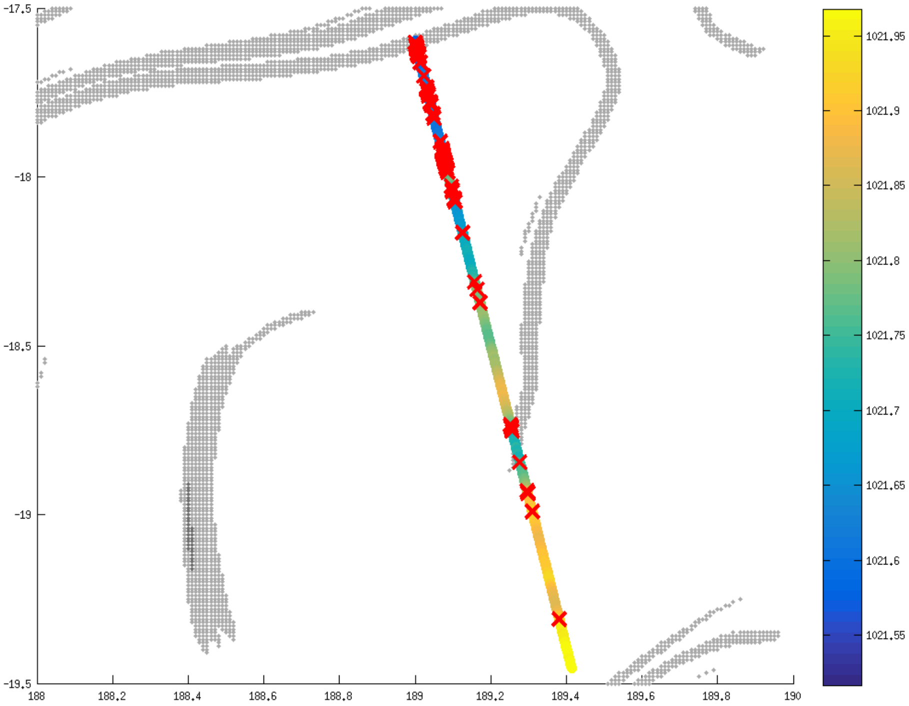

Fig. 7. Sea surface density calculated with TSG temperature and salinity (TEOS-10 standards) at the location of high frequency sampling during LDB (right). Red crosses show the position of stro

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Large to submesoscale surface circulation and its implications on biogeochemical/biological horizontal distributions during the OUTPACE cruise (SouthWest Pacific)

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Abstract. The patterns of the large-scale, meso- and submesoscale surface circulation on biogeochemical and biological distributions are examined in the Western Tropical South Pacific (WTSP) in the context of the OUTPACE cruise (Feb-April 2015). Multi-disciplinary original *in situ* observations were achieved along a zonal transect through the WTSP and their analysis was coupled with satellite data. The use of Lagrangian diagnostics allows for the identification of water mass pathways, mesoscale structures, and submesoscale features such as fronts. In particular, we confirmed the existence of a global wind-driven southward circulation of surface waters in the entire WTSP, using a new high-resolution altimetry-derived product, validated by *in situ* drifters, that includes cyclogeostrophy and Ekman components with geostrophy. ~~Two subregions show~~ The mesoscale activity is shown to be responsible for counter-intuitive water mass trajectories ~~due to mesoscale circulation~~in two subregions: i) the Coral Sea with surface exchanges between the North Vanuatu Jet and the North Caledonian Jet; and ii) ~~the zonal band between 180°W and~~ around 170°W with an eastward ~~propagation~~ pathway whereas a westward general direction dominates. Fronts and small-scale features, detected with Finite-Size Lyapunov Exponents (FSLE), are correlated with 25% of surface tracer gradients which reveals the significance of such structures in the generation of submesoscale surface gradients. Additionally, two high-frequency sampling transects of biogeochemical parameters and ~~micro-organism~~ microorganism abundances demonstrate the influence of fronts in controlling the spatial distribution of bacteria and phytoplankton, and as a consequence the microbial community structure. All circulation scales play an important role that has to be taken into account when analysing the data from OUTPACE but also, more generally, to understand the global distribution of biogeochemical components.

1 Introduction

The zonal trophic gradient of the Western Tropical South Pacific (WTSP) represents a remarkable opportunity to study the interactions between marine biogeochemical Carbon (C), Nitrogen (N), Phosphorus (P), Silica (Si), and Iron (Fe) cycles between different trophic regimes. One of the OUTPACE cruise's goals is to understand how N_2 fixation controls production, mineralisation and export of organic matter (Moutin and Bonnet, 2015; Moutin et al., 2017). The ocean's circulation, at different time/space scales, can play a key role in biological variability and dynamics. In particular the meso- and submesoscale, which occurs at scales typical of phytoplankton blooms (Dickey, 2003), enhance carbon export through vertical motion (Guidi et al., 2012; Lévy et al., 2012) and thus strongly impact the biological pump.

Indeed, mesoscale dynamics (features with time/space scales on the order of months/100 km such as eddies) can affect biological and biogeochemical cycling through transport processes such as horizontal advection, lateral stirring and eddy trapping, as well as through processes that modify nutrients and/or light availability such as eddy pumping, eddy-wind interaction or frontal instabilities (Williams and Follows, 1998; McGillicuddy Jr, 2016). Some observations, mostly collected during the JGOFS program, have shown the influence of eddy circulation in sustaining primary production in oligotrophic regions (Jenkins, 1988; McGillicuddy and Robinson, 1997). Numerically modelled eddy fields also show an enhancement of biological productivity in most provinces of the North Atlantic Ocean (Oschlies and Garcon, 1998; Garçon et al., 2001). ~~Then additional~~ Additional studies also discuss the structuring effect of mesoscale features, such as vortices, on ecological niche composition and distribution, depending on eddy characterictics and eddy stirring (Sweeney et al., 2003; d'Ovidio et al., 2010; Perruche et al., 2011; d'Ovidio et al., 2013). ~~Thus~~ Therefore mesoscale features can have strong ecological impacts through the enhancement of biological production and the creation of favourable conditions for less competitive species, with implications for higher trophic levels.

Smaller ~~scales~~ scale dynamics may also have a significant role in the distribution of biological variability. The submesoscale represents the ocean processes characterized by horizontal scales 1-10 km ~~whose~~ which origins might be linked with the stirring induced by mesoscale interactions and frontogenesis (Capet et al., 2008). At this typical scale, the flow can be characterized by strong stretching lines or vortex boundaries creating physical barriers such as fronts or filaments that are associated with sharp gradients. These structures can contribute to the separation or mixing of water masses and thus impact the horizontal distribution of tracers, biogeochemical and biological matter such as biomass of phytoplankton cells at a front boundary. Indeed microorganisms are buoyant material and their distribution, as well as the biogeochemical components, can be driven by submesoscale activity, whether through direct horizontal advection (Dandonneau et al., 2003), or indirectly following the biogeochemical dynamics. Nitrogen fixing organisms such as *Trichodesmium spp.*, which contribute in sustaining high primary productivity in the Pacific ocean, are known to concentrate around small-scale features in the North Pacific (Fong et al., 2008; Church et al., 2009; Guidi et al., 2012). In the WTSP, Bonnet et al. (2015) argued that *Trichodesmium spp.* abundances might follow gradient distributions. Besides regulating the spatial distribution of ~~micro-organisms~~microorganisms, these features can participate in biological dynamics as they can induce vertical movments of nutrient supplies and chlorophyll (Martin et al., 2001). Lévy et al. (2015) showed that the flow field brings populations into contact in frontal areas which can be characterized by a larger diversity of ~~micro-organisms~~ microorganisms and more fast-growing species. Consequently, submesoscale circulation can influence the planktonic community structure. However, due to their typical scales, mesoscale and submesoscale features, require substantial means to be adequately observed (Mahadevan and Tandon, 2006) and their interactions with biogeochemistry and biology are also hard to elucidate due to their ephemeral nature (McGillicuddy Jr, 2016).

In the ~~WSTP~~ WTSP the large scale circulation is dominated by the anticylonic South Pacific Gyre. The South Equatorial Current (SEC) flows in the equatorial band (0°S - 6°S) from East to West and is divided in multiple branches when approaching the Coral Sea (Webb, 2000; Sokolov and Rintoul, 2000) (Figure 1). On the western boundary, the East Australian Current (EAC) feeds, through the Tasman Sea, the southern branch of the gyre which then flows east and reaches the Peru/Chile Current (PCC) near the western South American coast (Tomczak and Godfrey, 2013). Superimposed on these large scale patterns, several studies indicate a strong mesoscale variability due to barotropic ~~instabilities and~~ and baroclinic instabilities and to the interactions of the major currents and jets with the numerous islands of the region ~~(Qiu et al., 2009; Hristova et al., 2014)~~ (Qiu and Chen, 2004; Qiu et al., As displayed in Figure 1, the OUTPACE cruise was conducted in the transition area between a zonal band of relatively high eddy kinetic energy ~~(Qiu et al., 2009)~~ south of 19°S (Qiu et al., 2009) and low eddy kinetic energy to the north. The influence of this intense variability, which results in mostly westward propagating eddies (Chelton et al., 2007; Rogé et al., 2015), has not been fully explored yet (Kessler and Cravatte, 2013), as well as its implications on biogeochemical/biological variations in the region. Recent studies have underlined the role of mesoscale activity as a conveyor of water masses, leading to the discovery of a potential water mass pathway in the Coral Sea (Maes et al., 2007; Ganachaud et al., 2008; Rousselet et al., 2016). This intense mesoscale activity is strongly linked to submesoscale fronts that might be responsible for surface small-scale features in temperature and salinity as shown by Maes et al. (2013) within the Coral Sea. Submesoscale dynamics are also thought to be responsible for ∼20% of new production in oligotrophic regions as suggested by Lévy et al. (2014b) using an idealized model. Since the frequency of oceanic fronts and eddy kinetic energy should increase in oligotrophic regions with climate change (Matear et al., 2013; Hogg et al., 2015) the OUTPACE cruise offers an unprecedented opportunity to study large, meso- and submesoscale influences along a zonal gradient crossing the oligotrophic to ultra-oligotrophic WTSP with coupled physical and biogeochemical measurements.

In this study we ~~investigate~~ place the *in situ* observations collected during the OUTPACE cruise into a synoptic view of the WTSP circulation at different horizontal scales. We investigate, through a descending approach, the large, meso- and submesoscale patterns using *in situ* observations~~obtained during the OUTPACE cruise~~, coupled with satellite data. Remote sensing provides daily physical and biological information over the entire WTSP for a time period covering the cruise duration and beyond (from June,1 2014 to May,31 2015). The inter-comparison between physical lagrangian diagnostics and available biogeochemical/biological measurements explores the potential influence of each scale on biogeochemical variations. In particular, we propose to focus on the possible impacts of horizontal small-scale ocean circulations on horizontal ~~dispersal of tracers such as~~ distribution of temperature, salinity or chlorophyll, as well as on ~~biological dynamics~~surface phytoplankton. Two original case studies are also presented to illustrate the fine-scale physical influence on horizontal microbial distributions. The use of multidisciplinary approaches, including *in situ* observations, remote sensing and numerical simulations is the key aspect of this study to investigate the surface circulation at different scales and try to ~~understand~~ examine their potential influence on ~~biogeochemical-biological distributions~~ the distribution of biogeochemical parameters and major groups of plankton measured during the OUTPACE cruise. In the following, we present the datasets and methods used and we discuss the results for each circulation scale, from large to submesoscale.

2 Materials and Methods

2.1 *In situ* observations

The OUTPACE (Oligotrophy to UlTra-oligotrophy PACific Experiment) cruise performed a zonal transect across the WTSP aboard R/V ~~Atalante~~ *L'Atalante* from February 18, 2015 to April 3, 2015 (Moutin and Bonnet, 2015). The main objectives of the cruise were to study the interactions between planktonic organisms and the cycling of biogenic elements across trophic and N_2 fixation gradients (Moutin et al., 2017). A total of 15 hydrological stations were sampled along the transect as well as three long-duration (LD) stations named LDA, LDB and LDC (Fig. 1). LD station sampling lasted for almost 8 days each, and aimed to study ~~the total export of carbon~~ carbon export in 3 biogeochemically different regions. More details about the sampling strategy are available in Moutin et al. (2017). The multi-disciplinary measurements used in this study are described hereinafter.

Of particular interest to understand the surface dynamics, SVP (*Surface Velocity Program*) floats were launched during each LD station to investigate the dispersion and the surface circulation relative to 15 m during the sampling period and beyond (Lumpkin and Pazos, 2007). Three SVPs were launched during LDA, 6 during LDB and 4 during LDC. The *in situ* trajectories of the floats ~~would be~~ were used to validate altimetry-derived surface velocities (see ~~Section 2.2~~Sec. 2.2, 2.4 and Fig.~~??~~2).

Continuous measurements of temperature and salinity were achieved using a ThermoSalinoGraph (TSG) that pumped sea water at 5 m depth. TSG data have been corrected and calibrated using ~~independant~~ independent measurements of salinity from water bottle samples collected daily onboard ~~RV~~ R/V *L'Atalante* (following the procedures described by Alory et al. (2015)) and are binned into minutes. In the following, temperature and salinity will refer to absolute salinity and conservative temperature, respectively, according to TEOS-10 standards (McDougall et al., 2012). A Wetstar SeaBird fluorimeter was deployed on the underway water flow. The fluorimeter provides measurements proportional to the chlorophyll a concentration with a time step of 10-15 min. Discrete samples were taken during the transit to calibrate the fluorimeter using the Aminot and Kérouel (2004) method:

$$\text{Chla [mg m}^{-3}] = 1.99 \times \text{FluorescenceValue} - 0.083 \ (R^2{=}0.87, n{=}55)$$

Due to technical issues the underway sampling of chlorophyll concentration started on March 7. Each of these data sets have been interpolated on a regular grid of 0.5 km resolution in order to keep the high resolution, but equally distributed along the travelled distance.

~~A high frequency sampling~~ Two high frequency samplings (every 20 min) ~~was performed~~were performed: the first one upon leaving LDA ~~until~~ and the second one upon arriving at LDB, in order to assess variability in 15 different biogeochemical parameters, in particular the Dissolved Inorganic ~~Phosphate~~ phosphate (DIP) turnover times and the abundances of bacteria (including the low and high nucleic acid content bacterial groups, LNA and HNA, respectively), *Prochlorococcus*, *Syne-*

chococcus and picophytoeukaryotes (PPE). Dissolved inorganic phosphate turnover times (TDIP) were determined using a dual ^{14}C - ^{33}P labelling method following Duhamel et al. (2006) . As described in Moutin et al. (2017) , TDIP represents the ratio between phosphate natural concentration and phosphate uptake by planktonic species (Thingstad et al., 1993) . It is considered the most reliable measurement of phosphate availability in the upper ocean waters (Moutin et al., 2007) . In the WTSP, the phytoplankton growth is often limited by phosphate availability. Consequently, this parameter gives important information on the biological activity in relation to resource availibility : a very short TDIP means rapid utilization of the ambient phosphate present in limiting concentration. To enumerate cell abundances of these different microbial groups, water samples were collected directly from the underway pump, fixed with 0.25% (w/v) paraformaldehyde, flash frozen and preserved at -80°C until analysis by flow cytometry following the protocol described in ~~?~~ Bock et al. (2018) . Briefly, bacteria were discriminated in a sample aliquot stained with SYBR Green I DNA dye (1:10,000 final) while pigmented groups were discriminated in an unstained sample aliquot. Reference beads (Fluoresbrite, YG, 1 μm) were added to each sample. Particles were excited at 488 nm (plus 457 nm for unstained samples) and bacteria were discriminated based on their green fluorescence and forward scatter (FSC) characteristics, while *Prochlorococcus*, *Synechococcus* and PPE were discriminated based on their chlorophyll (red) fluorescence and FSC characteristics. LNA and HNA groups were further distinguished based on their relatively low and high SYBR Green fluorescence, respectively, in a green fluorescence vs side scatter plot. *Prochlorococcus* were further distinguished from *Synechococcus* by their relative lack of a phycoerythrin signal (orange fluorescence). Using a FSC detector with small particle option and focusing a 488 plus a 457 nm (200 and 300 mW solid state, respectively) laser into the same pinhole greatly improved the resolution of dim surface *Prochlorococcus* population from background noise in unstained samples. Because the *Prochlorococcus* population cannot be uniquely distinguished in the SYBR stained surface samples, bacteria were determined as the difference between the total cell numbers of the SYBR stained sample and *Prochlorococcus* enumerated in unstained samples. Cytograms were analyzed using FCS Express 6 Flow Cytometry Software (De Novo Software, CA, US). These data are used to investigate the small-scale distribution of the different microbial community groups and its relation with the concomitant dynamics at submesoscale. To investigate each picoplankton group variability with respect to the other with more clarity, abundances are displayed in terms of cell count deviation. It represents the difference between picoplankton group abundance (cell mL^{-1}) measured at a certain location and the mean of the respective picoplankton group abundances throughout the transect.

2.2 Satellite data

Several satellite datasets were exploited during the campaign to guide the cruise through an adaptive sampling strategy using the SPASSO software package (http://www.mio.univ-amu.fr/SPASSO/) following the same approach ~~of~~ as described for previous cruises such as LATEX (Doglioli, 2013; Petrenko et al., 2017) and KEOPS2 (d'Ovidio et al., 2015). SPASSO was also used after the cruise in order to extend the spatial and temporal vision of the *in situ* observations.

Four different altimetry-derived velocity products were tested in this study to choose the product that best represents the surface circulation during the cruise. First the daily Ssalto/Duacs product (Ducet et al., 2000), from AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic 3) data base, for the period from 1 January 2004 to 31 December 2015, was used to extract daily delayed-time maps of absolute geostrophic velocities (1/4° x 1/4° on a Mercator grid, since 15 April 2014). Three other altimetry products were specifically produced, for the first time, at 1/8° resolution for the WTSP region by Ssalto/Duacs and CLS (Collecte Localisation Satellites), with support from CNES (Centre National d'Études Spatiales), from June 2014 to June 2015. In particular, they provided daily maps of absolute geostrophic velocities, daily maps of the sum of absolute geostrophic velocities and Ekman components, and the same product as the latter that also includes a cyclogeostrophy correction (Penven et al., 2014). Ekman surface currents refer to the wind-induced circulation relative to 15 m and are computed from ECMWF ERA INTERIM windstress with an Ekman model fitted onto drifting buoys (Rio et al., 2014).

A preliminary comparison between Lagrangian numerical particle trajectories (see ~~Section~~ Sec. 2.3.1), computed with each of the above products, and the observed trajectories of the different floats launched during OUTPACE (~~section~~ Sec. 2.1) allowed us to identify the product including geostrophic and Ekman components with the cyclogeostrophy correction (hereafter total altimetry-derived velocity field) as the most accurate *in situ* surface currents (see ~~figure ?? for a comparison between float trajectories and numerical particle derived streamfunction~~Sec. 2.4).

Daily near-real-time maps of sea surface temperature (SST) and ocean color were also specifically produced for the WTSP from December 2014 to May 2015 by CLS with support from CNES. They are constructed with a simple weighted data average over the 5 previous days (giving more weight to the most recent data), and have a 1/50° resolution (2 km at the Equator) in latitude and longitude. The temperature product corresponds to maps of SST deduced from a combination of several intercalibrated infrared sensors (AQUA/MODIS, TERRA/MODIS, METOP-A/AVHRR, METOP-B/AVHRR). The ocean color product corresponds to maps of chlorophyll concentration issued from the Suomi/NPP/VIIRS sensor (http://npp.gsfc.nasa.gov/viirs.html). These satellite data are compared with *in situ* data from the underway survey. A correlation of 0.8 between *in situ* measurements and co-located satellite data validates the satellite-derived SST and chlorophyll concentration. A supplementary correlation with the daily High-Resolution SST blended from NCDC/NOAA (Reynolds et al., 2007) and *in situ* SST showed a similar correlation. These results corroborate the accuracy of the CLS products in our region of interest.

2.3 Lagrangian diagnostics

2.3.1 Surface water mass pathways detection

To investigate the water mass movements at large and meso-scale, we used the Lagrangian diagnostic tool Ariane that can trace water mass movements from the trajectories of numerical particles that enter and exit a predefined domain (Blanke and Raynaud, 1997; Blanke et al., 1999). In this study the numerical particle trajectories are computed with altimetry-derived surface currents from the products listed above (see ~~section~~ Sec. 2.2). As many Lagrangian particles as desired can be integrated in two different ways: backward in time to assess the origins of the water masses or forward in time to investigate their fate. Additionally, this Lagrangian tool allows for the computation of two different diagnostics : i) qualitative diagnostics that compute typically few particles with a steady recording of the positions along their trajectories; ii) quantitative diagnostics that compute thousands of particles with statistics available for initial and final positions, and with the diagnostic of the main pathways. In this study we use 3 different configurations of the Ariane tool depending on the objectives.

First, to identify the altimeter product that best ~~fit~~ fits the observed trajectories of the floats launched during OUTPACE, a comparison ~~was done~~ is performed, in the following section 2.4, with the trajectories of ~~numerical particles (typically considering release of several hundred of particles)~~one hundred numerical particles. They were initially positioned around the launching position of the floats with a resolution of 1-2 km. The particles were advected forward in time for 96 (LDA), 78 (LDB) and 70 (LDC) days, corresponding to the time lapse between the launch day of the floats and the last available day of satellite data. These qualitative experiments allows for the comparison of successive positions (every 6 hours) of numerical particles computed with the 4 different products and those of the floats. Thus the choice of the best surface velocity product relied on the best fit between observed and numerical trajectories ~~. The total altimetry-derived velocity field (i.e. the product including geostrophy, cyclogeostrophy and Ekman components) will be used for all diagnostic computations, as it best fits *in situ* data (Fig. ??).~~ (see Sec. 2.4). To study the large scale circulation in the WTSP, quantitative experiments were performed to find the main pathways of the waters entering and exiting the box contouring the WTSP (Fig. 3). Particles were launched along each section of the box (North, East, South, West) and advected forward with the total altimetry-derived surface currents. We simulated ten years of particle trajectories by repeating ten times the available dataset. We ~~compare~~ compared the results of this simulation with the ten years integration of available geostrophic AVISO surface currents over this time period. The comparison between these simulations ensures that the use of a one year time period looped several times does not significantly modify statistical outputs. It is clearly more interesting to use CLS data instead of commonly used AVISO geostrophic surface currents because they include the wind effect and cyclogeostrophy with higher resolution, as well as better ~~represents~~ fitting with *in situ* data.

Another objective is to identify the mesoscale trajectories of surface water masses sampled at each of the LD stations. Backward and forward quantitative experiments were performed to identify the main pathways of the surface water masses arriving and leaving each LD station using total altimetry-derived surface currents~~(Figure 5)~~. Almost one million numerical particles were initially distributed along a square box surrounding the position of the LD station. The calculations were stopped whenever the particles return to the initial box (hereafter called meanders) or were intercepted on one of the four remote sections located around the LD station. The boxes size are tuned in order to minimize meanders and the loss of particles in the domain. Percentage of both quantities are reported in Table ~~??~~A1. Forward computation times are identical to the qualitative diagnostics. For backward experiments, the particles were advected for 183 (LDA), 201 (LDB) and 209 (LDC) days corresponding to the maximum time lapse allowed by CLS satellite data availability.

2.3.2 Eddies and filaments identification

To set up the mesoscale context during the OUTPACE cruise, we used the Lagrangian Averaged Vorticity Deviation method (Hadjighasem and Haller, 2016; Haller et al., 2016) that allows identification of coherent structures from altimetry-derived surface velocity fields (code available at https://github.com/Hadjighasem/Lagrangian-Averaged-Vorticity-Deviation-LAVD). The detected features are able to trap water masses for a certain period (defined by the integration time) and transport them along their route. In this study we computed the detection with the total altimetry-derived velocity field and chose an 8 day time integration with respect to the duration of LD stations. Indeed this time interval provides a confirmation or rebuttal of the assumption that LD stations have been performed in a coherent structure, as targeted during the cruise. This Lagrangian diagnostic is also compared with a hybrid Lagrangian and Eulerian approach combining the calculation of the Okubo-Weiss (OW) parameter and a retention parameter (RP), computed with the same velocity field. The OW parameter identifies structures such as eddies by separating the flow into a vorticity-dominated region and a strain-dominated region (Okubo, 1970; Weiss, 1981). The RP identifies the number of days a fluid parcel remains trapped within a structure core, defined by a negative OW parameter. Both parameter calculations are detailed in d'Ovidio et al. (2013). As for the LAVD detection method, the RP allows for the identification of potentially trapping coherent structures.

Submesoscale flow features in two-dimensional data are evaluated with altimetry-derived finite size Lyapunov exponents (FSLE), computed with the algorithm of d'Ovidio et al. (2004). This Lagrangian diagnostic detects frontal ~~zone~~ zones on which passive elements of the flow should theoretically align. Here we used the total altimetry-derived velocity field to compute the algorithm. The main parameter values for the algorithm are described in de Verneil et al. (2017b). The OUTPACE cruise occurred in the relatively open ocean and far enough from islands to trust the FSLE diagnostic calculated from altimetry. We compare the horizontal positions of the fronts, detected with FSLE, with surface gradients measured both with the TSG (temperature and salinity) and the underway survey (chlorophyll). Indeed these high frequency samplings provide access to submesoscale gradients. A point by point correlation is calculated whenever a strong gradient of density (or chlorophyll) corresponds or not to a high FSLE value (i.e. > 0.05 day^{-1}) indicative of a front. Sensitivity tests have been performed to choose the thresholds on density (chlorophyll) gradients to ensure the stability of the correlations calculated. These tests ended with the selection of gradient larger than 0.1 kg m^{-3} km^{-1} and a 0.2 mg m^{-3} km^{-1} as thresholds for density and chlorophyll gradients, respectively.

2.4 Comparison of satellite products with *in situ* drifters

The choice of the satellite product that best represents the surface dynamics relies on a qualitative comparison between the trajectories of *in situ* floats launched during the OUTPACE cruise (see Sec. 2.1) and the trajectories of numerical particles computed with each of the satellite-derived velocity field described in Section 2.2. Figure 2 shows the 8-days trajectories of in situ floats and numerical particles at each long-duration station and for each satellite-derived products considered (geostrophy 1/4°; geostrophy 1/8°; geostrophy and Ekman 1/8°; geostrophy, Ekman and cyclogeostrophy 1/8°). The comparison is restricted to 8 days for a better visualisation and to be consistent with the duration of the LD stations. In the case of station LDA, none of the products displays a significant improvement of numerical trajectories. This lack of refinement between the different products may be due to the lack of accuracy of satellite products when getting close to coasts. Indeed, altimetry measurements are not well resolved close to the coast, and especially near New Caledonia where the topography and bathymetry are very complex. In the cases of LDB and LDC, the increase in resolution does not modify the general pattern of the trajectories. However, when adding the Ekman component, we can notice an improvement in the direction of the numerical particle trajectories. Even if the particle positions are offset, their direction are consistent with those of in situ drifters. Cyclogeostrophy seems to accelerate the particles' displacements. The final positions of the numerical particles are closest to the final position of in situ drifters in the case of LDC. This latter point is not surprising considering that cyclogeostrophy represents the centrifugal acceleration. In the context of the OUTPACE cruise, we consider that the LDB and LDC examples illustrate clear improvements of the new satellite product including geostrophy, the Ekman component and cyclogeostrophy. In the case of LDA neither clear improvement or deterioration are obvious on the trajectories. Moreover when considering the surface circulation, it also remains important to take into account the wind effect, through the Ekman component, as it will strongly influence the trajectories of surface waters at large, meso- and submesoscale. As most of the diagnostics used in this study are calculated through particle trajectory computations, the Ekman component is of major significance. As a consequence, and to stay consistent throughout this study, we used the product combining geostrophy, the Ekman component and cyclogeostrophy at 1/8° resolution, referred as the total surface altimetry-derived velocity field, to compute every diagnostic.

3 Results and discussions

3.1 Large scale wind-driven pathways

The geostrophic large scale mean circulation and directions of the main currents in the WTSP are well established from the literature. However, the trajectories and pathways of surface waters may change and be more complex when the effect of the wind is added and resolution is increased especially in the context of inter-annual ENSO (El Niño Southern Oscillation) variability. We decided to use a Lagrangian integration of numerical particles to simulate the transport of surface fluid parcels at the scale of the WTSP region using altimetry-derived ocean currents including the wind effect. Figure 3 shows the transport calculated from the sum of almost 13 million numerical particles advected with the total surface altimetry-derived flow for 10 years (see ~~Section~~ Sec. 2.3.1). This figure highlights the westward transport of the SEC in the northwestern part of the domain, but also the eastward transport at 10°S due to the output of the South Equatorial Counter Current (SECC) from the Solomon Sea (Ganachaud et al., 2014). Both these pathways follow the well-known circulation of the SEC and SECC in this region. An eastward flow south of Fiji is also detectable on Figure 1 but does not seem to influence surface transport (Fig. 3). This flow has been discussed in several studies and is named the South Tropical Countercurrent (STCC) (Qiu and Chen, 2004) . Additionally, a clear surface meridional transport is noticeable from 10°S to 25°S. In the very south-eastern part of the domain some surface waters seem to recirculate to the east from 170°W, which is probably an indicator of the gyre circulation~~or an artefact of mesoscale dynamics due to the short averaging period considered by the present study~~. The meridional transport does not correspond to any ~~surface current~~ general surface geostrophic current previously described in the literature (Tomczak and Godfrey, 2013; Kessler and Cravatte, 2013; Ganachaud et al., 2014) , but is mainly due to the south-easterly trade winds. This meridional component appears due to the addition of the Ekman component in altimetry surface velocities (Fig.A1, Supplementary Material). The large scale transport of surface waters in the OUTPACE area is thus a combination of the transport by general well-known surface currents and wind-driven circulations. ~~Surface waters globally travel the WTSP from northeast to southwest. This meridional transport seems to separate the gyre surface waters that will~~

~~recirculate towards the east near 175°W and waters that will continue to be advected in the WTSP towards the Coral Sea~~Most of the surface waters travel southwest from the northern Ariane section, with a significant part that originates from northeast. At the scale of the WTSP, the individual transport calculated from each initial section (see ~~Section~~ Sec. 2.3.1) reveals that 80% of the surface waters crossed during the OUTPACE cruise originate from the «North» section, 8-15% from the «East» section and very few from the «South» and «West» sections (Fig. A2). We can thus identify a general wind-driven surface transport in the WTSP as follows: the surface waters enter the WTSP from the northeast with the SEC and are gradually advected to the south with a part (east of 170°W) that directly recirculates within the gyre and another part (west of 170°W) that follows a southwestern propagation through the different WTSP archipelagos. ~~From a biogeochemical point of view~~These results obtained with a Lagrangian diagnostic complete the largely elucidated eulerian vision of the large scale circulation in the WTSP.

Very few reports have studied the surface transport inferred by the wind in the WTSP. Indeed Tomczak and Godfrey (2013) calculated a streamfunction from wind stress and showed a global westward transport with very little meridional transport except in the EAC which is very close to the Australian coasts. Kessler and Cravatte (2013) also computed the Sverdrup transport streamfunction calculated from Godfrey's Island Rule and the wind stress curl field in the Coral Sea. They identified a comparable southward transport as visible in Figure 3, between 7°S and 12°S, due to the SECC. However, between 12°S and 25°S, they identified a westward transport whereas we show a meridional transport from north to south. Considering the large scale biogeochemical distribution, two types of waters can be differentiated: the relatively oligotrophic but richer Melanesian waters (from 160°E to 170°W) and the ultra-oligotrophic gyre waters (~~west~~ east of 170°W) ~~(Fumenia, personal communication)~~(Fumenia et al., 2018) . The wind-driven surface transport highlighted here could participate in the biogeochemical variations between western and eastern waters. ~~Indeed~~ Moreover, the path through the Melanesian area, which includes the multiple islands from Papua New Guinea to Fiji (140°E-170°W), may enrich these waters due to the contact with multiple islands. This could explain the relatively higher productivity of these waters, whereas waters that directly recirculate within the gyre keep their ultra-oligotrophic characteristics.~~This pathway induces complex recirculation through the Melanesian archipelago, not visible on the large scale transport.~~

The WTSP circulation is also strongly impacted by ENSO conditions, responsible for SST variability on inter-annual to decadal timescales (Sarmiento and Gruber, 2006). A negative Southern Oscillation Index (SOI), El Niño phase, is characterized by a decrease or even an overturn of trade winds whereas during La Niña phase (positive SOI) trade winds are strengthened. The mean wind velocity measured during OUTPACE is shown to be close to mean velocities during El Niño (data not shown) and Moutin et al. (2017) clearly showed that the OUTPACE cruise took place during an El Niño phase but they determined that climatological effects, upon the results of the cruise, were minimized ~~. Otherwise, as~~ for biogeochemical sampling. However we show that the circulation and transport are still strongly influenced by the trade winds.

As this region is characterized by an intense mesoscale circulation, we can also expect that it participates in the biogeochemical variations in the region. Thus we investigate the mesoscale feature trajectories on the entire WTSP and in particular the mesoscale circulation around three biogeochemically different locations: i) LDA located in the Coral Sea, at the end of the surface waters' journey across the WTSP; ii) LDB, in the Melanesian waters, west of the transition zone with gyre waters; iii) LDC, in the gyre waters.

3.2 Mesoscale activity and trajectories of surface waters

The major goal in this section is to identify whether mesoscale activity, and in particular trapping features, actively participate in the transport of different water mass properties across the WTSP ocean. The LAVD method is chosen in order to track the coherent structures for a time period of 8 days (see ~~Section~~ Sec. 2.3.2). Figure 4 shows the total altimetry-derived velocity field and the mesoscale structures identified for the first day of each LD station (LDA, LDB and LDC). It reveals that many mesoscale structures are ~~found~~ detected by the LAVD method in the entire WTSP with no specific region with higher abundances of these features. ~~A comparison with the~~ To ensure that this recent detection method is consistent with previous approaches that identify mesoscale features (eulerian Okubo-Weiss ~~(OW)~~parameter) or retention areas (RP), we compare the structures detected with both approaches. A comparison with the OW parameter method shows a good agreement with the LAVD detection method. Indeed, a mean OW parameter value of -0.24 day^{-2} is calculated inside the contour of coherent structures detected with the LAVD method. It indicates that wherever a coherent structure is identified, the OW parameter also identifies a mesoscale feature. Most of the mesoscale structures detected with the LAVD method are also identified as retention areas, with the RP, ensuring the trapping characteristics of these features (Fig. A3). A tracking of these coherent structures highlights that they all show a general ~~zonal~~ westward propagation as expected from the mean ~~transport~~ circulation in this area. ~~If the major part propagates westward, the meridional band between 180°W and 170°W is identified as a region with mostly eastward propagation of mesoscale structures. Several studies have discussed the eastward flow south of Fiji, detectable on Figure 1, named the South Tropical Countercurrent (STCC) (Qiu and Chen, 2004) . This flow, when bordering the Fijian coast, could lead to the eastward transport of mesoscale structures bounded east of Fiji. The location of this band is also interesting as it is found in the transition area between Melanesian waters and gyre waters.~~

Coherent mesoscale features are well-known to participate in the surface biogeochemical variations through eddy trapping and transport. Unfortunately, in our case, we are not able to observe the trapping and transport of different water masses by the mesoscale structures with *in situ* data. Indeed the zonal equidistant biogeochemical sampling during OUTPACE did not sample both mesoscale features and surrounding waters~~and consequently~~. Consequently no differentiation is possible between potentially trapped waters and surrounding waters. The small differences between water mass properties in this region (Gasparin et al., 2014) may also make it difficult to confidently notice a biogeochemical marker of different water masses. ~~However, the particular trajectories of these features could induce enriched-fluid transport into nutrient-poor gyre waters. Even if~~Even if, in this case, the influence of mesoscale activity, through eddy trapping and transport, on biogeochemical variations is not directly visible on *in situ* data, ~~through eddy trapping and transport,~~ the role of mesoscale dynamics on the trajectories of surface waters can document the possible exchanges between biogeochemically differentiated regions.~~Here we~~

Here we also dynamically explore the origins and fates of surface waters sampled during each LD station located in three different environments. LDA is situated on the path of the westward North Caledonian Jet (NCJ), that flows between New Caledonia and Vanuatu, in relatively highly productive waters (Fig.6). Far to the ~~west, LDB lies in the eastward eddy-propagation~~

~~band~~ east, LDB is positioned near the limit between oligotrophic and ultra-oligotrophic waters inside a phytoplankton bloom whereas LDC is located in nutrient-poor waters in the South Pacific (SP) gyre (Fig.6). Figure 5 shows the streamfunctions calculated from numerical particle advection using total altimetry-derived surface velocities (see ~~Section~~ Sec. 2.3.1). They represent the origin (Fig. 5 top) and the fate (Fig.5 bottom) of each LD stations' waters, respectively the backward and forward computations. One would expect LDA surface waters to come from the East as it is located on the path of the westward NCJ. However they seem to have multiple origins: i) easterly, directly from the NCJ transport; ii) northerly, directly from waters that have circulated between the Vanuatu islands before heading south to LDA; and iii) from a meridional tortuous recirculation path (∼162°E) within the Coral Sea. ~~Both~~ After LDA sampling, an intense signature of the NCJ is detected at the surface. Another portion of surface waters directly crash on New Caledonia's northern coast. In the eastern WTSP, LDB surface waters seem to follow the same general path: they flow from northeast towards southwest before they reach a group of islands and then recirculate to the east towards LDB. After LDB sampling, they continue their way to the east before heading back to the south or to the south-west. Further east, as one would expect, the waters sampled during LDC travelled from the east and flow to the west after LDC (Fig.5). We notice a recirculation area east of LDC where the waters seemed to follow a looping trajectory before reaching LDC. Both lagrangian methods (LAVD detection and advection of numerical particles) detect a coherent mesoscale structure that travelled westward in the surrounding region of LDC.

The identification of coherent structures during OUTPACE revealed that only station LDC could be influenced by a trapping structure. A tracking of this structure, as well as the high rates of meanders (70% and 44% for backward and forward integration, respectively) (Table A1), suggest that this coherent structure crossed the LDC sampling area. Indeed some CTD casts were performed inside or near the boundary of this structure whereas others, mostly at the end of the station were realised after the crossing of the structure. This observation can be associated with the results of de Verneil et al. (2017a) who identified, with *in situ* data, a modification in the water mass composition throughout the station. We thus suggest that the change in the physical environment during LDC could be due to the westaward transit of this coherent structure across LDC sampling site. If only LDC sampling site seems to be directly influenced by the transport of water masses through a coherent mesoscale structure, the trajectories at LDA and LDB highlight some interesting mesoscale path (circulation at the scale of the order of 10-100 km). Around LDA, both i) and ii) origins agree with the integrated transport entering the Coral Sea induced by the complex topography (Kessler and Cravatte, 2013). The ~~meridional recirculation determined here~~ westward circulation scheme is consistent with previous studies focusing on the NCJ (Ganachaud et al., 2008; Gasparin et al., 2011) and more consistently with the results analyzed by Barbot et al. (2018) within the same context and cruise. The pathway that crashes on New Caledonia's coast might not be so relevant due to the satellite's lack of resolution near coastal areas. The meridional recirculation previously determined suggests that eddy-eddy interactions might be responsible for the emergence of complex paths between the NVJ and the NCJ. ~~Indeed it matches~~ Moreover backward and forward streamfunctions cross around station LDA which suggests that the area between New Caledonia and Vanuatu is a region of complex recirculation with waters that stay in this region for a while before exiting the Coral Sea. These observations match the area described by Rousselet et al. (2016) as the region of exchange between NCJ and NVJ waters through eddy trapping and transport. We identify a probable water mass mixing area, in the Coral Sea center, through complex mesoscale stirring. This stirring may also create surface gradients as depicted by Maes et al. (2013). ~~After LDA sampling, an intense signature of the NCJ is detected at the surface. Another portion of surface waters directly crash on New Caledonia's northern coast but this pathway might not be so relevant due to the satellite's lack of resolution near coastal areas. The westward circulation scheme is consistent with previous studies focusing on the NCJ (Ganachaud et al., 2008; Gasparin et al., 2011) and the results reported by **?** .~~

~~In the eastern WTSP, LDB surface waters seem to follow the same general path: they flow from northeast towards southwest before they reach a group of islands and then recirculate to the east towards LDB. After LDB sampling, they continue their way to the east before heading back to the south or to the south-west. The eastward propagation of mesoscale structures, mentioned above, is sustained by the eastward circulation of surface waters around the LDB site (Fig. 5).~~ Around LDB, an eastward path is detected that could match with the eastward flow of the STCC. Moreover de Verneil et al. (2017b) also pointed out a possible eastward transport to explain the origin of the bloom sampled at LDB. Indeed the surface waters might be iron-enriched through contact with the islands and thus create ~~favorable~~ favourable conditions for a phytoplankton bloom. At this site, adjacent to the nutrient-poor SP gyre, the biological dynamics could be specially enhanced by the mesoscale eastward transport of essential chemical supplies for phytoplankton development. If this mesoscale eastward transport is revealed to be quasi-permanent, it could be associated with recurrent bloom events in this area but this assumption requires further analyses to be generalized.

~~Further west, as one would expect, the waters sampled during LDC travelled from the east and flow to the west after LDC (Fig.5). We notice a recirculation area east of LDC where the waters seemed to follow a looping trajectory before reaching LDC. Both lagrangian methods (LAVD detection and advection of numerical particles) agree that a mesoscale structure trapped water masses east of LDC (from 164°W) and transported them until the sampling region of LDC. Indeed, the high rates of meanders (70and 44for backward and forward integration, respectively) (Table **??**), also suggest the waters were still trapped in the structure core during LDC sampling. This observation is in good agreement with de Verneil et al. (2017a) who conclude that LDC was performed in a stable coherent water mass for the entire LDC sampling.~~

3.3 Fine scale distribution of tracers

The surface tracers' distribution is mostly driven by the wind-induced circulation but also by the transport through mesoscale activity. In a more ephemeral way, tracers can be dispersed following small-scale perturbations such as frontal features. Here we ~~try~~ aim to detect and quantify the influence of such features on the density and chlorophyll surface gradients using both *in situ* and satellite observations.

As described in Section 2.2 and shown by Figures 6a and 6b, the comparison between *in situ* observations and satellite-derived data results in reasonable correlations. The differences between in situ temperature (top), chlorophyll (bottom) and satellite data are plotted on Figure A4. We obtain differences between +1.5°C and -1°C which allows us to confidently use satellite temperature. For chlorophyll, the differences are smaller than ±0.1 mg m^{-3} which is also a reasonable deviation between satellite and *in situ* measurements, besides considering the colorbar scale of Figure 6 with values that vary from 0 to 1 mg m^{-3}. We can also note that the satellite data clearly underestimate chlorophyll concentrations in the Melanesian area. As both datasets are comparable, SST and chlorophyll concentrations from remote sensing are then used to investigate horizontal gradients in the WTSP (Fig. 6a and Fig. 6b). To assess the spatial scale of submesoscale gradients (typical of 1-10 km) in terms of ocean dynamics, we use a lagrangian methodology based on the calculation of FSLE (see ~~Section~~ Sec. 2.3.2) that allow for fronts detection. Figure 6c shows regions where fronts are frequently generated during the time period of the cruise. We notice that the gyre is a region less suitable for fronts to occur and persist. We also identify east of the Fiji islands a zonal band at 18°S where almost no fronts occur during the OUTPACE cruise. Southeast of LDB a mesoscale structure, that is also identified on Figure 4, creates a frontal barrier that lasted for more than 30 days. It seems that this structure matches with strong surface gradients in chlorophyll and in SST, consequently separating colder and relatively chlorophyll-rich waters to the south from warmer but chlorophyll-poor waters to the north of the front. Overall, as shown by Figure 6, the most frequent and long-lived fronts seem to help in structuring the spatial distribution of tracers such as SST and chlorophyll concentration by creating physical barriers, isolating areas with different biogeochemical characteristics. To try to quantify the influence of frontogenesis on the structuring effect of surface tracers, we decided to compare the surface sharp gradients measured by the TSG or with the underway fluorimeter with the presence of a front detected from ~~satellite products~~the total surface satellite product.

The strong surface density gradients (as defined in ~~Section~~ Sec. 2.3.2) represent 9% of the data measured by the TSG during the OUTPACE cruise. The comparison with FSLE reveals that 25% of the strong surface density gradients match with a physical front. Through a bootstrapping re-sampling, the same method is applied to the 91% of TSG data identified as non-gradient, and demonstrates that only 14 ± 1% of homogeneous density areas match with a front. These latter results also exhibit that an FSLE existence does not necessarily create a gradient but probably needs pre-existing tracer gradients and a lifetime longer than few days. The same calculations have also been performed for temperature and salinity gradients independently and show similar results. The relatively better correlation between density gradients and FSLEs than between no-density gradients and FSLEs, attests that gradients are not randomly distributed with regard to FSLE structure and proves that FSLE detection can be a good candidate to explain the presence of *in situ* surface gradients. The same approach was performed with a reactive tracer, the chlorophyll concentration sampled with high frequency. It shows that 35% of strong surface chlorophyll gradients, representative of 1% of the entire underway sampling, agree with the presence of FSLE. Re-sampling over the 99% of non-gradient areas, indicates that 28 ± 14% of homogeneous chlorophyll areas match with an FSLE.

The correlations with FSLE are not high enough to clearly demonstrate that physical fronts structure the entire surface distribution of tracers. However they give a relative confidence on the fact that they can structure the surface tracers' distribution. The relative orientation of the front with respect to the direction of the density gradient can also be a factor that controls the generation of a strong gradient. The zonal characteristic of the OUTPACE section forces the surface gradient identified with the TSG to be mainly representative of cross track fronts. Moreover the lack of precision of the calculation method may also cause a decrease in the correlations calculated. Despite the effort to increase the altimetry resolution to 1/8°, it is still not enough to fully resolve the submesoscale gradients. Consequently the correlation between surface gradients and FSLE can probably not increase much higher than the 25% calculated here. This result converges with Hernández-Carrasco et al. (2011) who ~~exhibited that FSLEs would~~ showed that FSLEs can still give an accurate picture of Lagrangian small-scale features despite some missing dynamics. Additionally, ~~we perform~~ our method relies on a comparison between absolute values of gradients and co-located FSLE. Due to the lack of resolution of satellite products, this point by point comparison may induce a few kilometer offset between the area identified with FSLE and the gradient sampled with the TSG~~, and consequently~~ . Consequently, the method applied here may not identify the match. Therefore the methodology could be improved by focusing on FSLE values around a certain radius from the position of the gradient to eliminate the uncertainty caused by the absolute point by point comparison. Another way to improve the method would be to only take into account cross-front gradients that are more likely to be induced by a physical front than along-front gradients. However, considering that the SST distribution is also governed by other processes than advection, such as the diurnal cycle ~~,~~ for example, the 25% correlation is large enough to sustain the idea that the submesoscale circulation can participate actively in the spatial structuring of surface tracers such as SSS, SST or density.

~~The same approach was performed with a reactive tracer, the chlorophyll concentration sampled with high frequency. It shows that 35of strong surface chlorophyll gradients, representative of 1of the entire underway sampling, agree with the presence of FSLE. Re-sampling over the 99of non-gradient areas, indicates that~~ Concerning the biological chlorophyll parameter, the high percentage (28~~± 14~~ %~~of homogeneous chlorophyll areas match with an FSLE. The high percentage~~) of FSLEs matching with a «no chlorophyll-gradient» area gives little confidence on the fact that 35% of chlorophyll gradients were actually caused by the presence of a physical barrier. As chlorophyll concentration is driven by many biological processes, it may be more accurate to associate gradients of phytoplankton abundances, responsible for chlorophyll gradients, with small-scale features. Hereinafter, using two case studies of plankton high frequency sampling, we propose to compare microbial abundances with frontal features.

3.4 ~~Physical~~ Example of physical barriers' influences on phytoplankton community

In this section we present two case studies that highlight the potential influence of fronts on phytoplankton horizontal distribution. To test the hypothesis of Bonnet et al. (2015), that pointed out the use of FSLE to explain some correlations between *Trichodesmium spp.* abundances and gradients, we measured the abundances of microbial groups of plankton in samples collected during two high-frequency sampling transects (Fig. 7 and 8). LDB high frequency sampling crosses from North to South the bloom patch described in de Verneil et al. (2017b). The spatial distribution of organisms presents relatively high concentration of bacteria at the center of the bloom but decreases when exiting this feature (Fig. 7). ~~The tip of an~~ An FSLE barrier is visible near the center of the transect. This barrier coincides with ~~a salinity and temperature gradient (data not shown)~~ what is identified as a strong density gradient by our methodology, depicted in Section 3.3. It is also associated with a sharp decrease in surface chlorophyll concentration ~~and in PPE~~(Fig. 7b). The variations in the abundance of *Synechococcus*, HNA and LNA (bacteria in general) ~~abundances (Fig. 7b)~~follow the pattern of surface chlorophyll. We can also notice a slight decrease of PPE abundance to the south of the front. *Prochlorococcus* show different variations: the abundance seem to increase when crossing the front and then decrease to the south of it. There is a sharp increase of ~~DIP turnover time~~ TDIP when exiting the patch in the south, indicating that ~~Phosphorus~~ phosphorus is quickly consumed inside the bloom. The front thus seems to create a barrier for certain organisms which grow and accumulate on one side of the front as demonstrated by relatively high surface chlorophyll (peak at 0.8 μg l^{-1}) and low ~~Phosphorus. According to Mann and Lazier (2013) phytoplankton growth may be stimulated in aggregates where they can easily take up nutrients released by bacterial decomposition of organic matter. This phenomenon may also support the persistency of the bloom during LDB. Indeed the bloom may be sustained in time by submesoscale features creating an aggregation of micro-organisms that can benefit from each other. Aggregates can thus influence the community structure by creating favorable growing conditions for a species at the expense of others. A good example is~~ phosphorus. For LDA high-frequency sampling (Fig. 8a)~~. Indeed~~ , we can notice a region of high abundance of bacteria at 165°E 15' ~~that is to be~~ bounded by two FSLE barriers. This trend is confirmed by figure 8b which shows ~~an~~ a relative increase of the abundance of *Prochlorococcus*, bacteria, HNA and LNA associated with a spike of FSLE values at 45~~km. At the same time~~ km. Interestingly, the abundance of PPE seems to decrease where bacterial abundances are the highest indicating that ~~this group may not find an advantage in these features. Another~~ condition favouring bacteria and picocyanobacteria are not necessarily favourable to PPE. In contrast, another FSLE peak at ~~80~~ 75 km was characterized by the decrease of *Prochlorococcus*, bacteria, HNA and LNA while the PPE abundance increases. The surface chlorophyll follows the same pattern as that of *Prochlorococcus*, bacteria, HNA and LNA with a relative increase of chlorophyll concentration (0.3 μg l^{-1}) within the region bounded by the FSLEs. On the contrary, *Synechococcus* abundance does not show any variations that coincide with submesoscale features. Another peak in chlorophyll concentration is noticeable around 30 km (0.4 μg l^{-1}) but may be associated with other organisms than those analysed with cytometry.~~The physical fronts thus~~

The previous observations suggest that physical barriers to transport, detected with FSLE, can influence phytoplankton community structure by separating or concentrating different picoplankton group. In the LDB case study, the front seems to act like a barrier along which some picoplankton groups aggregate with weak possibilities to cross the front. As a consequence, bacteria and phytoplankton grow on one side of the front whereas, on the other side, the abundances are quite low. According to Mann and Lazier (2013) phytoplankton growth may be stimulated in aggregates where they can easily take up nutrients released by bacterial decomposition of organic matter. This phenomenon may explain why the abundance is more important on one side of the front. It may also support the persistency of the bloom during LDB. Indeed the bloom may be sustained in time by submesoscale features creating an aggregation of microorganisms that can benefit from each other. de Verneil et al. (2017b) identified the influence of the mesoscale horizontal processes in generating the bloom. They also showed that the bloom was bounded by some physical features acting like barriers. The results previously presented in this paper support the significance of horizontal submesoscale processes in driving the bloom's dynamic. Here we show that the distribution of phytoplanktonic community inside the bloom is conditioned by submesoscale features.

Our case study at LDB indicates that submesoscale features could create favourable conditions for certain plankton groups at the expense of others. A similar phenomenon occurs at LDA: the abundances of PPE decrease inside the region bounded by FSLEs where bacterial abundances increase. This observation probably indicates that PPE may not find an advantage in these features. Thus the physical fronts not only structure the spatial distribution of organisms by creating barriers but ~~seems~~ seem to create border regions influencing the community structure, abundances and diversity. Indeed modelled fine-scale structures have already been shown to delimit niches of different phytoplankton types but also to modify phytoplankton assemblages and diversity (d'Ovidio et al., 2010; Lévy et al., 2014a). Consistent with these previous numerical results, ~~we therefore find out with~~ our *in situ* observations show that microbial growth ~~seems to~~ may benefit from the horizontal conditions engendered by frontal structures. ~~It~~ Marrec et al. (2017) also recently observed a peculiar distribution of phytoplankton types inside and outside a mesoscale structure, demonstrating the structuring effect of meso- and submesoscale dynamics on phytoplankton communities. It is also interesting to note that, for our case studies, some picoplankton groups horizontal distribution is not necessarily impacted by the presence of submesoscale features, as for *Synechococcus* during LDA or respond with a different dynamic as for *Prochlorococcus* during LDB. This observation demonstrates that physical features are a key component but not the only parameter that drives the horizontal variations of phytoplankton communities. Indeed some patterns can also be explained by inherent biological dynamics. In the context of the OUTPACE cruise, it thus remains important to ~~determine how these two study cases could be generalized for~~ investigate the role of N_2-fixing organisms during these two case studies and to determine how the organisms implied in ~~the~~ N_2 fixation ~~cycle~~respond to the presence of submesoscale features (Bonnet et al., 2015) .

4 Conclusions

We document here the surface circulation at different spatial scales (from 1000 km to 10 km) and its influence on horizontal dispersal of biogeochemical components in the WTSP during the OUTPACE cruise. This study is conducted thanks to the combined use of value-added high-resolution altimetry products, *in situ* observations and Lagrangian numerical simulations. The total altimetry-derived velocity field, combining geostrophy and wind components, revealed a wind-driven meridional pathway of surface waters in the WTSP. This surface trajectory can be linked to the biogeochemical differences between Melanesian waters and gyre waters: a part of the water masses directly recirculates into the gyre whereas the other part is driven across the multiple islands of the WTSP.

The mesoscale activity is confirmed to be intense and mostly westward~~except in the region of transition between Melanesian waters and gyre waters (180°W - 170°W)~~. Most of these mesoscale structures demonstrated ability to trap waters, however no obvious biogeochemical variations were linked to eddy entrapment. We identify two areas where the mesoscale circulation might have a strong influence on water mass transport. First, the central Coral Sea appears as a region of exchange between distinct NVJ and NCJ waters through eddy transport. Second, the band between 180°W and 170°W could emerge as a recurrent bloom formation area due to the simultaneous effect of N_2 fixation, well-known to sustain summertime blooms in the WTSP, and the eastward mesoscale transport of island-enriched waters.

Associating the surface small-scale gradients with Lagrangian diagnostics of frontal features, we showed a correlation of at least 25% highlighting the role of submesoscale activity in governing the horizontal dispersal of surface tracers. The small-scale features also participated in the horizontal distribution and community structure of phytoplankton patches sampled during two original high-frequency sampling of surface phytoplankton abundances.

Future studies in the area will need to take into account the interactions between physical features of the flow at large and ~~fine-scale~~ fine scales to better understand the phenomenon that drives the distribution of buoyant matter. In particular, the region around station LDB should be investigated during other bloom events to confirm the possible role of enriched-water mesoscale transport in instigating/driving the bloom. This study also revealed the necessity to perform high-frequency sampling during oceanographic cruises to fully resolve submesoscale impacts on biogeochemical distributions.

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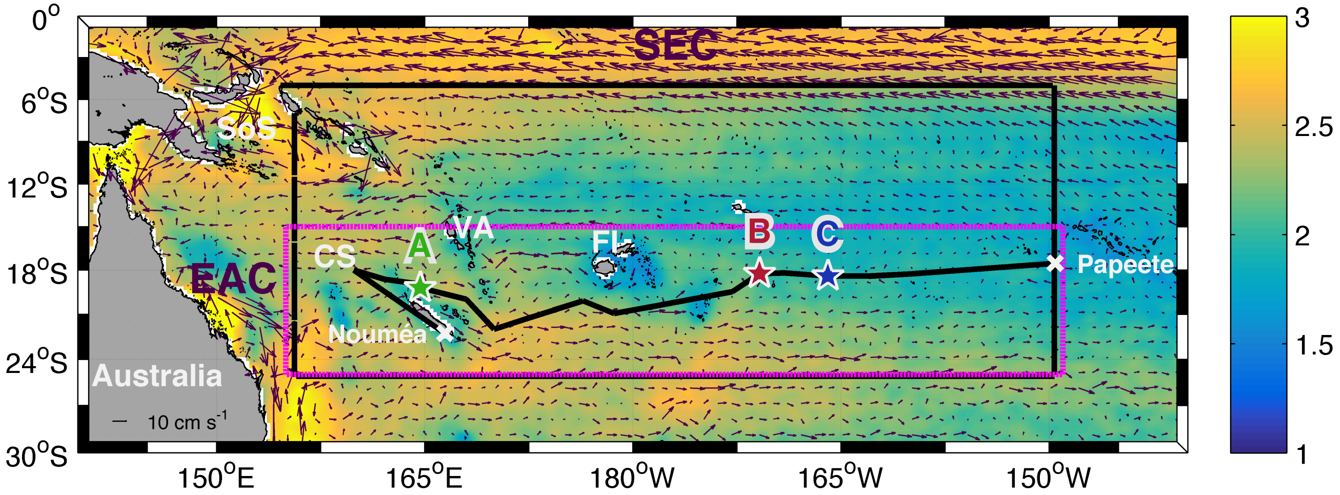


Figure 1. Mean eddy kinetic energy (log scale, colorbar) with surface velocity (arrows in cm s~~−1~~$^{-1}$) computed for 10 years (2005 - 2015) from ~~satellite-derived altimetry~~total altimetry-derived surface velocity field. The South Equatorial Current (SEC) and the western boundary East Australian Current (EAC) are indicated. The black line shows the ship track during OUTPACE from Nouméa to Papeete. The positions of the three Long-Duration (LD) stations are drawn with green, red and blue stars for LD-A, LD-B and LD-C respectively. SoS: Salomon Sea; CS: Coral Sea; VA: Vanuatu, FI: Fiji.

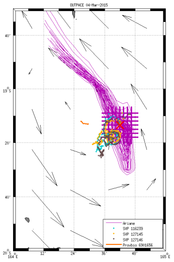
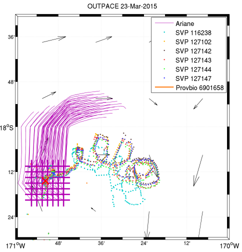
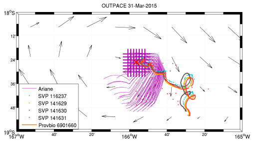
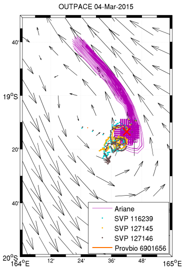
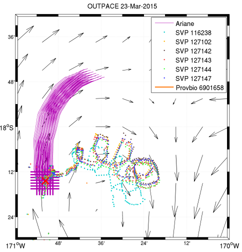
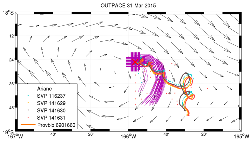
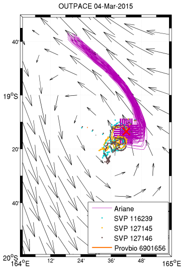
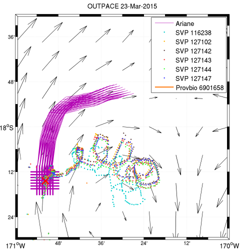
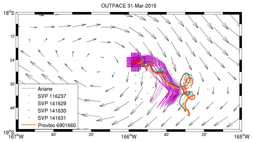
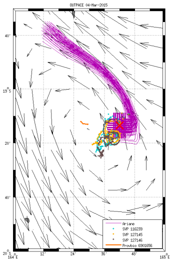
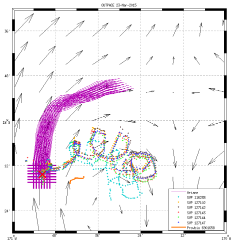
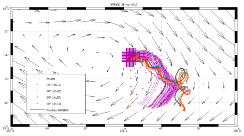
	LDA	LDB	LDC
Geostrophy 1/4°			
Geostrophy 1/8°			
Geostrophy + Ekman 1/8°			
Geostrophy + Ekman + Cyclogeostrophy 1/8°			

Figure 2. Trajectories of numerical particles computed with Ariane (purple) with each satellite products and in situ floats (colors) for 8 days after the starting date of each long-duration station (LDA, LDB LDC). The surface velocity fields of the last day of particle integration are also shown with black quivers.

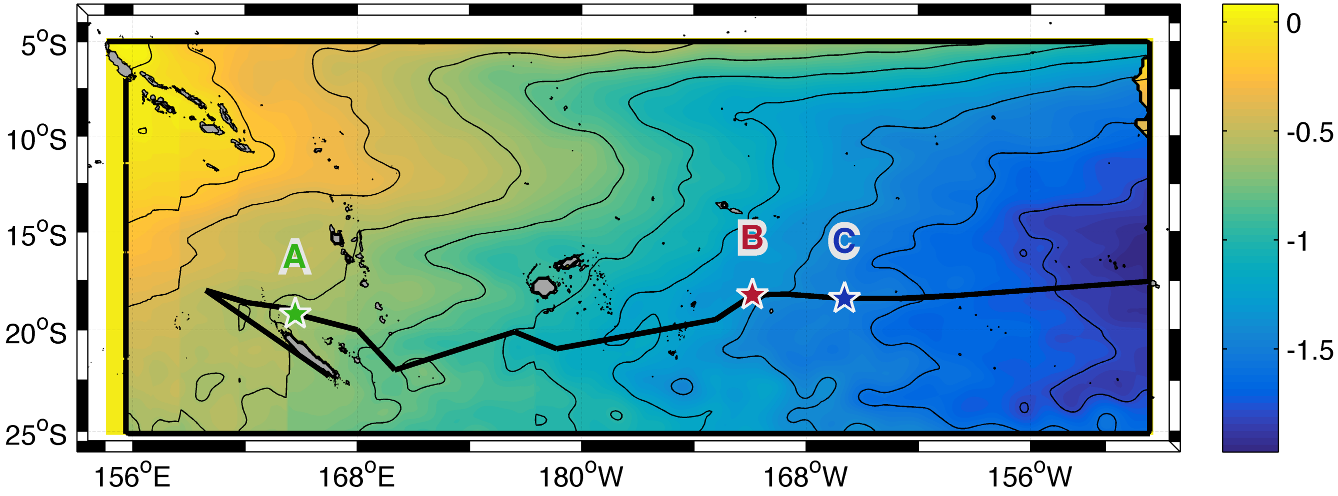


Figure 3. Total transport (Sv, colorbar) and streamfunction (black lines with contour interval of 0.25 Sv) computed for ten years with the total altimetry-derived surface velocity field~~combining geostrophy and Ekman components with correction for cyclogeostrophy~~. The ship track and locations of OUTPACE LD stations are indicated with the black line and colored stars as in Figure 1.

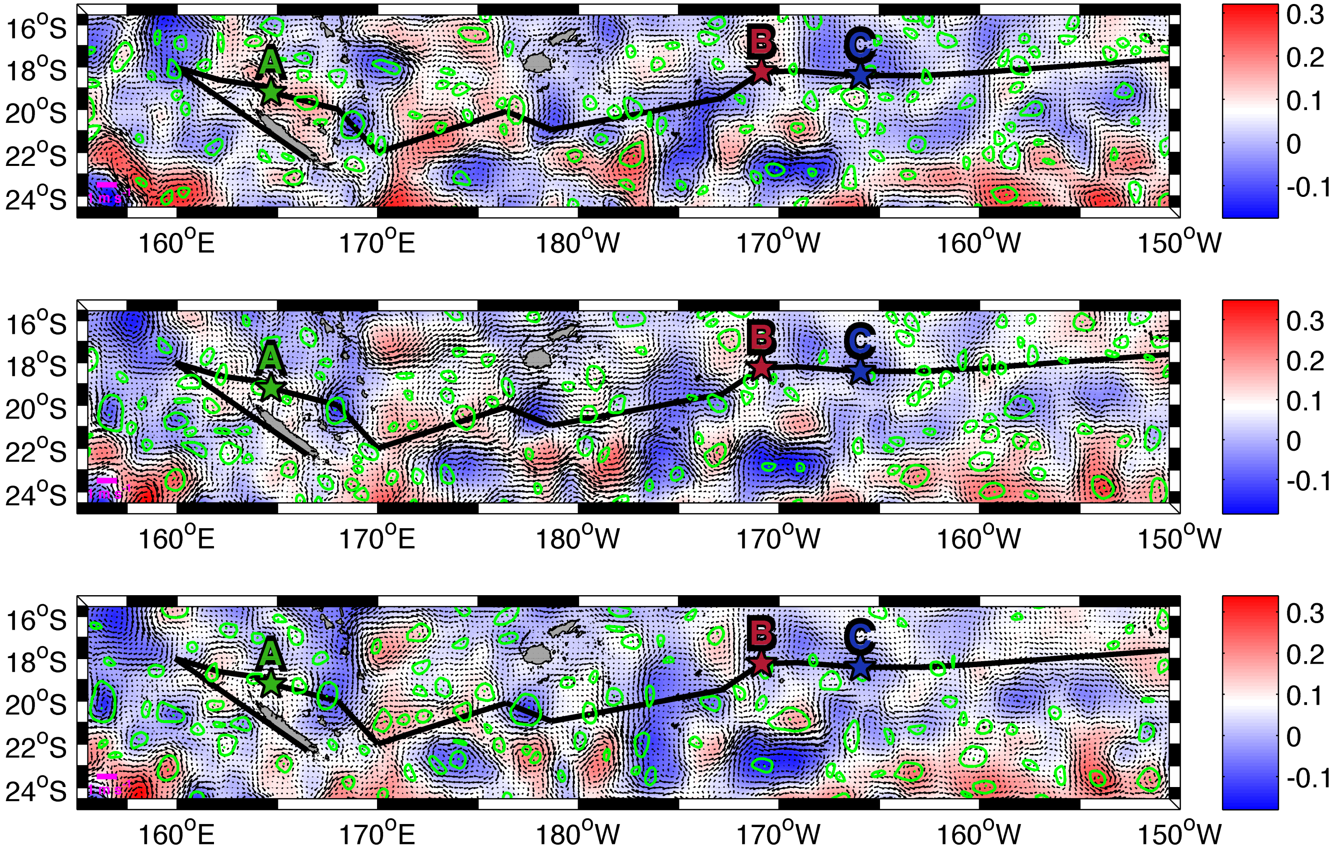


Figure 4. Daily sea surface level anomaly (m, colorbar) and velocity field (m s^{-1}) from the ~~geostrophy, Ekman and cyclogeostrophy included~~ total altimetry-derived surface product for the first day of LDA (February 25, top), LDB (March 15, center) and LDC (March 23, bottom). Contours of LAVD detected structures are drawn in green. The center of the structures is also indicated by a green point. The ship track and locations of OUTPACE LD stations are indicated with the black line and colored stars as in Figure 1.

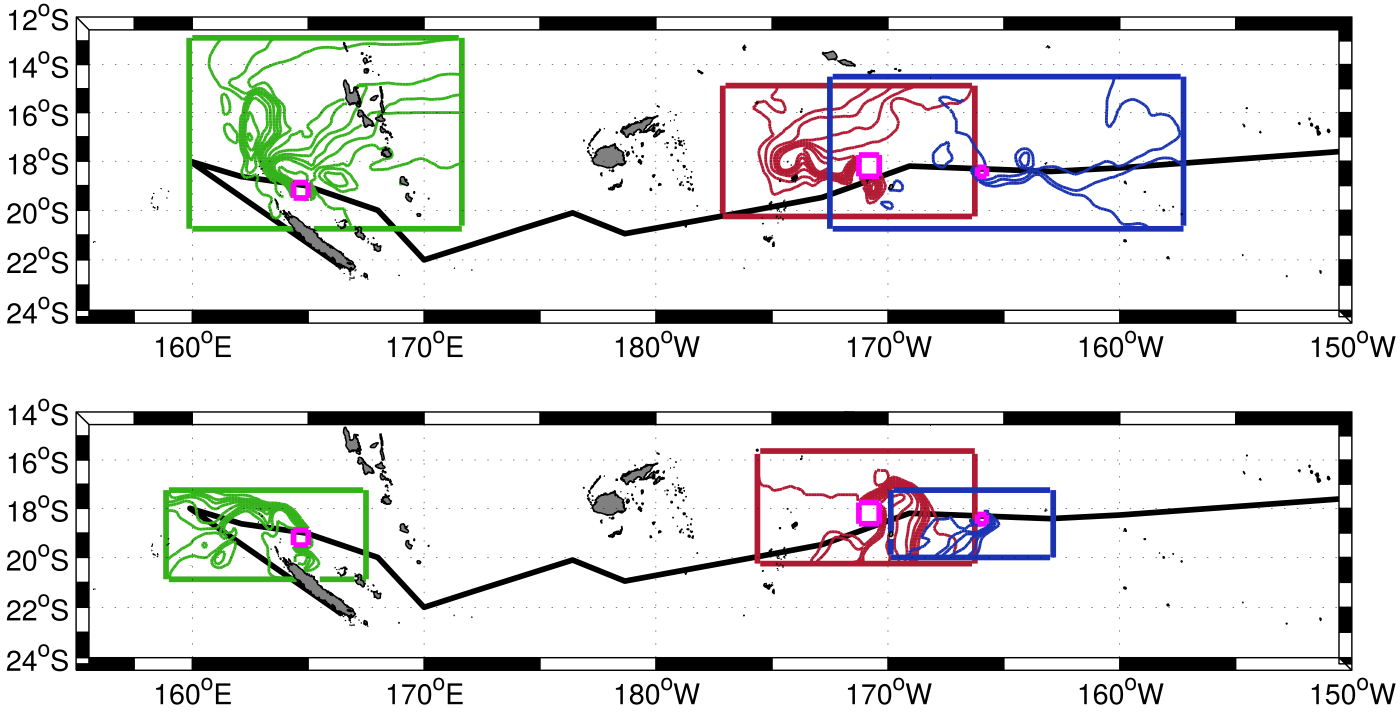


Figure 5. Backward (top) and forward (bottom) streamfunctions for LDA (green lines), LDB (red lines) and LDC (blue lines). Numerical particles are initially launched on the magenta boxes which represent the position of each LD station. The domain limit of each Ariane Lagrangian analysis are shown by the large green, red and blue boxes respectively. The ship track of OUTPACE is indicated with the black line.

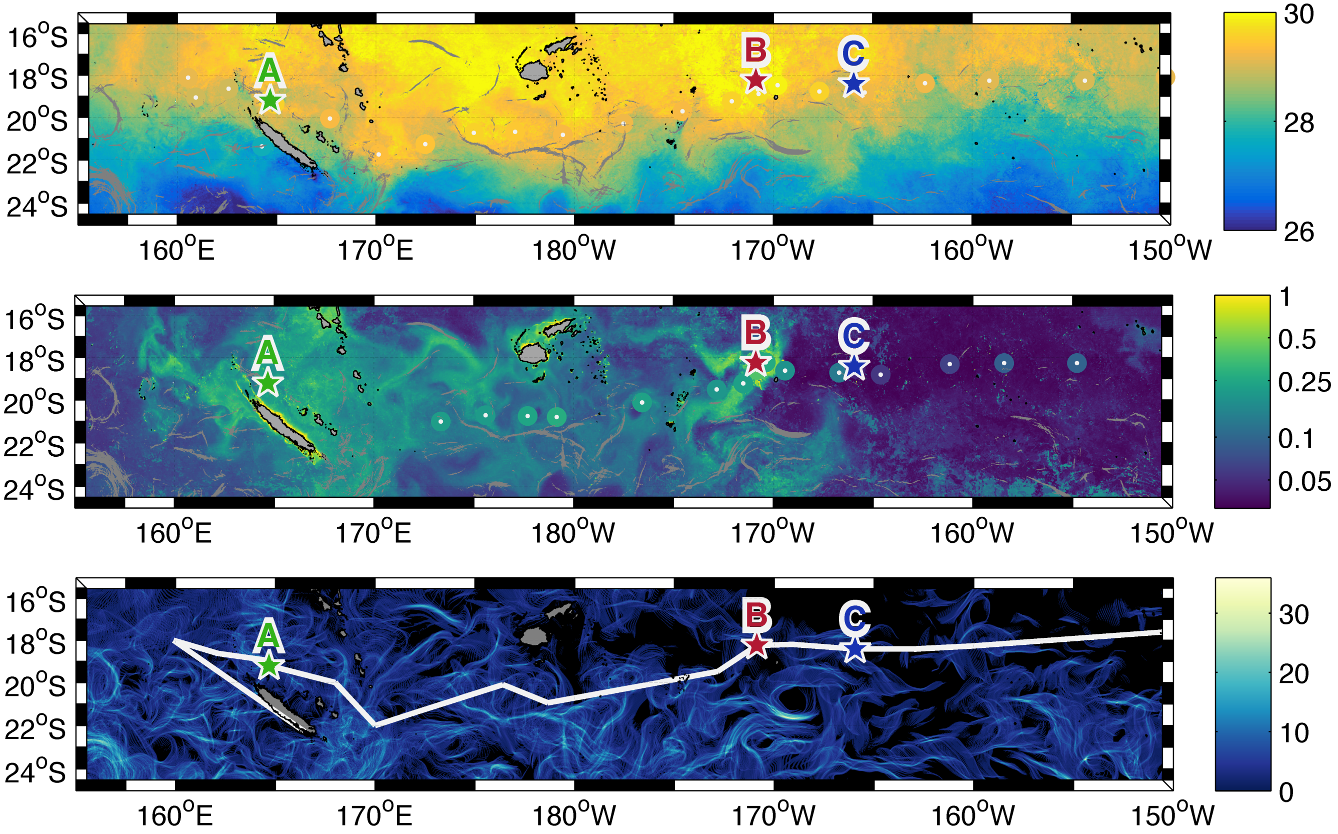


Figure 6. Top: Lagrangian satellite sea surface temperature (°C) (for the time period of the OUTPACE cruise, adapted from de Verneil et al. (2017b)) from CLS superimposed with 5 days weighted mean of sea surface temperature (°C) from TSG (colored circles with centres indicated in white). Center: Lagrangian satellite-derived surface chlorophyll concentration (mg m^{-3}) (for the time period of the OUTPACE cruise, adapted from de Verneil et al. (2017b)) from CLS superimposed with 5 days weighted mean of surface chlorophyll concentration (mg m^{-3}) measured onboard during OUTPACE (colored circles with centres indicated in white). Fronts present for at least 10 days during the OUTPACE cruise are indicated in gray in both figures. Bottom: Recurrence of FSLE structures (number of days of FSLE presence, colorbar).

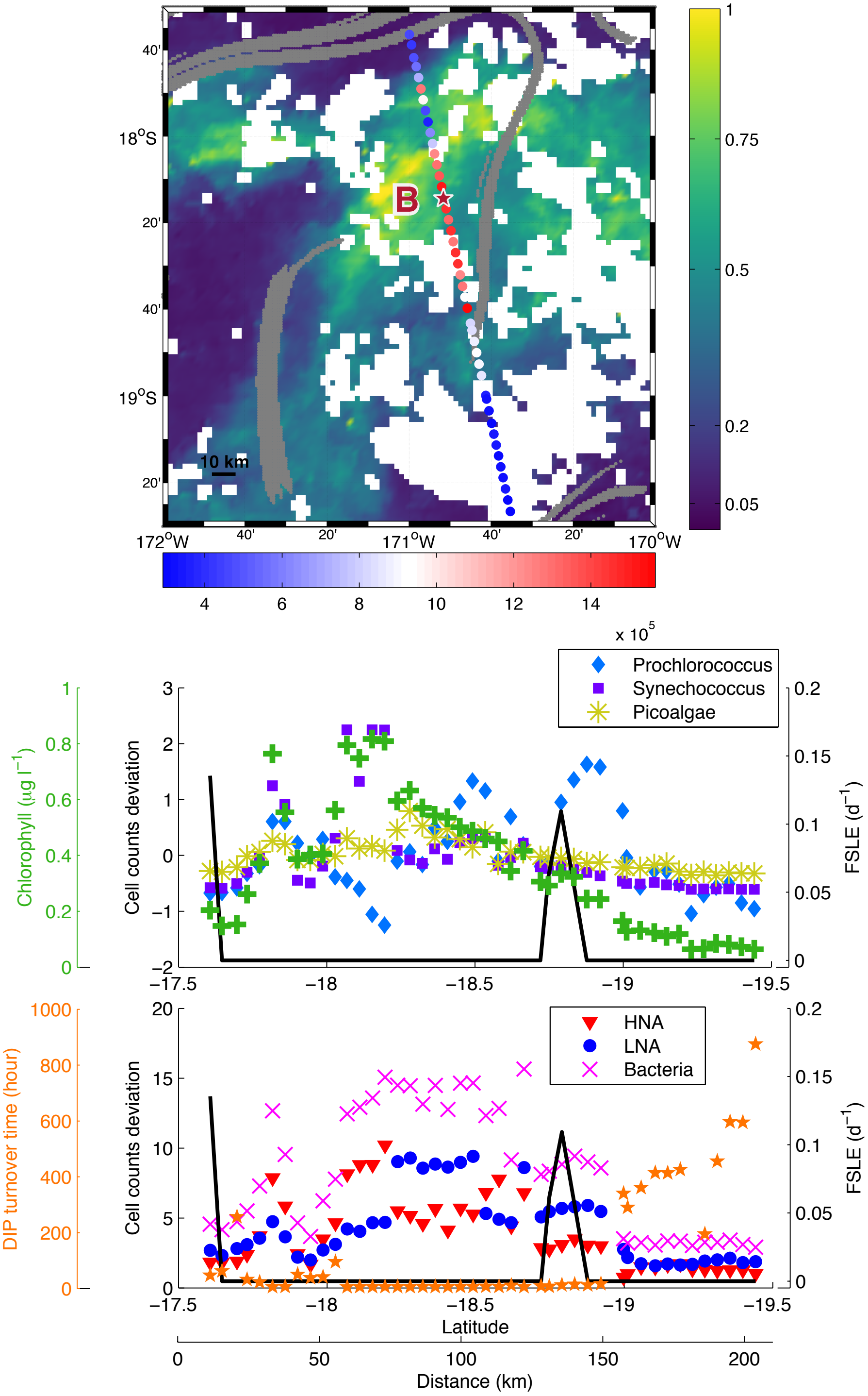


Figure 7. Top panel: chlorophyll concentration (mg m^{-3}, colorbar) from March 13, 2015 superimposed with bacteria counts (cell~~ml~~ mL^{-1}, red-blue colorbar) sampled during LDB. FSLE fronts (values > 0.05 day^{-1}) are shown in gray. The location of LDB is indicated with the red star. White squares are missing satellite data due to cloud cover. Bottom panel: Cell counts deviation ~~from mean~~ (see Sec. 2.1) of *Prochlorococcus, Synechococcus,* PPE and bacteria (HNA and LNA) superimposed with FSLE (day^{-1}, black line), surface chlorophyll concentration (μg~~l~~ L^{-1}, ~~dashed~~ green ~~line~~crosses) and dissolved inorganic phosphate turnover time (hours, ~~dashed~~ orange ~~line~~stars) along the high frequency transect of LDB.

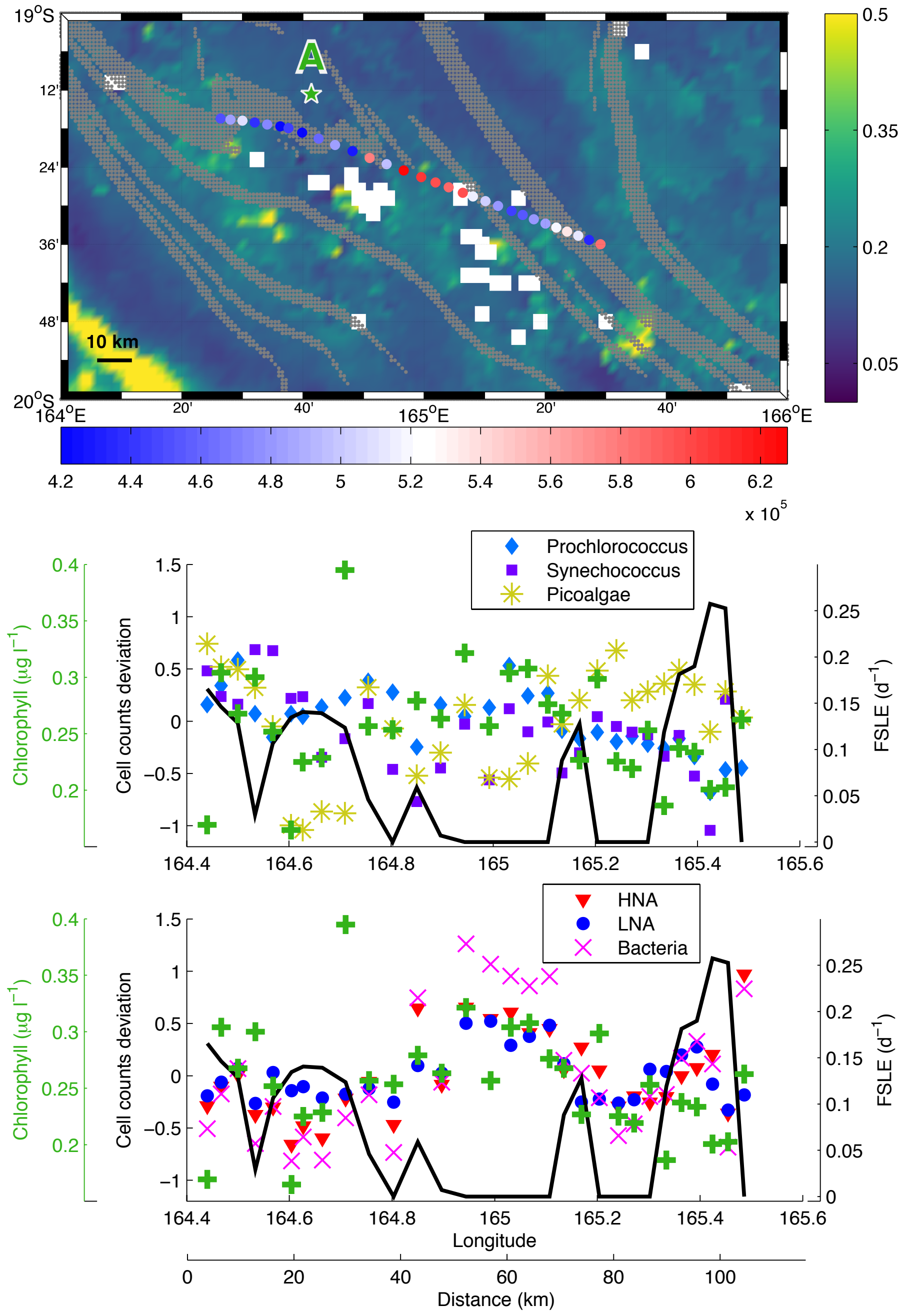


Figure 8. Top panel: chlorophyll concentration (mg m^{-3}, colorbar) from March 3, 2015 superimposed with bacteria counts (cell~~ml~~ mL^{-1}, red-blue colorbar) sampled during LDA. FSLE fronts (values > 0.05 day^{-1}) are shown in gray. The location of LDA is indicated with the green star. White squares are missing satellite data due to cloud cover. Bottom panel: Cell counts deviation (see Sec. 2.1) of *Prochlorococcus*, *Synechococcus*, PPE and bacteria (HNA and LNA) superimposed with FSLE values (day^{-1}, black line) and surface chlorophyll concentration (μg~~l~~ L^{-1}, ~~dashed~~ green ~~line~~crosses) along the high frequency transect of LDA.

Table A1. Statistics of meanders (see in the text for definition) and particles lost during each backward and forward lagrangian experiments near LD stations.

STATION	LDA		LDB		LDC	
	Backward	Forward	Backward	Forward	Backward	Forward
Meanders	39%	26%	65%	18%	70%	44%
Particle lost	22%	34%	2%	18%	3%	2%

~~Forward streamfunctions for LDA (top panel), LDB (middle panel) and LDC (bottom panel) superimposed with SVP trajectories (colored lines) launched during each LD station. Numerical particles are initially launched on the magenta boxes (roughly in the center) which represent the position of each LD station. The domain limit of each Ariane Lagrangian analysis are shown by the large green (LDA), red (LDB) and blue (LDC) boxes, respectively.~~

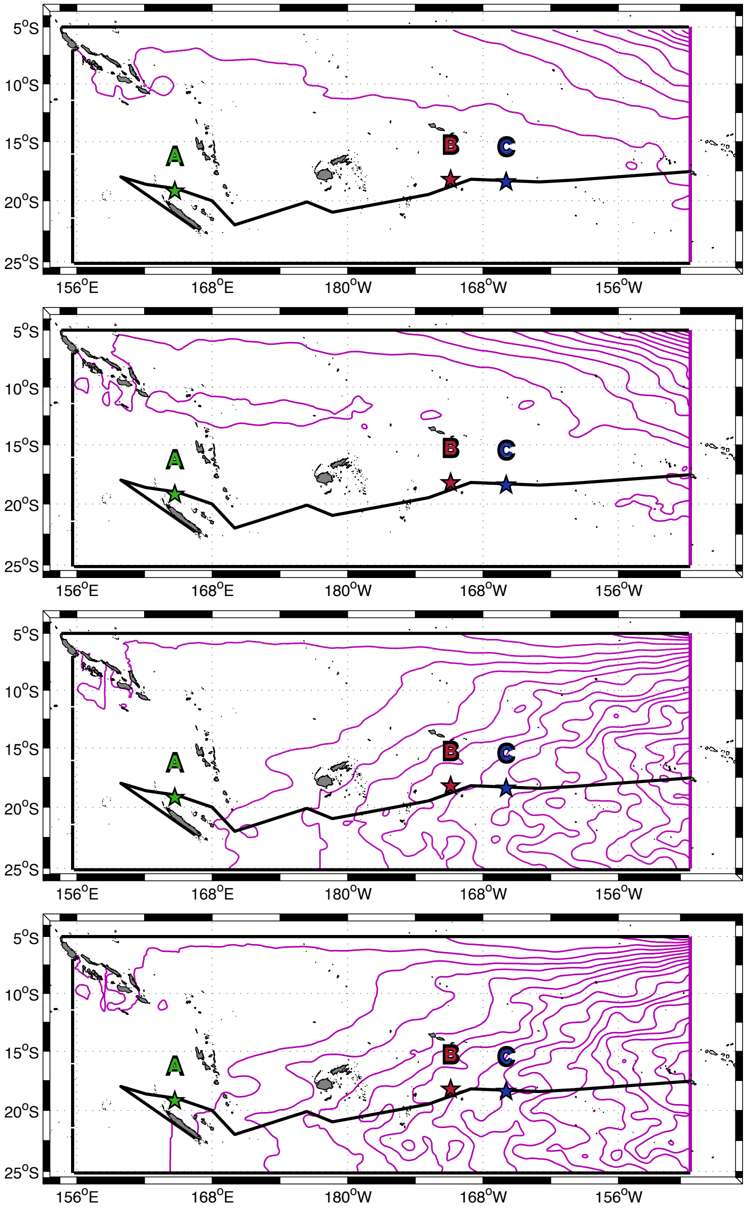


Figure A1. Forward streamfunctions computed for a ten year period with, from top to bottom: the low resolution geostrophic product of AVISO; the high resolution geostrophic product from CLS; the high resolution geostrophic and Ekman (at 15 m) product from CLS; and the high resolution geostrophic, Ekman (at 15 m) and cyclogeostrophic product from CLS (referred as the total altimetry-derived product in the text). The initial section of Ariane Lagrangian analysis is indicated with a purple vertical line to the east. The ship track and locations of OUTPACE LD stations are indicated with the black line and colored stars as referred to in Figure 1.

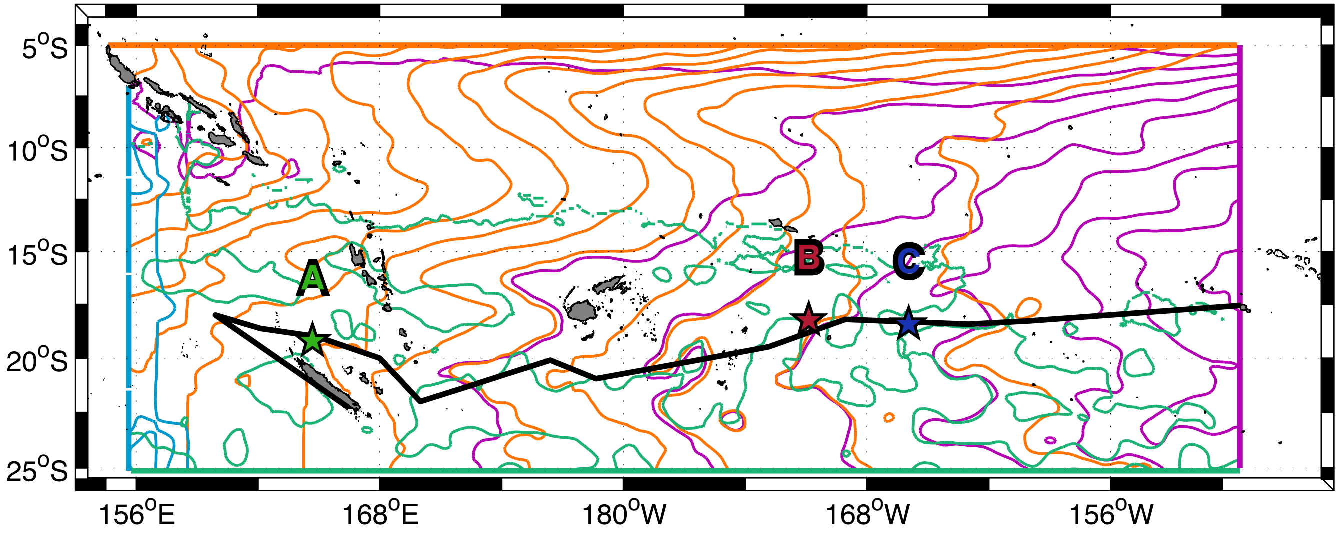


Figure A2. Forward streamfunctions computed for a ten year period with the total altimetry-derived product from CLS. Each streamline's color corresponds to the initial section of numerical particles: North section (orange lines), East section (purple lines), South section (green lines) and West section (magenta lines). The ship track and locations of OUTPACE LD stations are indicated with the black line and colored stars as in Figure 1.

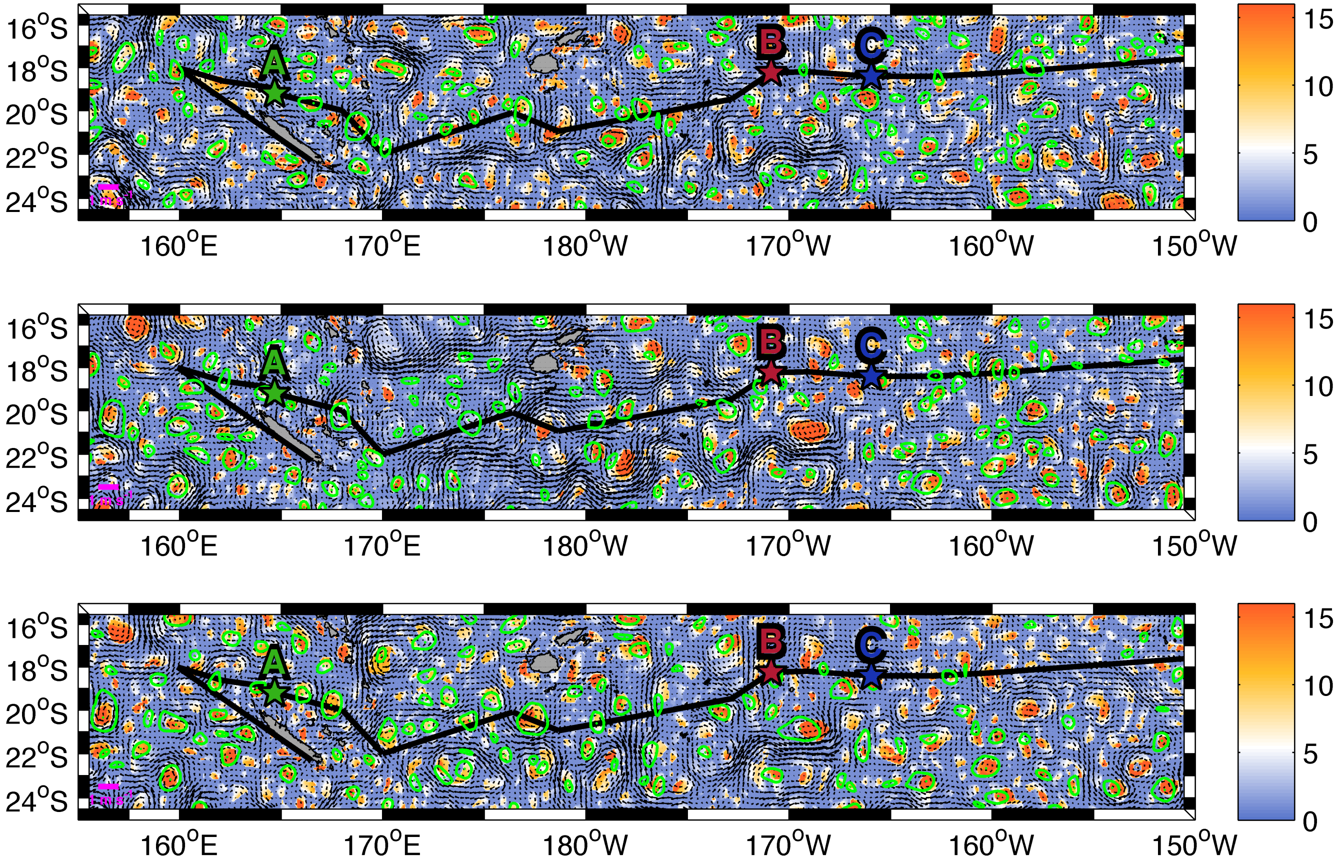


Figure A3. Particle retention time (days, colorbar) and velocity field (m s^{-1}) derived from the geostrophy, Ekman and cyclogeostrophy included product for the first day of LDA (February 25, top), LDB (March 15, center) and LDC (March 23, bottom). Contours of LAVD detected structures are drawn in green. The center of the each structure is marked with a green point. The ship track and locations of OUTPACE LD stations are indicated with the black line and colored stars as in Figure 1.

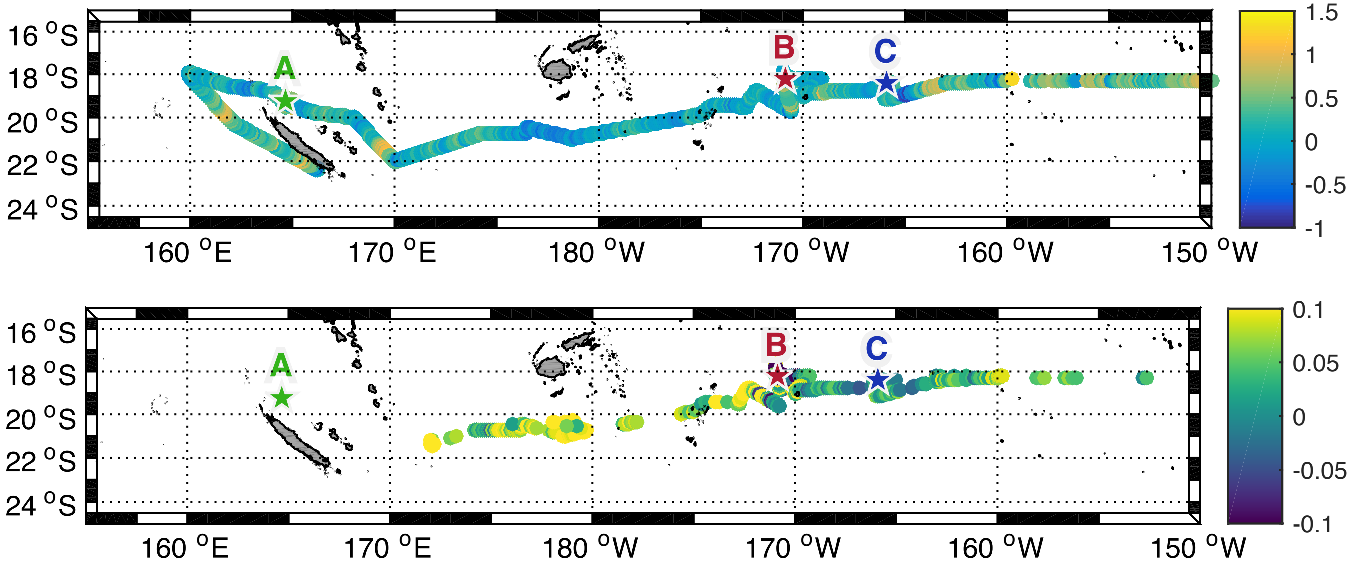


Figure A4. Top : Difference between in situ surface temperature from TSG and satellite-derived sea surface temperature from CLS (°C). Bottom : Difference between in situ surface chlorophyll concentration from the underway survey and satellite-derived sea surface chlorophyll concentration from CLS (mg m^{-3}).