Dear Editor and Referees,

Thank you for handling our manuscript and providing constructive comments. Both referees find our paper interesting, well-written and well-structured. We clearly introduce a novel concept based on Stommel's vision and demonstrate its potential. However, both reviewers raise substantial issues which may be grouped as:

a) lack of complete power budgets
b) lack of evaluation of the cost aspect
c) lack of demonstration of added scientific value

To address point (c), an Observing Systems Simulation Experiment (OSSE) must be conducted, simulating 100s of gliders. We suggest that this is beyond the scope of the paper and would need to be addressed in a separate paper. Our present work is an important prerequisite, introduction of concept and motivation for such further work.

Regarding points (a) and (b), we include two new sections to the paper as described below. This is followed by our point-by-point response to the referees' comments. We outline the necessary revisions to address these comments. Given the critical reviews, we submit this final response and await the Editor's recommendation for submission of a revised manuscript to be considered for *Ocean Science*. The authors think the manuscript will be of interest to *Ocean Science* readers, and that there is sufficient insight and novelty to qualify as a scientific paper.

In the event that the manuscript remains in the archives of *Ocean Science Discussions*, the study and the concept will be accessible, citable and informative to the interested readers. Hence, we would like to offer the best possible paper and provide a revised manuscript also in this case.

Best regards,

Erik Magnus Bruvik, corresponding author

Suggested amendments to the revised version:

2.7 Overall power budget

As an example of a complete power budget we use a low power and slow Seaglider dive. The dive was conducted in the Iceland Sea by Seaglider sg564 on 5 November 2015 (dive number 227). The vehicle was diving with a buoyancy of ± 21 cc only, and the average vertical velocity was 5 cm s^{-1}. The horizontal velocity was only approximately 8.5 cm s^{-1} which is 35 % slower than the velocity (13 cm s^{-1}) advocated by us (Figure 3).

Table 1. Energy/Power breakdown for low power Seaglider dive to 1000 m. Dive buoyancy was only ± 21 cc, and dive duration was 11 h. In total 860 CTD samples were collected.

Main component	Parts /(subcomponent)	energy (J)	power (mW)	fraction (%)
Buoyancy Engine	At inflection/apogee	1172	30	22
	Stratification	282	7	5
	At surface	179	5	3
	Sum	1633	41	30
Attitude mechanics and sensor	Roll motor	122	3	2
	Pitch motor	82	2	2
	Attitude sensor	210	5	4
	Sum	414	10	8
Controller	Active (sampling, vehicle ctrl., etc.)	1246	31	23
	Sleeping	782	20	14
	Sum	2028	51	37
Sensors	Temperature and conductivity	149	4	3
	Depth (+ analog circuits)	172	4	3
	Sum	321	8	6
Telemetry	GPS and Iridium	1014	26	19
Total		5410	136	100

The controller (processor) is the most power-hungry main component with 37 % of the total energy expenditure (Table 1). This, however, is not because of complex control, but rather due to the fact that the processor of the glider is severely outdated. The controller of both Seagliders and Slocums is based on a processor design from the 1980s (the Motorola 68000-series) in a 1990s package (the Persistor). We estimate that the power consumption could be reduced by a factor of 4 for a modern processor based on a conservative application of Moore’s Law.

Only 6 % of the total energy was expended on the CTD sensor – a figure that is arguably too low. We would like to allocate the savings from a new controller to sampling. Then the number of CTD samples could be increased and an O_2 optode (0.7 J sample^{-1}) could be included.

In this paper, we are mainly concerned with the energy expended by the buoyancy engine (Eq.(1) and Eq.(5)). Nevertheless, we allow for an additional 1 kJ per 2000 m dive to be allotted to vehicle heading and attitude control. This is justified by the fact that only 414 J were expended on this during the example 1000 m dive.

[The paragraph below should be read in the context of the second to last paragraph of the previous section 2.5 and the footnote there which states the specific energy content of lithium primary batteries].

Power budgets will be related to the vehicle volume as the displacement must make up for the weight of batteries. If we allocate 1/16th of a Watt (63 mW) to vehicle propulsion and heading control and another 1/16th of a Watt for the controller, sensors and telemetry, that would correspond to a 6.2 kg lithium battery pack for a two-year mission. Although challenging, it is possible to fit this battery into a vehicle with a displacement of 25 L. Please note how the example dive just falls slightly short of achieving the goal of 2/16th of a Watt (125 mW).

2.8 Mission cost

As a basis for estimating the mission cost we use the current costs for a core Argo float mission. The cost for the float itself is about 20 kUSD which approximately doubles when program management costs are included (Argo, 2019). Basing the cost estimate on Argo float costs can be justified for two reasons. The economy of scale for *O*(1000) slow gliders would approach that of floats rather than present gliders, and a winged float has many parts in common with regular floats; the hull, the buoyancy engine, GPS, Iridium, CTD, etc.

In Table 2 we include the additional costs for various glider specific items. A glider is inherently a more complex instrument than just a float with wings plus other components, and we also allow for costs associated with the increase in complexity of integrating the additional parts. Furthermore, we include a healthy profit of 50 % and development costs.

Table 2. Cost estimate for a slow glider mission based on an Argo float costs and Argo program costs.

Item	cost (kUSD)
Core Argo float	20
Wings and fins	1
Roll and pitch assy	5
Attitude sensor and altimeter	3
Lager batteries	3
Complexity of integration	10
Profit of 50% on above	21
Amortization of dev. costs	10
Vehicle price	73
Argo program and data mgmt.	20
Mgmt. of complex program and data	10
Piloting (semi-automatic)	10
Launch	5
Recovery	10
Value of recovered vehicle	-10
Program cost	45
Mission cost	118

The simple budget in Table 2 indicates that a slow glider (winged float) mission would cost about 3 times more than an Argo float mission (40 kUSD). This may or may not be deemed prohibitive depending on scientific potential and value of such an endeavour.

References

Argo project web pages, FAQ – How much does the project cost and who pays? http://www.argo.ucsd.edu/FAQ.html#cost last visited 21th of October 2019

Response to Referee 1

We apologize for the delay of our full response, but we opted to wait for the input from the second reviewer.

We thank the reviewer for the mindful comments on our manuscript. First, we want to comment the reviewer's general remarks below before proceeding to the detailed remarks. The referee's comment is given in *italic* font and blue colour followed by our response in regular font.

> *"The energy consumption by the sensors and controllers is marked as "beyond the scope of the research". I think that this is in fact a very important aspect."*

Referee number 2 (R#2) also points out this shortcoming of the paper, and we now address this aspect also, and focus not only on the energy consumed for propulsion. We now include a complete power breakdown of a low power glider dive (see Section 2.7 above).

> *"You do state that based on experience with a Seaglider, a cycle takes about 1 kJ for the electronics, which then would translate to 1/16 W, and could make the concept feasible."*

The 1 kJ we state is only for heading/attitude control per 2000m dive (this is included in our energy estimates). The detailed power analysis shows that this number is reasonable.

> *"… Slocum gliders, and, although the manufacturer has done a lot to reduce the power consumption of the electronics, a figure of 1-2 W is more appropriate. So clearly, sacrifices need to be made in terms what, how and how much is measured. "*

Indeed, but the Slocum glider focuses on sampling capabilities rather than ultra-low power operation. The Slocum science processor runs once every second potentially taking a sample every second. What if this was reduced to running the processor and sampling every 16 seconds? As far as the vertical resolution is concerned, we consider low sampling rates at a low vertical velocity to give adequate resolution for general hydrographic missions.

As R#1 points out later the controller must sleep most of the time. The Slocum glider has two processors and cycles them almost continuously. This is controlled by two master-data settings/sensors in the software, namely u_cycle_time(sec) and u_sci_cycle_time(sec). The cycle time might be increased for endurance missions.

> *"stratification may cause significant changes in the effective buoyancy drive, and as a consequence may require frequent monitoring of diving or climbing rates."*

True, but we believe this control problem is addressed for floats which also aim for low power and low buoyancy operation. The monitoring of depth rates should not have to be more frequent than regular sampling of the depth sensor.

We respond to this in the revised paper by adding the following to section 2.4: "The low excess buoyancy of 25 cc will be challenging to maintain over the dive in face of ocean in-situ stratification. We have stated the energy consumed to maintain this excess buoyancy as a continuous function in Eq.(1). The result of the calculation is depicted in Figure 2 (last panel) as a continuous curve. A real vertical velocity / buoyancy controller will discretise this curve as needed depending on the observed depth rate which might have to be monitored frequently."

"…then simply reducing the buoyancy drive would allow for existing gliders to be used as described in the manuscript."

We propose in the conclusions that: "Future work should firstly attempt to verify the concepts and findings presented here using existing gliders in the real ocean." If so, then one would be able to test the low buoyancy operation and potential upgrades to the vertical velocity control algorithm. We do not expect results that will render our concept infeasible.

"… if it is at all possible to build a vehicle half the size that contains all the hardware needed to function and sufficient amount of batteries. If batteries is the limiting factor, a bigger glider may be more advantageous."

We agree that present gliders indeed look compact and crammed enough already on the inside. Yet, Eq. (5) clearly shows that volume drives energy consumption. As energy considerations are of prime importance, vehicle volume must come down. This is achievable if the glider was designed with this consideration in mind from the start. This direction of development is necessary on the grounds of basic energy considerations. An example of a low volume vehicle is the SOLO-II float which has a volume of approximately 18 L – in its previous technological iteration, the SOLO-I float, it had a volume of 30 L (see table on second slide of Owens et al., 2012). Reduction of volume seems possible.

What if glider volume could only be reduced to 30 L one might ask and not the 25 L we call for. In this respect our paper is self-contained, since Eq. (5) is almost linear in volume and volume and energy consumption would both increase by roughly 20 %. This, we believe, would not invalidate the concept we propose.

In the revised version, we comment on the low volume challenge and integrate the above answer in section 2.5.

"The final issue I have, is the costs of such a down sized glider. I reckon that a guide price of today's conventional glider is about $ 200k. To be deployed in thousands, the price must come down enormously."

This issue is also raised by Referee 2 and we discuss it further in our paper. We now provide a cost estimate for slow glider missions (see above, Section 2.8, Table 2). This entails some uncertainties but is reasonably well justified and might be of interest to the reader.

"Sections 4.1-4.3 show the results of such a glider that is deployed in various parts of the world's oceans. Personally I felt that each case conveys more or less the same message, and the one case would be as good as any other."

We intended these missions to convey the same message in the sense that the proposed method of navigation (Eulerian roaming) is applicable in a pole-to-pole fashion in various scenarios. The real difference is how they supplement Argo-floats. In the Nordic Seas the slow glider is able to sample boundary currents, fronts and eddies in a manner that floats cannot do even if float density is high in the area. In the Gulf Stream and NAC mission we demonstrate how the slow glider may sample an intensified boundary current and the ensuing intense eddy field. Float coverage here is good but too low considering the energetic dynamics of the area. The slow glider will provide local snapshots of this variability. Finally, in the Drake Passage mission we demonstrate a mission in an area which is under-sampled by floats.

“Like one float, one glider would not tell much about the state of the ocean, and the appeal is a large number of devices. I thought that focussing on one case, where you look at how the added information of a Eulerian-roaming device, as opposed to a Lagrangian device would give, would be more compelling.”

Admittedly, what we would like to do in future work is to simulate how 100 slow gliders in the Gulf Stream and NAC would add significant (or not) scientific value to the floats in the area. The current paper is a necessary steppingstone introducing a novel concept with the intent to pursue such future work.

Below we respond to R#1’s detailed remarks/comments.

(P1, L23): ““in that sense fall short of realizing his vision”, this sentence suggests that as long as it has wings, all is well. I think what you mean is that the dynamic positioning is what is failing.”

We have changed this sentence to read: “and in this sense fall short of realizing his vision as far as wings also allow for dynamic positioning of the robots”.

(P2, L4): ““simpler”, simpler than what? Also related to this paragraph is that “just adding wings to a float” in reality comes with a serious increase in the level of complexity.

We will omit the word simpler. The sentence will then read: “Floats, without wings, are now a robust and mature technology that has been developed since the 1950’s …”

Note that we already in the next sentence state that gliders are “more complex [than floats]”. We do not think that we should elaborate on the specific complexities, mainly heading/attitude control, in the introduction.

(P3, L16): “This sentence initially confused me, but it made sense after I looked up some details of the Argo float. I think the words “pause” and “parking” in this context are not clear for someone who is not very familiar with how floats are typically operated.”

We appreciate the referee’s efforts to make sense of this sentence. To clarify this we will include a reference to http://www.argo.ucsd.edu/How_Argo_floats.html (Argo, 2019) at the end of the sentence. In the introduction we give ample float references and find we cannot elaborate further on float operations in the paper.

(P6, L9): “A considerable part of the lift is generated by the hull of the glider.”

(P7, L14-16): “(Related to the previous point) “… to compensate for …. smaller hull”: this suggest that, at least for the Slocum gliders, the design of the wings (size/shape) is somehow optimized. I suspect it is not, as the leading principle in the design of the Slocum glider is easy construction and I don’t think much thought has gone into the size of the wings.”

We acknowledge that the hull also contributes to lift. Probably, as R#1 suggests, not much thought has gone into the shape and size of the wings. For instance, Eq. (7) of Merckelbach et al. (2010) suggests that lift from the wings can be increased by 25% if the large sweep angle is reduced from 43 degrees to a more reasonable 10 degrees. If also made a little bit bigger, the wings should more than make up for the decrease in lift from a smaller hull.

In the paper we do not give a full account on the generation of lift. The main reason is that we are primarily concerned with the energy consumed, which is determined by drag.

> *(P8, L15): "Here I thought it might be difficult to achieve gliding with just 25 g of buoyancy, because the effective buoyancy may change more than this in a stratified ocean, and using a vehicle that has not a compressibility that is exactly matching that of seawater. This requires frequently adjusting the buoyancy on both the down and up casts. In my experience gliders typically reduce speed on both the down and up casts, due to stratification effects."*

It is true that the buoyancy control will have to be finer grained than what is currently implemented in gliders. Present gliders are not designed with low buoyancy operation in mind. However, floats manage to cope with this low-buoyancy and low-power control problem with neither excessive complexity to the controller nor excessive power consumption.

> *"You could, I suppose, store energy when reducing the volume on the down cast and releasing it again on the upcast, but still you will look at a hysteresis-like effect, and a much more technically complicated design (read: losing volume for batteries, increased costs)."*

R#1 here points to an interesting development of a self-regulating and recuperating buoyancy engine. We do not assume such a development in the paper and only presuppose regular buoyancy engines. Consequently, we will not have a more complicated design which adds vehicle volume and increases costs.

> *(P11, L19): "Here you say you set the glider's velocity vector. It is not clear to me where you specified the just that, the speed, or that you would specify the buoyancy of 25 cc. I guess you prescribed the speed."*

R#1 is correct that we prescribe the speed given that we in Section 2.4 (Figure 3) establish the operating point for the buoyancy to be 25 cc (for a speed of 13 cm s^{-1} in the horizontal plane). We have clarified this by adding the following sentence to the paragraph:

"The speed of 13 cm s^{-1} in the horizontal plane was established in section 2.4 (Figure 3) for the operating point of 25 cc in excess buoyancy."

> *"In that case, my previous point should some how be addressed. If you specified the buoyancy, I suggest you include a small discussion on how frequently the buoyancy needs to be changed, and what the energetic costs are."*

We do include these costs in energy to maintain an excess buoyancy of 25 cc as we evaluate energy consumption using Eq.(1) in conjunction with the salinity and temperature fields from the reanalysis product. Such a calculation is exemplified in Figure 2. The buoyancy engine must pump where the energy needs to be increased (last panel of Figure 2). We evaluate the continuous integral of Eq.(1) but do not suggest how this should be discretized by a real vertical velocity controller.

Such a vertical velocity controller would not have to be significantly different than what is currently implemented in floats and gliders. The Seaglider, for instance, monitors the pressure rate and pumps if depth rate sinks below a certain value (i.e. simple threshold control). We do not see why we would need a substantially more complex and more energy-consuming controller.

(P14, L12): "Here (and also in following paragraphs) you specify the energy consumption. I read this number as 691 cycles, at 1 cycle a day, using 1/16 W gives 2.9 MJ. Or is this computed using equation 5, taking into account the actual velocity the glider made, and stratification it faced, and the effort done to compensate for it? Also I think, this includes only the power required for propulsion. So what about the electronics?"

R#1 is confused and rightly so. We were not clear on how we calculate the energy consumption and have expanded this paragraph as follows:

"The glider performed 691 cycles and the energy consumption was 2.9 MJ (or 2.3 kg of Lithium primary batteries). This is calculated by evaluating Eq.(1) using the established operating point with an excess buoyancy of 25 cc and using the salinity and temperature fields of the reanalysis product. Then 1 kJ is added per dive for heading/attitude control and finally 0.5 kJ is added for surface pumping to raise the antenna out of the water. The full EOS of water and hull (Eq.(2)) is taken into consideration. Values for compressibility and thermal expansion are as given in Section 2.1 and the result of the calculation is depicted in Figure 2 panel d)."

As far as the electronics is concerned, it is hard to account for it given that the main component of the power consumption is an obsolete processor (see Section 2.7 and the low power dive exemplified there). Notice how we do include energy consumed by the electro-mechanics needed for vehicle heading and attitude control and the associated sensor.

New References

Owens B., Roemmich D. and Dufour J.: Status of SOLO-II Floats Development, presentation given to the Argo Steering Team meeting No. 13, Paris, France, 2012 http://www.argo.ucsd.edu/AST13_SOLO-II_Status.pdf

Argo web pages, How do Argo floats work, http://www.argo.ucsd.edu/How_Argo_floats.html last visited 18th of October 2019

Response to Referee 2

Thank you for your thoughtful comments on our manuscript. Your general comments suggest that we solve the following generalized ocean observing problem:

> Given n_f floats, n_{rg} regular gliders and $\boldsymbol{D}_a$ altimetric data
> Show that n_{sg} slow gliders would add scientific value in an economic fashion

This is indeed an interesting and necessary problem for an Observing Systems Simulation Experiment (OSSE) which must be undertaken before the oceanographic community implements Stommel's vision. Such an OSSE, we argue, is beyond the scope of our manuscript and present study. Note that this manuscript forms a necessary steppingstone for such an OSSE and motivates further research.

On several occasions concerns over the costs of such slow glider missions have been expressed, and we have addressed this better in the revised version of our paper. Please see our letter to the editor and the referees (Section 2.8 above).

We have added the following paragraph to our Section 4.6 to alleviate your concern that this undertaking will become a waste of resources better directed at other more established methods:

"While the tracks of the slow glider (/winged float) presented in this section clearly demonstrate oceanographic *potential* it remains to prove scientific *value* added to the existing network of Argo floats, regular gliders and altimetry. The scientific value could be explored and possibly quantified by an Observing System Simulation Experiment which would include all observing elements of the GOOS including our slow virtual glider. Such future work might build on the concepts and methods presented here. In Section 2.8 we roughly estimate that such glider missions will cost 3 times more than a float mission, which requires that the scientific value be correspondingly enhanced if Stommel's vision is to be implemented in the form of slow gliders as we propose."

Below we provide answers to the referee's comments which are given in *italic* font and blue colour followed by our response in regular font.

> *"Attempts to justify the Eulerian roaming were not convincing, especially for single missions."*

As far as the navigation in areas of key oceanographic interest is concerned, we disagree. The single missions demonstrate clear scientific potential using the Eulerian roaming approach in various scenarios. Notice how the slow glider employing Eulerian roaming successfully and in an oceanographic meaningful way navigates an important marginal sea, an intensified boundary current and eddy field, and the remote Southern Ocean. However, we do not attempt to explore how a fleet of roaming gliders would generate scientific value. This relates to our comments above.

> *"What scientific questions beyond the lucky detection of an episode or feature would such a large scale network address that ARGO floats do not already address?"*

We consistently target high-value oceanographic features. In the Nordic Seas, for instance, we target major oceanographic features and pathways. This includes fronts, boundary currents and eddies. Most of these go un- or under-sampled by the Argo floats who rely strictly on Lagrangian luck.

> *"What is so special about 1000 gliders exactly? Are the reasons Stommel used to justify that number still relevant today?"*

Stommel meant *O*(1000) gliders and never gave a scientific rationale for the number, instead presenting his vision as a short science fiction story. The 1000 gliders was a number he mentioned probably based on his intuition and gut feeling. But as far as oceanographic intuition and gut feelings go, Stommel's cannot be easily dismissed. Hence, we start from his order of magnitude as a reference. The design specification of the Argo array mentions the potential of a gliding float with wings. Taken together, we suggest that these two sources form a relevant premise for the paper.

> *"Central to this question is cost, which was essentially brushed aside.. Presently, gliders cost about 10 times more than floats to purchase."*

True, and we have addressed the costs in a separate section (2.8). We then argue that the price of the slow glider is a factor of 3 cheaper than present gliders given *O*(1000) units.

> *(P7, L10) : "it may be stated that those glider manufacturers now have different designs and that performance may differ (e.g. Seaglider ogive fairing or larger Slocum G3 hull). It would be interesting to update the results for those and to run more simulations for reduced volume versions, rather than just one."*

We are not aware of any hydrodynamic models and associated coefficients for the Slocum G3 or the Seaglider Ogive fairing. We believe we must stick to established models in this section. Also, please note how little is gained by a glider with 20 % reduced drag in terms of velocity. Simulating more drag coefficients would clutter Figure 3 with clusters of intersecting lines making the figure harder to read. We ask that we may keep the figure as is.

> *(P9, L20-25): "It is not clear if a CTD-only glider will best serve the global observing system: there are many more Essential Ocean Variables that gliders can (and soon will) be able to measure. This flexibility is one of the strengths of current gliders. Some examination of what payloads would be possible compared to what is normally done now would be interesting, and I think not outside the scope of the paper. Later in the paper, microstructure is mentioned. That paragraph could be expanded to include other potential payloads for the small glider."*

In addition to the microstructure we also mention the Argo biogeochemical (BGC) suite. However, we must admit that we cannot fit these into our small ultra-low power glider – neither volume wise nor power wise. At present, we would like to add. However, three future developments are likely to improve the situation. Batteries will have larger capacities, and sensors will become smaller and consume less power thus making a small slow BGC glider possible. A slow glider would also provide a depth averaged current which is more useful than the 1000 db (typical) current produced by floats.

The concept we propose consists of three elements; smallness, slowness and a novel way of navigation (Eulerian roaming). This novel concept needs not be taken wholesale. Existing gliders using existing sensor suites measuring more EOVs may be operated according to the principles of slowness and Eulerian roaming. In particular, the slow speed may conserve a lot of power (Eq. (3)) which may be directed at powering advanced EOV sensor suites.

> *"I am not sure why detailed power budgets and engineering calculations should be excluded from the paper. It seems to me that would strongly support the main point of the paper."*

Agreed. R#1 also laments this short-coming, and we have thus decided that we need to provide a complete power budget for a low power Seaglider dive. Please see the beginning of our letter to reviewers and the editor for a new section (2.7) on the matter.

> *"More details about the strengths and weaknesses of Eulerian roaming are necessary if the reader is to believe this is a viable alternative. The simulations following help, but no indications are given on how such data could be/have been handled other than a simple citation (Todd et al., 2016)."*

Agreed. Todd et al show that even highly irregular glider tracks obtained using "current-crossing navigation" (similar to our Eulerian roaming) in energetic regions (Todd et al., 2016, figure 1) can be used to obtain valuable oceanographic measurements. This is supportive of the insight that can be gained from Eulerian roaming; however, caution is needed when calculation distribution of geostrophic currents and related parameters. We now expand on the concept, assumptions, and also reference a recent paper. The paragraph at (P20, L3) will be augmented with an additional paragraph as follows:

"The key assumption in using the local streamwise coordinate system for geostrophic current calculations along the glider trajectory is that all flow is parallel to the depth-averaged current (DAC). When the depth-average current direction is not perpendicular to the transect segment of the glider path, a decomposition into cross-track and along-track components must be made. In these conditions, using the currents from the local streamwise coordinate system will be in error; however, the transport will remain relatively unaffected. In a recent study, Bosse and Fer (2019) reported geostrophic velocities associated with the Norwegian Atlantic Front Current along the Mohn Ridge, using Seaglider data, following Todd et al. (2016) and assuming DAC is aligned with the baroclinic surface jet. They also calculated the geostrophic velocities and transports using the traditional method, i.e. across a glider track line, and found that the peak velocities of the frontal jet were 10-20 % smaller but the volume transports were identical to within error estimates. The Eulerian roaming can thus be used to obtain representative volume transport estimates of relatively well-defined currents. We also note that the present 1000-m depth capability of gliders limits our ability to compose the geostrophic currents into barotropic and baroclinic components in water depths substantially deeper than 1000 m. A 2000-m range will allow us to more reliably approximate barotropic currents as the depth averaged profile, up to depths of around 2000 m."

> *"This section 2.6 seems out of place, and fits better in the next section."*

We agree and have moved section 2.6 to 3.1.

> *"Section 4. Results and Discussion. The hypothetical case studies are interesting and show the potential, but are not convincing in terms of scientific value. An attempt is made in 4.4, but the analysis from the mission is oversimplified in my opinion. Separating temporal and spatial variability on these year long missions over large horizontal gradients would be very*

difficult and it is not always possible with one long track to collect data "useful in understanding the role" or that will "capture the properties and variability". The section about altimetry begins to touch on what could be the scientific goal of such a fleet: the surface topography problem. The number of gliders needed to reduce the current errors in the altimetric eddy field (number, phase and intensity) could be quantified in this paper and justify the existence of the fleet."

We agree with the reviewer that separating temporal and spatial variability requires a fleet of gliders. It was not our intention to claim that a single glider would capture the properties and variability of different current systems. We clearly state, in the end of the section: "While we have shown tracks of individual gliders, it should be clear that the impact of a slow roaming glider concept will increase when employed in large numbers. Also, the simulations here where a few gliders are hand-piloted does not show the full potential of the approach." We exemplify the potential skill of single missions, and advocate for deployment in numbers. Authors, reviewers and the reader all know that only then we can harvest meaningful information from the missions and describe the properties and variability of the ocean circulation and dynamics. We close this response by repeating that a demonstration of the full potential of the approach with simulations of numerous missions is left for future research. Careful considerations and optimization must be made to design a suite of missions. Even a naïve approach of deploying, from the same location and with similar target missions, every month for a duration of 1 year (12 deployments) would return a highly informative data set and would allow sufficient averaging and separation of temporal variability. Exchanges across the Greenland and Norwegian Seas are poorly known, transport of the frontal branch of the Atlantic Water in the Norwegian Sea is poorly known, the return Atlantic current in Fram Strait is poorly known, the role of winter convection in water mass transformations in the Nordic Seas is poorly known. While targeted, regular glider missions would help filling gaps in our knowledge, Eulerian roaming of a fleet of slow gliders would be complementary and provide a different mapping capability between Argo floats and regular gliders.

"Section 5. Specific methods of piloting large numbers should be cited (optimal fleet mission planning) as well as the scientific objectives one might achieve with this (e.g. optimized for data assimilation for altimetry or some other objective). This was very briefly touched upon in the conclusions and future work, but really this should provide a solid background to why the reader should even dig into the paper. Clearly this concept is most valuable in a complex large fleet sampling context and some work has been done already."

The reference, L'Hévéder et al., 2013, we provide in the conclusion and further work is the most relevant citation and appropriate starting point for continued research. In their work, which is centred around an OSSE, they study how a fleet of gliders could reconstruct a mesoscale temperature field. We believe the conclusion (Section 5) should be as succinct as possible and would like to keep the conclusion as is. However, R#2 correctly points out that we need to better address the problem of fleet control with respect to a certain scientific objective. Notice that this is a vast topic (Rudnick, 2016) and that we will only be able to scratch the surface. Still, we would like to add the following paragraph to our discussion (Section 4.4):

"The control and steering of a network or fleet of slow gliders should aim to optimize for some scientific objective possibly in conjunction with other sensing platforms. Alvarez and co-workers (2007) have looked at synergies between floats and gliders to improve reconstruction of the temperature field. Synergies also exists between a glider fleet and altimetry to map geostrophic currents (Alvarez et al., 2013). We suggest that future work should see the slow glider concept not as a homogenous fleet, but rather as a part of a heterogenous suite of ocean sensing technologies. The topology of the network needs some consideration and one interesting option is to cluster the gliders in and near an oceanographic feature to explore it in greater detail. Some in-situ experiments with glider fleets have been conducted (e.g. Leonard et al., 2010; Lermusiaux et al., 2017a). The problem of planning optimal paths for gliders is reviewed by Lermusiaux et al. (2017b)."

New references

Alvarez A., Chiggiato J. and Schroeder K.: Mapping sub-surface geostrophic currents from altimetry and a fleet of gliders, Deep Sea Research Part I, 74, 115-129, doi: https://doi.org/10.1016/j.dsr.2012.10.014, 2013

Alvarez A., Garau B. and Caiti A.: Combining networks of drifting profiling floats and gliders for adaptive sampling of the Ocean, IEEE International Conference on Robotics and Automation, Roma, Italy, 10-14 April, doi: https://doi.org/10.1109/ROBOT.2007.363780, 2007

Bosse, A. and Fer, I.: Mean structure and seasonality of the Norwegian Atlantic Front Current along the Mohn Ridge from repeated glider transects, Geophysical Research Letters, 46, doi: https://doi.org/10.1029/2019GL084723, 2019

Leonard, N. E., Paley D. A., Davis R. E., Fratantoni D. M., Lekien F. and Zhang F.: Coordinated control of an underwater glider fleet in an adaptive ocean sampling field experiment in Monterey Bay, J. Field Robot., 27, 718–740, doi: https://doi.org/10.1002/rob.20366, 2010

Lermusiaux P.F.J., Haley Jr. P.J., Jana S., Gupta A., Kulkarni C.S., Mirabito C., Ali W.H., Subramani D.N., Dutt A., Lin J., Shcherbina A.Y., Lee C.M. and Gangopadhyay A.: Optimal planning and sampling predictions for autonomous and Lagrangian platforms and sensors in the northern Arabian Sea, Oceanography 30, 172–185, doi: https://doi.org/10.5670/oceanog.2017.242, 2017a

Lermusiaux P.F.J., Subramani D.N., Lin J., Kulkarni C.S., Gupta A., Dutt A., Lolla T., Haley Jr. P.J., Ali W.H., Mirabito C. and Jana S.: A future for intelligent autonomous ocean observing systems, Journal of Marine Research, 75, 765–813, doi: https://doi.org/10.1357/002224017823524035, 2017b