Reply to the referees' comments

We are very grateful to Kim Yates and Sam Dupont for their thoughtful and constructive comments and are addressing below each of the points they raised.

1 Reply to Kimberley Yates' comments

- *It seems that the main goal and motivation of this paper is to introduce the xFOCE program to the scientific community to promote awareness and availability as an important resource for ocean acidification studies, and to build a user community. This should be stated in the abstract and introduction. The information in section 6, pg. 4028 should be moved up front to make this clear.*

  That is correct. One of the goals is to introduce xFOCE, a community-led initiative to promote awareness, provide resources for *in situ* perturbation experiments, and to build a user community. However, the main goal is to provide guidelines on the general design, engineering, and sensors required to conduct FOCE experiments. This is now made clear in the abstract. We are reluctant to move information of section 6 earlier in the paper because it would give too much emphasis on community building at the expense of engineering and scientific guidelines.

- *The readers also need to be clearly informed up front on the concept that the xFOCE system has been developed as a modular system to provide some flexibility for modifying to fit specific environments. The concept of modularity for flexibility and the motivation for that should be addressed before a description of the general system. The sections describing the specific FOCE systems should more clearly point out the differences between the systems and how the system was customized for each environment. . .along with advantages and disadvantages as examples.*

  Agreed. Two sentences have been added early in section 2.

- *A generalized diagram of the xFOCE system concept and standard modular elements common to most/all FOCE systems would be helpful for readers who are not familiar with mesocosm technology. Even better would be inclusion of concept diagrams for each of the different FOCE systems (as in figure 4) highlighting their differences since the pictures of each of the FOCE systems in figure 3 look like completely different systems.*

It is an excellent idea to introduce FOCE systems using a generalized diagram. Such a figure has been added (Fig. 1 of the revised manuscript).

- *Section 7 (overarching activities, pg. 4029) could use some more thought and detail. It seems more like a list of proposed program elements that need to be developed for a network of FOCE experiments, and these are common to all regional and global network programs. There have been several FOCE experiments in different environments, so there has likely been some insight into lessons learned, what has worked well and has not, and some thought on how to approach inter-comparison exercises, data management, dissemination and outreach etc. The issues within each of these elements that are unique to FOCE technology should be explored, discussed, and recommendations made on how to proceed with a robust network program. For example, it seems like a first logical step forward is an inter-comparison exercise among the existing FOCE systems that seem to use different sensor packages to examine the comparability of results with existing units.*

  Agreed. This section has been strengthen in the revised version of the manuscript to include more specific examples.

- *I am unable to locate the xFOCE open source package of plans and software at the url provided http://www.xfoce.org. I found reference to Kecy et al. 2013* `http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6741086` *regarding open source instrumentation nodes for the oceanographic community. But no other publications, plans, or software are available. If the information is not yet available, then state an expected time frame for delivery.*

  That is correct. Some of these resources (electrical designs) have now been uploaded and two new sections "Mechanical designs" and "Software designs" will be populated in the coming days and weeks.

- *In the conclusions, a statement is made that all current FOCE users have experienced setbacks due to engineering issues or failures. A discussion of the specifics of these and how future modifications can be made to overcome them would be particularly useful for new users to know.*

  It is agreed that this is useful and we have added some examples as a footnote of the conclusion. We are reluctant to go into too much detail because it would greatly exceed the scope of a scientific publication.

- *Pg. 4008, line 27: dpFOCE – spell out acronyms on first use in text throughout the paper.*

  Done.

- *Pg. 4014, line 6: Yates et al. 2007 reference is missing from reference list.*

  Fixed.

- *Pg. 4016, line 23: insert the word data between "meaningful" and "to"*

  Done.

- *Pg 4017, line 13: It is stated that pH sensors with a precision better than 0.003 pH unit are required for FOCE experiments and a few sensors are discussed on pg. 4018, lines 1 – 14. But no precision or accuracy values are given for these sensors. This information should be included.*

  We now mention the precision of the electrode used by most systems and also provide information on the issue of drift.

- *Pg. 4019, lines 22-25: Information in available systems for continuous CT measurements. Also see the work of Burke Hales (OSU) and Alec Wang (WHOI) who have developed CT sensors.*

  We are familiar with the work of Hales and Wang but, unless we are mistaken, the instruments that they described are not designed to operate underwater, in contrast to the one described by Liu (cited in the paper). Hence, we do not think that it is necessary to cite these earlier systems.

- *Pg. 4020, line 21: typo – community production*

  Fixed.

- *Pg. 4020, line 24-26: sentence needs to be restructured*

  Done.

- *Pg. 4022, line 1-2: sentence grammar*

  Done.

- *Pg. 4022, line 18-19: sentence beginning "Hydrodynamics. . ." is not a complete sentence*

  Fixed.

- *Pg. 4029, line 19-20: delete "be" from the sentence.*

  Done.

- *Pg. 4038, Table 1. It would be most helpful to include in this table a list of benefits and limitations of each system to help compare and contrast them. Also include system materials and design.*

  We are afraid that it is not possible to provide a list of benefits and limitations of each system. They are all based on the same original MBARI design and modified to suit specific environments, communities, or research questions. Providing all materials and designs is well beyond the scope this manuscript and would turn our contribution into an engineering report, which is not our objective. Whenever such information is available, the paper(s) is/are cited in section 4.

- *Pg. 4046, Figure 4. I have some concerns about the use of heaters at the in/out flow changing seawater chemistry in the system outside of natural temperature ranges or if the heaters can keep up with ice production. This will be an interesting test.*

  Yes, it is very challenging issue. The antFOCE system is now on its way to Antarctica and will be deployed next Austral summer.

2 Reply to Sam Dupont's comments

- *Of course, FOCE can be used in the context of ocean acidification. However, it could also be considered for other CO2 related questions. As mentioned in the manuscript, it may be interesting to increase pH to answer some evolutionary questions or test hypothesis regarding artificial alkalnization. I suggest to extend the focus of the paper by replacing "ocean acidification" by something like "pH/CO2 changes" (e.g. page 4003, line 3; page 4005, line 10; page 4006, line 3; page 431, line 10).*

  We need to be careful here. While increasing pH by adding alkalinity (such as a strong base) is technologically easy, this is not the same as raising pH by decreasing the C_{T} (which is technologically harder as it requires a working fluid of seawater that has been "stripped" of its CO_2)$justasoceanacidificationbyacidrainisdifferentfromoceanacidificationby CO_2 enric$

- *Authors justify the use of FOCE by the fact that it allows working at the ecosystem level and compare with laboratory based experiments focusing on single-species. Something that is not very well presented in the manuscript is that you can also work at the ecosystem level in the*

lab (land-based mesocosms). This is a very important approach that can allow overcoming some of the drawbacks of the FOCE (but with other limitations): more replication, more controlled conditions (e.g. artificial or simplified ecosystems), etc. This approach has been used in the context of ocean acidification and should be better presented in the text.

Agreed. Sam Dupont's advice (below) to add a table describing the benefits and limitations of the various approaches used to investigate the effects of ocean acidification should fix this issue. This is Table 1 of the revised manuscript.

- *Page 4006, line 26, delete "Although ideal in concept". No experimental approach is ideal.*

  Rephrased as "*Although straightforward in concept, engineering and logistic aspects of FOCE technology are very challenging to implement.*"

- *Page 4011, lines 10-16. This argumentation sounds a little desperate and is not needed. I suggest deleting. Sure there is value in using FOCE. All experimental approaches have value and no need to try to rank them ("more useful").*

  We disagree. The lack of replication is often given far too much emphasis by editors and referees. We feel that it is important to cite divergent opinions .

- *Page 4016, line 16. "more realistic" than lab. This may not always be true if you consider large scale lab-based mesocosms.*

  Agreed. We have toned down this sentence as :"*A strength of FOCE systems is their exposure to environmental conditions which are generally more realistic than laboratory-based studies*".

- *Page 4029, line 7 "will deliver", this is pushing it too far. "will contribute" would be better.*

  Agreed; this change has been made in the revised version of the manuscript.

- *It is important to mention somewhere that all approach are important and that not a single approach is ideal when it comes to project future environmental changes. It is the combination of information collected in single-species perturbation experiments, monitoring, mesocosms, modeling that will allow to provide the needed mechanistic understanding and predictive power that is needed (we tried to make this point in our opinion paper Dupont & Pörtner 2013). For example, our*

group developed some physiological models that allow making prediction for the response of a given species in a multiple and fluctuating world. We then validated this model in mesocosms (real world but only a limited set of conditions).

One of the major limitations of the FOCE is that you can only test a few scenarios (due to low replication) and that it is then difficult to make strong generalization of mechanisms across a gradient. It is also true for the limitation in multiple sampling points (point 2.5). It is then important to keep the link and collaboration with the lab based work. A table summarizing pros and cons (e.g. costs, replication, realisms, etc.) of different approaches may be interesting as well as a discussion on how these different approaches can help each other. This can be integrated in the conclusion and highlight the key role of FOCE in a multidisciplinary context.

Adding a table presenting the benefits and limitations of the main approaches used to investigate the effects of ocean acidification is an excellent suggestion. This is table 6 of the revised manuscript. The following paragraph has been added to the conclusion: "*All approaches available to investigate the effects of ocean acidification have benefits and limitations (Table 6) and there is not a single ideal approach. It is the combination of information collected in laboratory experiments, field observations (monitoring),* $CO_2vents, laboratorymesocosms, FOCE, andmodelingthatwillallowto$

- *For the point 7.4. you may also want to add that FOCE are charismatic experiments that can be used to attract public attention and contribute to ocean and climate literacy in the society.*

  Very good idea, the suggestion has been added to the text.

- *page 4004, line 6 "decreased availability of carbonate ions, used by many species to build calcareous shells". Many species are actually independent from carbonate ions in seawater for their calcification are rather use HCO3- or metabolic CO2 as a source. Maybe delete this?*

  Agreed but we say: "... decreased availability of carbonate ions, used by **many** species to build calcareous shells and skeletons", which should be fine as it indicates that some species do not rely on CO_3^{2-}.

- *page 4011, line 29, Barry et al. (2010) was not putting a lot of emphasis on the importance to take into account natural variability when designing experiments. I suggest to delete this sentence.*

It is true that Barry et al. (2010) do not provide a lot of emphasis on natural variability (it is actually a major omission...). However, this work is not cited in the context of natural variability but for the guidance that it provides to select relevant levels of perturbation levels.

- *page 4012, line 9, "In contrast to many laboratory experiment..." I agree that using constant conditions is not realistic and that one of the exciting features of FOCE is to offset the natural variability. However, it is equally possible to mimic variability in the lab and many laboratories are not including variability in lab-based experiments. So i would avoid this comparison.*

  Agreed. Rephrased as follows: "*In contrast to many laboratory experiments which used a constant carbonate chemistry, the FOCE technology is one of the approaches which maintain the natural daily and seasonal pH changes.*"

- *Page 4020, line 9, "ocean acidification is detrimental to the precipitation of calcium carbonate". In many example, it is not the precipitation in itself that is the problem but the maitenance of adequate internal conditions for calcification due to energy disturbance and increased dissolution. The paragraph is about net calcification so rather say that net calcification is often impacted by OA (very well documented).*

  Agreed. Rephrased as follows: "*Ocean acidification is detrimental to the net precipitation of calcium carbonate (CaCO3) shells and skeletons by many marine organisms (Gazeau et al., 2013; Kroeker et al., 2013). Net calcification is therefore an important process in FOCE experiments involving calcifying organisms.*"