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Biogeosciences Editorial Team

January 27th 2023

Dear Dr. Bond-Lamberty,

hereby I submit a revised version of our manuscript "*Ideas and perspectives: Land-ocean connectivity through groundwater*" to be considered for publication in Biogeosciences.

We are glad to hear that you and the two new referees have a positive opinion of our manuscript, and that our revised version has addressed well the comments provided by the referees during the first round.

Attached we are sending the marked-up document which includes the changes highlighted in our replies to both referees' comments. In addition to those changes, we made a few minor modifications which we saw necessary after reading the latest version of our paper. A detailed list of those changes is provided below (see Annex 1). We hope with these improvements the manuscript can be approved for publication.

We appreciate your attention and look forward to your reply.

Yours faithfully,

Damian L. Arévalo-Martínez

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Annex 1 – Comments for Editor (Dr. Ben Bond-Lamberty)

These changes were not derived from the referee’s comments, but from the authors’ own assessment of the revised version after implementing the replies to those comments.

- We updated the numbering of affiliations of all authors to accommodate the new affiliation of the first author (l. 4–28).
- We removed “climate change” from the first sentence to avoid confusion since it would give the impression that this is related to land only (see l. 230).
- We removed the space between “ground” and “water” (l. 307).
- We exchanged “model” by “models” (l. 321).
- We removed the word “can” since it was not relevant in this context (l. 336)
- We removed extra parenthesis in the citation of Worzewski et al. (l. 347)
- We added the word “dynamics” for more clarity (l. 461)
- We slightly changed one sentence in the acknowledgements: from “This manuscript is a contribution to” to “This manuscript contains contributions to”, added a missing acknowledgement (SMART Project), and changed the position of one of the acknowledged projects in the text. (see l. 487–492).
- Previous versions of the manuscript included a work in press (book chapter by Böttcher et al.). In the revised version we added the missing information (see l. 549–551).
- We added a missing year on the citation of the work by Church et al. (see l. 594–598).
- Following the editor’s and reviewer’s suggestions, we modified Figure 1 for more clarity.

Author's response to comments by anonymous referee #3

On behalf of the authors, I thank anonymous referee #3 for the positive assessment of our manuscript and the constructive comments and suggestions. On the following we provide a point-by-point response to the issues raised during the review, and list/discuss the changes done to the revised version:

This manuscript provides a brief overview of coastal groundwater dynamics, which is an important, timely, and understudied topic. The main message of the manuscript seems to be that more synergy is needed between research studying fresh submarine groundwater discharge and offshore freshened groundwater discharge and techniques applied in each domain should be merged in future interdisciplinary efforts. This is a notable cause for the research community to take on.

Reply by authors:

Many thanks. We are glad to hear that our manuscript conveys the need of taking on international multidisciplinary efforts for investigating coastal groundwater dynamics. We hope other readers will also share this opinion and that our manuscript serves as starting point for fruitful discussions in the community.

Overall, the manuscript gives a nice high-level overview of the topic and is generally approachable to a general audience, though at first the frequent use of acronyms is a bit jarring. Having table 1 shown in the first several pages in the final version will help this, as I found myself needing to look up the difference between FSGD and OFG several times while reading the introduction and section 2.

Reply by authors:

We fully agree. In the current version we refer to Table 1 on the second paragraph of the introduction and are therefore confident that the editorial team will identify the right place for it in the first pages of the manuscript.

This review details mostly conceptual information and highlights key methods used in this domain of research. The study could be substantially more impactful if some form of quantitative analysis or summarization was performed such as a table showing ranges in discharge yields by geological setting, etc. However, I understand that such analyses would require substantial effort and is probably outside the scope of this short perspective paper. Considering the intended purpose of this perspective (i.e., high level overview of the field of research and call to action) I only have several specific comments below. The authors have done a nice job responding to previous reviews and I'm supportive of its publication.

Reply by authors:

Many thanks for your constructive comments. We indeed opted for avoiding a quantitative analysis in the framework of this manuscript, because there are excellent review papers which address our current knowledge on hydrological, geological, geochemical and biological aspects of groundwater fluxes and reservoirs. Some of the examples cited in our manuscript are:

Micallef, A., et al.: Offshore freshened groundwater in continental margins, *Rev. Geophys.*, 58, e2020RG000706, <https://doi.org/10.1029/2020RG000706>, 2021.

Ruiz-González, C., et al.: The microbial dimension of submarine groundwater discharge: current challenges and future directions, *FEMS Microbiol. Rev.*, 45(5), fuab010, <https://doi.org/10.1093/femsre/fuab010>, 2021.

Santos, I. R., et al.: Submarine groundwater discharge impacts on coastal nutrient biogeochemistry, *Nat. Rev. Earth. Environ.*, 2, 307 – 323, <https://doi.org/10.1038/s43017-021-00152-0>, 2021.

Taniguchi, M., et al.: Submarine Groundwater Discharge: Updates on Its Measurement Techniques, Geophysical Drivers, Magnitudes, and Effects, *Front. Environ. Sci.*, 7, 141, 2019.

Figure 1: I like the simple figure, but there are some confusing details if you look closely beyond the fact that FSGD happens nearshore and OFG happens offshore. For example, should saltwater intrusion also be shown in this figure, or is that implied by the dark blue parts of FSGD and OFG and red arrows? On that note, with the current design, it actually doesn't look like the light blue freshwater ever reaches the sea. I'm not sure what the solution is, perhaps more of a color gradient? Salt water intrusion can also occur in the shallower terrestrial subsurface while fresh groundwater is discharged deeper/further offshore. Also, perhaps a dashed line could also represent rising sea levels? There are just suggestions should you have ideas how to improve on these nuances. With some improvements, the figure would be very useful for conceptual and educational purposes. As noted in my general comments, considering this perspective paper provides a high level overview, a very nice conceptual figure that gets widely used and shared would elevate the paper's impact and influence.

Reply by authors:

This is a very good point and we are glad it was brought to our attention. The revised Figure 1 includes a colour gradient that illustrates the progressive change in the dominance between fresh and saltwater along the land-ocean transition and different topographic levels. Moreover, we increased the thickness of the aquifers to improve visibility, and made sure the interfaces between fresh and saltwater components are kept as realistic as possible for such a schematic representation. These modifications supplement the green and red arrows which are now in more places and are thicker for better visibility.

Line 40 and throughout: What is the reason for using parentheses for (bio)geochemists here and a few other places?

Reply by authors:

We introduced this notation in order to highlight that the investigation of coastal groundwater dynamics will require expertise not only from biogeochemists, but also from inorganic geochemists. We preferred this short version instead of mentioning both groups separately every time.

Line 201: The influence of pumping practices and local reservoir properties on saltwater intrusion are astutely pointed out in this paragraph. Not much is said about sea level rise impacts on SWI aside from broad discussion of global rates of in the introduction. It might be worth adding some content either in the introduction or this section pointing out that rates of relative sea level rise vary substantially due to local factors such as subsidence and sedimentation. Local relative SLR is what influences saltwater intrusion, not global average rates.

Reply by authors:

Many thanks for the suggestion; this is an important point to highlight in the context of our manuscript. We added a sentence to address this issue in the revised version of the manuscript (see l. 66–69). The work cited in this context was added to the list of references (see l. 831–833).

Line 430: This may be implicit in point #3 as well as others, but I wonder if a task related to scaling, specifically would be useful? For example, once these various tasks are achieved will we be able to understand submarine discharge impacts on global scale processes, or is an additional task needed such as representing these fluxes in global Earth system models?

Reply by authors:

Thanks for the suggestion. We included an additional task that addresses this point (l. 451–452):

“(7) implement the knowledge gained through models and observations to improve the representation of FSGD and OFG in Earth System models.”

To keep the logical sequence of arguments for the reader, we shifted the position of tasks 4–6 (see l. 442–452).

Kind regards,

Damian L. Arévalo-Martínez

Author's response to comments by anonymous referee #4

On behalf of the authors, I thank anonymous referee #4 for the positive assessment of our manuscript and the constructive comments and suggestions. On the following we provide a point-by-point response to the issues raised during the review, and list/discuss the changes done to the revised version:

This manuscript gives an overview of land-ocean connectivity through groundwater and highlights knowledge gaps in the current knowledge of the connection between meteoric groundwater discharged at the coastline and groundwater discharged offshore. The authors describe methodologies used to characterize flow paths, connectivity, and quantify discharge via groundwater and highlight the difficulties associated with connecting groundwater and its related impacts across the terrestrial-aquatic interface. The authors identify research areas to be addressed in future work to better understand groundwater across spatial and temporal scales.

They stress the importance of leveraging interdisciplinary teams in order to accurately work across land and sea boundaries and to fully understand the impacts of groundwater in the face of anthropogenic stresses and a changing climate.

Previous reviewers offered suggestions to clarify the manuscript, add references, and suggest a more compelling conclusion. The authors addressed these suggestions in their response and made changes to clarify the manuscript. They make it clear that this article aims to be a discussion of knowledge gaps rather than a full review of the literature or a detailed description of a framework for future research. I feel this manuscript is suitable for publication in Biogeosciences. I suggest the authors consider only a few minor revisions prior to publication the manuscript, which are outlined below. I feel these minor comments will add to the clarity of the manuscript and make a more citable paper.

Reply by authors:

Many thanks for the positive assessment. We are glad to hear that our revision addressed the issues raised during the first round of review, and that our suggested approaches for advancing in joint FSGD-OFG research come across clearly.

There are a lot of complex lists and parentheses throughout the manuscript that can make it hard for the reader. It may be worth varying sentence structure a bit and breaking up some long sentences.

Reply by authors:

Thanks for the suggestion. We have revised the text thoroughly to check for sentences that needed improvement in this regard.

It was suggested by a previous reviewer to have a 'conclusions' section. I found the authors rebuttal to adding this section adequate, but I would urge the authors to consider adding a few sentences that add value to their recommended future research areas. Although it is clear the authors do not hope to provide a framework for how to conduct interdisciplinary groundwater research, simply identifying the need for interdisciplinary work does not feel like a very novel conclusion or suggestion for the field. Perhaps the instead of ending with the need for interdisciplinary teams and then how this work will address the sustainable development goals, this last section could be rearranged to conclude with reiterating the impacts of groundwater globally and why these research areas and interdisciplinary action to address them are so vital to understanding the global ocean. The sustainable development goals could provide structure for these suggested few sentences to re-establish the importance and take-home point of the paper.

Reply by authors:

Thanks for the constructive suggestion. Nevertheless, we contend that the current structure of section 5 is adequate, since for us it is important to first reiterate the importance of FSGD/OFG within the context of basic and applied (societal relevant) research. Only after that is clear, we can take the reader through the tasks which we think are critical for improving our understanding of groundwater dynamics in coastal systems. We argue that the main contribution of the manuscript is not merely identifying the need for multidisciplinary research, but rather joint efforts to address what in our opinion are urgent research tasks. A detailed discussion on how each of the specific tasks links to Sustainable Development Goals is certainly a logical step; however it falls beyond the scope of our manuscript. We hope that readers will be motivated to elaborate on such links as part of future projects.

Line 58: The sentence “Coastal margins play a disproportionately important role for productive marine ecosystems compared to the open ocean due to their greater biological productivity, sediment-water...” reads awkwardly. I suggest removing the first word ‘productive’ and simply say “important role for marine ecosystems”

Reply by authors:

Changed as suggested (see l. 58–60).

Line 75: The sentence, “The first comprises meteoric groundwater flux from terrestrial aquifers through the seabed (including the intertidal zone) into the coastal ocean,…” has awkward wording. Perhaps “The first is comprised of the meteoric groundwater flux from terrestrial aquifers..”

Reply by authors:

Thanks for the suggestion. However, we prefer to keep the current sentence because it has an active rather than a passive voice that fits better to the style in which the manuscript is written.

Line 146: “OFG resides beneath the seafloor along continental shelves and, in contrast to FSGD, is commonly assumed to have minimal groundwater flow velocities (e.g. Micallef et al. 2020).” Perhaps “have low groundwater flow velocities”

Reply by authors:

Changed as suggested (see l. 142).

Line 417: “FSGD and the associated fluxes of biogeochemical tracers might affect the physical structure, chemical composition and reactivity and the (micro)biology of the coastal ocean ecosystems.” I would add a comma after reactivity and I would remove “the” before coastal ocean ecosystems

Reply by authors:

Thanks for the suggestion. Changed accordingly (see l. 418–420).

Figure 1: The Arrows in figure 1 are very small and hard to see – I didn’t realize they were arrows at first. Perhaps they could be made a different color that stands out or made larger.

Reply by authors:

Thanks for raising this issue. The updated version of Figure 1 has thicker and more abundant arrows which are easier to see. Additionally, we increased the thickness of the aquifers and applied a color gradient so that it is clearer what are the groundwater reservoirs and fluxes we aim to illustrate. We hope that this change (in addition to the changes suggested by anonymous referee #3) make now clearer the features we aim to show with the schematic.

Kind regards,

Damian L. Arévalo-Martínez