nature portfolio

Peer Review File

The coastal transition zone is an underexplored frontier in hydrology and geoscience

Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality

29th Mar 22

Dear Professor Weymer,

Your manuscript titled "Completing the hydrologic cycle deep beneath the coastal transition zone" has now been seen by 3 reviewers, whose comments are appended below. You will see that they find your work of some potential interest. However, they have raised quite substantial concerns that must be addressed. In light of these comments, we cannot accept the manuscript for publication, but would be interested in considering a revised version that fully addresses these serious concerns.

For the publication of a revised manuscript in Communications Earth & Environment to be appropriate, we would need you to:
• Re-focus the manuscript to bring out a novel perspective on the importance of and potential future developments in understanding offshore freshened groundwater, emphasizing the changes in understanding and outlook that have developed since the publication of previous overview papers in this field,
• Remove or strongly tone down your claims on the potential for offshore freshened groundwater to represent a future exploitable water resource.

We hope you will find the reviewers' comments useful as you decide how to proceed. Should additional work allow you to address these criticisms, we would be happy to look at a substantially revised manuscript. If you choose to take up this option, please highlight all changes in the manuscript text file and provide a list of the changes to the manuscript with your responses to the reviewers.

Please bear in mind that we will be reluctant to approach the reviewers again in the absence of substantial revisions.

If the revision process takes significantly longer than three months, we will be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We understand that due to the current global situation, the time required for revision may be longer than usual. We would appreciate it if you could keep us informed about an estimated timescale for resubmission, to facilitate our planning. Of course, if you are unable to estimate, we are happy to accommodate necessary extensions nevertheless.

We are committed to providing a fair and constructive peer-review process. Please do not hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the reviewers' comments with a list of your changes to the manuscript text (which should be in a separate document to any cover letter) and any completed checklist:

[link redacted]

** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

Please do not hesitate to contact me if you have any questions or would like to discuss the required revisions further. Thank you for the opportunity to review your work.

Best regards,

Rahim Barzegar, PhD
Editorial Board Member
Communications Earth & Environment
orcid.org/0000-0002-1941-2991

Joe Aslin
Senior Editor
Communications Earth & Environment

EDITORIAL POLICIES AND FORMAT

If you decide to resubmit your paper, please ensure that your manuscript complies with our editorial policies and complete and upload the checklist below as a Related Manuscript file type with the revised article:

Editorial Policy Policy requirements

For your information, you can find some guidance regarding format requirements summarized on the following checklist:(https://www.nature.com/documents/commsj-phys-style-formatting-checklist-article.pdf) and formatting guide (https://www.nature.com/documents/commsj-phys-style-formatting-guide-accept.pdf).

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The manuscript “Completing the hydrologic cycle deep beneath the coastal transition zone” by Weymer et al. describes methods to find and characterize offshore freshened groundwater reservoirs. It provides an overview focusing geophysical methods and mentioning hydrogeological modeling. The manuscript is overall excellently written and in a very advanced stage. However, my quite basic concern about it is that it does not really emphasize additional value over the literature it discusses. The discussions stay very technical and to a large degree focused on geophysical methodology. In the light of several review-

style publications that were published recently about offshore fresh groundwater I think this manuscript should emphasize more the added value it provides for a broad scientific discussion.

Some specific points follow below:

This reference could be good to discuss:
https://iopscience.iop.org/article/10.1088/1748-9326/ac4073/meta

Line 75: Best for all uses of the word “water” define if you refer to fresh water, drinking water or water in general (including saltwater). Most of the times the wording seems to refer to drinking water, but please be explicit about it.

Line 97: The abbreviation SGD is usually used for a combination of terrestrial and marine water (using the definition of Burnett at al 2003) – here it is just used for terrestrial groundwater discharge – please shortly make this discrepancy explicit to avoid misunderstandings.

Line 106: Please provide a reference that supports the increasing interest in the hydrogeology community.

Line 124: It seems to me that actually the principal driver of terrestrial SGD is permeability in the aquifer (as shown e.g. in Luijendijk et al., 2020), of course followed by the hydraulic gradient. The former is much more variable than the latter.

Line 127: Which river network are you referring to?

Line 137: What is the presumption based on that the deeper SGD happens outside the CTZ? Also, I think the paper could benefit from defining the CTZ with a bit more detail – how big is it, what are its boundaries? If deep SGD is supposed to be beyond them, it would be good to know what they are. I see that it is better defined later, maybe this part can be moved to a part of the manuscript behind the discussion of the CTZ.

Line 222: Could you be more explicit about the statistics – the provided numbers are many, and it is not immediately clear why they imply that considerable volume is stored deep (how deep is “deep”?) beneath the seafloor.

Line 227: A discharge in the CTZ itself seems to contradict line 137?

Line 349: There have been papers on parallelization recently that could be good references here: https://www.sciencedirect.com/science/article/pii/S1364815221001353

Figure 2: Fig 2 has aspect asking about a recharge regime – before it was stated that OFG would not require discharge, and thus also would not be depending on recharge – I’d also

understand the majority of OFG not necessarily connected to active recharge – the connectivity would be a major question, to, would it not?

Literature:
Burnett, W.C., Bokuniewicz, H., Huettel, M., Moore, W.S., Taniguchi, M., 2003. Groundwater and pore water inputs to the coastal zone. Biogeochemistry, 66(1-2): 3-33.
Luijendijk, E., Gleeson, T., Moosdorf, N., 2020. Fresh groundwater discharge insignificant for the world's oceans but important for coastal ecosystems. Nature Communications, 11(1): 1260.

Reviewer #2 (Remarks to the Author):

The ms 'Completing the hydrologic cycle deep beneath the coastal transition zone' by BA Weymer et al provides a perspective on the methodology how to study to date little understood deep groundwater reservoirs, arguing for the combination of geophysical mapping tools and hydrogeological modelling.

This is highly interesting from a scientific perspective, but I remain skeptical about the importance of deep OFG (offshore freshened groundwater) as a water resource or as an active part of the modern water cycle. This ms has not done much to convince me otherwise. Overall, I suggest the ms to be re-oriented to not make the claim that (a) understanding OFG will close the hydrological cycle; (b) that mining OFG is a solution to water shortage. The very existence of deep OFG and the challenges associated with exploring them are a good enough theme for a Nature Perspective.

I have three main comments:
1) The title does not reflect the paper. Overall, the authors present a very valuable description of a missing piece of the hydrological 'puzzle' but there is no evidence that OFG actually makes any contributions to the modern hydrological cycle. Much of it is to be considered paleo-aquifers as described by the authors, and no evidence of discharge is presented (occurrence is not either, but the authors refer to numerous previously published studies).
2) In numerous sections, the ms refers to the potential importance of deep or offshore fresh groundwater mining. In addition to mining any groundwater beneath the ocean being prohibitively expensive it is highly likely that this is brackish anyway which would require desalinization. It is much cheaper and easier to desalinize seawater….. In the preface you state you include saline GW in your description (as the ' freshened' in OFG suggests) but this is at odds with OFG being an exploitable freshwater resource. You mention for example 305

studies of OFG reservoirs but no information on properties, eg potential GW salinity. I understand that this is difficult to obtain, but in the absence of this information you can not sustain the argument that OFG can be an exploitable freshwater resource. I strongly suggest to remove the notion of this being an exploitable freshwater resource until there is substantial evidence (to my knowledge there is no or very little current exploitation of OFG anywhere in the world).
3) The ms combines two topics – both interesting but not immediately connected in my view: (a) the lack of our understanding of continuity in the shallow zone (b) deep OFG. The interesting and main topic is deep groundwater (as the title suggests). Much of the presented discussion presents arguments on shallow systems. This should be better differentiated, and maybe not even included?
4) How is hydrogeological modelling going to help to understand paleo aquifers which are disconnected from the hydrological cycle?
5)

Additional comments:
Page 3 1st paragraph – very large-scale description. you could just start by introducing at how much you estimate the OFG fraction of the total groundwater reservoirs instead of starting that the global water volume.
Page 3 line 99 – 50% of what?
Page 4 line 103 – in my view there is very little proof for OFG discharge, and there is little physical reason for this either because there is, in most cases, no GW head (you mention confined aquifers but no indication where this information comes from?).
Page 4 line 115 – 1st and 2nd paragraph – you switch form deep subsurface to the' white ribbon' and talk about lack of methods to study them. I agree, but you should be more explicit and separate the issues clearly – the white ribbon is not connected to deep OFG which is the main study object. BTW, in my view the 'white ribbon' is the real big issue, bigger than deep OFGs, and I invite the consortium of expert authors of this ms to consider a different ms on how to study the white ribbon…. You make a nice start in the section 'new horizons for onshore-offshore mapping'.
Page 4 line 118 – in my view bathymetry data is not useful for OFG description?
Page 4 line 121-122 – this sentence is central to the issue of OFG, should be included in the abstract etc and should be critically expanded upon.
Page 5 line 144 – I really do not believe that you can make the case that deep groundwater below the CTZ can help in any way a 'water stressed' society….
Page 5 line 149 – how is hydrogeological modelling going to help identify / describe OFG reservoirs?
Section' deep GW systems' – you cite numerous studies without summarizing or providing example data. I believe this should be part of a Perspective paper.
Page 7 line 196 – more details please on salinity values.
Page 8 line 212 – it is also unclear if resistivity anomalies are related to porewater salinity variations or pore space variations.

Page 8 line 215 – how is this Perspective different to the published paper by Micallef et al (2021)?
Page 8 line 216 – how many of the 305 studies indicate fresh of low-salinity water (let's say less than S=5, representing a value that is fit for consumption)?
Page 8 line 225 – what makes you believe that the OFGs are confined and underpressure? Is there any data/ evidence for this?
Page 8 line 230 – 'considerable volume' of OFG – provide numbers
Table 1 – all methods presented have limitations associated with spatial resolution. You acknowledge this in one sentence on page 11 line 284 – I suggest you discuss implications based on experiences / requirements in the 305 studies you cite in some detail to provide a way forward.
Chapter ' new horizons…' – I am surprised to see no mention of sediment coring approaches?
Section 'combining GW modelling with geophysics' – you mention dynamic processes, which in my view is at odds with the paleo nature of much deep OFG. Also, small exchange fluxes can not easily be resolved in models either, in particular given the current uncertainty of model parameters (they may not play a significant role in water budgets either). Can you provide some kind of sensitivity analysis which parameters are required to be better constrained (well, they all are, but in which order)?
Page 13 line 336 – the cited paper (a) is treating seawater recirculation and not fresh GW (b) only applies to shallow and not deep coastal groundwater.
Page 13 line 342 – you talk about pumping – this only applies to shallow GW / OFG and as such there is little novelty. The real novelty of this contribution is, and should be more worked on, is how to improve our understanding of deep OFG.
Page 13 line 346 – it is not limitations of computational power that has hampered progress, but limitations in available data. And this is still the case. Your ms makes that point.
Page 13 line 372 – I do not believe that you can make the case that there is an urgency in order to tap into deep OFG to solve the world's freshwater crisis. For shallow systems this has been discussed in previous papers, and as such is not new.
Page 16 line 433-434 – this should be the 1st sentence of your paper and developed from there on!
Page 17 line 437-439 – remove this sentence. The deep CTZ is not playing a role to decision makers, water resource management etc at this stage. Concentrate the ms on the tools and approaches need to understand these systems.

Reviewer #3 (Remarks to the Author):

See attachment

Review of "Completing the hydrologic cycle deep beneath the coastal transition zone"

Summary

The Perspective manuscript claims that the hydrologic storage and fluxes within the subsurface of the coastal transition zone are essential and difficult to measure unknowns for better understanding geologic processes and its potential as a water resource. The ultimate solution for this challenge posed in the manuscript is further study with a combined applied geophysical observation and numerical modeling framework. Broad and poorly developed research questions are included that represent common questions in hydrologic studies.

Comments

1. I do not find this Perspective novel with its current focus. The Review by Post et al. (2013, ref 42) established nearly all of the concepts introduced in this manuscript with more nuance and completeness. This manuscript does focus more on a specific location of offshore-freshened groundwater and spends a paragraph developing the challenges – this was the major conceptual advancement that I found between the two. Using geophysics to constrain numerical model structure is a standard approach.
2. I disagree with the idea that offshore-freshened groundwater is "essential", "crucial", or any other similar word. I believe the authors sensationalize OFG without sufficient support. OFG is absolutely not missing from the hydrologic budget calculations. The storage could be missing, but then so is all of the saline porewater stored in ocean sediment – where studies have computed global water storage (e.g., Bodnar et al., 2013), albeit that may not resolve fresh vs saline marine porewater. The Oki reference used provide the evidence for missing OFG is outdated, especially from the groundwater perspective.
3. Another comment on the motivation for studying OFG is the idea that this could be a groundwater resource for coastal communities, mentioned several times in this perspective. This is an almost worst-case option as a water resource, requiring substantial infrastructure for extraction, delivery, and treatment. Suggesting, in a high-level journal, that this is a reasonable solution over protecting and carefully managing existing water resources is socially irresponsible. Yes, it could become economically feasible and could be considered for some cases (as discussed in Post et al., 2013), but then so would relocating full cities to wetter climates. Some careful discussion of absolute unsustainability of these OFG resources from a pumping perspective should be provided. Using the confined aquifers inland of the CTZ would be easier all around and what most coastal groundwater users already do.
4. I found the manuscript to read like sales pitch for geophysics with modeling as secondary (although, modeling is more useful from a quantification of hydrologic processing, in my experience). I found it very strange that the manuscript contained almost no development of groundtruthing with boreholes or any type of sampling. The paragraph starting on line 361 mentions tracers and water samples from deep boreholes as a possibility, where any geochemical sampling from deep groundwater systems (and developing the methods to do this) should be front and center in these studies. Geophysical methods and numerical models are the main tools that have been used since the Post et al. (2013) review popularized offshore-freshened groundwater. It is unclear why more people need to be convinced that the most used tools for this topic need to be highlighted further. That

review also mentioned nearly every point in this perspective, and a quick literature search shows even older studies discussing geophysical method development for freshened offshore groundwater with more honesty (e.g., Hoefel and Evans, 2001). Yes, this is a short format perspective/journal, but the content should be understandable by a broad scientific audience. I do not think hydrologists or geophysicists would find this perspective novel, and I do not think anyone else would understand enough about the content to discern novelty.

5. The lack of development of the resolutions and potential gains that geophysical methods could provide groundwater models left the justification of their use underdeveloped. Several geophysical methods are mentioned and their resolutions and drawbacks slightly mentioned, but how do those limitations intersect with the hydrogeologic reality, as it is currently understood?
6. The claim that geological heterogeneity requires a "rethinking" of OFG's is not a novel contribution of this work – as it specifically develops this from other studies that have tested the roles of heterogeneity in such systems. It is unclear why this click-bait type wording is used here. Introduce me to a hydrogeologist or geophysicist who doesn't recognize the importance of heterogeneity in the subsurface on physiochemical distributions.
7. Table 1 appears to be a selection of incomplete paragraphs converted into a table. I do not find the tabular presentation helpful. In paragraph form, the entries could be presented with context. This seems to be a trick of getting around a word limit. I expect a table to present content more succinctly and efficiently – neither of these are true for this "table".
8. Figure 2 – The order of the questions, categories, and contents are simplistic and appear to be thrown together without much thought. Colloquial questions with incomplete development within the scientific context renders this figure nearly useless. The questions are, for the most part, standard hydrologic research questions with the addition of "OFG" to them. Many of these questions could be linked to more than one topic and interrelated with each other (or follow from understanding another question). The novelty of OFG was established at least as early as 2013, and these questions have been asked for much longer than 10 years. The corresponding "research directions" in the paragraph starting in line 406 provide no clear paths for improvement, only that improvement should be made. I would suggest that every community always wants to do their work better with more resolution, and the novelty comes when someone comes up with how rather than describing the common goal.

Line items

Line(s)	Comment
47	The idea that OFG is commonly found but presents an information gap does not flow logically. These sentences need to be rewritten to clarify the meaning of what the information gap is vs what is known. "subterranean groundwater" is redundant.
48	The "essential" closing of chemical budgets is not developed in the manuscript – what is the uncertainty of such budgets and is the OFG contribution above the uncertainty level? This is also developed in studies elsewhere.
51	Phrase after "as" is false given the commonality of such groundwater globally.
104	Old reference to cite for this.
145	Could be important. This is an example of over-the-top claims

149	Plus groundtruth with borehole data/geochemistry. Too strong of language without sufficient development.
156	As the focus of this manuscript, this sentence should clearly state what is being defined rather than defining “the latter”
162	This statement does not agree with the white dashed lines in Fig 1.
165	I disagree that the unconfined coastal aquifers are well-studied. For SGD studies, yes, but for water resources and other fluxes, no. The confined aquifers are the primary subsurface water resource. The confined aquifers are the best studied and observed. The confined aquifers are the ones that link to OFG. It’s fine to not include this in the focus, but treating unconfined aquifers this way is incorrect.
195	Need to link this paragraph more clearly to OFG.
199	Ref support needed
200	Ref needed or use “could have”
208	Diameter? In which dimension? Is the pathway a circle?
212	No development of bulk resistivity and its relationship to identifying OFG.
215-24	Are all of these sentences only referring to conduit-based transfer? The “It is not necessary” sentence implies that conduits are the primary transport mechanism over more normal porous media.
228	What “latter pathways”? Conduits? unclear use of latter
228	A more poignant point here would be to develop why such imaging matters for understanding systems/processes over being a technological challenge.
235	need to develop resolution/depth requirements and challenges more than currently done. Plus effect of diffusion/dispersion on water properties/target ID?
244	Run-on sentence
250	Unclear reasoning/development for this table dump.
270	Hasn’t it already? Why “likely”?
285	Ref needed
299	Ref needed
361	Refs needed. Rather out of place paragraph. Could have a whole section developing geochemical/non-geophysical observation needs.
372	Sensational use of “urgent” – timing nor need established.
429	Develop this policy connection more or remove. How?
431	Sensational use of “precious”. I would counter that it is some of the least precious water on Earth.
434	Misplaced may be a more accurate term. Or mislabeled.

References

Bodnar, R. J., T. Azbej, S. P. Becker, C. Cannatelli, A. Fall, and M. J. Severs (2013), Whole Earth geohydrologic cycle, from the clouds to the core: The distribution of water in the dynamic Earth system, *Geol. Soc. Am. Spec. Pap.*, *500*, 431–461, doi:10.1130/2013.2500(13).

Hoefel, F. G., and R. L. Evans (2001), Impact of Low Salinity Porewater on Seafloor Electromagnetic Data: A Means of Detecting Submarine Groundwater Discharge?, *Estuar. Coast. Shelf Sci.*, *52*(2), 179–189, doi:https://doi.org/10.1006/ecss.2000.0718.

SCHOOL OF OCEANOGRAPHY
SHANGHAI JIAO TONG UNIVERSITY
上海交通大学 海洋学院

Response to referees letter

31 August, 2022

Dear Editors and Reviewers,

Attached please find the revised version of "**Completing the hydrologic cycle deep beneath the coastal transition zone**" (COMMSENV-22-0052A), which we now title "**Probing the deep frontier beneath the coastal white ribbon**". On behalf of my co-authors, I thank the editors and the three reviewers for your constructive comments. Please find our point-by-point responses to the reviewers' comments below highlighted in red. We also include the clean and marked versions of the revised manuscript in the submission package for your review.

Responses to Reviewer 1:

1. *The manuscript "Completing the hydrologic cycle deep beneath the coastal transition zone" by Weymer et al. describes methods to find and characterize offshore freshened groundwater reservoirs. It provides an overview focusing geophysical methods and mentioning hydrogeological modeling. The manuscript is overall excellently written and in a very advanced stage. However, my quite basic concern about it is that it does not really emphasize additional value over the literature it discusses. The discussions stay very technical and to a large degree focused on geophysical methodology. In the light of several review-style publications that were published recently about offshore fresh groundwater I think this manuscript should emphasize more the added value it provides for a broad scientific discussion.*

We refocused the main message to avoid confusion on what we intend to address in this Perspective. We built on the reviewer's comments and revised the paper to have a singular focus, which is the deep frontier beneath the coastal white ribbon. We now emphasize this more clearly in the manuscript.

The main revisions are as follows:

- We reworked the paper substantially and include additional relevant examples (e.g., tectonics, hydrocarbons, geohazards) of why the deep coastal white ribbon is an important frontier to study and what new technologies are needed (including coring)

- We use coastal hydrogeology as a prime example to illustrate the benefits and limitations of using geophysics, modeling and coring that can also be applied to other research applications

- We shortened the discussion on offshore freshened groundwater (OFG) and toned down the

notion of OFG as an unconventional resource, as these topics have already been discussed in the recent review papers by Post et al. (2013), Micallef et al. (2021), and Zamrsky et al. (2021)

- We moved the hydrogeology discussion to the back of the paper, into a box (Box 1) as a prime example

Line comments:

Some specific points follow below:

This reference could be good to discuss:
https://iopscience.iop.org/article/10.1088/1748-9326/ac4073/meta

We added a sentence in the first paragraph of the "Defining the deep white ribbon section" that includes this reference.

"The OFG's of the deep white ribbon are important to study because of their potential as an unconventional resource[24]."

Line 75: Best for all uses of the word "water" define if you refer to fresh water, drinking water or water in general (including saltwater). Most of the times the wording seems to refer to drinking water, but please be explicit about it.

We have made a more careful distinction between the various uses of the word "water" in the manuscript.

Line 97: The abbreviation SGD is usually used for a combination of terrestrial and marine water (using the definition of Burnett at al 2003) – here it is just used for terrestrial groundwater discharge – please shortly make this discrepancy explicit to avoid misunderstandings.

Fixed.

Line 106: Please provide a reference that supports the increasing interest in the hydrogeology community.

This sentence has been removed.

Line 124: It seems to me that actually the principal driver of terrestrial SGD is permeability in the aquifer (as shown e.g. in Luijendijk et al., 2020), of course followed by the hydraulic gradient. The former is much more variable than the latter.

This paragraph has been removed.

Line 127: Which river network are you referring to?

This paragraph has been removed.

Line 137: What is the presumption based on that the deeper SGD happens outside the CTZ?

Also, I think the paper could benefit from defining the CTZ with a bit more detail – how big is it, what are its boundaries? If deep SGD is supposed to be beyond them, it would be good to know what they are. I see that it is better defined later, maybe this part can be moved to a part of the manuscript behind the discussion of the CTZ.

The outer boundary of the white ribbon is defined as where the water depth is too shallow for conventional geophysical research vessels to go, so its location depends on how fast the water depth increases from the shore. There will probably be some places where deep SGD occurs outside the white ribbon, but we are not too interested in that because our primary concern is the region deep beneath the white ribbon, typically below the first aquifer confining layer. So whether or not any deep SGD emerges seaward of the white ribbon is not of primary interest in this paper. We chose to keep the discussion on the location, dimensions, etc. of the white ribbon in the next section "Deep coastal groundwater systems" as this section specifically focuses on these details.

Line 222: Could you be more explicit about the statistics – the provided numbers are many, and it is not immediately clear why they imply that considerable volume is stored deep (how deep is "deep"?) beneath the seafloor.

This discussion has been removed.

Line 227: A discharge in the CTZ itself seems to contradict line 137?

Deep confined groundwater likely will not discharge at the seafloor beneath the white ribbon unless there is some kind of break in the confining layer that allows deep groundwater to migrate upward and discharge within the white ribbon zone. This sentence has been removed.

Line 349: There have been papers on parallelization recently that could be good references here: https://www.sciencedirect.com/science/article/pii/S1364815221001353

Ok, added this reference. Thank you for bringing this recent paper to our attention.

Fig 2 has aspect asking about a recharge regime – before it was stated that OFG would not require discharge, and thus also would not be depending on recharge – I'd also understand the majority of OFG not necessarily connected to active recharge – the connectivity would be a major question, to, would it not?

Figure 2 illustrates the motivation for studying the deep coastal white ribbon from a hydrogeological perspective, but can also be drawn for the other applications we now mention in the revised paper. Recharge and discharge questions, for example, are beyond the scope of this paper.

The three larger bubbles correspond to where does the water come from (emplacement), where is it now (long-term storage) and where is it going (utilization). These categories are similar to the original ones. The smaller bubbles are also similar, but aren't framed as research questions. So, on the whole, the figure represents aspects of deep white ribbon aquifers we'd like to know more about, to motivate additional research.

We changed the figure caption to better reflect these points in the revised figure:

*"**Figure 2**. Aspects of deep coastal white ribbon aquifers that motivate future research. The three larger bubbles correspond to where does the water come from (emplacement), where is it now (long-term storage) and where is it going (utilization)? Note: similar diagrams can be drawn for other research applications (e.g., tectonics, hydrocarbons, geohazards) crossing the white ribbon."*

Literature:

Burnett, W.C., Bokuniewicz, H., Huettel, M., Moore, W.S., Taniguchi, M., 2003. Groundwater and pore water inputs to the coastal zone. Biogeochemistry, 66(1-2): 3-33.

Luijendijk, E., Gleeson, T., Moosdorf, N., 2020. Fresh groundwater discharge insignificant for the world's oceans but important for coastal ecosystems. Nature Communications, 11(1): 1260.

Responses to Reviewer 2:

Summary: *The ms 'Completing the hydrologic cycle deep beneath the coastal transition zone' by BA Weymer et al provides a perspective on the methodology how to study to date little understood deep groundwater reservoirs, arguing for the combination of geophysical mapping tools and hydrogeological modelling. This is highly interesting from a scientific perspective, but I remain skeptical about the importance of deep OFG (offshore freshened groundwater) as a water resource or as an active part of the modern water cycle. This ms has not done much to convince me otherwise. Overall, I suggest the ms to be re-oriented to not make the claim that (a) understanding OFG will close the hydrological cycle; (b) that mining OFG is a solution to water shortage. The very existence of deep OFG and the challenges associated with exploring them are a good enough theme for a Nature Perspective.*

I have three main comments:

1. *The title does not reflect the paper. Overall, the authors present a very valuable description of a missing piece of the hydrological 'puzzle' but there is no evidence that OFG actually makes any contributions to the modern hydrological cycle. Much of it is to be considered paleo-aquifers as described by the authors, and no evidence of discharge is presented (occurrence is not either, but the authors refer to numerous previously published studies).*

We updated the title to better emphasize the purpose of this paper focusing on the deep coastal transition zone (white ribbon) as a frontier area with the coastal hydrogeolofy application simply as a prominent example.

Revised title: "**Probing the deep frontier beneath the coastal white ribbon"**

Regarding the comment about discharge, there is evidence of discharge from OFG systems, which has been described in Paldor et al. (2020). In addition, offshore SGD can trigger submarine landslides as another important reason to study the deep white ribbon zone from a geohazards perspective that we added to the paper. Whether or not the system is connected and actively discharging is important for understanding whether there is the potential for that to occur.

Reference:

Paldor, A. *et al*. Deep submarine groundwater discharge—evidence from Achziv submarine canyon at the exposure of the Judea group confined aquifer, Eastern Mediterranean. *Journal of Geophysical Research: Oceans* **125**, e2019JC015435 (2020).

2. *In numerous sections, the ms refers to the potential importance of deep or offshore fresh groundwater mining. In addition to mining any groundwater beneath the ocean being prohibitively expensive it is highly likely that this is brackish anyway which would require desalinization. It is much cheaper and easier to desalinize seawater….. In the preface you state you include saline GW in your description (as the 'freshened' in OFG suggests) but this is at odds with OFG being an exploitable freshwater resource. You mention for example 305 studies of OFG reservoirs but no information on properties, eg potential GW salinity. I understand that this is difficult to obtain, but in the absence of this information you cannot sustain the argument that OFG can be*

an exploitable freshwater resource. I strongly suggest to remove the notion of this being an exploitable freshwater resource until there is substantial evidence (to my knowledge there is no or very little current exploitation of OFG anywhere in the world).

As mentioned above, the main point of this Perspective is to draw attention to the poorly-studied "frontier region" lying deep beneath the coastal white ribbon, using OFGs (and associated groundwater fluxes) as the prime example of its importance. To avoid confusion, we removed any discussion of the exploitation potential of this non-renewable resource. We refer the reviewer to the recent paper by Zamrsky et al. (2021) (see comment by Reviewer 1) that discusses resource potential in more detail.

*Zamrsky, D., Essink, G. H. O., Sutanudjaja, E. H., van Beek, L. R. & Bierkens, M. F. Offshore fresh groundwater in coastal unconsolidated sediment systems as a potential fresh water source in the 21st century. Environmental Research Letters **17**, 014021 (2021).*

3. *The ms combines two topics – both interesting but not immediately connected in my view: (a) the lack of our understanding of continuity in the shallow zone (b) deep OFG. The interesting and main topic is deep groundwater (as the title suggests). Much of the presented discussion presents arguments on shallow systems. This should be better differentiated, and maybe not even included?*

In revising the paper, we made a better effort to emphasize that we do not want to fill the white ribbon per se, but rather we want to identify and suggest means to characterize the frontier region deep below the white ribbon. To avoid confusion, we reduced the discussion on the shallow system i.e., Lines 121-125 (also see response to comment on Lines 121-122 below). We are not interested so much in continuity of the shallow structure, which can largely be filled in by certain extant technologies, but rather in continuity of deep structure for which current technology is lacking.

4. *How is hydrogeological modelling going to help to understand paleo aquifers which are disconnected from the hydrological cycle?*

We added the following discussion in the **Combining groundwater modeling with coastal hydrogeophysics** section to clarify this point. This discussion has been now moved to the back of the paper in Box 1 as one example of studying the deep coastal white ribbon.

"Hydrological modeling can and has been used to simulate hydrologic processes over geologic timescales [new refs listed below]. In fact, that is one of the great strengths of adding a modeling component to observations – it is a means to test hypotheses about the evolution of a system over time in order to understand how the present conditions came to be, and then how the system may evolve in the future. Geophysical observations usually only provide a snapshot of present conditions, whereas hydrogeological models provide physics-based context."

New references added (in addition to Zamrsky et al., 2021 and Cohen at al., 2010):

Thomas, A. T., Reiche, S. & Clauser, C. Influence of Pleistocene sea-level lows on offshore fresh groundwater reservoirs-a numerical case study on the New Jersey shelf. (2021).

Thomas, A. T., von Harten, J., Jusri, T., Reiche, S. & Wellmann, F. An integrated modeling scheme for characterizing 3D hydrogeological heterogeneity of the New Jersey shelf. *Marine Geophysical Research* **43**, 1-19 (2022).

Line comments:

Page 3 1st paragraph – very large-scale description. you could just start by introducing at how much you estimate the OFG fraction of the total groundwater reservoirs instead of starting that the global water volume.

This paragraph has been removed.

Page 3 line 99 – 50% of what?

This has been removed.

Page 4 line 103 – in my view there is very little proof for OFG discharge, and there is little physical reason for this either because there is, in most cases, no GW head (you mention confined aquifers but no indication where this information comes from?).

This discussion has been removed.

Page 4 line 115 – 1st and 2nd paragraph – you switch form deep subsurface to the' white ribbon' and talk about lack of methods to study them. I agree, but you should be more explicit and separate the issues clearly – the white ribbon is not connected to deep OFG which is the main study object. BTW, in my view the 'white ribbon' is the real big issue, bigger than deep OFGs, and I invite the consortium of expert authors of this ms to consider a different ms on how to study the white ribbon…. You make a nice start in the section 'new horizons for onshore-offshore mapping'.

Agreed. Building on this comment, we re-worked the paper to focus specifically on the research challenges deep beneath the coastal white ribbon. We use coastal aquifers as a prime example to illustrate the importance of this frontier region, but also include additional research applications (e.g., tectonics, hydrocarbons, geohazards) that are of comparable significance. We have removed most of the discussions on offshore freshened groundwater as well as the potential of these systems as an unconventional resource. The novel contribution of this work is that no methodology currently exists to provide seamless data coverage crossing and deep beneath the coastal white ribbon and that this problem is not unique to coastal hydrogeology, but other important research applications.

Page 4 line 118 – in my view bathymetry data is not useful for OFG description?

This sentence has been removed.

Page 4 line 121-122 – this sentence is central to the issue of OFG, should be included in the abstract etc and should be critically expanded upon.

We added the following discussion in the new ***Coastal hydrogeology*** subsection to strengthen this argument.

"Herein we must differentiate between groundwater that discharges directly into the ocean as submarine groundwater discharge (SGD) and groundwater that remains stored underground beneath the coastal zone. Central to the latter is the role of the hydrostratigraphy, a continuum of strata of varying grain sizes ranging from clay to gravel deposits of different thickness and extent. Active groundwater flow is restricted to the more permeable layers when these have inlets and outlets that allow recharge and discharge, but groundwater may also be virtually stagnant in confined regions or low-permeability strata[19]."

Page 5 line 144 – I really do not believe that you can make the case that deep groundwater below the CTZ can help in any way a 'water stressed' society….

This sentence has been removed as it is not essential to the main point of the paper focusing on the missing information gap.

Page 5 line 149 – how is hydrogeological modelling going to help identify / describe OFG reservoirs?

We refer the reviewer to the revised section "Combining coastal hydrogeophysics with groundwater modeling" in Box 1 that discusses these points in more detail.

Section' deep GW systems' – you cite numerous studies without summarizing or providing example data. I believe this should be part of a Perspective paper.

This section has been substantially modified and these studies have been removed as they are not relevant to the revised discussion that defines the deep coastal white ribbon.

Page 7 line 196 – more details please on salinity values.

This sentence has been removed.

Page 8 line 212 – it is also unclear if resistivity anomalies are related to porewater salinity variations or pore space variations.

Removed.

Resistivity depends on both porewater salinity and porosity, according to Archie's law. There is a tradeoff, as indicated in Gustafson et al. (2019; Fig. 3), and many other places.

Reference: Archie, G. E. The electrical resistivity log as an aid in determining some reservoir characteristics. *Transactions of the AIME* **146**, 54-62 (1942).

Page 8 line 215 – how is this Perspective different to the published paper by Micallef et al (2021)?

This has already been addressed (see comments above).

Page 8 line 216 – how many of the 305 studies indicate fresh of low-salinity water (let's say less than S=5, representing a value that is fit for consumption)?

Removed.

Page 8 line 225 – what makes you believe that the OFGs are confined and underpressure? Is there any data/ evidence for this?

Unconfined OFG's are very unlikely to exist as the absence of a confining unit makes them prone to vertical salinization by seawater.

We are mostly interested in trapped OFG below the first confining layer and that would naturally be under some type of pressure. The OFG's that are in the upper unconfined aquifer are shallow and potentially can contribute to SGD, but they are not the most important concern of the paper.

Page 8 line 230 – 'considerable volume' of OFG – provide numbers

Fixed. The most recent estimate of the global volume of OFG is 1×10^6 km^3 (Micallef et al., 2021).

Table 1 – all methods presented have limitations associated with spatial resolution. You acknowledge this in one sentence on page 11 line 284 – I suggest you discuss implications based on experiences / requirements in the 305 studies you cite in some detail to provide a way forward.

We have condensed Table 1 by 50% to address this comment as well as comments on the Table made by Reviewer 3. The 305 records of OFG occurrence complied by Micallef (2020) mentioned earlier in the text are not directly related to the information presented in Table 1, which focuses specifically on the existing geophysical methods that offer promise in deep exploration of groundwater beneath the white ribbon.

Micallef, A. A global database of offshore freshened groundwater records. *Creative Commons Attribution 4.0 International, htpps://doi.org/10.5281/zenodo.4247833.* (2020).

Chapter ' new horizons…' – I am surprised to see no mention of sediment coring approaches?

This is a good point. We renamed this section "***Technological needs and future research directions"*** and now include a new discussion on the importance and challenges of ocean drilling in shallow coastal waters for deep white ribbon investigations.

Section 'combining GW modelling with geophysics' – you mention dynamic processes, which in my view is at odds with the paleo nature of much deep OFG. Also, small exchange fluxes cannot easily be resolved in models either, in particular given the current uncertainty of model parameters (they may not play a significant role in water budgets either). Can you

provide some kind of sensitivity analysis which parameters are required to be better constrained (well, they all are, but in which order)?

We do not understand the reviewers comment on small fluxes and sensitivity analysis? We now make it more clear in the discussion in Box 1 that by modeling we do not only mean to model the current state, but also the geological past during which OFGs were formed.

Page 13 line 336 – the cited paper (a) is treating seawater recirculation and not fresh GW (b) only applies to shallow and not deep coastal groundwater.

We disagree and leave this discussion in the paper. This comment is similar to Point 6 made by Reviewer 3. Please refer to our detailed response to Reviewer 3 below.

Page 13 line 342 – you talk about pumping – this only applies to shallow GW / OFG and as such there is little novelty. The real novelty of this contribution is, and should be more worked on, is how to improve our understanding of deep OFG.

We do not discuss this point in the revised manuscript.

Page 13 line 346 – it is not limitations of computational power that has hampered progress, but limitations in available data. And this is still the case. Your ms makes that point.

Agreed. We deleted "computational power" and replaced with "data"

Page 13 line 372 – I do not believe that you can make the case that there is an urgency in order to tap into deep OFG to solve the world's freshwater crisis. For shallow systems this has been discussed in previous papers, and as such is not new.

Removed.

Page 16 line 433-434 – this should be the 1st sentence of your paper and developed from there on!

The revised paper does not focus on this statement.

Page 17 line 437-439 – remove this sentence. The deep CTZ is not playing a role to decision makers, water resource management etc at this stage. Concentrate the ms on the tools and approaches need to understand these systems.

Deleted.

Responses to Reviewer 3:

1. *I do not find this Perspective novel with its current focus. The Review by Post et al. (2013, ref 42) established nearly all of the concepts introduced in this manuscript with more nuance and completeness. This manuscript does focus more on a specific location of offshore-freshened groundwater and spends a paragraph developing the challenges – this was the major conceptual advancement that I found between the two. Using geophysics to constrain numerical model structure is a standard approach.*

The application of new geophysical methods and numerical modeling to investigate the nature and dynamics of deep coastal aquifers crossing the transition from land to sea is not a standard approach and is still very much under development. We now make the distinction between this Perspective and the review papers by Post et al. (2013), and Micallef et al. (2021) more clearly throughout the manuscript.

2. *I disagree with the idea that offshore-freshened groundwater is "essential", "crucial", or any other similar word. I believe the authors sensationalize OFG without sufficient support. OFG is absolutely not missing from the hydrologic budget calculations. The storage could be missing, but then so is all of the saline porewater stored in ocean sediment – where studies have computed global water storage (e.g., Bodnar et al., 2013), albeit that may not resolve fresh vs saline marine porewater. The Oki reference used provide the evidence for missing OFG is outdated, especially from the groundwater perspective.*

The assumption that deep coastal aquifers are not connected to the offshore OFG system is not correct. It is unknown how much freshened water is stored in these aquifers, how they are connected to their onshore counterparts, and how much flux is being transferred across the white ribbon into deep offshore storage. We emphasize this more clearly that we are considering regions that are deeper than conventional groundwater exploration studies investigating groundwater in shallow offshore aquifers.

3. *Another comment on the motivation for studying OFG is the idea that this could be a groundwater resource for coastal communities, mentioned several times in this perspective. This is an almost worst-case option as a water resource, requiring substantial infrastructure for extraction, delivery, and treatment. Suggesting, in a high-level journal, that this is a reasonable solution over protecting and carefully managing existing water resources is socially irresponsible. Yes, it could become economically feasible and could be considered for some cases (as discussed in Post et al., 2013), but then so would relocating full cities to wetter climates. Some careful discussion of absolute unsustainability of these OFG resources from a pumping perspective should be provided. Using the confined aquifers inland of the CTZ would be easier all around and what most coastal groundwater users already do.*

This comment has already been addressed.

4. *I found the manuscript to read like sales pitch for geophysics with modeling as secondary (although, modeling is more useful from a quantification of hydrologic processing, in my experience). I found it very strange that the manuscript contained almost no development of groundtruthing with boreholes or any type of sampling. The*

paragraph starting on line 361 mentions tracers and water samples from deep boreholes as a possibility, where any geochemical sampling from deep groundwater systems (and developing the methods to do this) should be front and center in these studies. Geophysical methods and numerical models are the main tools that have been used since the Post et al. (2013) review popularized offshore-freshened groundwater. It is unclear why more people need to be convinced that the most used tools for this topic need to be highlighted further. That review also mentioned nearly every point in this perspective, and a quick literature search shows even older studies discussing geophysical method development for freshened offshore groundwater with more honesty (e.g., Hoefel and Evans, 2001). Yes, this is a short format perspective/journal, but the content should be understandable by a broad scientific audience. I do not think hydrologists or geophysicists would find this perspective novel, and I do not think anyone else would understand enough about the content to discern novelty.

The point of this paper is that the deeper parts of the white ribbon, which is what we are interested in, cannot be reached by currently utilized geophysical methods. We emphasize that currently used geophysical strategies are perfectly fine for shallow structure, or deep structure onshore or further offshore, but they do not provide information about the deep coastal transition zone which hosts the critical onshore-offshore connectivity we are trying to determine. Currently we have no way to assess deep onshore-offshore connectivity of any kind of structure, including aquifers. Deep boreholes cannot be drilled in the shallow-water zone unless they are drilled elsewhere and are very expensively steered horizontally into the deep white ribbon. Thus, the paper is not a sales pitch for existing geophysical methods, but rather a call to arms for developing new geophysical methods.

5. *The lack of development of the resolutions and potential gains that geophysical methods could provide groundwater models left the justification of their use underdeveloped. Several geophysical methods are mentioned and their resolutions and drawbacks slightly mentioned, but how do those limitations intersect with the hydrogeologic reality, as it is currently understood?*

We need to keep in mind that we don't know what new deep-CTZ-probing geophysical tools will look like so we can hardly talk about their technical capabilities.

6. *The claim that geological heterogeneity requires a "rethinking" of OFG's is not a novel contribution of this work – as it specifically develops this from other studies that have tested the roles of heterogeneity in such systems. It is unclear why this click-bait type wording is used here. Introduce me to a hydrogeologist or geophysicist who doesn't recognize the importance of heterogeneity in the subsurface on physiochemical distributions.*

This point is accepted, but only as far as the well-studied and well-understood shallow structure is considered. We are concerned primarily with the particular type of heterogeneity that determines onshore-offshore hydraulic connectivity at depth. Presumably, establishing this connectivity does require a re-thinking of hydrogeological modeling as well as new geophysical techniques. Until recently, the broad assumption was that OFGs were exclusively paleo features that are not actively recharging. The work, which we reference, on the effects of different patterns of heterogeneity on OFG shows that with certain distributions of high- and low- permeability material, it is relatively easy to get offshore freshened groundwater that is actively recharging and discharging, even in systems with relatively low onshore

hydraulic head. Thus, we are not arguing that we need to rethink OFGs because of heterogeneity. Rather, we are arguing that we need to rethink the assumptions about their formation due to our new understanding about how heterogeneity affects OFG. We believe that the sentence as written states that clearly.

7. *Table 1 appears to be a selection of incomplete paragraphs converted into a table. I do not find the tabular presentation helpful. In paragraph form, the entries could be presented with context. This seems to be a trick of getting around a word limit. I expect a table to present content more succinctly and efficiently – neither of these are true for this "table".*

Agreed. We now provide more succinct information in the table and reduced the text by 50%.

Geophysical method	Application	Approx. depth of investigation
magnetotellurics	Gustafson et al.[45] recorded 100-Hz offshore MT responses, probing the deep white ribbon. Blatter et al.[47] jointly inverted offshore MT/CSEM data.	**60 km**
marine CSEM	Attias et al.[28] describe marine CSEM data offshore Hawai'i aimed at connecting terrestrial to offshore freshwater reservoirs. The survey vessel was navigated close to the shoreline.	**500 m**
semi-airborne CSEM	Abd Allah et al.[48] describe the time-domain GREATEM[49] configuration wherein a terrestrial grounded electric dipole source is deployed and airborne receivers measure magnetic field variations along flight lines crossing the white ribbon. A similar semi-airborne system SATEM[50] exists but has not been used for deep white ribbon studies. The frequency-domain semi-airborne system DESMEX[51] for terrestrial applications achieves depth penetration of several km.	**0.4-2.0 km**
seismic reflection	Seismic reflection has been used to map deep aquifers beneath the white ribbon[52] in the North Atlantic and Mediterranean, offshore Florida, and elsewhere. Offshore seismic data are sometimes tied to onshore boreholes[53]. Seismic imaging provides structural boundaries and lithology which can be used to convert marine-CSEM resistivity maps into subsurface fluid distributions[54].	**3 km**
borehole	IODP Expedition 313[55] drilled three shallow-water boreholes in ~35 m water depth specifically for OFG exploration with core recovery to ~500 m depth.	**500 m**
satellite-based	Gravity data have mapped offshore geology on the continental shelf including the ocean-continent boundary[56] important to the petroleum industry. The sensitivity of gravity data to deep-white ribbon hydrogeology is insufficient to map offshore aquifers and/or establish onshore connectivity. Similar remarks hold for magnetic data[57] for which the sensed property is magnetization.	**basement**

8. *Figure 2 – The order of the questions, categories, and contents are simplistic and appear to be thrown together without much thought. Colloquial questions with incomplete development within the scientific context renders this figure nearly useless. The questions are, for the most part, standard hydrologic research questions with the addition of "OFG" to them. Many of these questions could be linked to more than one topic and interrelated with each other (or follow from understanding another question). The novelty of OFG was established at least as early as 2013, and these questions have been asked for much longer than 10 years. The corresponding*

"research directions" in the paragraph starting in line 406 provide no clear paths for improvement, only that improvement should be made. I would suggest that every community always wants to do their work better with more resolution, and the novelty comes when someone comes up with how rather than describing the common goal.

We have addressed these and similar comments on Figure 2 by Reviewer 1 (see response and revised Figure/Figure caption above). Additionally, we revised the "research directions" discussion that now includes a discussion on the need for scientific ocean drilling, long-term borehole observatories, and reactive tracers to complement the geophysics and hydrogeological modeling as ways to fill the white ribbon information gap.

Line(s) Comment

47 The idea that OFG is commonly found but presents an information gap does not flow logically. These sentences need to be rewritten to clarify the meaning of what the information gap is vs what is known. "subterranean groundwater" is redundant.

Deleted "subterranean".

48 The "essential" closing of chemical budgets is not developed in the manuscript – what is the uncertainty of such budgets and is the OFG contribution above the uncertainty level? This is also developed in studies elsewhere.

We revised the abstract considerably and removed this statement as *"…the closing of chemical budgets…"* is not within the scope of this paper.

51 Phrase after "as" is false given the commonality of such groundwater globally.

Deleted.

104 Old reference to cite for this.

This sentence has been removed.

145 Could be important. This is an example of over-the-top claims

Deleted.

149 Plus groundtruth with borehole data/geochemistry. Too strong of language without sufficient development.

Deleted.

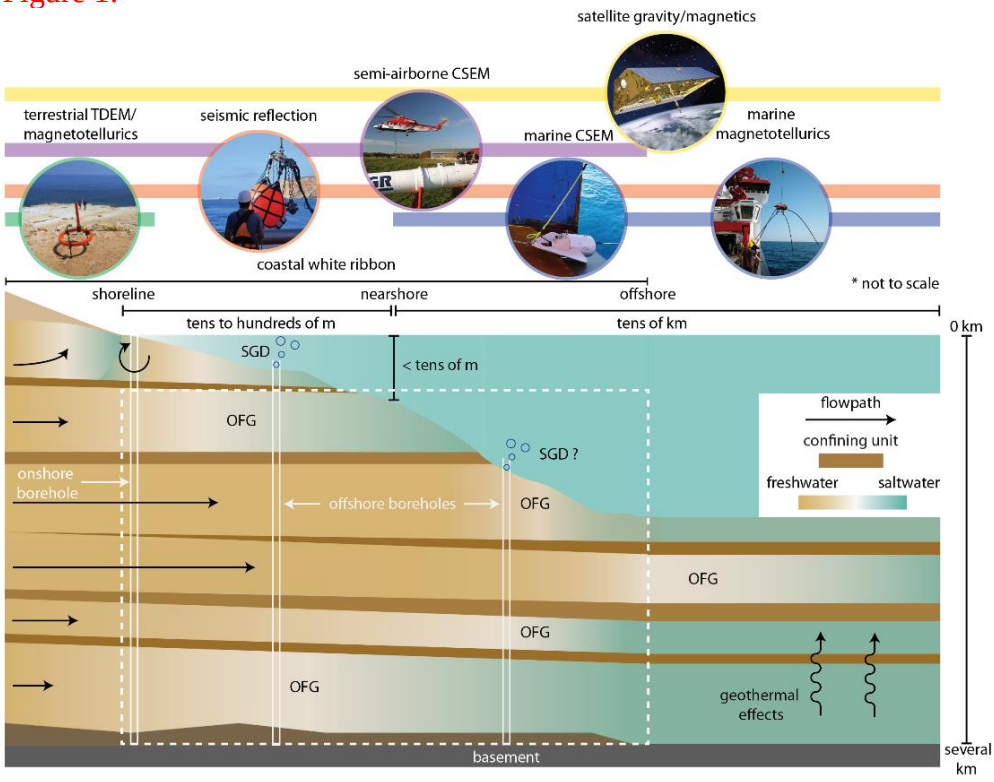
156 As the focus of this manuscript, this sentence should clearly state what is being defined rather than defining "the latter"

Fixed.

162 This statement does not agree with the white dashed lines in Fig 1.

We changed the landward boundary in Figure 1 to lie directly beneath the present-day shoreline as stated in the text. In addition, the preferred borehole locations are now included.

Revised Figure 1:



165 I disagree that the unconfined coastal aquifers are well-studied. For SGD studies, yes, but for water resources and other fluxes, no. The confined aquifers are the primary subsurface water resource. The confined aquifers are the best studied and observed. The confined aquifers are the ones that link to OFG. It's fine to not include this in the focus, but treating unconfined aquifers this way is incorrect.

This was a careless mistake. We agree and removed "well-studied"

195 Need to link this paragraph more clearly to OFG.

This paragraph has been modified and is now presented as an example of one of the important reasons for studying the deep coastal white ribbon. Please refer to the revised discussion in the Coastal hydrogeology subsection in the Introduction.

199 Ref support needed

This sentence has been removed.

200 Ref needed or use "could have"

Fixed.

208 Diameter? In which dimension? Is the pathway a circle?

This was a careless mistake and should have read "wide" instead of "diameter".

212 No development of bulk resistivity and its relationship to identifying OFG.

Fixed. A similar comment was also made by Reviewer #2 (see response above).

215-24 Are all of these sentences only referring to conduit-based transfer? The "It is not necessary" sentence implies that conduits are the primary transport mechanism over more normal porous media.

Removed, as this sentence is not central to the main discussion in this paragraph.

228 What "latter pathways"? Conduits? unclear use of latter

Deleted "latter"

228 A more poignant point here would be to develop why such imaging matters for understanding systems/processes over being a technological challenge.

We revised this discussion, which is now included the Coastal hydrogeology subsection to strengthen this point.

"Recent numerical modeling suggests that mid-shelf offshore freshened groundwater (OFG) reservoirs[20,21] offshore the New Jersey coast may be laterally compartmentalized by downward fingering of seawater[22,23]. Imaging the full vertical extent of the seawater's pathways is one of the challenges for deep-white ribbon geophysics. Speaking more broadly, knowledge is lacking about the groundwater salinity distribution below continental shelves, as well as information about the (dis)connectedness of low-salinity groundwater bodies between the on- and offshore."

New references:

Thomas, A. T., Reiche, S. & Clauser, C. Influence of Pleistocene sea-level lows on offshore fresh groundwater reservoirs-a numerical case study on the New Jersey shelf. (2021).

Thomas, A. T., von Harten, J., Jusri, T., Reiche, S. & Wellmann, F. An integrated modeling scheme for characterizing 3D hydrogeological heterogeneity of the New Jersey shelf. *Marine Geophysical Research* **43**, 1-19 (2022).

235 need to develop resolution/depth requirements and challenges more than currently done. Plus effect of diffusion/dispersion on water properties/target ID?

Ok, we updated the text here to say:

"*Geophysical technologies are also prone to a range-to-resolution tradeoff meaning that vertical resolution decreases with increasing depth of investigation. How then can we account for this elusive part of the global hydrologic cycle, keeping in mind the high spatial resolution that is necessary for imaging aquifers that may only be tens of meters thick in some locations?"*

244 Run-on sentence

Fixed.

250 Unclear reasoning/development for this table dump.

This has been addressed (see comment #7 above).

270 Hasn't it already? Why "likely"?

This was a careless mistake. Deleted "likely"

285 Ref needed

Reference added: Key, K. and Constable, S., 2011. Coast effect distortion of marine magnetotelluric data: Insights from a pilot study offshore northeastern Japan. *Physics of the Earth and Planetary Interiors*, *184*(3-4), pp.194-207.

299 Ref needed

Reference added: Shearer, P. M. *Introduction to seismology*. (Cambridge university press, 2019).

361 Refs needed. Rather out of place paragraph. Could have a whole section developing geochemical/non-geophysical observation needs.

Agreed. We added a new discussion in the last section (**Technological needs and future research directions**) focusing on the needs and challenges of scientific drilling (*see response to Reviewer #2 Chapter 'new horizons' comment above*).

372 Sensational use of "urgent" – timing nor need established.

Deleted.

429 Develop this policy connection more or remove. How?

Removed.

431 Sensational use of "precious". I would counter that it is some of the least precious water on Earth.

Deleted.

434 Misplaced may be a more accurate term. Or mislabeled.

Fixed.

4th Nov 22

Dear Professor Weymer,

Please allow us to apologise for the delay in sending a decision on your manuscript titled "Probing the deep frontier beneath the coastal white ribbon". It has now been seen by two reviewers, whose comments appear below. Previous Reviewers #1 and #2 were unfortunately unable to provide further reports so, while Reviewer #3 is the same as before, Reviewer #4 is new this round. In light of the combined advice we have received I am delighted to say that we are happy, in principle, to publish a suitably revised version of your Perspective in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License).

We therefore invite you to revise your paper one last time to address the remaining concerns of Reviewer #3. In particular, please consider revising or removing some of the metaphors and terms used. If you wish to keep reference to the 'white ribbon' we suggest replacing 'deep white ribbon' with 'coastal white ribbon'. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

Please note that it may still be possible for your paper to be published before the end of 2022, but in order to do this we will need you to address these points as quickly as possible so that we can move forward with your paper.

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Best regards,

Rahim Barzegar, PhD
Editorial Board Member
Communications Earth & Environment
orcid.org/0000-0002-1941-2991

Joe Aslin
Senior Editor,
Communications Earth & Environment
https://www.nature.com/commsenv/
Twitter: @CommsEarth

REVIEWERS' COMMENTS:

Reviewer #3 (Remarks to the Author):

The Perspective is much improved with the refocusing around the many benefits of further understanding the deep coastal zone. I believe there are still some small opportunities for improving the message and content, but I believe the Perspective will be a meaningful nudge for several scientific communities.

Comments:

The “deep white ribbon” implies a vertical continuum of sandy material. While this has been described as not homogeneous with the stratigraphy section, non-geologists might get confused by the repeated use of the deep white ribbon. The white ribbon implies wave action or white sands? This term is more (potentially) misleading that the original use of CTZ. “Below the white ribbon” captures the idea more clearly (in my opinion) and doesn’t imply connectivity. The idea of the “white ribbon” could be explicitly stated – why white? why ribbon? An artistic/metaphorical description in a scientific Perspective? The “deep land-sea transition zone”, spelled out, doesn’t seem too much

more to write.

(line numbers from “related” pdf)
Line 176 – Zamrsky et al 2018 could be used/referenced here to support/enhance this statement.
186 – to more effectively manage pumping onland?
310 – is this definition application dependent? If so, that should be stated. If not, then why is this only introduced after the examples and not immediately after the introduction?
311 – basement is not clear, though it connects well with the label in the figure. An architect might not agree with this unqualified use of basement.
366 – reference needed
391 – can replace “whereas information regarding…” with “informing.... to better understand groundwater hydraulics and dynamics”. No need to detract from the value of the geophysical datasets in the modeling.
441-44 – I would be surprised if ref 72 stated that “folks don’t know stuff about coastal groundwater”. These two sentences should be reworded to highlight the unknowns rather than the ignorance of “quite a few people” – are these people scientists or managers or chemists or teachers or babysitters? A lot of wishy-washy phrased could be honed for what is likely an important statement in this Perspective (e.g., “to some extent”, “quite a few”, “is often”). I don’t see the reference support to justify “often”.
445 – Too many oftens
485 – “promising” how? most realistic/imageable? These expensive surveys and models are likely motivated by either strong scientific or societal need, not based on “where will work best”
519 – comma needed to correct run-on

Box 1
902 – “remains in its infancy” seems fairly pejorative for the researchers who have been studying this for 10 years. I don’t see specific reasons why infancy and not adulthood – and what really is the difference in this metaphor? Do we know how to improve the representation of groundwater processes in this domain? If so, what are those ways and how do geophysical techniques offer solutions? This statement is not supported with a justification.
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Reviewer #4 (Remarks to the Author):

I provide a disclosed review in my effort to encourage an unblinded peer review process, as I believe transparency mitigates discourtesy, reduces subjective bias, and reveals possible conflicts of interest. By avoiding anonymity, I hope to promote a more self-regulated peer review process that yields objective and thoughtful reviews.

10.04.2022

Journal: *Commun. Earth Environ.*

Review letter : A review for manuscript: #22-0052A

Manuscript title: Probing the deep frontier beneath the coastal white ribbon

Authors: B. Weymer, M. Everett, A. Haroon, M. Jegen-Kulcsar, A. Micallef, C. Berndt, H. Michael, R. Evans, and V. Post

Reviewer: E. Attias

Opening remarks:

- I provide a disclosed review in my effort to encourage an unblinded peer review process, as I believe transparency mitigates discourtesy, reduces subjective bias, and reveals possible conflicts of interest. By avoiding anonymity, I hope to promote a more self-regulated peer review process that yields objective and thoughtful reviews.

- My review considers the author's response to a previous round of review. Particularly, as requested by *Commun. Earth Environ.* editorial board, I examined the author's responses to the comments raised by reviewers #1 and #2. To that aim, I evaluated the extent, relevance, and quality of the modifications applied to the revised manuscript.

Summary & Decision:

This manuscript focuses on coastal aquifers transition zone, highlighting the gap in knowledge associated with the white ribbon (WR). It reviews current methodologies to study this zone, points-out technical/logistical limitations and suggests mitigation pathways.

The three reviewers raised valid comments (with some, I agree). Consequently, the authors modified the manuscript substantially, shifted the main focus as suggested by reviewers #1 and #2, and addressed the other comments adequately.

I find this manuscript relevant, as it points the lamp towards a severely understudied region (due to logistical hurdles) though of high hydrological value. Thereby promoting both the importance of the WR globally, as well as the necessity to develop new, specifically-designed methodologies and instruments to study the WR. The manuscript is well written and within the scope of *Commun. Earth Environ.* Therefore, I recommend publication in its current form.

SCHOOL OF OCEANOGRAPHY
SHANGHAI JIAO TONG UNIVERSITY
上海交通大学 海洋学院

Response to referees letter (R2)

17 November, 2022

Dear editors and reviewers,

Attached please find the second revised version of "**Probing the deep frontier beneath the coastal white ribbon**" (COMMSENV-22-0052B), which we finally title "**The coastal transition zone is an underexplored frontier in hydrology and geoscience**" as suggested by the editors. On behalf of my co-authors, I thank the editors and the four reviewers for your additional constructive comments. Please find our point-by-point responses to Reviewer 3 highlighted in red. We also include the clean and marked versions of the revised manuscript in the submission package along with the required editorial forms for your review.

REVIEWERS' COMMENTS:

Reviewer #3 (Remarks to the Author):

The Perspective is much improved with the refocusing around the many benefits of further understanding the deep coastal zone. I believe there are still some small opportunities for improving the message and content, but I believe the Perspective will be a meaningful nudge for several scientific communities.

We thank the reviewer for their additional constructive comments.

Comments:

The "deep white ribbon" implies a vertical continuum of sandy material. While this has been described as not homogeneous with the stratigraphy section, non-geologists might get confused by the repeated use of the deep white ribbon. The white ribbon implies wave action or white sands? This term is more (potentially) misleading that the original use of CTZ. "Below the white ribbon" captures the idea more clearly (in my opinion) and doesn't imply connectivity. The idea of the "white ribbon" could be explicitly stated – why white? why ribbon? An artistic/metaphorical description in a scientific Perspective? The "deep land-sea transition zone", spelled out, doesn't seem too much more to write.

The term "white ribbon" is in fairly common usage (see references below for a few examples) as the zone near the coast in which data are not available, and hence it is more descriptive of the central thesis of the article than the land-sea transition zone, or similar, which does not

imply a lack of data. However, we agree to switch to using "coastal transition zone" in the beginning of the manuscript, but also keep the term "white ribbon" in the article since the lack of data spanning the coastal zone is the raison d'etre of the paper. We added the following statement in the first paragraph of the Introduction (second sentence) to clarify this point:

"Herein referred to as the "coastal white ribbon", it is the zone near the coast in which data are not available resulting in a critical information gap between the land and sea."

We also include a new figure (Figure 1) to further illustrate the white ribbon region.

***"Figure 1**. The coastal white ribbon spans the transition between land and sea; it is herein defined as the nearshore shallow water region below which there exists a paucity of data constraining deep structure and processes. The image shows breaking waves resembling a "white ribbon" in the nearshore zone at Padre Island National Seashore, Texas, USA (Photo credit: B. Weymer. 29 November, 2013)."*

References:

Carvalho, R.C., Hamylton, S. and Woodroffe, C.D., 2017, July. Filling the 'white ribbon'in temperate Australia: a multi-approach method to map the terrestrial-marine interface. In *2017 IEEE/OES Acoustics in Underwater Geosciences Symposium (RIO Acoustics)* (pp. 1-5). IEEE.

Prampolini, M., Savini, A., Foglini, F. and Soldati, M., 2020. Seven good reasons for integrating terrestrial and marine spatial datasets in changing environments. *Water*, *12*(8), p.2221.

Mason, T., Rainbow, B. and McVey, S., 2006. Colouring the 'White Ribbon–Strategic Coastal Monitoring in the South-East of England. *Hydro International*, *10*(4), pp.19-21.

Leon, J.X., Phinn, S.R., Hamylton, S. and Saunders, M.I., 2013. Filling the 'white ribbon'–a multisource seamless digital elevation model for Lizard Island, northern Great Barrier Reef. *International Journal of Remote Sensing*, *34*(18), pp.6337-6354.

https://www.cheetahmarine.co.uk/en/deliveries/white_ribbon_will_enable_british_geological_survey_to_map_infamous_datagap

Line comments:

(line numbers from "related" pdf)
Line 176 – Zamrsky et al 2018 could be used/referenced here to support/enhance this statement.

Ok, Zamrsky et al. reference added.

Zamrsky, D., Oude Essink, G.H. and Bierkens, M.F., 2018. Estimating the thickness of unconsolidated coastal aquifers along the global coastline. *Earth System Science Data*, *10*(3), pp.1591-1603.

186 – to more effectively manage pumping onland?

We keep this sentence as is, as imaging the pathways are not only important for effectively managing pumping strategies on land.

310 – is this definition application dependent? If so, that should be stated. If not, then why is this only introduced after the examples and not immediately after the introduction?

Yes, our definition is primarily based on the application of the various deep-probing geophysical techniques that we highlight in the paper. We added a new sentence to clarify this point:

"Following the nomenclature of Bratton[26], we define the coastal white ribbon zone to be that which ranges in the vertical from the top of the uppermost confining layer downward to the top of the geological basement, as shown by the dashed lines in Fig. 2. Note that this definition is primarily based on the application of the various deep-probing techniques that we highlight in this Perspective."

311 – basement is not clear, though it connects well with the label in the figure. An architect might not agree with this unqualified use of basement.

Ok, changed to "the geological basement."

366 – reference needed

Ok, added the Micallef et al (2021) reference, which describes existing geophysical methods for mapping offshore aquifers.

Micallef, A. *et al.* Offshore freshened groundwater in continental margins. *Reviews of Geophysics*, e2020RG000706 (2021).

391 – can replace "whereas information regarding…" with "informing.... to better understand groundwater hydraulics and dynamics". No need to detract from the value of the geophysical datasets in the modeling.

Ok, we changed this sentence to:

"Mapping geologic structure and salinity distributions with geophysical measurements informs us about the location and overall geometry of coastal groundwater systems, informing how they function under hydrologic change including sea level change and pumping to better understand groundwater hydraulics and dynamics (see Box 1 for further details)."

441-44 – I would be surprised if ref 72 stated that "folks don't know stuff about coastal groundwater". These two sentences should be reworded to highlight the unknowns rather than the ignorance of "quite a few people" – are these people scientists or managers or chemists or teachers or babysitters? A lot of wishy-washy phrased could be honed for what is likely an important statement in this Perspective (e.g., "to some extent", "quite a few", "is often"). I don't see the reference support to justify "often".

We modified these sentences to the following:

"Because of the inherent multi-disciplinary nature in coastal hydrogeological research, understanding the connections, storage and fluxes of groundwater beneath the white ribbon is likely to benefit from new data collected by deep-probing geophysical and drilling technologies. A lack of data often forces groundwater modelers to make simplified assumptions about the offshore groundwater salinity distribution (e.g. all groundwater is saline) that may not be in line with the more complex reality[77]."

445 – Too many oftens

Fixed.

485 – "promising" how? most realistic/imageable? These expensive surveys and models are likely motivated by either strong scientific or societal need, not based on "where will work best"

We modified this sentence to:

"The research directions displayed in Fig. 3 are motivated by either strong scientific and/or societal needs offering opportunities for investigators working together to close the elusive information gap beneath the coastal white ribbon."

519 – comma needed to correct run-on

Fixed.

Box 1
902 – "remains in its infancy" seems fairly pejorative for the researchers who have been studying this for 10 years. I don't see specific reasons why infancy and not adulthood – and what really is the difference in this metaphor? Do we know how to improve the representation of groundwater processes in this domain? If so, what are those ways and how do geophysical techniques offer solutions? This statement is not supported with a justification.

We combined these two sentences to the following:

"Despite the widespread use of groundwater models for understanding onshore coastal groundwater resources and seawater intrusion[87] and for quantifying SGD offshore, progress in groundwater modeling to capture the dynamics of OFGs is constrained by the white ribbon information gap, as in geophysics."

910 – Adrian Werner's papers on coastal aquifers absolutely counter this statement. We have known that freshwater hydraulics and confining units can push freshened groundwater offshore for over a hundred years. "rethinking" is the wrong word, as the sentence starting in 911 states that heterogeneity is another driver beyond sea-level. Is there some community that believes this? It isn't the hydrogeology community. Highlighting that there are two primary drivers of OFG – temporal (sea-level) and spatial (geologic heterogeneity) would be a strong way to start this paragraph without this sensationalized "rethinking". The balance between the importance of the spatial and temporal drivers may be reserve-dependent, which I think is worth noting and potentially what the authors intended to state here.

We deleted the first sentence (*"These results necessitate a rethinking of the way offshore low-salinity water bodies are formed."*). We now include the reviewers suggestion regarding the balance between spatial and temporal drivers in the following revised discussion:

"Geological heterogeneity as an OFG driver breaks the paradigm that sea-level lowstands are a prerequisite for the formation of fresh groundwater reserves below the continental shelf. Recent global compilations of offshore sedimentary systems[90,91] have shown that both heterogeneity and sea-level changes influence OFG systems and the balance between these spatial and temporal drivers may be reserve-dependent."

Reviewer #4 (Remarks to the Author):

I provide a disclosed review in my effort to encourage an unblinded peer review process, as I believe transparency mitigates discourtesy, reduces subjective bias, and reveals possible conflicts of interest. By avoiding anonymity, I hope to promote a more self-regulated peer review process that yields objective and thoughtful reviews.

We thank the reviewer (Dr. Eric Attias) for his constructive comments and transparent review.

14th Sep 22

Dear Professor Wang,

Your manuscript titled "A stream capture event triggered the abandonment of an ancient cities" has now been seen by our reviewers, whose comments appear below. In light of their advice I am delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License).

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

EDITORIAL REQUESTS:

Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table". Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files as a Related Manuscript file.

If you have any questions or concerns about any of our requests, please do not hesitate to contact me.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Michael Storozum
Editorial Board Member
Communications Earth & Environment

Joe Aslin
Locum Chief Editor,
Communications Earth & Environment
https://www.nature.com/commsenv/
Twitter: @CommsEarth

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

I think most of my previous comments have been carefully considered by the authors. In general I recommend this paper to be accepted. One suggestion is that the authors should give more details on the OSL dating procedures. For example, the preheating test, recycling ratio, recuperation, the decay curves and growth curve for the samples should be provided in the Supplementary Information, which will make the OSL dates more convincing.

Reviewer #2 (Remarks to the Author):

Most of my questions were well resolved, I suggest minor rivision.
Three minor suggestions:
Line 4-5 in the abstract: Show the TL age of the well.
Figure 2 a-1 “Huaining” not “Huailing”.
The paper Fan et al. (2018) need to be referred.