Anonymous Referee #1

Page numbers in referee responses refer to pages in the revised manuscript. Responses to reviewer comments are in blue.

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Summary

This article looks at two sources of total alkalinity – discharge of fresh groundwater and advective circulation of water through permeable sediments – in Muri Lagoon on the island of Rarotonga. Radon is used as a tracer of fresh groundwater discharge while chambers are used to measure porewater exchange. The groundwater endmember is characterized using a single piezometer, which is sampled at two depths. The study period is 28.5 hours (1 diel cycle or 2 tidal cycles) on March 17, 2012. The authors found significant inputs of TA from both groundwater sources. Fresh groundwater discharge was always a TA source, while porewater exchange varied between being a source and a sink. Fresh groundwater discharge seemed to be driven by the tides and was greatest at low tide, while porewater exchange was affected more by diel biological cycles of photosynthesis, respiration and coral calcification.

Review

In general, I found this article to be interesting and well-written, with no major problems, and I would recommend it for publication.

Thank you for your encouraging remarks.

Minor comments, which I feel could improve the quality of the manuscript, are listed below.

1. p. 15504, line 3: Please explain how calcification rates are determined based on changes in water column TA using the equation provided. One sentence summarizing the idea behind this method would be sufficient.

We added the following text:

(p. 4, line 11) "Because CO_3^{2-} is equal to 2 TA equivalents, calcification rates are equal to half the change of TA concentrations."

2. p. 15504, line 19: You say that "Porewater advection can occur on various temporal and spatial scales resulting in numerous exchange rates over variable time scales". However, in this paper you quantify this advection at only one location in the lagoon, over a very short time scale (28.5 hours). Please comment somewhere in the paper about how much spatial and longer-term temporal variability might occur, and how this variability could be addressed in future work.

We added the following text to address this comment:

(p. 20 line 12) "Also, any seasonal variability in rainfall may influence SGD flux rates over larger temporal scales."

(p. 20, line 23) "Since currents are the main driver of porewater advection, the different stirring rates would likely reflect any variability within the lagoon."

(p. 22 line 20) "It is important to constrain the variability of these fluxes over larger temporal and spatial scales by measuring ^{222}Rn concentrations across broad areas of coral reef environments."

3. p. 15505, line 8. The authors state that few studies have looked at SGD on coral reefs. I know that more studies have been done than the ones they cite – at least studies that look at SGD in areas that have coral reefs, even if they don't quantify fluxes of SGD directly onto the reefs. Some examples of additional articles the authors could cite are: Knee et al. 2008, 2010; Street et al. 2008; Blanco et al. 2011; Kim et al. 2011 (listed at the end of the review).

We added some of the suggested citations to the paper:

(p. 5, line 21) "The few studies assessing SGD rates on coral reefs describe a range from 52 to 4,732 L m^{-1} h^{-1}, and suggest that SGD can be an important source of solutes to coral reef ecosystems (Lewis, 1987;D'Elia and Wiebe, 1990;Paytan et al., 2006;Knee et al., 2010;Blanco et al., 2011)."

4. p. 15507, line 1. Can you comment on how similar or different the water-column monitoring site and the porewater chamber site were, and how this could have affected the results? Also, was there any particular rationale for where you decided to locate these two sampling sites?

We added the following text to clarify:

(p. 7, line 18) "The chamber sampling site was located further (~75 m) from shore to minimize any SGD impact, and because of the large area of carbonate sediments free from macrophytes."

5. p. 15507, line 6: Change "MuriLagoon" to "Muri Lagoon".

Change made.

6. p. 15507, line 22: Please explain why you used three different spinning rates for the chambers. Was it one of the study goals to compare them? Is it standard to use three rates? We added the following text:

(p. 8, line 19) "Three stirring rates were chosen in order to investigate any effect of advection on alkalinity flux rates, similar to studies done in other coral lagoons (Glud et al., 2008;Cyronak et al., 2012)."

7. p. 15507, line 28: Typo: change "dusing" to "using".

Change made.

8. p. 15508, line 11: When you say "a moving average period of 3" what does that mean? Three measurements? Please clarify.

Text was changed in order to clarify:
(p. 9, line 15). "For the monitoring data, an average over one hour (30 min before and after) was taken over half hour intervals in order to smooth the data and better reveal any trends."

9. p. 15508, line 26: Did you make sure that the use of the peristaltic pump did not result in any loss of Rn? I ask because I tried to use a peristaltic pump to collect samples for Rn analysis from a piezometer, and when I compared it to a submersible pump (Whale, 12V) the Rn concentrations from the peristaltic pump were always lower. If you did anything to control or account for Rn loss, please note it, or if you have a reason for thinking this would not be a problem, please explain. Otherwise, there's not that much that can be done at this point, but it might be something to think about for the future.

We understand the reviewer's concern as some peristaltic pumps rely on gas permeable silicone tubing. We used minimal silicone tubing and have previously compared the results obtained from our peristaltic pump with bilge pumps in the laboratory and obtained undistinguishable results. We added the following to the paper:

(p. 10, line 6) "Gas permeable silicone tubing was only used in the pump head in order to minimize any losses of ^{222}Rn and CO_2. Laboratory experiments revealed no differences in concentrations when using a peristaltic pump and other pumps to feed the exchanger."

10. p. 15509, line 4: Would you expect a significant amount of 226Ra decay to occur on the time scale of this study (28.5 hours)? It seems to me that it would be negligible since the half-life of 226Rn is about 1200 years.

There was a typo in the original paper. The model does not account for ^{226}Ra decay, however, it does account for ^{222}Rn decay which has a shorter half-life (3.8 days). ^{226}Ra was removed from the manuscript.

11. p. 15509, line 24. Please explain at this point in the paper or earlier the purpose of looking at _13C DIC.

We added the following text:

(p. 11, line 10) "δ^{13}C DIC was measured in order to separate any sources of TA and DIC in the groundwater and water column."

12. p. 15511, line 9. "TA had a complex dynamics that was related to both diel and tidal cycles". Is your time series actually long enough to support this assertion?

Although we weren't able to make these measurements over a large temporal scale, we feel they support the statement because TA varied over both tidal cycles measured during the study and showed obvious variations over a diel cycle. We added the following text to highlight this point:

(p. 12, line 23) "In contrast, TA had a complex dynamics that was related to both diel and tidal cycles, supported by the variation in TA concentrations measured over one diel cycle and two tidal cycles (Fig. 4C)."

13. p. 15512, line 7: “which would alter the chemistry of porewaters in the permeable sediments thereby affecting both flux rates. . .”. Can you be more specific about how the chemistry would be altered and how the flux rates would be affected? The current statement is quite vague.

We agree and changed the text in the manuscript:

(p. 13, line 22): “This is consistent with the availability of PAR driving rates of benthic photosynthesis. Photosynthesis would alter the chemistry of porewaters by taking up DIC and releasing DO into the pore waters, thereby affecting both flux rates of TA_C and H^+ (Cook and Røy, 2006;Cyronak et al., 2013).”

14. p. 15512, line 16. Looking at Fig. 2, it seems like you see almost the exact same patterns regardless of the chamber (diffusive, 40 RPM or 60 RPM). Based on that figure, I would never conclude that the 40 RPM chamber data would give you a large positive flux, and the other two would give you a negative flux – they basically look the same. Yet in the text and in Table 2 you say that the difference is large and significant. Can you reconcile these apparently conflicting views of the data?

We agree there is minimal difference between the hourly flux rates in the three chambers, however, when calculating daily flux rates, the 40 RPM chamber has positive TA flux rates. We added the following line:

(p. 14, line 25) “Although hourly rates between the three chambers were similar (Fig. 2), integrated daily rates in the 40 RPM chamber were higher than both the diffusive and 80 RPM chambers.”

15. p. 15514: I think you need to recognize the possibility that the groundwater endmember could be variable and/or different from the estimate you got based on very limited piezometer sampling. The large difference between the two depths sampled seems to open the possibility that if you sampled more depths or more locations on the beach, you would see a wider range of Rn activities, and the average could also be different.

We agree and added the following text:

(p. 16, line 22). “We recognize that since ^{222}Rn concentrations were variable with depth the groundwater endmember could be variable over larger spatial scales (Dulaiova et al., 2008;Santos et al., 2009). A large number of groundwater samples would be important to decrease any potential uncertainties with the groundwater endmember, and better elucidate fluxes over larger spatial scales.”

16. p. 15516, line 1: Can you calculate the net flux of TA for the one-day study period from 1) Rn-derived SGD and 2) porewater exchange and present it in the text? Fig. 12 gets at this a bit, but I think it would be better to actually present it in the text as well.

We changed the following paragraph to highlight this point:

(p. 16, line 3) “The fluxes of TA associated with advective processes were both negative and positive while the groundwater fluxes were always positive (Fig. 12). Combined TA flux rates from both SGD and pore water advection along the 750 m transect were between 62.1 and 72.9 mmol m^{-2} d^{-1}, which is above the TA uptake rates of coral lagoons (26-42 mmol m^{-2} d^{-1}) as measured by Kinsey (1983). These flux rates are consistent with the elevated TA concentrations measured at our sampling site. Across the 750 m transect, groundwater (from both porewater advection and SGD) contributed 46.3 to 52.8 mol TA d^{-1} to the water column. On a daily basis, pore water advection fluxed from 1.6 to 3.5 mol TA d^{-1} into the lagoon, while SGD fluxed 50 mol TA d^{-1} along the 750 m transect. SGD contributed 27% to 97% of the combined groundwater fluxes over a diel cycle, with the percent contribution dependant on both the time of day and the tidal cycle (Fig. 12). Since groundwater seepage is correlated to tidal height (Chanton et al., 2003), larger tides would have more of an effect on groundwater flow, potentially allowing more TA to be fluxed into the system during those tidal cycles. However, because advective processes follow a diel cycle and groundwater is driven by tidal cycles, seasonal experiments may be needed to reveal which of the processes is more influential over the long term."

17. Please comment somewhere in the text about how representative the tidal cycle you sampled was for the area in general. Did you sample during a spring or neap tide?

We added the following text to address this comment:

(p. 8, line 2) "The tidal range during our sampling period was 0.4 m and was towards the end of the spring tide cycle."

18. p. 15517, line 26. Typo: Change "coralcover" to "coral cover".

Change made.

19. p. 15518, line 12: Please state clearly whether porewater exchange is a net source, net sink, or neither for TA according to your results.

We added the following:

(p. 22, line 13) "Based off the average of the 40 and 80 RPM chambers, pore water advection was a net source of TA to the lagoon (2.1 to 4.7 mmol m^{-2} d^{-1})."

20. Figs 2 and 3: I found Fig. 3 somewhat difficult to interpret and I thought it might be better to eliminate Fig. 3 and instead add a dashed line to each panel on Fig.2, showing the PAR. You could eliminate the gray bar because the variation in PAR would indicate whether it was day or night. That way it would be really easy to see how trends in TAC flux, DO flux, DIC flux and H+ flux match up in time with variation in PAR.

We added PAR to the top of each panel in Fig. 2. However, we opted for keeping Fig. 3 to demonstrate the hysteretic patterns in flux rates that are occurring and somewhat unexpected for those systems.

21. Fig. 11. It was unclear to me by the SGD TA flux was represented as columns while all other fluxes were represented as points with error bars and/or lines.

We changed the Rn derived advection rates to columns because we feel it better demonstrates the variability of the fluxes.

Additional References:
Knee, K.L., et al. . 2010. Nutrient inputs to the coastal ocean from submarine groundwater discharge in a groundwater-dominated system: Relation to land use (Kona Coast, Hawai‘i, USA). Limnology and Oceanography.
Knee, K.L., et al. 2008. Sources of nutrients and fecal indicator bacteria to nearshore waters on the north shore of Kaua‘i (Hawai‘i, USA). Estuaries and Coasts.
Street, J.H., et al. 2008. Submarine groundwater discharge and nutrient addition to the coastal zone and coral reefs of leeward Hawai‘i. Marine Chemistry.
Kim, G. et al. 2011. Submarine groundwater discharge from oceanic islands standing in oligotrophic oceans: Implications for global biological production and organic carbon fluxes. Limnology and Oceanography.
Blanco, A.C., et al. 2011. Estimation of nearshore groundwater discharge and its potential effects on a fringing coral reef. Marine Pollution Bulletin.

We have incorporated some of these overlooked references into the paper.