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The Cryosphere Discussions

Interactive comment on "Discovery and characterization of submarine groundwater discharge in the Siberian Arctic seas: A case study in Buor-Khaya Gulf, Laptev Sea" *by* Alexander N. Charkin et al.

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We thank all three reviewers for their large effort and for providing valuable and very constructive comments, which have been useful in our revisions of the manuscript. Naturally, we are encouraged that all reviewers support our study of submarine groundwater discharge (SGD) in the Bhuor-Khaya Bay, SE Laptev Sea, and the conclusion that it provides a previously largely unexplored vector for transport from land to the East Siberian Arctic shelf, yet complicated by geocryological conditions such as permafrost. Below, each review comment is listed first, followed by our response and a description

of resulting edit. Author comments are marked below as AC.

General comments by anonymous referee 2 (Reviewer 2).

RC: General comments: This paper is the first to provide direct evidence of submarine groundwater discharge in the Arctic, which is an important contribution to our understanding of the Arctic system and how it may respond to climate change. Because of this exciting new finding I recommend that this paper be published after revisions to improve the clarity of the discussion and methods.

AC: Thanks for the appreciation of our manuscript.

Specific comments by Reviewer 2

RC: Introduction: The background on SGD in the Arctic is lacking, and expanding upon this will help place the importance of the current study in context. There are a few C1 TCD Interactive comment Printer-friendly version Discussion paper other references that support the existence of groundwater discharge in regions of continuous permafrost based on thermal gradients (Deming et al., 1992), the mapping of springs (Kane et al., 2013), and modeling of permafrost extent taking into account freshwater inputs from SGD (Frederick and Buffett, 2015). Also, the year for Walvoord and Striegl should be 2007, not 2000.

AC: Thanks for the constructive remark. We will edit the introduction accordingly - using the proposed literature and correct the year for Walvoord and Striegl.

RC: p. 3 lines 24-27: Missing/incorrect references in discussion of previous studies of Ra in the Arctic: Kadko and Muench (2005) were the first to measure 224Ra in the Arctic but are not included in the list, Kadko and Aagaard (2009) did not report any short lived isotopes, and Smith et al. (2003) report 228Ra and 226Ra activities for the Beaufort Sea and central Arctic. Radium-228 activities are also reported in Trimble et al. (2004) and Cochran et al. (1995), although the main focus of these two papers is on Th and not Ra.

AC: Thank you. We will edit accordingly.

RC: p. 5 line 21: Why were the samples not counted a third time to correct for 227Ac? If this contribution is assumed to be negligible this should be noted in the text. Clarify why total 223Ra is used instead of excess.

AC: Yes, the samples were counted a third time to correct for 227 Ac. The Ac activity was in the error range. Thus, the Ac contribution is assumed to be negligible. We will note this in the revised text.

RC: p. 7 line 38: There is no mention of how 226Ra or 228Ra are measured, but these long-lived isotopes show up later in the manuscript. The first mention of 226Ra is in the section 3.3, where it is stated that 222Rn has been corrected for ingrowth from 226Ra, but there is no explanation of how this is done. Radium-228 and 226Ra activities are also mentioned later in this section, but there is no explanation of how they are measured. If the 228Ra and 226Ra measurements were made it would be great if this data could be published, even if they long-lived isotopes are not the focus of this study!

AC: We still do not have data on long-lived isotopes for wintertime (see our detailed response to a similar question by Rev. 1). However, in the final version of the manuscript we will include data on long-lived isotopes in the summertime: Regarding methods for Ra isotopes, this will be included in the revised ms. Briefly, in the shorebased/home laboratory, Ra was leached from the fibre with hot 6N HCl, coprecipitated as BaSO4 and counted with gamma spectroscopy for 226Ra and 228Ra (Moore, W.S., 1984. Radium isotope measurements using germanium detectors. Nuclear Instruments and Methods in Physics Research 223, 407-411).

RC: p. 9 line 9: In the description of the river water endmember it is stated that the activities of 224Ra, 223Ra, and 222Rn are higher than those in seawater, but the average 224Ra in RW is less than that of SW.

AC: In this paper we consider three freshest samples as the riverine (RW), but to choose the “best” end-member we use 222Rn, 223 Ra, 224Ra obtained at the station 1502 which is characterized by the lowest salinity (0.98psu).

RC: p. 9 line 17: In the SW description it says that the 228Th/227Th ratio increases by ingrowth. Should this say increases by decay instead of ingrowth? My understanding is that the ratio increasing because Th becomes adsorbed to the particles and then the 227Th decays faster than the 228Th while the particles are sitting in the bottom nepheloid layer.

AC: Yes, you are right. In principle, we had this in mind, but a little confused, because we are not native speakers of English. This will be corrected.

RC: p. 9: Section 3.4 could be better organized; it’s a bit hard to follow the way it’s written because the descriptions of the endmembers are mixed in with the interpretations of the data. It would be better if the endmember descriptions were first, and then the data were discussed in the context of the two figures (11a and 11b) separately. As is, there is really no discussion of figure 11b.

AC: We agree; we will re-organize this section and add more discussion about figure 11b. Thank you.

RC: p. 10 line 28: Figure 12c is referenced, but I think this should be a reference to figure 12d? I recommend introducing this figure (12d) in section 3.4 instead of section 3.5.1 (make it a separate figure), because this helps in the interpretation/understanding of the endmember descriptions.

AC: Yes, correct, it should be 12d. It is a typo, which will be corrrected. Yes, you are right, it is better to make this figure separately and include it in section 3.4. We will revise the ms to this effect.

RC: 9. p.11 line 18: Was permafrost thaw considered as a source of Ra? The source of the high Ra is at the place of contact between the ice hummocks and bottom sediments,

so if the ice hummocks are thawing this would be a logical place to have some runoff of the melted ice, which could be enriched in Ra.

AC: Runoff of the melted ice is unlikely, because during our wintertime studies, the air temperature did not rise above -10 degrees Celsius during the day, and at night, it dropped to -30. The temperature of the water was negative everywhere. Moreover, the high salinity of the waters along the ice hummocks periphery also indicates cryogenic squeezing out of brine and water-soluble salts as plausible mechanism of the radium enrichment. We will seek to clarify this information further in the revised text

RC: It would be helpful to compare the magnitude of the discharge near Cape Muostakh to that near the Kharaulakh hydrogeological massif; this comparison might aid in the differentiation of the two discharge mechanisms.

AC: In the final version of this paper, we plan to show calculations of SGD discharge from the Kharaulakh hydrogeological massif and transit times using 224Ra and 223Ra. However, we have not enough statistics (only one station) to calculate the magnitude of discharge near Cape Muostakh, so this is a task for our future research.

RC: Why is supplementary table 2 (which is incorrectly labeled as supplementary table 1) considered supplementary and not included in the main text? In my opinion if the wintertime data are included in the main text, the summertime data should be included as well.

AC: We will move this table from suppl materials into the main text and add there the data on long-lived isotopes. Thank you.

Technical comments:

RC: Figure 7: numbers need to be larger (can barely read contours, can't read colorbar scales for salinity/density easily), map needs to be larger (can't read labels).

AC: We will rework figure 7 to increase visibility and clarity.

RC: Figure 13: cryogenic squeezing out of brine is labeled as CSB in the caption but CSW in the figure. Recently frozen soil is labeled as RFS in the caption but RFP in the figure.

AC: Sorry. It is a typo. We will edit the figure.

Thank you for your valuable comments which help to improve our manuscript.

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