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Interactive comment on "Satellite ice extent, sea surface temperature, and atmospheric methane trends in the Barents and Kara seas" *by* Ira Leifer et al.

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Response to Review 2 Review of "Satellite ice extent, sea surface temperature, and atmospheric methane trends in the Barents and Kara Seas" by Ira Leifer et al.

General comments The submitted paper looks rather interesting. The authors carried out study in considering one of the current warming consequences, namely: increasing methane concentrations. They made a detailed enough review of the relevant literature and presented rather detailed analysis of the subject.

However, the paper needs reworking in some ways listed below.

> Thank you. Our primary study finding is that heat transfer by currents is driving increasing seabed methane emissions and that shoaling by the same currents is allowing this seabed methane to escape to the atmosphere. Methane shoaling is a newly described process that is neglected in a range of published studies to date, which focus on the local area; yet shoaling can occur far downcurrent, potentially in waters of another nation (Russia). We also provide novel SST climatology that shows that currents are not only important on the gross scale (WIGAR), and on the regional scale in parts of the Barents Sea, but even on the small scale – tens of kilometers. Specifically, if the SST trends only represented a skin effect, it would not have any effect on seabed methane.

The introduction and methods seem to be too long. These two chapters take about 11 pages of text compared to about 10 pages for the results and discussions.

> We have shortened significantly, rearranged and removed redundancy of the intro material, and moved information that is relevant but not central into supplemental material sections S1 and S2, for example. the Alaskan arctic methane review, and the summary of IASI satellite details and its validation (this supports the IASI Arctic review that remains in the main text). We deleted the discussion of SWIR satellite methane sensors (not relevant).

> Intro material is now 5.5 pages, Methods 1.25 pages, Results 6 pages, Discussion & Conclusion 7 pages.

Subchapter 2.3 Setting looks redundant, especially for the chapter describing materials and methods, except the very last paragraph.

> All of Subchapter 2.3 was moved into section 1.4 and 1.5 and duplication was removed. As well, these sections, and the beginning introduction were reorganized on a sentence by sentence basis to flow better and remove redundancy.

Some inaccurate using of Barents Sea currents names take place in the paper (see

below).

> We have worked hard to correct names, add additional names as needed to the maps, and improved clarity of the maps. We also added a few more details on current flow strength (Sv) and citations.

Drawing conclusions about variability in currents taking into account only variability of SST is incorrect.

> We recognize this and have improved the text. See extensive responses to Reviewer 1. That said, we argue that if SST trends only represented a skin effect or changes in downwelling thermal radiation, they would not have an effect on seabed methane. Moreover, the importance of shoaling argues that just as seabed methane is not being effectively transported vertically to the sea surface, then atmospheric heat transfer to the upper ocean cannot be effectively transported to the seabed (to affect seabed methane emissions).

Most figures are too small, of a poor quality and, as a result, hardly readable.

> The original uploaded figures are high quality. It is unclear why the system provided you with low quality images and we apologize.

Specific comments

Line 26: The Murman Coastal Current flows mainly eastward. The Murman Current also flows eastwards towards Novaya Zemlya, and in the eastern part, the flow (usually called as the Novaya Zemlya Current) is generally northeastwards along the slopes of the North Kanin, Goose and Novaya Zemlya Banks.

> Fixed in Fig. 4. Also added to the text in Section 2.3.1.

Line 27: SST depends on both currents and air temperature. Air temperature plays a key role in SST variability in shallow waters of the south-eastern Barents Sea and southern Kara Sea. Heat fluxes between ocean and atmosphere are important there.

> This is a highlight (and thus must be very short). Not really certain about this comment. We now note that currents transport heat.

Line 55 and on: There is one confusing term in the paper, namely: albedo. Usually, surface albedo is defined as the ratio of irradiance reflected to the irradiance received by a surface, and ranges from about 0.9 for fresh snow to about 0.04 for charcoal, one of the darkest substances. In the paper, albedo seems to be defined as the ratio of irradiance absorbed to the irradiance received, doesn't it?

> This was a mistake and is fixed.

Line 60: The word "Arctic" is unnecessary in the phrase "the East Siberian Arctic Sea".

> We think this is still an open question as there is quite a bit of literature that does refer to it as the ESAS (e.g., Shakhova et al., 2014)

Line 330: Novaya Zemlya is an archipelago, not an island, and includes two large islands (Southern and Northern) and lots of small.

> Fixed. Thanks. To emphasize, the Matochkin Strait is now labeled in Fig. 2.

Line 327: The phrase "The relatively shallow (230-m average depth) Barents Sea (Fig. 4) is characterized by a deep Arctic shelf. . ." is ununderstandable.

> Agreed. Rewritten to be understandable.

Line 335 and on: The Norwegian, Greenland, Barents, Kara and some other seas are included in the Arctic Ocean. Therefore, it is better to say the Arctic Basin (the central area of the Arctic Ocean beyond all these seas) in this context.

> Fixed everywhere including in the figure captions. Thanks,

Line 338: There is no current in the Barents Sea called "Bear Island Channel Current". There are warm North Cape current flowing eastwards in the Bear Island Trough and cold Bear Island Current flowing southwest along the southeastern slope of the

Spitsbergen Bank.

> We now note that the BICC designation is our own notation for the warm current, referenced in Li and McClimans (1998). The SST climatology clearly shows its impact on heat transport towards the Svalbard Bank, an area of shoaling. The change in PC to BIC occurs near Hopen and is noted and changed in the main figures; it was correctly shown in Supp. Fig. S1.

Line 340: The Grand bank mentioned in the paper is commonly known as the Great bank.

> Corrected here, and in figures 2 and 4 and in the supplemental material

Lines 385–387: There is a repetition in this place: "cooler surface water . . . flows in NZCC and exit through the Kara Strait". The NZCC abbreviation expansion needs being done at the first mention in line 385.

> This entire paragraph (379-394) on currents in the Kara Sea was confused and mixed up, jumping back and forth between topics. It has been rewritten for clarity and to remove duplication.

Line 403: The cold Bear Island Current flows there, not the Persey Current that is located further northeast.

> Thanks. Some of the maps we relied on to assemble our map did not designate the BIC, Corrected in figures and texts, and citations added.

Line 404: Both focus areas (A8 and A10) are only influenced by Atlantic waters, the Persey Current does not influence them (this is clearly seen in picture 4a).

> Not sure how we missed this. Thanks. The summary of focus areas A8-A10 rewritten for correctness and clarity.

Line 418: The Saint Anna Trough is a correct name.

> Thanks for identifying that typo. Corrected

Line 418: The focus areas are shown in figure 4, not 3.

> Corrected

Line 430: According to bathymetry shown in figure 4a, focus area 7 covers the shelf slope, and focus area 8 covers depths of more than 200 m. They do not seem to cover banks.

> Corrected. Thanks.

Lines 435 and 451: All three northern focus areas (A1–A3) are located south of the FJL, none of them are east of the FJL.

> Thanks, corrected to south and southeast. Also in line 463 and elsewhere. Also corrected is the north arrow in Fig. 4b.north arrow in Fig. 4b

Line 450: According to figure 7, trends are almost absent in some areas (A3 and A6, for example).

> Re-organized sentence to direct reader to Table 1, which shows that dSST/dt>0 for all focus areas.

Line 453: This is a moot point that trends in SST are consistent with strengthening or weakening of currents. Advection of waters with higher temperatures and local conditions affect these trends as well. For example, the volume flux into the Barents Sea was rather low from 2007 to 2015 (ICES. 2017. Report of the Working Group on the Integrated Assessments of the Barents Sea. WGIBAR 2017 Report 16-18 March 2017. Murmansk, Russia. ICES CM 2017/SSGIEA:04. 186 pp.).

> Agreed that this sentence is redundant and not needed. Deleted.

Lines 483–484: Measured volume fluxes through the Barents Sea Opening (see reference above) are weakly consistent with this statement.

> Sentence added to cite WGIBAR 2017

Lines 489–490: The mentioned importance is not clear from figure 9 at all.

> Should have referenced Fig. 10. Fixed.

Line 491: It is ununderstandable what current is mentioned (BIC). Along the eastern coastline of the Svalbard, the cold East Spitsbergen Current only flows southwards.

> We agree this was unclear – we revised this paragraph to only focus on the flow of warm water into the south and west and east Barents Sea (and the BICC spur). The relationship between currents and SST climatology is now elucidated much more clearly in Supp. Fig. S3, and provides new fine scale detail of the importance and how this changes with season. This paragraph now includes these details.

Lines 498–499: This is the Bear Island Current, not the Persey Current.

> Yes. Thanks. Rewritten.

“In June, the edge of the cold (Arctic water) Percey Current/Bear Island Current corresponds well with the warm water’s edge and also corresponds fairly well with the median ice edge location. Southeast of Svalbard, the Bear Island Current penetrates southward as a narrow extension of cold water ending south of Bear Island. Slightly cooler water is observed over the two banks in the central Barents Sea.”

Line 540: The Kara Sea is ice-free in September and almost ice-free in August but not in July (even during the last warm period). In July, the northern and northeastern parts of the Kara Sea as well as the area close to the eastern coastline of the Novaya Zemlya Archipelago are still ice-covered often.

> Yes – this is shown in Fig. 2a

Lines 614–617: The authors need to pay more attention to winds over the Barents and Kara Seas; the role of atmospheric circulation seems to be underestimated.

> It is hard to explain the methane anomalies by distant sources from Europe or Russia for two reasons, described in the paragraph. The paragraph was rewritten for clarity:

> We have only considered the effect of vertical mixing due to wind. At these scales, wind transport shoves water to the right (Ekman transport), which is beyond the scope of our study. In an earlier paper (McClimans & Nilsen, 1993) it was shown that most details of the currents, including the Polar Front were produced by controlling the inflows of Atlantic and Arctic Surface waters from the NAC and the PC. [McClimans, T. A. and Nilsen, J. H, Laboratory simulation of the ocean currents in the Barents Sea. Dynamics of Atmospheres and Oceans. 19:3-26].

“The presence of a localized, atmospheric CH4 anomalies can reflect either local seabed emissions being vertically transported to the WML / atmosphere, or distant seabed emissions that currents transport laterally upslope into the WML where air sea exchange transports the CH4 into the atmosphere. Detangling these processes leverages the strength of the continuous and synoptic view of satellite data. Atmospheric transport of a distant source would not be localized.”

Line 682: The evidence of the statement that currents are strengthening is not provided. The phrase "larger oceanographic trends" is ununderstandable.

> As written, it is simply one of several possibilities (or hypotheses). We have rewritten the paragraph (deleting the phrase “larger oceanographic trends,” which is beyond the scope of this study – whether the driving force is the NAO, or global warming, or other processes). In summary, we simply conclude that greater heat transport is critical for increased tropospheric methane and is consistent with the hypothesis that it is strengthening heat transport by currents to both the seabed and sea surface.

“There are a number of possible hypotheses for why SST is warming fastest in regions along the Murman Current and NAC. One is sea-ice retreat; however, the warming occurs several months after the retreat of the sea ice. Another is that the pycnocline is becoming shallower, allowing more cooling to the atmosphere. This would imply a

weakening of storms and winds – which firstly is inconsistent with warmer SST, and secondly, there is no indication that Barents Sea storminess is changing or progressing further northwards (Koyama et al., 2017). Another hypothesis is that increasing current transport of heat is driving the SST warming. Although SST derives from several factors including heat transfer from the bulk ocean (i.e., currents), its co-spatial relationship to enhanced CH4 anomaly is consistent with currents playing a major role both at the sea surface (SST anomaly trend) and at the seabed. Greater heat transport could occur from strengthening currents, or warming currents, or a combination of both. “

Lines 731 and 732: There is some mess in using "northwest" and "northeast". The FJL and St. Anna Trough are in the northeastern Barents Sea, not in the northwestern. The southwestern and southern parts of the Barents Sea are ice-free year round, but not the northeastern part.

> Thanks for catching that mistake. Fixed.

Figure 4a: The East Greenland Current looks like having the wrong direction. This current is flowing southwards (Skjoldal H.R. (Ed.). 2004. The Norwegian Sea Ecosystem. Tapir Academic Press, Trondheim. 559 pp.; Dickson R.R., Meincke J., Rhines P. (Eds). 2008. Arctic–Subarctic Ocean Fluxes: Defining the Role of the Northern Seas in Climate. Springer, Dordrecht. 736 pp.). The detailed description of the Barents Sea currents is also presented in: Jakobsen T., Ozhigin V.K. (Eds). 2011. The Barents Sea: ecosystem, resources, management: Half a century of Russian-Norwegian cooperation. Tapir Academic Press, Trondheim. 825 pp. (scanned version of this book is available at https://brage.bibsys.no/xmlui/handle/11250/109444).

> Fixed. This was an error of the drawing program that we didn’t catch. We also improved the currents in Fig. 4a for the southeast Barents Sea, and cite Jakobsen and Ozhigin (2011).

Figure 6: The caption mentions figure 3c that is absent.âĂĺ

> Fixed – changed to 4a

Figures 7, 8 and 9: There is no explanation for symbols and lines on the graphs.

> Added to caption that lines are three year rolling average, and symbols are not.

Figures 8 and 9: There are data series and their rolling-averages, but not trends.

> Figures 8 and 9 captions corrected.

Technical correctionsâĂĺ

Lines 2 and 93: The word "seas" needs writing with a capital letter.âĂĺ Lines 487 and 781: The word "Sea" needs writing in the plural.âĂĺ

> Corrected throughout the entire manuscript

Line 512: A mistype in the Persey Current name.

> Some literature refers to the Percey Current, some to Persey Current. We now note this.

âĂĺFigure 2: One mistype needs correcting: Jul should be replaced with Jan in the legend.

> Yes! Thanks. Fixed.

Figure 5: A mistype in the PINRO abbreviation.

> Typo fixed. Thanks

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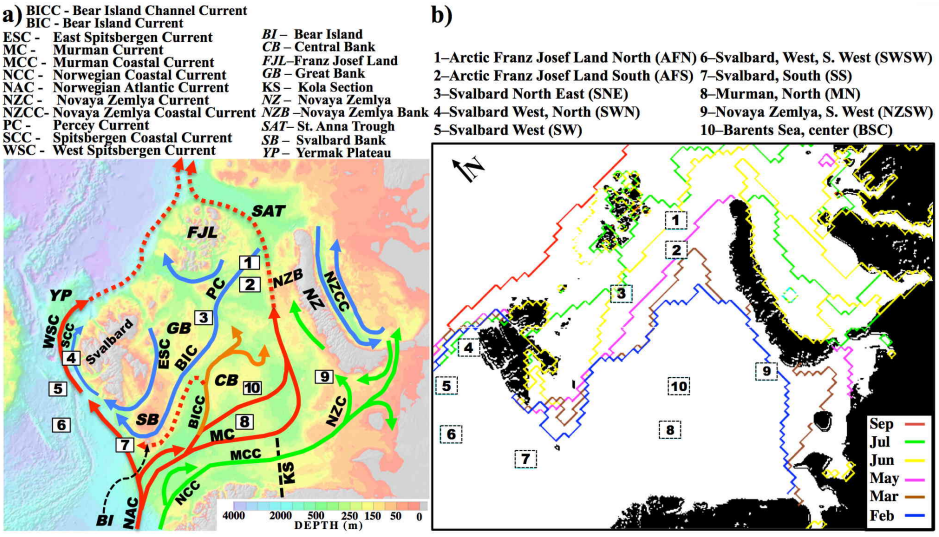

Fig. 1. Revised figure 4