Interactive comment on "Dimethylsulfide dynamics in first-year sea ice melt ponds in the Canadian Arctic Archipelago" *by* Margaux Gourdal et al.

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Referee #1: This is a generally well written and interesting manuscript describing novel measurements of Dimethylsulfide (DMS, DMSPd and DMSPp) concentrations and dynamics (derived from labelled DMSP and DMSO isotopic marker incubations) in Arctic sea ice melt ponds. A shortcoming of the paper is that it is based on a rather limited dataset with consequent problems for statistical analyses. Only two (brackish) melt ponds were sampled for incubations in this study, and statistics are based on an N=2 (with additional duplicate - but apparently dependent - samples taken from each incubation). While a t-test can be employed for a dataset with an N=2(4), the dataset

appears extremely small to make any statistical relevant conclusions. This reviewer therefore suggests to clarify (provide df or define N values) or alternatively delete these statistical analyses and rephrase some of the statements in relation to DMSP transformation into DMS. This said, other methods applied in this study appear to be solid (noting that this reviewer is not an expert in GC/GC-MS DMS(P) analyses) and raise some important new research questions for future research on DMS dynamics in sea ice melt ponds. In summary this reviewer suggests publication of the manuscript after amending the statistical analyses (t-test) and some other (minor) shortcomings including a re-consideration of the estimate of the overall DMS reservoir in Arctic melt-ponds, and a more detailed discussion on the sea ice surface permeability.

Author's response to general comments: We thank the reviewer for his/her positive general evaluation of the paper and helpful comments. The following actions were taken:

-We acknowledge that our restricted dataset limited the power of the chosen statistics analyses. We thus removed the results of the Student's t-test (P8, L25) and used a non-parametric Mann-Whitney U test (a replacement for independent groups t-test) that allowed us to compare the two independent groups of samples from the Ice1-MPI and Ice4-MP1 incubation experiments. The Mann-Whitney U test revealed no significant differences between the distributions of the reduced-sulfur compounds (i.e. DMS, DMSPd and DMSPp) from the Ice1-MP1 and Ice4-MP1 incubation results (n=45, df=16, α=0.05). The conclusions from this first step warranted the combination of the Ice1-MP1 and Ice4-MP1 datasets resulting in both greater sample size and statistical power for further analyses.

-Based on the results of the Mann-Whitney U test, the second step involved using a series of Wilcoxon Signed-rank tests on the combined datasets in order to 1) assess the presence of statistical differences between the Controls and each Treatment L-DMSP/O and D-DMSP/O; 2) assess the potential effect of light on the concentrations and change rates of the reduced sulfur compounds under study (DMS, DMSPd

and DMSPp) by comparing paired dependent samples (repeated measures) from L-DMSP/O and D-DMSP/O. As recommended, df values are now provided for each statistical test performed.

- We deleted the section of the discussion where we tentatively estimated the overall size of the DMS reservoir in Arctic melt-ponds. We agree that a greater spatial coverage of MPs is needed to come up with a more robust estimate.

- In the initial submission, brine volumes were calculated from the T–S measurements. In the revised version, full depth temperature, salinity and brine volume profiles in sea ice are presented in a new figure (FigureÂă4) for stations Ice1, Ice3 and Ice4 in support of a more detailed discussion on the sea-ice surface permeability.

Author's response to specific comments:

R1: P2, L1: delete "natural" in first sentence of abstract, this word is not needed. Response: Done.

R1: P2, L12: This calculation of the DMS reservoir in Arctic melt-ponds is based on 2 single measurements of 2 very specific (=brackish) melt ponds in a very defined study area (e.g. the Canadian Archipelago). This reviewer considers up-scaling the results from this study to the entire Arctic as highly problematic. It is suggested to delete this estimate from the manuscript (see also page 16) or at least to delete this broad-brush estimate from the Abstract. Response: We deleted the calculation of the size of the DMS reservoir in Arctic FYI melt-ponds from the manuscript.

R1: P4, L17: No need to start a new paragraph. Response: This paragraph was merged with the previous paragraph.

R1: P4, L32: be more specific: "of melted ice samples" rather than "melt water samples" Response: The sentence now states "of melted ice [. . .]".

R1: P5, L1: The T and S data from the 10 cm surface ice allow the accurate calculation of the brine volume fraction according to established formulas, see e.g., Eicken, H.,

H. R. Krouse, D. Kadko, and D. K. Perovich, Tracer studies of pathways and rates of meltwater transport through Arctic summer sea ice, J. Geophys. Res., 107(C10), 8046, doi:10.1029/2000JC000583, 2002; an references therein. Applying these formulas (e.g. those for high T and low S sea ice values, e.g. Manninen and Leppaeranta 1988, cited in above reference), and using the values reported in the manuscript of T = -0.2C and S = 0 psu actually indicates "im"-permeable ice, while a T = -0.2C and S = 0.8 psu indicates a brine volume of about 20% (= highly permeable ice). This reviewer suggest that brine volumes are calculated for the T – S measurements and that a more detailed discussion on ice permeability/sea water percolation is given. Please also note that a) "the rule of 5s" is primarily based on a brine volume fraction of 5% (which can be achieved by different T-S combinations, including T = -5C and S = 5, b) that this percolation threshold is only valid during thermodynamic equilibrium, and c) also only applies for columnar ice (likely the case in these samples), but this surface ice might have also undergone some melting/metamorphosis). In summary this reviewers suggest a more detailed discussion of the sea ice permeability. The current conclusions are fine, but just stating "according to the rule of 5s" is insufficient. Response: A more detailed discussion on ice permeability/sea water percolation is now included in the manuscript. Full ice depth T and S profiles are now presented in figureÂă4 for stations Ice1, Ice3 and Ice4, and brine volumes were calculated from the T–S measurements. The method section was changed accordingly (P4, L28) and now states that : "In order to estimate the possibility of a connexion between the melt ponds sampled and the underlying sea ice (i.e. through ice permeability or water percolation), sea-ice salinity and temperature were measured. For each station where sea ice was sampled, an in situ sea-ice temperature profile was measured directly, at 0.1Âăm intervals, using a high-precision thermometer (Testo 720). Corresponding sea-ice salinity profiles were also determined at 0.1Âăm intervals. Each 0.1Âăm section was cut with a handsaw, stored in a plastic container, and allowed to melt at room temperature. Bulk salinity of the melted ice section was determined using a conductivity probe (Cond 330i, WTW). Brine volume profiles were calculated using the recorded sea-ice bulk salinity and in

situ temperature (Cox and Weeks 1983, Petrich and Eicken 2010)".

Consequently, the result section was also modified (P9, L5). The text now reads: "Averaged values for bulk sea-ice salinity over the full thickness of the ice were 1.73, 2.83 and 3.75 at stations Ice1, Ice3 and Ice4, respectively. Maximum bulk salinity never exceeded 5.00 (Ice4, 1.2-1.3 m section). In situ temperatures, averaged over the full thickness of the ice, were -0.54 C, -0.52 C and -0.98 C at stations Ice1, Ice3 and Ice4, respectively, and reached a minimum value of -1.39 C (Ice4, 0.8-0.9 m section). Brine volume fraction constantly exceeded 10% in the ice profiles, except in the upper 0.1 m section of the Ice3 station."

R1: P5, L 11: "replicates" How many? Response: This was changed to "duplicates".

R1: P5, L25: This reviewer suggest to add a sentence and a definition of "HNA" here, e.g. what nucleic acid stain was used in this fly cytometry protocol? Response: The following sentence was added to the text: "Heterotrophic bacteria samples were stained with SYBR Green I and measured at 525 nm to quantify bacteria with Low Nucleic Acid (LNA; potentially less active) and High Nucleic Acid (HNA; potentially more active) content (Gasol and del Giorgio 2000, Lebaron et al. 2001). Analyses were performed on an Epics Altra flow cytometer (Beckman Coulter), fitted with a 488 nm laser (15 mW output; blue), using Expo32 v1.2b software (Beckman Coulter)."

R1: P6, L23: It is unusual to refer to PAR as "700-400", normally one would write "400-700". This also applies to the UVA and UVB wavelengths given in the text. Response: All the wavelengths presented in the text are now written in the suggested format.

R1: P 8, L25: As discussed above, this reviewer suggests to revisit the t-test statistics applied: It appears that N equals 2, which makes application of the t-test problematic. At least more explanation is needed. Response: As recommended, results from the Student's t-test are no longer presented. We nevertheless wanted to base our analysis on statistical tests. To do so, we explored the possibility of pooling our incubations data in order to increase 'n'. A non-parametric Mann-Whitney U test was first used to

determine whether the distributions of reduced-sulfur compounds (i.e. DMS, DMSPp and DMSPd) in the Ice1-MP1 and Ice4-MP1 incubations experiments were statistically different from one another. The difference in reduced-sulfur compound concentrations between the two incubation experiments was not found to be statistically significant (n=45, df=16 α=0.05). As explained previously in the general comments section, this allows us to combine the results of Ice1-MP1 and Ice4-MP1 when testing for differences in responses between Treatments. This doubling of sample size (n) for each test (combining Ice1-MP1 and Ice4-MP1) led to an increase of the statistical power of the analysis conducted hereafter. A Wilcoxon Signed-rank test was used to assess potential statistical differences between the Controls and each Treatment L-DMSP/O and D-DMSP/O. Results reveal significant differences (p≤0.05) between the Controls and each Treatment of the incubation experiments (n=30, df=8, α=0.05). Further detail on the other statistical tests conducted is provided in the response to the "(P11, L10 -15)" comment.

R1: P 9, L3: This reviewer suggest to use the SI unit "m" rather than "cm" as unit for length measurements throughout the manuscript/figures. Response: "cm" was replaced with SI unit "m" throughout the manuscript and figures.

R1: P9, L7: As per above more details is required than just stating the "rule of fives". Response: More details are provided for this section in the response to the "P5, L1:" comment.

R1: P9, L 16: use singular, e.g. "detail" Response: The singular is now used in the text.

R1: P11, L10 -15: If "significantly" is used test-statistics should be given, also provide df value and/or N. Given the low N, these statistical results are of little relevance. Response: Each statement of the paragraph (between quotation marks) is now followed by a description of the statistical test used. As stated previously, results of Ice1-MP1 and Ice4-MP1 were combined (as justified by the the results of the Mann-Whitney U

test), resulting in an increase of the statistical power of the analysis conducted. "During both Ice1-MP1 and Ice4-MP1 incubation experiments, the light Treatment had no effect on the net changes in DMSPd concentrations between the L-DMSP/O and D-DMSP/O TreatmentsÂă[...]". →This was assessed using a Wilcoxon Signed-rank test (n=8, df=3, α=0.05) comparing pairwise DMSPd concentrations at T6, T12, T18, and T24 for both incubation experiments Ice1-MP1 and Ice4-MP1, p≥0.05 .

"[...] But significantly impacted the rates of net accumulation of DMS" → This was assessed using a Wilcoxon Signed-rank test (n=12, df=5, α=0.05) with a significance level of p≤0.05 comparing pairwise the DMS accumulation rates in L-DMSP/O versus D-DMSP/O at T0-T6, T6-T12, T12-T18, T18-T24, T6-T24 and daily rates (T0-T24) for both incubation experiments Ice1-MP1 and Ice4-MP1.

"The accumulation of DMS over 24h in the L-DMSP/O Treatments were consistently and significantly lower than in the corresponding D-DMSP/O Treatments (p≤0.05) (Fig. 3b, d)." → This was assessed using a Wilcoxon Signed-rank test (n=8, df=3 ,α=0.05) comparing pairwise DMS concentrations in L-DMSP/O versus D-DMSP/O at T6-T12-T18 and T24 in both incubation experiments Ice1-MP1 and Ice4-MP1.

R1: P 12, L 17: Sea "spray" rather than "spay" Response: Typo corrected.

AR1: P12, L28: Here "gravity drainage" and "brine flushing" are used to describe the same process, while classically "brine drainage" refers to the release of cold salt brines in surface-cooled sea ice, while "brine flushing" refers to the flushing out of salt through meltwater, e.g. they are technical terms used for different physical processes. Response: The technical terms are now correctly used in the text. The discussion on the salt movements through sea ice has also been amended. The corrected section is described below: (P12, L27) "It is also unlikely that sea-ice brine intrusion contributed to the salinization of the melt ponds since the ponded FYI sampled in this study appears to be almost fresh (using the terminology proposed in Vancoppenolle et al., 2007) (FigureÂă4). Consolidated cold FYI generally exhibits a characteristic C-shaped salinity

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profile (Nakawo and Sinha, 1981) after loosing approximately two thirds of the initial seawater salt content through gravity drainage in winter (Kovacs, 1996). Then, according to the mushy-layer theoretical representation of sea ice, most of the salted brines are usually lost through full depth brine convection well before melt ponds start to form (Jardon et al., 2013). Finally, residual salts are lost during brine flushing events, typical of the summer season (Weeks and Ackley, 1986, Eicken et al., 2002; Vancoppenolle et al., 2007). The low salinity values and the flattened salinity profile observed in the sampled sea ice suggest that the ice had already been subjected to brine flushing. We thus exclude sea-ice brine enrichment of melt ponds as a significant salinization mechanism".

(P13, L3): "This leaves seawater intrusion through highly porous sea ice as the most likely process responsible for bringing salts, microorganisms, and DMS in melt ponds. Above a brine volume threshold of 5%, sea ice becomes permeable to fluid transport through its interconnected brine network (Golden et al., 1998). Melt ponds form and persist despite the high porosity of FYI due to the infiltration and subsequent freezing of a freshwater layer into the pore structure of sea ice that prevents percolation drainage of pond meltwater (Polashenski et al., 2017). Here, the brine volume fraction calculated for each 0.1Âăm section always exceeds 10%, suggesting that sea ice was highly permeable throughout the full ice depth (except for the upper 0.1Âăm of Ice3). As brines flushes out of the ice, seawater fills the channel network (Widell et al., 2006). Some degree of connectivity is thus expected to take place between superficial melt ponds and seawater. Specifying whether the intruding seawater originates from lateral or direct upward flow is difficult since these processes are not yet well understood (Vancoppenolle et al., 2007). Sea-ice freeboard was either low or negative near the melt ponds sampled (Table 1), suggesting that seawater intrusion through highly porous low-freeboard sea ice was possible in the observed sea ice. The somewhat higher freeboard measured at station Ice3 may indicate refreezing metamorphosis of snow. Sea-ice recrystallization could explain the impermeability of the upper 0.1Âăm of sea ice at station Ice3. The low-freeboard configuration at stations Ice1 and Ice4 is

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the general fate of melting sea ice, and inherent to the loss of sea-ice thickness. Our hypothesis of seawater intrusion through highly porous low-freeboard sea ice is also supported by the presence of both pelagic and ice-associated algae in the microbial assemblages of the melt ponds, along with the similarity observed between algal species composition in the waters of the melt ponds and those beneath the ice (Charette et al., personal comm.). The seeding of these seawater microorganisms into melt ponds may also affect the cycling of DMS as discussed in sect. 4.2".

P 13, L 10: No data are shown that demonstrate: "full depth desalinization" -> please clarify Response: This statement was removed from the manuscript. Calculations provided by Jardon et al. (2013) deal with the permeability threshold of sea ice with salinity greater than 5 psu. With a bulk sea ice salinity of 2.79 (averaged for the three stations), with a maximum value of 5.00 at station ice4 (1.2-1.3 m section), we fall outside of this range.

R1: P 13, L 20: Avoid the use of "significant" if no statistical test was conducted /or provide statistical results. Response: This was changed to "A daily net DMS production [. . .]".

Fig and Tables:

R1: Fig 3: Unusual numbering of panels: "c" should be "b" and "b" should be "c"? Response: The numbering was changed as suggested.

R1: Tab 7: "control" or "Control" -> consistency in spelling needed Response: The consistency of "control" spelling was checked and applied throughout the text.

Figure 4: In situ temperature (ŮŔ) and bulk ice salinity (ŮŃ) profiles of the sea ice surrounding the melt ponds sampled at stations Ice1 (a), Ice3 (b) and Ice4 (c). Temperature and salinity values of each 10 cm sea ice section were used to calculate brine volumes (orange bars) throughout the full depth of sea ice, an indicator of sea ice permeability.
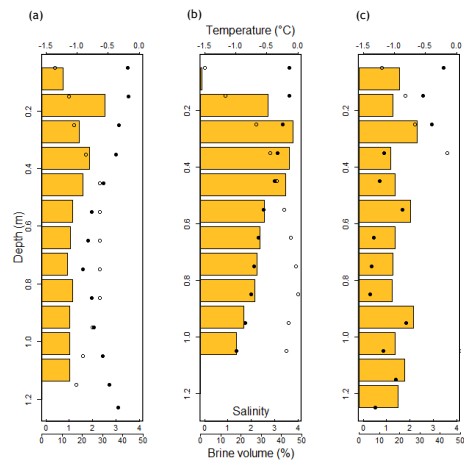

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Fig. 1. In situ temperature (dark circles), bulk salinity (open circles) and brine volume (orange bars) profiles of the sea ice surrounding the melt ponds sampled at stations Ice1 (a), Ice3 (b) and Ice4 (c).

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