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Interactive comment on "Effect of crustose lichen (*Ochrolecia frigida*) on soil CO_2 efflux in a sphagnum moss community over western Alaska tundra" *by* Yongwon Kim et al.

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Point-by-point response to Referee's comments

I appreciate the invaluable comments from the Biogeosciences Editorial Office regarding the improvement of this manuscript through careful revision.

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BG-2019-121 (RED color)

"Effect of crustose lichen (Ochrolecia frigida) on soil CO2 efflux in a sphagnum moss community over western Alaska tundra" by Kim, Park and Lee

For clarity, see the Referee #1 in the corrected word file (BG-2019-121-RC1.docx).

Also, I have corrected the manuscript according to the professional English-language editor (Mr. Nate Bauer) of the University of Alaska Fairbanks. âĂČ Referee #1

This manuscript investigates soil CO2 fluxes in a sphagnum moss community under healthy vs infested by crustose lichen. The authors used novel instrumentation called forced diffusion chamber that allows them to collect high frequency measurement of CO2 fluxes at a microsite during the growing season. From the two growing season observations, the authors show that soil CO2 fluxes in the two microsites are different in a particularly warmer and drier conditions. The authors conclude from these results that higher soil temperature and lower moisture in crustose lichen patches are attributed to enhanced soil CO2 emission. The dataset presented in the manuscript is quite novel, where the observations focus on the microsite scale measurements of soil CO2 fluxes in healthy sphagnum community and sphagnum community infested with lichen. Unfortunately, the writing is rather poorly executed, making the manuscript a mere presentation of the measurements. I have several major concerns throughout the manuscript. »> I appreciate your invaluable advices and comments on this manuscript, and will correct/rewrite/add text for reader comprehension about the scientific importance.

First, the way the manuscript is currently written, authors do not provide much insight towards answering ‘why’ they observed what they observed. Much of the manuscript focuses on methodology of how they came up with modelling yearlong soil CO2 fluxes, which to me could have been a part of supplementary information. The Introduction section goes over a bit far fetched into the biological effects of crustose lichen, but fails to make the link between how lichen infestation affects microclimate or microsite environmental changes to eventually affect soil CO2 fluxes. To me, a novel dataset cannot automatically be granted a publication unless it is written well with a scientific focus. After reading the whole manuscript, I was left with the question ‘why is this interesting and important?’. The main conclusion of this study is that the sphagnum and lichen communities showed different soil CO2 fluxes in one of the growing seasons observed and temperature and soil moisture were important parameters in predicting it. However, it is already a widely accepted knowledge that soil respiration largely depends on temperature and moisture. So the question here should be 'what did the lichen infestation do in those microsites to alter temperature and moisture to affect soil CO2 fluxes?'. But the authors fail to provide that link in this manuscript. It is unclear to me whether the reason soil CO2 fluxes in sphagnum vs lichen communities are different is due to sphagnum community affecting environmental conditions or vise versa. What could help the authors to make the manuscript more interesting is to try to focus on hypothesis testing based on the data they have. Perhaps the authors can focus more on answering the question 'why' throughout the manuscript »> I may have been unclear about the hypotheses/questions about the difference between CO2 emissions from intact and lichen infested sphagnum moss communities. As you suggest, the text may fail to make the link between how lichen infection affects microclimate or microsite environmental changes to eventually affect soil CO2 emission.

»> I added the paragraphs in L23 of P4 and rewrote L23-25 of P4, as suggested.

»> These are the direct biological effect of lichen infestation on intact sphagnum moss. The indirect thermal and biogeochemical effects of lichen-infested sphagnum moss occur under the microclimate conditions of in soil temperature and soil moisture, decomposition of soil organic matter, and subsequently soil CO2 emission at the microsite, compared to the intact sphagnum moss. As a result, uncertainty still remains about the ecological and biogeochemical roles of crustose lichen-infested sphagnum moss, despite of gradual widespread occurrence of lichen infestation in the recently warming Subarctic and Arctic.

»> Here we investigated the difference in soil carbon emission from intact and crustose lichen-infested sphagnum moss in a microsite tundra ecosystem during the growing season

»> I also added sentences before L9 of P5 and corrected L9-14 of P5, as suggested.

»> We propose the important question of how crustose lichen infestation affects intact sphagnum functions, alters soil temperature and moisture and governs soil CO2 emission. This study focuses on the biogeochemical effects of crutose lichen-infested sphagnum moss at the microsite, in response to microclimate changes in soil temperature and moisture, as well as in soil CO2 emission. In response, the purposes of this study are to 1) determine the environmental drivers (e.g., soil temperature and moisture) resolving soil CO2 emissions in intact and crustose lichen infested sphagnum moss of the tundra ecosystem in western Alaska; 2) estimate soil CO2 emission in these microsites by continuous forced diffusion (FD) chamber system during the growing seasons of 2015 and 2016; and 3) assess the contributions from seasonally snow-covered- and snow-free-period carbon toward the simulated annual carbon budget, based on in-situ temperature and snow depth.

Second, the other major concern I have about the methods is the attempt the authors make to compute running Q10s using the two depths of soil temperature and air temperature. The authors go on in depth showing the fit of Q10 and use this in modelling yearlong soil CO2 fluxes. I do not understand why the authors did this exercise at length. Conventionally, temperature sensitivity of soil respiration, Q10, is computed using soil temperature and when computing Q10 the data are pooled to achieve the best fit of Q10. The authors model yearlong soil CO2 fluxes using this Q10 fit in three different model fits they compute for the two different years' of observations, but I also do not understand why the authors did this exercise when they actually have high frequency measurement of soil CO2 fluxes. What is the purpose of modelling soil CO2 fluxes that show three different sensitivity in temperature when they already have observational data? The modelling should only be used as part of gap filling in this case. The authors should provide better justification of this method. »> I have described the estimation of Q10 regarding 1) the gap-filling of the early growing season of 2016 and the contribution of soil CO2 emission (equations 2 and 3) as suggested, and 2) the temporal variation of Q10 (e.g., temperature sensitivity of soil CO2 emissions in response to ambient and soil temperatures at intact and crustose lichen-infested sphagnum moss during the growing season (equations 4 and 5).

»> I agree with the comments about the analysis of high-resolution CO2 flux-measurement with FD chamber. However, because soil CO2 emissions in intact and crustose lichen infested sphagnum moss represent only a subtle difference, despite high-frequency measurements of soil CO2 fluxes, I have tried to assess the biogeochemical effect of crustose lichen-infested sphagnum moss. Furthermore, although the temperature is a more significant driver in regulating soil CO2 emissions in intact sphagnum than in crustose lichen-infested sphagnum moss, soil CO2 emission in crustose lichen infested sphagnum is only a little higher than in intact sphagnum moss. And so I calculated annually simulated soil CO2 emission based on the equations 2 and 3.

»> Because I measured high-frequency measurement of soil CO2 emissions, I then computed the temporal variation in Q10 in response to atmospheric and soil temperatures in intact and crustose lichen infested sphagnum moss microsites during the two growing seasons of 2015 and 2016. I added the sentence to the end of L24 of P8, as suggested.

»> using the following two models for the temporal variation of Q10 on the atmospheric and soil temperatures (Ueyama et al., 2014):

»> I have plotted the relationship between soil CO2 efflux and soil moisture in intact and crustose lichen infested sphagnum moss. However, because the relationships were weaker, I did not report the Figure in the text.

Third, the authors need to be more careful about the use of language (apart from the use of English as a language) in the manuscript such that the language they use is consistent throughout the manuscript. For instance, one of the most important terms they use in this manuscript is ‘sphagnum moss communities’, however, several different terms are used throughout (e.g. sphagnum moss regime, crustose lichen patches, sphagnum moss colony, intact sphagnum, sphagnum habitat, and etc.). I suggest consistent use of ‘sphagnum dominated’ vs ‘lichen infested (dominated)’ community throughout the manuscript. This is just one example and the authors need more careful usage of terminology throughout. The word ‘infected’ is used throughout this manuscript to describe lichen dominant sphagnum patches. ‘Infected’ to describe an invasion of microorganisms and thus the authors should use ‘lichen infested or lichen affected’ throughout the manuscript. The authors acknowledge that the manuscript has gone through a language check by a native speaker of English, however, I still see language issues throughout the manuscript. I suggest the authors to have the final version edited by a native speaker of English more thoroughly. »> I corrected ‘intact sphagnum moss’ and ‘crustose lichen-infested sphagnum moss’ throughout the text for consistent terminology, as suggested. I deleted words such as ‘regime’, ‘patches’, ‘colony’ and ‘habitat’ except for ‘community’ in the text, as suggested.

»> Also, A native speaker of English has thoroughly checked the final version, as suggested.

Introduction - The second paragraph is a very important component of the introduction, where it introduces the logical flow of this study. However, it focuses rather too much on the form and biology of sphagnum and lichen rather than the environmental effects of these two. As the paragraph is unfocused, it makes the logical flow unnatural and weak. The second to last sentence of this paragraph even goes into saying that moss could wither and die, losing its preservation of permafrost. This is a bit of an overstatement making the logical flow weak for this study. Please consider revising the paragraph. »> I deleted L21 to 23 of P4, and added text for the biological and biogeochemical effects of crustose lichen-infested sphagnum moss in L21 of P4, as suggested.

Methods - There needs a section for data analysis. Please specify what tools are used for data analysis and modelling. »> Section 2.3 is for data analysis and modeling. I have added the title of section 2.3 and two phases of L20 and L24 of P8, as follows.

»> 2.3 Simulated Soil CO2 Efflux and Temporal Variation of Q10

»> L20 of P8: for the seasonal variation of soil CO2 efflux in response to temperature, were calculated as:

»> L24 of P8: using the following two models for the temporal variation of Q10 on the atmospheric and soil temperatures (Ueyama et al., 2014):

»> Could you please let me know your specific comments about tools for data analysis and modeling?

2.1 Sampling Descriptions and Methods - P6L22: The authors state that the air temperature is measured at 2 m height. This also comes up in P9L12. Then what is Air50 in Table 2 and Figure 7? Please specify this in methods. »> It is 2 m in height. I corrected it in Figure 7 and Table 2 in the text, as suggested.

2.2 Forced Diffusion (FD) CO2 Efflux Chamber - Please specify what soil CO2 efflux includes in this study. If surface vegetation (sphagnum/lichen) have been removed, please clarify how lichen infestation may affect soil CO2 efflux. »> Because the crustose lichen was infested on the surface sphagnum moss, I could not remove the surface plants, with Risk et al. (2011) for reference.

- Figure1 and associated text (P7L20-26). This is a technical part that does not add much to the science of this manuscript. I suggest moving this part to supplementary information. »> I wholly understand the issue as suggested. However, this is very important information, because measuring time frequency could provide comparisons between automatic open-top chamber (3.75-m resolution) and eddy covariance tower methods (30-m frequency) at the site. My colleagues have used automatic chamber and eddy covariance tower systems. However, they did not obtain satisfactory data due to the frequent malfunction of power supply systems. Unfortunately, I could not compare my data with theirs. Therefore, I wish to introduce Figure 1 and the associated paragraph in the text for additional study in the future.

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2.3 Simulated Soil CO2 Efflux - It would be helpful for the readers to understand why the authors compute temperature sensitivity in this study and why this is important. Some background information and justification of methods used here would be necessary. »> I added text in L2 of P8 as follows, as suggested.

»> Based on the recently increasing temperature of Alaska (Bieniek et al., 2014), crustose lichen may have recently infested over intact sphagnum moss on a microsite scale (see Figure S1). Furthermore, the increase in temperature may have triggered new soil CO2 emissions from 2008 to 2015 in the tundra ecosystem of Alaska, which would represent a significant feedback toward further warming (Euskirchen et al., 2017). Here we investigated how soil CO2 efflux in crustose sphagnum moss responds to microclimate changes in temperature within a microsite.

3.1 Temporal Variations in Environmental Parameters - This section can be more focused around how environmental conditions are different under the two different communities investigated and explain why that should be. At this stage, it is rather too lengthy and unfocused. As a result, it is very difficult to grasp what the main findings are. »> I added two paragraphs in L7 of P10 as follows, as suggested.

»> Further, the mean growing season differences in soil temperature between the two growing seasons of 2015 and 2016 were 1.51 °C at 2 cm depth and 1.40 °C at 5-cm depth for intact sphagnum moss, respectively. At crustose lichen-infested sphagnum moss, the differences were 1.51 °C at 2-cm depth, and 1.46 °C at 5-cm depth, respectively. This results from the higher atmospheric temperature in 2016 relative to 2015.

»> The mean growing season differences in soil temperature between intact and crustose lichen-infested sphagnum moss were -0.47 and 0.98 °C at 2-cm depth in 2015 and -0.47 and 1.04 °C at 5-cm depth in 2016, respectively. Crustose lichen-infested sphagnum moss consists of dried dead sphagnum, and loses water-holding capacity. Because the heat capacity at surface intact sphagnum moss is higher than for crustose lichen-infested sphagnum, soil temperature at 2-cm depth living sphagnum is relatively higher than for crustose lichen-infested sphagnum. Soil temperature at 5-cm depth for intact sphagnum is much lower than for the crustose sphagnum moss community.

- P10L7-10 is better suited in the next sub-section. »> I moved L7-10 of P10 to L23 of P11 to after the correction as follows, as suggested.

»> The increase in soil CO_2 emission during the growing season of 2016 relative to 2015 is thought to be causally connected to higher temperatures in air and soil, as well as lower soil water content in 2016 than 2015âĂŤkey drivers in regulating soil CO_2 production and emission to the atmosphere (Xu and Qi, 2001; Davidson and Janssens, 2006; Kim et al., 2014b; 2016).

- P10L22-25: I have a hard time understanding this sentence. It should be revised and perhaps adding a reference would be helpful. »> I revised L22-25 of P10 as follows, as suggested.

»> Differences in soil moistures between 2 and 5 cm depths for crustose infested sphagnum moss relative to intact sphagnum moss did not appear remarkable, reflecting that the infestation of crustose lichen (O. frigida) on intact sphagnum moss may induce the loss of physiological and ecological functions in sphagnum moss (Hahn et al., 1993; Lange et al., 1996). Therefore, crustose lichen-infested sphagnum moss loses its unique water holding capacity.

- P11L5-7: This contradicts to the earlier statement 'Peaks in soil moisture during the soil thawing of early May were found at 2- and 5-cm depths in 2015 and 2016 (Figure 2), suggesting the response from soil moisture at 2- and 5-cm depths for intact sphagnum is much more sensitive to soil thawing than at crustose regime'. Please clarify. »> I corrected L5-7 of P11 as follows, as suggested.

»> There was no difference in thawing rate between 2- and 5-cm depths for the crustose lichen-infested sphagnum community in early spring, reflecting that the inherent higher water-holding capacity for intact sphagnum was completely lost, as the former sphagnum moss was dead.

- P11L11-14: Why is it that in 2016 soil moisture was higher in crustose at 2cm depth? The soil temperature and moisture dynamics in relation to lichen dominance should be explained a bit better. »> I have completely checked data for July-August hourly variations in soil temperature (above) and moisture (below) at intact and crustose lichen-infested sphagnum moss, as follows.

»> However, I could not find any clues about why soil moisture at 2-cm depth of crustose lichen-infested sphagnum moss relative to 5-cm depth. Hence, we must have additional observations, such as soil moisture and temperature at several centimeter depths, for the ascertainment of soil temperature and moisture dynamics for the unusual results. I appreciate your invaluable comments and suggestions for future work.

3.2 Seasonal Variations in Soil CO2 Emissions - P11L23-28: This part largely overlaps with methods and should be moved to methods section. »> I deleted L24-25 of P11 and moved L26-28 of P11 to L26 of P7 in the end of session 2.2, as suggested.

- P12L11-14: Usually when moisture increases, the rate of organic matter decomposition also increases. Why is it the other way around in this case? »> According to Kim et al. (2014b), CO2 efflux tended to increase with an increase in soil moisture when soil moisture value was at the optimum 0.228 m3 m-3 in the tundra ecosystem. CO2 efflux decreases over the optimum soil moisture (Kim et al., 2014b). Davidson et al. (1998) also reported a correlation between soil water content and CO2 efflux in different drainage classes. CO2 efflux increased when soil water content was less than 0.2 m3 m-3; on the other hand, higher soil moisture resulted in a decrease in CO2 efflux (see Fig. 7, Davidson et al., 1998).

»> The two papers are listed in the references.

-P12L24: I'm not sure if this is a good comparison as Svalbard soil is very low in soil

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C compared to AK. »> I agreed with your comments; however, it is difficult to find references despite the difference of soil organic carbon at the two sites.

3.3 Sensitivity of Soil CO2 Emissions to Temperature and Soil Moisture - P13L16: The authors discuss seasonal dependence of soil CO2 efflux here. I do not understand this explanation. The only two environmental variable measured in this study are temperature (at various depths) and soil moisture. So what is the seasonality that regulates soil CO2 efflux in this case? Usually seasonal dependence of ecosystem C exchange is due to physiological changes of vegetation through the season or temperature dependence of respiration with season. In this study, photosynthesis does not come into play and the authors tease out temperature sensitivity in this section, but then what is the seasonal dependence are they referring to? Please clarify.

- P13L16: The authors discuss seasonal dependence of soil CO2 efflux here. I do not understand this explanation. »> Soil CO2 efflux depends on seasonal changes in ambient and soil temperature, with regard to your comments. If so, I do not doubt it based on other references.

»> I have noted this in L17 of P13, in which ambient and soil temperatures explain 60 % of growing season variability in soil CO2 efflux at intact and crustose lichen-infested sphagnum moss communities.

»> Due to the temperature sensitivity of soil CO2 efflux, I made comparisons between observed and simulated CO2 efflux (Figure 8), computed using equations 2 and 3, based on equation 1.

»> Therefore, soil CO2 efflux is determined by seasonal changes in temperature. Soil moisture does not regulate soil CO2 efflux (not shown), and the relationship between soil CO2 efflux and soil moisture is much weaker (> R^2 of 0.15).

- P14L7-9: This is also a key explanation the authors keep referring to. I am curious why this is. It would be important to link theories with observations in this case. Otherwise,

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one of the most important support would largely remain as part of speculation. »> I corrected and added text about the relationship between soil CO_2 efflux and soil moisture to the L8 of P13 after deleting L8-9 of P13, as follows, and did not show them in the text.

»> Soil moisture acts as a well-known key role in restraining soil CO_2 emissions; CO_2 flux = 2.61 exp (-8.73×SM2 cm) (R^2=0.08) and CO_2 flux = 1.68 exp (-6.66×SM5 cm) (R^2=0.14) at two depths of intact sphagnum moss, and CO_2 flux = 0.81 exp (-4.01×SM2 cm) (R^2=0.03) and CO_2 flux = 6.89 exp (-13.1×SM5 cm) (R^2=0.12) in crustose sphagnum moss during two growing seasons of 2015 and 2016, respectively (not shown).

- P16 last paragraph: The authors are discussing the usefulness of using FD chambers in this paragraph, but I think it is a bit too far fetched from the main point of the study. Please consider making the final part of the discussion rather focused on the main point of the study. »> I agree with your comments, and deleted L18-25 of 16 for the better comprehension, as suggested.

Technical corrections: - P3L3: Either 'in time and space' or 'on temporal or spatial scales' »> I corrected to 'in time and space,' as suggested.

- P3L5-8: This only applies to high latitude ecosystems. Please specify. »> Yes, it applies to high northern latitude ecosystem, as suggested.

- P4L16-19: Please revise this sentence. »> I revised L16-19 of P4 as follows.

»> However, it is not well-known how crustose lichen-infested sphagnum moss affects intact sphagnum moss, which is commonly distributed over several moss species and peats in the high Arctic (Gary Laursen; personal communication)

- P5L21-23: This sentence already appears in the Introduction section. Please remove. »> I deleted L21-23 of P5, as commented.

- P5L24: ecosystem 'dominated by' »> I added to 'dominant by' L21-23 of P5.

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- P6L6: these should be mean annual temperature and mean annual precipitation »> I think the mean annual temperature is correct, but the precipitation is total annual amount (ca, 400 mm), as follows.

- P6L11: Is ‘average ambient temperature’ air temperature? Please clarify. »> I changed ‘ambient temperature’ to ‘air temperature’ throughout the text, as suggested.

- P7L17: Please specify that this is due to loss of power. »> I rewrote the following sentence, as suggested.

»> However, we could not determine the winter season CO2 efflux during the observation periods of 2015 and 2016 due to the loss of electric power.

- P9L7: equation (6) should be (5) instead. Throughout the manuscript, equation (6) is referred to. This needs to be revised. »> I changed ‘(6)’ to ‘(5)’ throughout the text, as suggested.

- P9L18: Soil temperature is ‘higher’. This should be consistent throughout. »> I changed ‘greater’ to ‘higher’ throughout the text, as suggested.

- P11L1: a sharp jump ‘in’. »> I changed ‘of’ to ‘in,’ as suggested.

- P11L16: ‘These changes’ should be ‘The changes’. »> I changed ‘These’ to ‘The,’ as suggested.

- P13L17: Please clarify whether this is combined effects or not. »> I rewrote L17-19 of P13, as follows.

»> Average temperatures in air and soil at 2 and 5 cm depths elucidates 63 % and 45 % of variability in soil CO2 effluxes at intact sphagnum moss during the two growing seasons of 2015 and 2016, respectively. Also, average temperature in air and soil at 2 and 5 cm depths of crutose lichen-infested sphagnum moss explains 50 % and 35 % of variability in soil CO2 effluxes during the two growing seasons. Hence the sensitivity of soil CO2 effluxes to temperature in 2016 was much lower than in 2015.

- P13L21: temperature is 'the' most significant »> I changed 'a' to 'the,' as suggested.

- P13L28: either 'in' or 'during' August »> I changed 'for' to 'in,' as suggested.

- P14L12-13: Q10 values at . . . Delete this sentence. »> I deleted L12-13 of P14, as suggested.

- P16L10-12: This sentence is very difficult to understand and grammatically incorrect. Please revise. »> I revised L10-12 of P16 as follows.

»> The contribution from winter carbon emissions was 20.0, 30.5, and 20.0 % of annual soil CO2 effluxes simulated by temperatures of air and soil 2- and 5-cm depths of intact sphagnum moss, and 16.2, 28.4, and 30.4 % of simulated annual soil CO2 effluxes in crustose lichen-infested sphagnum moss. Although this study did not conduct winter soil CO2 efflux due to loss of power, simulated soil CO2 effluxes during non-growing seasons were within the ranges observed in the Subarctic and Arctic.

- P16L13: delete '-measurement' from 'soil CO2 efflux-measurement'. »> I corrected '-measurement,' as suggested.

- P16L21: Please clarify why sunny sky matters. This is winter measurements we're referring to. »> I deleted L18-25 of P16, as previously described, as suggested.

- Table1: I do not think this table is very useful. It largely overlaps with the information shown in coFigure 2&3. Please consider making it a supplementary information. »> Your comments are appreciated. However, Table 1 also shows important data despite daily temporal variations in environmental and soil CO2 efflux, as shown in Figures 2 and 3. I think Table 1 provides the readers with information about the monthly ratio of crustose-infested lichen to intact sphagnum moss for soil CO2 efflux, soil temperature, and soil moisture.

»> If possible, I do not want to remove Table 1 in the text relative to the supplementary table.

- Figure2: Delete the small a) inside the figure. The lines (solid/dotted) of Crustose T and M are easy to identify as they are different colours, but Intact T and M are very difficult to distinguish. Please consider using a different colour for one of them. To me, soil temperature and moisture can both be effect variables and response variables at the same time in this study. This means that soil T and M are the two variables that affects CO2 efflux, but at the same time, they can be affected by the presence of lichen. Therefore, this figure should include air temperature and rainfall data and the description of results should focus around how soil T and M change under variation of air T and rainfall and how intact and crustose moss affect soil T and M during these events (rainfall) and why that is. »> Figure 2 consists of two panels of a) 2-cm (upper) and b) 5-cm (lower).

»> I changed the different colors of T and M for better comprehension, and added heavy rainfall events with downward arrow marks to Figure 2(a) during two growing seasons, as suggested.

»> I re-plotted Figure 2(a) including air temperature. Air temperature is synchronized with soil temperature in intact and lichen-infested sphagnum moss, which may be hard to demonstrate alongside three temperatures for air and soil in the modified Figure 2(a), as follows.

»> I have also added heavy rainfall events (e.g., downward grey arrows) to Figure 2(a), which affects the response from soil moisture, as commented.

»> Soil moisture in intact sphagnum moss is more sensitive to heavy rainfall events than lichen-infested sphagnum moss, suggesting that dead sphagnum moss infested by crustose lichen lost its water retaining ability, compared to healthy sphagnum moss. Soil temperature is a significant driver in regulating soil CO2 efflux in lichen-infested sphagnum moss relative to soil moisture. On the other hand, soil temperature and moisture are important parameters for modulating soil CO2 efflux, as is well known.

- Figure3: The left y axis should be 'CO2 efflux'. What are the different colours for

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SD (pink and light purple)? Can the colours (or line form) for two different communities consistent throughout the manuscript? »> I changed the y-axis to ‘CO2 efflux (umol/m2/s), as suggested. Also, mean ± SD is solid ± 95% SD, intact sphagnum is a solid line ± grey, crustose is an orange solid line, and ± pale orange.

- Figure4: Make a legend indicating dotted and solid lines. »> I added the legend to Figure 4, as suggested.

Please also note the supplement to this comment:
https://www.biogeosciences-discuss.net/bg-2019-121/bg-2019-121-AC1-supplement.pdf

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Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2019-121, 2019.

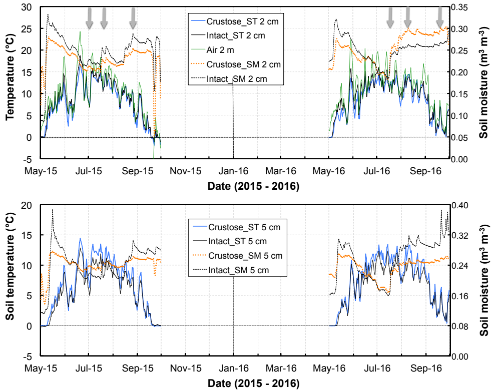

Fig. 1. Temporal variations in temperature and moisture

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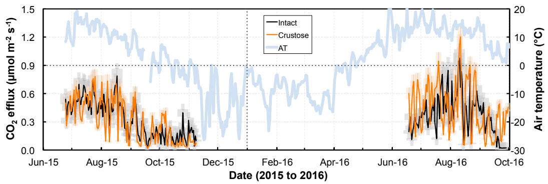

Fig. 2. Temporal variations in soil CO2 emission and air temperature

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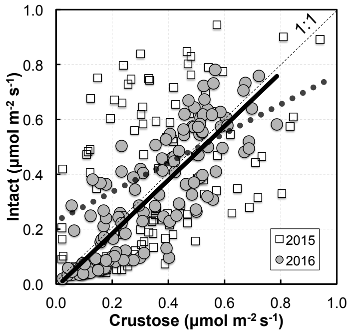

Fig. 3. Responses from soil CO2 effluxes at intact to crustose sphagnum moss

Table 1. Monthly mean (standard deviation) in CO_2 efflux, ratio of crustose to intact efflux (C/I), and soil temperature and soil moisture at 2 and 5 cm depths in intact and crustose sphagnum moss communities during the growing seasons of 2015 and 2016

Year	Month	CO_2 efflux (μmol m^{-2} s^{-1})		C/I	Soil temperature (°C)				Soil moisture (m^3 m^{-3})			
		Intact	Crustose	Ratio	Intact		Crustose		Intact		Crustose	
					2 cm	5 cm	2 cm	5 cm	2 cm	5 cm	2 cm	5 cm
2015	June*	0.45 (0.09)	0.42 (0.11)	0.93	10.5 (2.13)	7.53 (1.18)	9.94 (1.51)	8.93 (1.18)	0.22 (0.11)	0.21 (0.02)	0.20 (0.02)	0.24 (0.03)
	July	0.53 (01.0)	0.51 (0.15)	0.97	13.0 (2.21)	9.59 (1.62)	12.4 (1.93)	11.3 (1.71)	0.23 (0.01)	0.23 (0.02)	0.21 (0.01)	0.23 (0.02)
	August	0.42 (0.16)	0.41 (0.22)	0.95	9.27 (1.50)	7.24 (0.98)	8.79 (1.33)	8.26 (1.04)	0.25 (0.02)	0.24 (0.03)	0.23 (0.02)	0.25 (0.04)
	September	0.21 (0.13)	0.19 (0.16)	0.86	2.68 (3.32)	2.24 (2.39)	2.28 (3.29)	2.35 (2.83)	0.26 (0.03)	0.28 (0.04)	0.22 (0.05)	0.25 (0.04)
	Growing season #	0.39 (0.18)	0.38 (0.22)	0.93	8.49 (4.94)	6.47 (3.54)	8.02 (4.86)	7.45 (4.24)	0.24 (0.03)	0.24 (0.03)	0.22 (0.03)	0.24 (0.03)
2016	June**	0.27 (0.07)	0.47 (0.22)	2.01	12.5 (1.72)	9.19 (1.24)	11.9 (1.14)	10.6 (1.09)	0.23 (0.01)	0.20 (0.01)	0.23 (0.02)	0.21 (0.03)
	July	0.45 (0.17)	0.52 (0.21)	1.36	12.8 (1.88)	10.1 (1.34)	12.1 (1.65)	11.3 (1.37)	0.22 (0.03)	0.21 (0.04)	0.22 (0.03)	0.20 (0.02)
	August	0.50 (0.22)	0.51 (0.33)	1.13	11.3 (1.52)	8.91 (1.11)	11.0 (2.09)	10.3 (1.73)	0.26 (0.02)	0.30 (0.02)	0.29 (0.04)	0.25 (0.05)
	September**	0.21 (0.15)	0.23 (0.15)	1.99	4.34 (2.79)	3.73 (2.05)	3.93 (2.78)	3.98 (2.41)	0.26 (0.01)	0.31 (0.04)	0.29 (0.03)	0.25 (0.03)
	Growing season #	0.38 (0.21)	0.43 (0.27)	1.70	10.0 (4.06)	7.87 (2.98)	9.53 (4.04)	8.91 (3.52)	0.24 (0.03)	0.26 (0.06)	0.26 (0.04)	0.23 (0.03)

* The peridof 2015 is June 25 to 30.

** The period of 2016 is June 18 to 30 and September 1 to 28.

The growing season denotes June to September of 2015 and 2016.

Fig. 4. Table 1

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Table 2. Q_{10} values and correlaton coefficients in the exponential equation for soil CO_2 efflux response to temperature in intact and crustose sphagnum moss communities of tundra , western Alaska during the obserweration periods of 2015 and 2016, for which is the the equation is CO_2 efflux = β_0 x $\exp^{(\beta 1 x T)}$, based on a t-test at the 95% confidence level

Year	Month	Depth	Intact		Crutose	
Year		(cm)	Q_{10}	R^2	Q_{10}	R^2
2015*	June+July	Air 200	1.15	0.05	0.90	0.01
		2	1.25	0.07	1.34	0.03
		5	1.44	0.10	1.28	0.02
	August	Air 200	3.51	0.53	6.34	0.37
		2	3.53	0.49	7.99	0.47
		5	5.89	0.47	9.38	0.38
	September	Air 200	2.18	0.50	2.29	0.23
		2	3.90	0.44	4.80	0.30
		5	6.12	0.41	5.46	0.26
	Oct + Nov	Air 200	1.18	0.01	3.48	0.38
		2	1.47	0.03	6.01	0.44
		5	1.43	0.01	11.40	0.33
	Mean	Air 200	2.42	0.61	3.10	0.59
		2	2.82	0.65	3.87	0.64
		5	4.29	0.65	4.53	0.60
2016**	June+July	Air 200	1.27	0.02	0.83	0.11
		2	2.00	0.08	2.01	0.03
		5	3.79	0.17	1.42	0.01
	August	Air 200	3.16	0.12	3.32	0.07
		2	5.92	0.17	15.90	0.42
		5	5.34	0.08	16.30	0.30
	September	Air 200	10.80	0.56	1.55	0.05
		2	17.30	0.47	2.23	0.09
		5	48.60	0.47	2.03	0.05
	Mean	Air 200	3.88	0.45	2.05	0.16
		2	4.46	0.45	3.30	0.43
		5	7.88	0.46	3.59	0.40

* The measuring period of 2015 is from June 25 to November 9.
** The period of 2016 is from June 18 to September 28.

Fig. 5. Table2

Table 3. Observed and simulated CO_2 efflux based on temperature in intact and crustose sphagnum moss communities during 2015 and 2016

Date	CO_2 efflux ($\mu mol\ m^{-2}\ s^{-1}$)							
	Observed	Simulated			Observed	Simulated		
(mm-yy)	Intact	Air	2 cm	5 cm	Crustose	Air	2 cm	5 cm
Jul-15	0.53 (0.10)	0.46 (0.11)	0.40 (0.07)	0.29 (0.04)	0.51 (0.15)	0.47 (0.13)	0.37 (0.13)	0.33 (0.05)
Aug-15	0.42 (0.16)	0.31 (0.07)	0.29 (0.06)	0.24 (0.04)	0.41 (0.22)	0.30 (0.08)	0.26 (0.06)	0.24 (0.05)
Sep-15	0.21 (0.13)	0.18 (0.08)	0.16 (0.06)	0.15 (0.04)	0.19 (0.16)	0.16 (0.08)	0.14 (0.05)	0.14 (0.05)
Oct-15	0.14 (0.08)	0.13 (0.05)	0.12 (0.04)	0.13 (0.02)	0.14 (0.12)	0.11 (0.05)	0.10 (0.03)	0.10 (0.02)
Nov-15	0.17 (0.06)	0.08 (0.04)	0.12 (0.01)	0.12 (0.01)	0.09 (0.04)	0.06 (0.04)	0.09 (0.01)	0.09 (0.01)
2015**	0.39 (0.19)	0.32 (0.15)	0.28 (0.11)	0.23 (0.07)	0.37 (0.20)	0.31 (0.16)	0.26 (0.11)	0.24 (0.09)
Jun-16	0.27 (0.07)*	0.40 (0.12)	0.34 (0.07)	0.25 (0.04)	0.47 (0.22)*	0.40 (0.14)	0.29 (0.08)	0.26 (0.06)
Jul-16	0.45 (0.17)	0.45 (0.12)	0.39 (0.06)	0.30 (0.04)	0.52 (0.21)	0.46 (0.14)	0.36 (0.06)	0.33 (0.04)
Aug-16	0.50 (0.22)	0.40 (0.07)	0.34 (0.05)	0.27 (0.03)	0.51 (0.33)	0.39 (0.08)	0.32 (0.07)	0.30 (0.05)
Sep-16	0.21 (0.15)	0.22 (0.08)	0.19 (0.05)	0.17 (0.03)	0.24 (0.15)	0.20 (0.09)	0.16 (0.05)	0.16 (0.04)
2016**	0.40 (0.22)	0.36 (0.13)	0.31 (0.10)	0.25 (0.06)	0.43 (0.28)	0.36 (0.15)	0.28 (0.10)	0.27 (0.09)

* The observed value is June 18 to 30, 2015.
** denote growing season (July to September) of 2015 and 2016.

Fig. 6. Table3

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