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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

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

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For clarity, see the Referee #2 in the corrected word file (BG-2019-121-RC2-Kim.doc).

Also, I have corrected the manuscript according to the professional English-language editor (Mr. Nate Bauer) of the University of Alaska Fairbanks. âĂČ Referee #2

The paper by Kim et al. presents an interesting premise: that crustose lichen may affect the CO2 flux of Sphagnum moss, and that this infection may also affect the stability of the permafrost beneath. They argue this by presenting data from two flux chambers in a patch of Sphagnum moss in western Alaska. This kind of research is valuable, since not much is known on how the spread of lichens influences CO2 fluxes, but unfortunately this study falls short on too many fronts to make meaningful conclusions about this phenomenon. I don't think that the presented data convincingly show that there is a strong effect of crustose lichen on the CO2 flux from these ecosystems.

To begin with the study setup: it's commonly known that CO2 fluxes vary strongly spatially, and it's therefore advisable to use multiple measurements within each vegetation type to reliably determine whether two vegetation types exhibit different CO2 fluxes. The same goes for soil moisture and soil temperature. This experiment, however, uses only one chamber in healthy Sphagnum and one in crustose-infected Sphagnum. The results then show minute differences between the two, which the authors extrapolate to say something about CO2 fluxes between infected and non-infected Sphagnum in general. But without knowing what the variation within each group is, we don't know whether the differences between infected and non-infected Sphagnum are meaningful. »> I fully understand your invaluable comments on the spatiotemporal variations of CO2 effluxes in intact and crutose-lichen infected sphagnum.

»> To infer the difference of CO2 effluxes between intact and infected sphagnum, the environmental parameters (e.g., soil temperature and moisture) are significant drivers in directly influencing two different environments. The quantitative elucidation of these data might be helped the reason in difference of CO2 effluxes from both patches. As Alaska is getting warmer, the extent of crutose lichen will widely spread and wither more

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sphagnum moss that is directly associated with the extent and depth of permafrost in the tundra ecosystem.

»> Furthermore, before the deployment of FD (forced diffusion) chamber systems, I have observed Re (ecosystem respiration) and NEE (net ecosystem exchange) in eight patches that are covered by intact sphagnum and crustose lichen infected mosses with portable opaque and transparent chambers for the growing season (June to September) of 2013 and 2014 (Figure S1). As the results, ecosystem respirations in intact and crutose-infected moss patches were 0.94±0.75 and 1.36±0.73 μmol/m2/s for 2013 (n=28) and 1.92±1.67 and 2.45±1.40 μmol/m2/s for 2014 (n=60), respectively. It represented distinct differences in spatiotemporal variation between both communities. Then, we selected the representative sites for the monitoring of continuous CO2 efflux in two communities with FD chamber systems during the growing seasons of 2015 and 2016.

»> I added the data to the text (end of L28 of page 6) as your comments for the better understanding of spatial variation in CO2 effluxes, as follows.

»> To select representative intact and crustose infected sphagnum sites, ecosystem respiration (Re) and net ecosystem exchange (NEE) were observed in seven communities with manual opaque and transparent chambers during the growing seasons (June to September) of 2013 and 2014. Mean growing season ecosystem respirations in intact and crutose lichen-infested sphagnum mosses were 0.94 ± 0.75 and 1.36 ± 0.73 μmol m-2 s-1 for 2013 (n = 28) and 1.92 ± 1.67 and 2.45 ± 1.40 μmol m-2 s-1 for 2014 (n = 60), respectively. Respiration demonstrated distinct differences in spatiotemporal variation across both communities. We also chose representative sites for monitoring of continuous CO2 efflux across two communities using FD (forced diffusion) chamber systems during the growing seasons of 2015 and 2016.

The authors claim that the two are different, based on a one-way ANOVA, but this statistical method is not suitable for this study. A one-way ANOVA is used to show whether

two groups are taken from the same population by studying the variance between and among groups. In this study, we don't have two groups. Just two time series of repeated measurements. In this situation, a one-way ANOVA is not applicable since the repeated measures are not independent. »> I have two groups: one is intact sphagnum moss and the other is crutose lichen infected sphagnum moss with two FD chamber systems at the representative sites. However, I changed a one-way ANOVA to a t-test in the text, Figures, and Tables, as your comment.

With just two measurement locations, it's not possible to show that the two populations from which these measurements were taken (intact and infected Sphagnum) exhibit statistically different fluxes since we don't know the variation within each group. In any case, the differences are very small. Visually, it appears that the only period where there are clear differences is for two weeks in June 2016 but the overlap between the two is huge for the rest of the time, which shows that more samples from each group would be required to argue that a difference exists. »> As previously described, I have observed CO2 effluxes at the representative sites with two FD chamber systems. It may be difficult to distinguish the visible difference in the seasonal variations of mean daily CO2 effluxes between both communities as shown Figure 3 and mean growing seasons of 2015 and 2016 as R2 pointed out. However, I showed the evident differences in Table 1 (mean monthly CO2 efflux) and Figure 4 (mean daily CO2 efflux) as described in the chapter 3.2 of text.

»> In special, the ratio of infected to intact CO2 efflux during the growing seasons of 2015 and 2016 enables the readers to understand the enhancement of CO2 efflux in crutose lichen infected relative to intact sphagnum moss for 2016. Further, if mean daily CO2 effluxes between both communities have a little difference, I would not present Figure 3. And then, I need to additional work such as winter contribution of CO2 effluxes from infected and intact sphagnum after the improvement of power supply system.

Furthermore, the authors claim that their study shows that the spread of crustose lichen

would lead to the rapid degradation of permafrost, but not a single measurement of active layer depth is shown in this study. Actually, at a depth of 2 cm, temperatures are lower under the crustose lichen. This is unsurprising, since the photo of the field plots shows that these lichens are completely white, and therefore have a high albedo. This means that a lot of sunlight is reflected, which would actually cool the surface and prevent permafrost degradation. This important property of these lichens is not mentioned in the paper, and the conclusion that these would lead to rapid permafrost degradation is unsupported. »> I agreed to your comments on a single measurement of active layer depth for rapid degradation of permafrost. Also, I understand the effect of albedo in white-colored crustose infected sphagnum. As I showed in Figure A1 (b to d), new crustose is much white than aged crustose, and two colonies are co-existed nearby. Therefore, it is really difficult to monitor the changes in albedo from new crustose to old with time on a tiny scale and to install the sensors that are required to lots of efforts.

»> I knew that the infected patches were fissured with time as shown in Figure S1. According to the degeneration of crutose lichen, the surface color was getting darker as shown in Figure S1 (b to d). I showed the full size of Figure S1 (d), as follows.

Figure A. The dotted yellow line denotes the boundary of infected and intact sphagnum. Old crustose (dotted green circle) colonies represent much darker relative to new crustose (dotted green oval) and intact brown sphagnum moss communities. It represents the difference in albedo at each colony.

»> It is remarkable that the cortex of the “host lichen” occasionally turns black at the early contact points with O. frigida. Light microscopical investigations and even scanning electron micrographs do not show any apparent anatomical or morphological changes in the cortex (Grβmann and Ott, 2000). So, I can infer the change in color of cortex through the growth processes.

»> Although I have measured the thawing depths at 81 points at an interval of 5 m

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within 40 m x 40 m plot, I could not do the thawing depth in crutose infected sphagnum colonies. It is due to close two location and disturbance after the measurement of thawing depth with a fiberglass tile probe (1.0 cm diameter, 150 cm long). Also, I have tried to monitor the temperature profile of active layer and permafrost in crutose infected sphagnum patches; however, it is really hard to dig the hole with commercial SIPRE corer (US Snow, Ice and Permafrost Research Establishment: 3" diameter). If I dig a hole with SIPRE corer for the measurement of temperature profile, the surrounding of hole will evidently be disturbed, and the area will not use it any more.

»> I expect that the soil temperature in old crustose colony will be higher than intact and old crustose sphagnum moss. Additional work will be helped me assess the difference in temperatures between new and old crustose communities through the life history.

»> R2 pointed out the prevention of degrading permafrost by the reflection of sunlight in crustose colony; however, I showed the response of air temperature to soil temperature at 2 and 5 cm depths at intact and infected colonies during the growing seasons of 2015 and 2016, as follows.

Figure B. Response from air temperature to soil temperature at 2 and 5 cm depths in intact and infected patches during the growing seasons of 2015 and 2016.

»> In Figure B, there is a little difference in gradient of temperature at 2 cm depth at intact sphagnum (green) between 2015 and 2016. However, increase of temperature gradient at 2 cm depth at crutose (blue) between both years may be the change in surface morphology at crutose infected sphagnum moss and the smooth surface at infected colony might be cracked under hot and dry growing season of 2016, as I described in chapter 3.1.

The presentation of the paper, unfortunately, is also lacking. The writing is often confusing (despite a language check) and many statements are not well-supported by either the data or a citation to another study. The authors try to solve some of the problems caused by the limited data by applying a model, but this shows a poor performance and

is subsequently extended to the full winter, a time period on which it was not tested. It's better to focus on the measurements themselves instead of using an imperfect model to draw conclusions. »> The revised text will be reviewed by the native English speaker (e.g., Nate Bauer of the International Arctic Research Center (IARC) at the University of Alaska Fairbanks) for the more understandable manuscript.

»> I checked the used data or references to cite in the text.

»> The model on the temperature sensitivity was frequently used for the flux-measuring scientists, as listed 16 cited references. As you know, growing season CO2 emission elucidates > 70 % of annual carbon emission. Furthermore, Figure 8 represents the relationship between mean daily observed and simulated growing season CO2 effluxes, excluding winter CO2 effluxes. However, I am not sure how much contributes winter carbon emission to the annual carbon budget in crutose infected sphagnum regime despite of the significance of winter carbon emission (Natali et al., Larger loss of CO2 in winter observed across the northern permafrost region, Nature Climate Change, accepted). I act a co-author in this paper.

»> I thought the readers might want the winter carbon contribution in intact and infected sphagnum.

»> Therefore, I deleted Figure 7 on simulated CO2 efflux, as R2 commented. However, I want to list Figure 8 on the relationship between daily observed and simulated CO2 effluxes, and Table 3 except for simulated winter CO2 effluxes in the text for the assessment of temperature sensitivity.

Overall, I think it's a pity the authors did not do a better job because the data itself is truly interesting. But too many questions remain. For example: the flux measurements are only soil respiration, not net ecosystem exchange. Perhaps the growth of crustose lichen compensates for the loss of carbon from the infected Sphagnum? Unfortunately, due to the flaws in the study setup and analysis we are not closer to understanding whether crustose lichens do actually affect the CO2 flux of Sphagnum mosses. »>

This study is on the investigation of soil CO2 emission (e.g., soil respiration), not net ecosystem exchange (NEE), as R2 commented. In fact, it is really difficult to examine NEE and Re in intact and infected sphagnum communities with FD chamber, not eddy covariance tower.

»> I have measured the preliminary observation (e.g., NEE and Re) with opaque and transparent chamber system in 8 intact and 8 infected sites for the growing seasons of 2013 and 2014, as previously description. Based on the investigation of NEE and Re observation, crutose lichens were completely annihilated intact sphagnum that protects the evaporation of soil moisture and the degradation of permafrost. However, the manual chamber system used in preliminary observation is constrained to monitor the continuous soil CO2 efflux-measurement, as described in L18 to L21 of page 16 (Kim et al., 2016).

»> I have wanted to investigate the difference in soil CO2 effluxes from intact and neighboring infected sphagnum after the two growing season observations, which is the aim of this study. The conclusion is increase (14%) of soil CO2 emission in crutose infected relative to intact sphagnum regime during growing seasons of 2015 and 2016.

More specific comments: Page 4, line 21-23: this statement is essential to the premise of this paper, but it's not supported by a citation. »> First of all, I corrected Otto et al. (1996) to Lange et al. (1996) in the text.

»> I corrected the L20-21 of page 4 as commented, as follows.

»> provides a protection for the photobiont as it reflects high light intensities (Gaβmann and Ott, 2000), and shows clear response characteristics with respect to light, water contents, and temperature (Hahn et al., 1993; Lange et al., 1996).

Page 4, line 27-30: this is a very basic statement but for some reason the authors need to cite 13 studies including 6 by the main author himself! One citation would suffice. »> I corrected the references in the L27-30 of page 4 as commented, as follows.

»> (Lloyd and Taylor, 1994; Davidson et al., 1998; Davidson and Janssens, 2006; Rayment and Jarvis, 2000; Oberbauer et al., 2007; Kim et al., 2007; 2013; 2014a; 2014b; 2016; Jansen et al., 2014; Kim, 2014; Euskirchen et al., 2017) »> Because it is hard to select for one representative paper to list as commented, I listed six references on the northern high latitudinal terrestrial ecosystems.

1. Temperature sensitivity: Davidson and Janssens (2006), Kim (2014), Euskirchen et al. (2017); 2. Moisture sensitivity: Oberbauer et al. (2007), Kim et al. (2014b), Jansen et al. (2014);

Page 6, lines 2-3: this paper does not specify which species of Sphagnum the measurements are done on. Judging from the photo, I assume it's Sphagnum fuscum? »> I added the name of the species to the L2-3 of page 6 as rightly commented, as follows.

»> (64°51'42.8"N; 163°42'39.1"W; 42 a.s.l.m.; Sphagnum fuscum)

Page 6, line 22: has this sensor been calibrated for moss? It's normally only calibrated for mineral soil (which Sphagnum certainly isn't). »> The commercial temperature sensor is calibrated for mineral soil excluding northern high latitude terrestrial ecosystem soil. Most of scientists have extensively used this sensor in sub-Arctic and Arctic regions.

»> Nevertheless, I did not calibrate soil temperature at the moss community. It is because 1) the depth of mineral layer is much deeper and corresponds to the top of permafrost that is the boundary (ca. 90 cm) of active layer and permafrost, and 2) the temperature in boundary layer is not representative of atmospheric temperature. Furthermore, because the sphagnum moss patches are compact, the variation of soil temperature in the patches is harmonized with change in atmospheric temperature, as previously shown in Figure B.

Page 8, line 3: this makes no sense. You estimated CO2 flux sensitivity from the exponential relationship between air and soil temperature? »> I corrected the paragraph

(L2-4 of page 8) as pointed out, as follows. Actually, the relationship between air and soil temperature is not exponential, but line, as shown in Figure B.

»> We estimated the temperature sensitivity of soil CO2 efflux collected by FD chamber by plotting the exponential relationship between soil CO2 efflux and air temperature as well as soil temperature at depths of 2 and 5 cm, in intact and crustose lichen-infected sphagnum moss colonies, by using the following equation, as shown in Figure 5 in the text.

Page 9, line 3: air temperature at 0.5 m, but you measure at 2 m! »> I corrected the height (2.0 m) of air temperature.

Section 3: Why are the results and discussion combined? These should be separated in two sections. »> I have personally used the combination of two sections for the better understanding of readers; however, separated in '3 Results and 4 Discussion', as commented.

Page 10, line 24: what do you mean with 'forfeiture' in this context? »> It means 'loss' and I changed 'forfeiture' to 'loss'.

Page 10, line 26: indicate where this is shown in the figure. »> I added the arrows (eg, rainfall events) to Figure 2 and corrected Figure 2, as commented.

Page 11, line 2: how were these thawing rates calculated? »> I simply calculated the thawing rate with taking time between two peaks at 2 cm and 5 cm in crutose-infected and intact sphagnum moss in early spring.

Page 11, line 5: a thawing rate of 0 cm/day? »> In crutose sphagnum moss, two peaks of soil moisture at 2 cm and 5 cm depth were synchronized with same date. Then, the thawing rate between both depths is almost no difference. However, in intact moss, there is distinct difference between both depths.

Page 11, line 9-10: the sudden drop in soil moisture (and the sudden rise in spring) are probably due to the fact that your moisture sensor doesn't work below 0_ C. This is

clear from your temperature sensor. Moisture data from days with temperatures below freezing should not be used. »> I definitely agree with your comments on the fast response of soil moisture to soil temperature. However, I found that soil moisture at 2 cm of crustose moss was much higher than 5 cm, which is not common sense in 2016 despite of normal data in 2015. Exactly I am not sure the reason.

Page 11, line 16-21: these snow depth measurements appear to be from a different location, judging from the vegetation. Why not point a timelapse camera at your plots so you know when the snow melted there, rather than at another place which may not be representative of your measurement location? »> The site is within 5 m in diameter. Also, time-lapsed camera was installed the edge of the boundary. The camera may slightly move by strong wind and the pole attached to camera was heaved. Then, the photos taken by the camera seem to be different background. Also, the heavy snowfall events have frequently covered the camera and I could not measure the snow depth.

Page 11, line 11-14: it is pure speculation to say that this is due to a hotter and drier environment. Again, soil temperatures at 2 cm are lower in the crustose lichen location. Soil moisture is also regularly higher under the crustose lichen. Besides, there is no large difference in 2015 despite similar differences in moisture. »> Overall, this site is hotter and wetter growing seasons of 2015 and 2016, as described in L14-15 of page 6. I agreed with your comments, which soil temperature at 2-cm depth of crutose moss is lower than in intact sphagnum community. However, soil moisture at 2-cm depth of crutose is also lower than in intact during the growing season of 2015 (see Figure 2a), which differs from your comments. During the growing season of 2016, soil moisture at 2-cm depth of crutose is higher than in intact sphagnum since August of 2016; on the other hand, soil temperature at 2 cm of crutos is lower than in intact as 2015.

Page 14, line 8-9: this relation with soil moisture is not shown in this study. »> Yes, I did not plot the relationship soil CO2 efflux and soil moisture and added the exponential equations between soil CO2 efflux and soil moisture at crutose and intact sphagnum moss during the growing seasons of 2015 and 2016. I corrected and added to L8-9 of

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page 14, as follows, as commented by R1 and R2.

»> CO2 flux = 2.61 exp (-8.73 × SM2 cm) (R2 = 0.08) and CO2 flux = 1.68 exp (-6.66 × SM5 cm) (R2 = 0.14) at two depths of intact sphagnum moss, and CO2 flux = 0.81 exp (-4.01 × SM2 cm) (R2 = 0.03) and CO2 flux = 6.89 exp (-13.1 × SM5 cm) (R2 = 0.12) in crustose sphagnum moss during the two growing seasons of 2015 and 2016, respectively (not shown).

Page 15, line 8: it's commonly known that air temperature governs soil temperature. There's no need to cite yourself twice to support that statement. »> I deleted two references, as commented.

Page 17, line 17: the data presented in this paper do not show a loss of ecological and thermal functions. »> I corrected L17 of P17, as follows.

»> , suggesting this may be an ecological effect of the airborne infection by crustose lichen (O. frigida) on intact sphagnum moss.

Page 17, line 27-28: by only measuring soil respiration, rather than net ecosystem exchange, it's impossible to say whether shriveled Sphagnum moss is a source of CO2 to the atmosphere. »> The monitoring of continuous soil CO2 emission with FD chamber is targeted to the soil respiration, as commented. However, I conducted CO2 flux-measurement before the installation of FD chamber for the representative site.

»> As previously described, I added the research results to the end paragraph of session 2.1.

»> The crustose sphagnum moss community cannot uptake atmospheric CO2, but is the source of ambient CO2 due to the only decomposition of dead sphagnum moss. Then I rewrote the sentence, as follows.

»> This finding demonstrates that crutose lichen-infested sphagnum moss will be a source of atmospheric CO2, and that the degradation of permafrost will be stimulated by the widespread outbreak of airborne crustose lichen on the intact sphagnum moss

community in the Subarctic and Arctic.

Please also note the supplement to this comment:
https://www.biogeosciences-discuss.net/bg-2019-121/bg-2019-121-AC2-supplement.pdf

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

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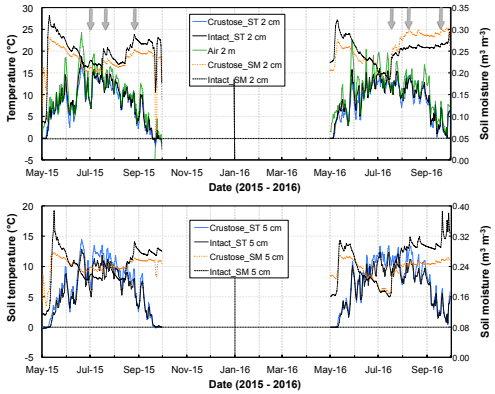

Fig. 1. Temporal variations in temperature and moisture

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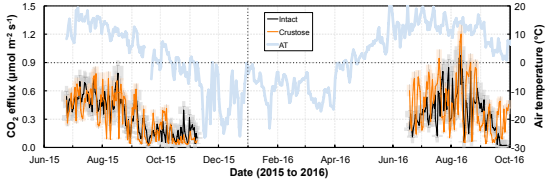

Fig. 2. Temporal variations in soil CO2 emission and air temperature

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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 Ratio	Soil temperature (°C)				Soil moisture (m^3 m^{-3})			
		Intact	Crustose		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)	0.98	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 (4.58)	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 period of 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. 3. Table 1

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 observeration periods of 2015 and 2016, for which is the the equation is CO_2 efflux = β_0 x $exp^{\beta 1 \times T}$, 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. 4. Table 2

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 (μmol 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. 5. Table 3

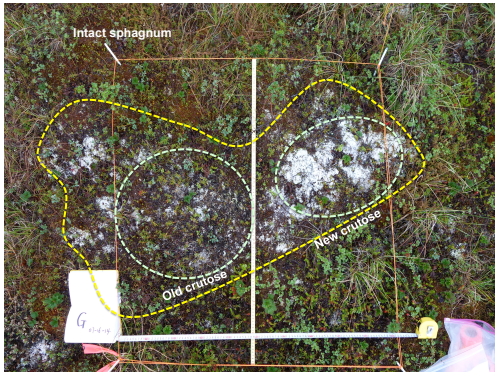

Figure A. The dotted yellow line denotes the boundary of infected and intact sphagnum. Old crustose (dotted green circle) colonies represent much darker relative to new crustose (dotted green oval) and intact brown sphagnum moss communities. It represents the difference in albedo at each colony.

Fig. 6. Figure A: Crustose and intact sphagnum

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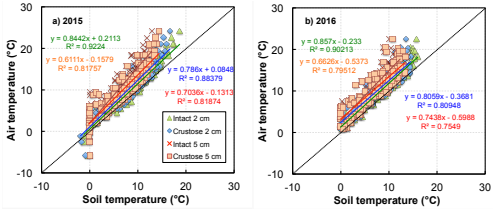

Figure B. Response from air temperature to soil temperature at 2 and 5 cm depths in intact and infected patches during the growing seasons of 2015 and 2016.

Fig. 7. Figure B: Response from air temperature to soil temperature