Summary:

The manuscript tries to understand the link between snow algae growth and its relationship with albedo and ablation rates. The authors use field observations to monitor changes in snow algae over the melt season and apply these results to a model to simulate algae blooms. This research is relevant to further understanding of how algae abundance on snowpacks evolution over a season and what effects they have on surface albedo and melt rates. While I believe this work is relevant to the community, I think the manuscript could be written in a more compelling way, with greater connections and applicability to the Greenland ice sheet. And, while the model serves its purpose for this study, I think its functionality should not be overstated. And, the linkage with snow algae to surface albedo and melt rates is not made in the manuscript. I think greater emphasis and connection with albedo and melting should be added. And, what these observation and modeling efforts mean for implementation into regional climate models.

We would appreciate very much a number of constructive comments. We also appreciate that you evaluated our approach to further understanding of temporal change in algal abundance on snowpacks although our manuscript needs more revising. Our responses (blue text) to each the reviewer's comment (in black text) were described as follows. We also uploaded manuscript, which was revised with yellow marker as suggested, on the discussion board.

Major Comments:

1. How representative is the model for use in other regions, beyond a glacier ice cap? Can the numerical model be feasibly used elsewhere on the ice sheet?

Logistic model requires three parameters, which are initial cell concentration, growth rate and carrying capacity, to calculate temporal change in algal cell abundance, so we consider that it is important to decide the parameters in various snow fields for reproduction of algal abundance in various regions. Although there is a little information of these parameters in other regions, the initial cell concentration and carrying capacity is likely to be related to mineral particle weight and snow chemical properties in our study, respectively. The growth rate of snow algae may be decided to constant value each species because the growth rates in two study sites were close to each other. The factors effect on the model parameters will be studied for improvement of the model. In addition, we'll validate and calibrate the model parameters in various fields in the future. Observational data of snow algal abundance for the validation and calibration will be collected from field or satellite observation. We consider that we may be able to validate and calibrate the model parameters in various fields because the method to estimate algal cell abundance on surface snow using Landsat8 images have been presented (Ganey et al., 2017). We have added an explanation about future task to

reproduce algal abundance on other snow fields (from Pg 11 lines from 1 to 3).

2. What are the larger impacts of this study? I think the authors should discuss this further and link the field and modeling study to broader application and regions of the Greenland ice sheet.

We consider that reproduction of temporal change in snow algal abundance using a numerical model is important to estimate mass balance of Greenland ice sheet more accurately with modeling because blooming of red snow algae can reduce snow albedo. For the estimation of the algal effect on snow albedo in Greenland ice sheet, logistic model should be coupled with a regional snow physical model (e.g. Niwano et al., 2018) to simulate snow physical properties including snow albedo in future. Also, a numerical model for algal growth may supply the useful information for study about life cycle of snow algae based on field observation by glacial biologist. For example, glacial biologist may able to project the timing of algal blooming from the simulation result of the algal growth model. As reviewer pointed out, our discussion was insufficient about potential of contribution to other modeling or field observation. We have added the explanation to the manuscript (Pg 11 lines from 6 to 9). The following reference has been added at Pg 11 line 6.

Niwano, M., Aoki, T., Hashimoto, A., Matoba, S., Yamaguchi, S., Tanikawa, T., Fujita, K., Tsushima, A., Iizuka, Y., Shimada, R. and Hori, M.: NHM–SMAP: spatially and temporally high-resolution nonhydrostatic atmospheric model coupled with detailed snow process model for Greenland Ice Sheet, The Cryosphere, 12, 635–655, https://doi.org/10.5194/tc-12-635-2018, 2018.

3. There appears to be large uncertainty associated with the algae cell observations (Fig. 7b). How can the authors argue that a good fit is achieved between the field and modeled algal cell concentration? There needs to be further discussion on the utility of the logistic model as well as its deficiencies. How can we improve the model? What data and additional variables are needed? And, what is the greater link to surface albedo and melting?

In this study, we aim to propose a simple numerical model for reproduction of algal growth in snowpacks. As reviewer pointed out, although further improvement of algal growth model is needed to reproduce a temporal change in algal abundance on snowpack more accurately, our results suggest that logistic model can simulate the timing of algal blooming. We didn't propose more complex model, which can simulate algal abundance including other factors affecting algal growth (e.g. movement of algal cells in snowpack), and estimate the effect of algal growth on snow albedo. However, we'll try to simulate a temporal change in algal abundance and snow albedo using a coupled logistic model with a snow physical model (e.g. Aoki et al., 2011; Niwano et al., 2012) in

the future. For example, we consider that the coupled logistic model tries to simulate algal abundance including the effect of the cells outflow by melt water on algal growth or snow albedo including the effect of algal blooming on light absorption in snow. Temporal changes in algal abundance and physical properties each snow layer should be needed to validate and calibrate the coupled algal growth model. We have revised the manuscript to reflect reviewer's comments (from Pg 2 line 32 to Pg 3 line 1 and Pg 11 lines from 6 to 9). The following reference has been added at Pg 2 line 33.

Aoki, T., Kuchiki, K., Niwano, M., Kodama, Y., Hosaka, M., and Tanaka, T.: Physically based snow albedo model for calculating broadband albedos and the solar heating profile in snowpack for general circulation models, J. Geophys. Res., 116, D11114, https://doi.org/10.1029/2010JD015507, 2011.

Niwano, M., Aoki, T., Kuchiki, K., Hosaka, M., and Kodama, Y.: Snow Metamorphism and Albedo Process (SMAP) model for climate studies: Model validation using meteorological and snow impurity data measured at Sapporo, Japan, J. Geophys. Res., 117, F03008, https://doi.org/10.1029/2011JF002239, 2012.

Specific Comments:

1. Pg. 6 line 2: Change to '3.1*10^3 cells m^-2'. And, again on line 4.

The words have been corrected (Pg 6 lines 13 and 15).

2. Pg. 6 line 17-18: What evidence do you have to validate that the red algal cells originate from windblown spores? Is there a way to verify this further and possible local sources (eg. nearby tundra)?

Our result and previous studies suggest that the algal cell spores in the study sites are supplied with mineral particles from moraine near Qaanaaq Glacier. As described in the manuscript, initial cell concentration is likely to be related to mineral particle weight. Previous studies reported that mineral dust on glaciers in northwest and southwest Greenland is likely to be supplied from local sediments (e.g. moraine near the glacier), rather than the distant areas (Nagatsuka et al., 2014; 2016). The algal cell spores may be on the moraine near the glacier because the algal cells are probably flowed to outside (e.g. moraine) of the glacier when snowpack including algal cells was disappeared. Therefore, origination of the algal cell spores may be moraine near the glacier. We have revised the manuscript to discuss about origination of algal cell spores more (Pg 7 lines from 9 to 13). The following reference has been added at Pg 7 line 11.

Nagatsuka, N., Takeuchi, N., Uetake, J. and Shimada, R.: Mineralogical composition of cryoconite on glaciers in northwest Greenland. Bull. Glaciol. Res., 32, 107–114, doi:10.5331/bgr.32.107, 2014.

Nagatsuka, N., Takeuchi, N., Uetake, J., Shimada, R., Onuma, Y., Tanaka, S. and Nakano, T.: Variations in Sr and Nd isotopic ratios of mineral particles in cryoconite in western Greenland. Front. Earth Sci., 4, 93, doi: 10.3389/feart. 2016.00093, 2016.

3. Pg. 7 line 5-6: reword sentence structure.

The sentence has been revised (Pg 7 lines from 23 to 24).

4. Pg. 7 Equations 1 and 2: These equations may be better placed in the Methods section.

It is possible to cause misunderstanding regarding our objective if the equations are placed in the Method section because our objective in the study is suggestion of algal growth model to reproduce a temporal change in algal cell abundance in Greenland glacier. Therefore, we described the explanation of the equations in Discussion section.

5. Pg. 8 line 2-3: are these numbers correct? The text states the initial concentration was substantially smaller than the final concentration. Check the concentration numbers.

We checked the concentration numbers in the sentence, but there was no contradiction in the concentration numbers in the sentence. We have revised the sentence because it seems that the previous sentence causes a misunderstanding (Pg 8 lines from 18 to 21).

6. Pg. 8 line 4-5: Why aren't the authors using two separate carrying capacities for Site-A and Site-B, if they have different maximum concentrations of algal cells?

Results suggest that algal cell concentration at Site-A reached to carrying capacity, but it at Site-B continued to increase significantly. The continuous increase of algal abundance suggests that the carrying capacity did not limit affect the algal growth at Site-B. The algal cell concentration at Site-B is likely to increase gradually after day 215 because the calculated snow surface temperature at Site-B was above 0°C after the day. The maximum concentration of algal cell at Site-B possibly close to the carrying capacity at Site-A after day 215. For this reason, we assumed that the carrying capacity at Site-B is a same value of it at Site-A in this study although the carrying capacity may vary among sites. We have added the explanation about the carrying capacity at Site-B to the manuscript (from Pg 8 line 30 to Pg 9 line 2).

7. Pg. 8 line 21-22: The text of 100 times more at Site-A than Site-B is redundant to the previous few lines of text.

We have revised the sentence (Pg 9 lines from 17 to 19).

8. Pg. 24 Fig. 7b and c: Error bounds are needed for the logistic model (solid) line. Similarly, for Fig. 8b and c.

The variance of the algal cell concentration calculated by the logistic model probably increase over time. Since the confidence interval (error bound) possibly be affected by the variance, we consider it will be difficult to calculate the confidence interval. From this reason, we did not estimate the confidence interval for the logistic model line in the study. We have added the explanation about the confidence interval to the manuscript (Pg 9 lines from 5 to 6).