Anonymous Referee #2 Received and published: 23 November 2017

We thank the referee for the comments on our manuscript. The comments have been helpful to improve the manuscript a lot. Our responses are addressed point by point below.

The paper of "the color of melt ponds on Arctic sea ice" give a new insight on the optical properties of Arctic melt pond, which is very important for the knowledge of melt pond thermodynamic processes and remote sensing. There are very few papers have been published on this topic because of the complexity of influencing factors. Thus, it is worthy of publication. However, in the current state, I think this study just can give the knowledge on the color of idealized and simple melt pond because it just give the model of two-layer pond (ice covered by water) and just in the state of overcast sky: (1) Most melt ponds in Arctic would be covered by a thin ice although in the midsummer because the cold air at night, and the snow accumulated on the thin ice and itself would influence the optical characteristics of melt pond, as shown in the Fig.1 (Not all of them are open melt pond) ; (2) overcast sky is prevailing but not always during summer in Arctic and the incident spectrum would obvious influence the pond color. Thus, if the authors can add some works on (1) three- or four- layers model and (2) the influences of incident spectrum, this study would be effectively improved both for the preciseness and applicability.

Reply: (1) We investigated the case that a thin-ice layer is placed on top of the melt pond (three-layer model) in section 3.5 as comparing simulated color with field observations, as some observed melt ponds by Istomina et al. (2016) were indeed covered by a very thin ice layer as the reviewer said. However, the differences in the results determined by an open pond model and an ice-covered pond model are very limited, and less that 3% in the HSL values of the pond color (as shown on Figure A below). That means the influence from the transparent ice layer (1–3 cm) on pond reflection can be ignored.

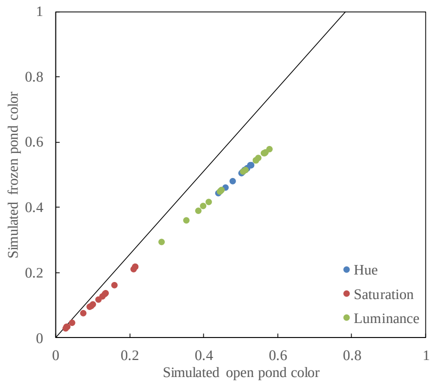

Figure A. Comparison between the simulated color of an open pond and a frozen pond. Note that this figure is only used to show here, and will not be included into the revised manuscript because the comparison in the figure is straightforward and can be explained clearly by text.

(2) The incident solar spectrum is different day to day although under overcast sky conditions. In section 3.2, we selected six different measurements of F_0 according to Grenfell and Perovich (2008), and then investigated the influence of solar spectrum on the color of melt pond. A diffuse incident solar radiation is the basic assumption of the present two-

stream radiative transfer model, so the influence of the direction of solar beam in clear days cannot be investigated in this study. It is the same with the studies in Perovich (1990), Taylor and Feltham (2004), Flocco et al. (2015) who employed the similar two-stream radiative transfer model. Additionally, as the reviewer said, overcast sky is prevailing but not always during summer in Arctic. It is acceptable if most, not all, situations can be treated in a single paper. Of course, we agreed that "further work is still needed to cover clear sky conditions." (in section 4.2 and conclusions).

Here are some other detail comments:

(1) Color can be equivalent to albedo. Color only covers the visible light.

Reply: We agree. Both color and albedo are representations on the spectral radiation reflected back from the pond surface. The differences between them are (1) color covers only the visible band, but albedo covers a larger band, for example, 350 – 950 nm, if measured by a RAMSES radiometer; (2) color can be sensed by CCD cameras or human eyes, but albedo can only be measured by a radiometer. Color is more easily to be measured and observed directly by human eyes, so a study on the color of melt pond is necessary although extensive studies have been conducted on the albedo of melt pond.

(2) Scattering in meltwater and ocean water is neglected. Why?

Reply: We ignored the scattering in water because (1) this has been shown to be a valid approximation for melt ponds with a depth less than 1 m (Podgorny and Grenfell, 1996a; Taylor and Feltham, 2004). (2) The scattering coefficient of pure water is 2-3 orders of magnitude lower than that of sea ice (Smith and Baker, 1981), scattering in water is therefore not a main factor affecting the optics of melt pond as comparing with ice scattering. (3) There are no observations of any optically active impurities in melt ponds to the authors' knowledge. (4) Clear melt ponds are the focus of this study, and dirty ponds with a sediment-covered floor or with cryoconite holes as observed by Eicken et al. (1994) have been excluded. (5) The ocean beneath ice is always regarded as a semi-infinite medium and there is no radiation scattered upward within the ocean, for examples, in Taylor and Feltham (2004), and Lu et al. (2016). As a result, no scattering is an acceptable approximation for meltwater and ocean.

We added these explanations in section 4.1.

(3) 3.3 Influence of optical properties of ice. – how about the porosity of the ice under the melt water. Many cases, the density of ice under melt pond is only about 1/3 of that of level ice because the large porosity and the salinity is as large as the upper ocean.

Reply: Ice porosity is indeed an important parameter of melting sea ice. However, it cannot be directly included into the radiative transfer model in this study. Instead, the influence of ice porosity was investigated through considering ice absorption and scattering coefficients. In Fig. 7a, different values of ice scattering coefficient corresponded to different content of gas bubbles in sea ice, which has been studied in Perovich (1990). In Fig. 7b, the absorption coefficient of sea ice was calculated by the weighted-average of that of water and pure ice, and the ice absorption coefficient is actually determined by the volume fractions of pure ice and brine pockets in sea ice. As a result, although ice porosity is not explicitly included in section 3.3, it poses an impact on both absorption and scattering in sea ice, and further on the color of melt pond.

We clearly stated these now in section 3.3 as "However, the microstructure and physical properties of sea ice cannot be treated directly by our RTM. In this section, the scattering coefficient σ_i and the absorption coefficient $k_{\lambda,i}$, actually functions of the ice microstructure (Light et al., 2004), are investigated for their impact on pond color".

Also we presented a possibility to fully consider ice porosity in the conclusion section: "In a real melt process, phase transition exists not only at ice surface but also in ice interior. If H_i and H_p are calculated by a thermodynamic model (e.g. Tsamados et a., 2015), and IOPs of sea ice are associated with ice physical parameters (e.g. Light et al., 2004), for example, ice porosity, then the seasonal evolutions in the color and albedo of melt ponds can be determined straightforwardly. However, it is out of the scope of the present paper and can be investigated in further studies".

(4) 4.2 Possibility of retrieving pond depth and ice thickness.—I would like remove this section because: (1) the visible color of pond is very difficult to obtained by satellite remote sensing due to the cloud and small scale of the pond, (2) we cannot judge which pond is covered by ice and/or snow by satellite/aerial images, (3) the color of pond also depends on many factors, especially for the porosity of ice under the ice, it also can be found that the relationship is very unreliable as shown in fig.11.

Reply: We disagree with reviewer on this comment and would still prefer to keep our discussion in this section because:

(1) We were not promoting retrieve ice thickness from melt pond colors that are detected by the satellite data. Instead, we would argue that "hand-held photography, ship-borne photography, and airborne photography are very effective ways to get the small-scale information on ice surface" and to be used to retrieve thin ice thickness. Especially, with the wide applications of unmanned aerial vehicles (UAVs) in sea ice investigations, it is easy for UAVs equipped with a digital camera to get the information of pond color.

(2) It is indeed difficult to judge if the pond is covered by ice or snow by images. However, according to our newly added analyses in section 3.5 and Figure A above, a thin ice cover on top of a melt pond does not change the color of the melt pond very much. So the error introduced by the thin ice cover can be ignore as retrieving ice thickness from pond color. The ponds that covered by snow or thick ice are most likely beyond the Arctic summer season and are therefore excluded from this study.

We have added a new paragraph in section 4.2 to clarify the limitations and applicability of the color-retrieval method, including the text presented in (1) and (2).

(3) The color of melt pond indeed depends on many factors, as we have investigated in sections 3.1, 3.2, and 3.3. However, once we identified the primary factors, the pond color can be determined. And We have improved the retrieve model (c.f. Eq. 7) and the results showed some improvement for thin ice thickness detection:

$$\Delta = |(H,S,L)_{\mathrm{SIM}} - (H,S,L)_{\mathrm{MEA}}| = \sqrt{c_H \cdot (H_{\mathrm{SIM}} - H_{\mathrm{MEA}})^2 + c_S \cdot (S_{\mathrm{SIM}} - S_{\mathrm{MEA}})^2 + c_L \cdot (L_{\mathrm{SIM}} - L_{\mathrm{MEA}})^2} , \quad (7)$$

The parameters c_H, c_S, and c_L indicate the different sensitivity of hue, saturation, and luminance values of pond color on pond depth and ice thickness, and they are determined by normalizing the square of correlation coefficient R^2 between the HSL values and the measured Hi and Hp. According to the statistical analyses in Istomina et al. (2016), there is c_H = 0.255, c_S = 0.712, and c_L = 0.033 (the Table to calculate these values was included in the revised manuscript).

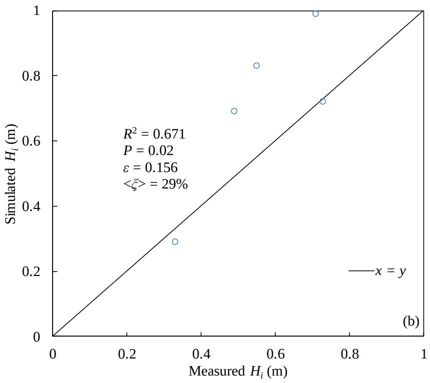

Figure B. This is a subset of ice-thickness retrievals for H_i < 1 m. R is the correlation coefficient between simulated and measured H_i. P is the significance level of the correlation. ε is the root-mean-square error, and <ξ> is the mean of relative error in simulated H_i.

The different sensitivity of hue, saturation, and luminance values of pond color on H_i and H_p were considered using the parameters c_H, c_S, and c_L in Eq. (7). Then the results of ice thickness retrievals were improved. Especially for thin ice H_i < 1 m (Figure B), the correlation coefficient between simulated and measured ice thickness R^2 = 0.671 and the correlation is significant (P = 0.02). The relative error ξ between simulated and measured values presents an average of 29%.

We think the result is acceptable considering available data is very limited. More validations from field observations in future are needed in order to improve the retrieve model and reduce the errors.

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