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Interactive comment on "A linear model to derive melt pond depth from hyperspectral data" *by* Marcel König and Natascha Oppelt

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Dear Anonymous Referee 2,

thanks a lot for your evaluation of our manuscript. Your valuable comments were a big help. We tried to improve the manuscript accordingly. Please find our answers to your questions and our suggestions for integration of your improvements in the following paragraphs. For reasons of clarity referee comments are italic and answers are blue.

Best regards, Marcel König

The authors provide no justification for deriving melt pond depths in the introduction.

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Discussion paper

Do deeper ponds have a substantial impact on sea ice energy balance? Are melt pond volumes required inputs for sea ice modeling? From the introduction, it appears we only need melt pond fraction for forecasting September sea ice area. Without these statements, it is difficult to understand why the authors have put effort into deriving a model for simulating melt pond depths.

Thanks a lot asking these questions. Melt pond depth is a parameter in the Los Alamos sea ice model CICE (Flocco et al., 2012 [doi: 10.1029/2012JC008195]; Hunke et al., 2013 [doi: 10.1016/j.ocemod.2012.11.008]) and the ECHAM5 general simulation model (Pedersen et al., 2009 [doi: 10.1029/2008JD010440]). Polashenski, Perovich and Courville (2012, doi: 10.1029/2011JC007231) showed that deriving pond depth from area fraction is impractical. Lecomte et al. (2011 [doi: 10.3189/172756411795931453], 2015 [doi: 10.1016/j.ocemod.2014.12.003]) use pond depth to parameterize melt pond albedo. Palmer et al. (2014 [doi: 10.1016/j.dsr2.2014.03.016]) use melt pond depth to model primary production below the sea ice. Lee et al. (2012) [doi: 10.1029/2011JC007717] call for more measurements to increase our understanding of how melt ponds on sea ice change in the context of climate change. We will integrate this information into the introduction of our manuscript.

The conclusions of this study are not supported by the evidence. In L204-205, the authors claim that their approach is "universal" and able to derive depths from dark and bright melt ponds. However, in the results, it looks like the R2 for the dark ponds is much worse than for bright ponds. It is misleading to claim that their model is accurate for dark ponds.

We agree that "universal" is overstated and suggest changing "universality" in L206 to "applicability". You are right that R2 is worse for the data subset from the dark pond. The problem here is that measurements from the dark pond are few (n=11) and

shallow (6 cm - 14 cm). Thus, measurement inaccuracies and outliers have a large impact on r and R2. For a precise assessment, we need more data from deep, dark ponds. The same is true for bright ponds: We need more data from shallow bright ponds and more data from ponds deeper than 25 cm in general. However, Figure 10 illustrates that measurements from the dark pond and bright ponds scatter well around the 1:1 line, suggesting that the model's accuracy is similar for dark and bright ponds. This is supported by their similar RMSEs (3.04 cm for the dark pond and 2.49 cm for the bright pond, respectively). We therefore suggest adding a few lines to the discussion section to address these issues.

Likewise, the authors state that their study provides "the most comprehensive set of Rrs and depth measurements from Arctic melt ponds...". However, the study only presents 49 depths from three melt ponds with a depth range of 6 to 25 cm. A quick search of the literature reveals that this statement misleading. Malinka et al. (2018) https://doi.org/10.5194/tc-12-1921-2018 used coincident depth and spectra measurements from three different areas of the Arctic (SHEBA experiment in 1998, Barrow in2008 and the Polarstern in 2012). Tedesco and Steiner (2011) doi:10.5194/tc-5-445-2011 and Legleiter et al. (2014) doi:10.5194/tc-8-215-2014 collected hundreds if not thousands of coincident depth and spectra measurements in a melt pond on the Greenland Ice Sheet that had depths of up to 10 m. The authors should review this literature (including those studies from the Greenland Ice Sheet) before making such claims.

You are right that a huge data set of spectral measurements exists. However, the data sets mentioned in Malinka et al. 2018 are in units of albedo not Rrs. Our reasons to measure Rrs instead of albedo are explained in Section 4.1.1. Melt ponds on ice sheets and sea ice differ substantially due to the optical thickness of the bottom ice and maximum depth. While melt ponds on ice sheets can reach depths of tens of meters, ponds on sea ice are mostly shallower than 1 m. More importantly, pond bottoms

on sea ice may be optically thin, i.e. ice thickness influences the reflectance signal, whereas this is not the case in glacial ponds. As suggested by Anonymous Referee 1, we will include "sea ice" into the title to avoid confusions with melt ponds on glaciers.

The problems outlined above raise questions about the novelty and significance of the study. The only real result in the abstract is that the "...results indicate that pond depth is retrievable from optical data under clear sky conditions". As far as I understand (and based on the references in the previous paragraph) this is not a novel finding. The authors should think more deeply about how their study advances our understanding and build on previous research. However, in the present version, this study may only have limited interest to the cryospheric community.

Thanks for your thorough review. We assume that the model presented by Malinka et al. struggles to retrieve melt pond depth because different combinations of ice scattering coefficient, ice thickness and pond depth may result in ambiguous spectra. Therefore, we propagate to use information from specific wavelength regions influenced primarily by the thickness of the melt water layer for the retrieval of pond depth. We will emphasize this in the updated version of the manuscript.

The writing style is vague in many places. For example: L5: "Key elements" L33:"easy-to-use" L96: "expert knowledge" L234: "hitting the same spot" L235: "tricky"L245: "widely independent" The authors should consider being more specific where possible to improve the readability.

L5: We do not understand the problem with "key elements".
L33: We suggest changing "easy-to-use" to "easy to apply".
L96: We will change "expert knowledge" to "knowledge about local conditions".
L234f: According to your comments, we will change the sentence to: "In addition, performing two measurements with a spectrometer and folding ruler at the exact same

location is difficult."
L245: "widely independent" is explained in the following lines of the paragraph.

Specific comments

L28-209: Considering the apparent similarity between this work and Malinka et al. (2018), the authors should consider adding a much more thorough description of how the two models differ in the introduction.

See comment above.

L29: R2 of 0.62...against what? In situ depth measurements?

Yes. We suggest changing the sentence to: ". . . resulting in an R2 of 0.62 (N=26) against in situ pond depths between 6 cm and 50 cm . . . "

L52: How long was the pole?

The pole had a length of 1 m. We will add this information.

L57: Replace "has been" with "was"

We will replace "has been" with "was".

L67: Why was the ice surface dark?

The color and brightness of an ice surface is governed by the scattering characteristics of the ice, which in turn are defined by its physical properties, e.g. bubbles, structure, thickness etc. However, we do not have any measurements that may be

used to assess this information.

P126: Please justify why pond depth is extrapolated to 1 m when the maximum pond depths in this study were 25 cm.

We suggest adding the following: "... in intervals of 1 cm, adequate for the great majority of melt ponds on Arctic sea ice."

L186: Excessive referencing of Pedregosa et al. (2011) and scikit-learn developers is unnecessary. Consider removing some of these references.

We will remove the second reference in L187.

L191: Please separate dark and bright ponds when presenting correlation coefficients.

As described above we will rewrite the discussion section and integrate separate performance measures for bright and dark ponds.

L194: "18.17" check precision

We will change "18.17" to "18".

Figure 1: Scale bar required for images

Adding a scale bar after taking the images is unfortunately not possible. Diameters of the bare ice surfaces are approximately 0.5 m (A) and 0.3 m (B). We can include this information in the caption.

Figure 2A: I thought the spectrometer was mounted on a pole. Why is it on the

icesurface?

Only the Ocean Optics setup was mounted on a pole. Figure 2A shows the Ibsen setup mounted on the field goniometer described in Section 2.1.

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