

August 6, 2015

Dear Dr. Sulsky,

We thank the reviewer for the extensive comments which we believe have significantly improved the paper. Below we give detailed responses to the reviewer in bold italic to indicate how we addressed the criticisms in the revision.

We hope the paper is now ready for publication.

Thank you very much for your consideration.

Sincerely yours,

Ken Golden

Reviewer #2: Review of "Network Modeling of Arctic Melt Ponds"

General comment:

The paper present an algorithmic technique to map photographic images of melt ponds onto a discrete conductance network with the intention of allowing in future studies the ease of lateral flow in summer melt pond covered sea ice. The algorithm consists of 4 steps: i) preprocessing to eliminate small ponds and small elements of floating ice; ii) identification of individual melt ponds; iii) in parallel finding connections between melt ponds; iv) and small node deletion.

The paper focuses on the model description and applies the algorithm to a small subsample of remote sensing images at the expense of systematically analysing extensive datasets of summer melt ponds images. While this choice can be justified in principle it calls for an extremely clear presentation of the algorithm itself. As it stands I do not think that the authors achieve a high enough standard in presenting their algorithm. I believe that in its current state the paper does not allow the reader to reproduce the method without a substantial amount of additional bibliographical research. I recommend at the very list a clearer presentation possibly including a detailed schematic of the algorithm in Appendix or as a figure. I would also urge the authors to make their algorithm available to the scientific community, maybe as supplementary material.

Nevertheless I consider the approach presented here worth publication and I recommend the paper to be accepted with major revisions.

***To provide a clearer picture of the algorithm we have included a flow chart of the methods we use in the paper. We believe this is sufficient with the updated text to explain the algorithm. We are also willing to make the algorithm available to researchers requesting it from the authors.***

In addition to this main comment I list below a series of suggestions that I think need to be addressed for the paper to be accepted for publication.

Below I describe in more details the places that I think could be improved.

Abstract:

- In the version I received there are 2 abstracts and they differ. Correct

***We have corrected this, thank you.***

- You mention seal holes. Is this an important contribution to water drainage?

***It can be, in a local region - seal holes have large diameters and connect to the ocean below. If located in or next to a large pond which is connected to many others it can be a significant sink of melt water. However, we are unaware of any quantitative studies, and have not pursued this further in the manuscript.***

- You state in the last sentence that the number of mislabels is used to evaluate performance while I find this is not done in the paper.

***We have added our analysis to the text, and have also more clearly defined what we mean by a "mislabel". We visually inspected each image looking for mislabels and found that less than 10 percent of ponds were obviously mislabeled. This however does not have much impact on the calculation of the conductance as two connected ponds contribute to the conductance in the same way as one large pond. We have also added a statement on missed connections which also occur less than 10% of the time, and only when pond size is much larger than channel size. It should be noted however that we have a small sample size to use for this analysis, which is why it was left out to begin with, but upon further thought we agree with the reviewer that some measure of the performance of the method is indeed important.***

- You mention graph theory. I am not an expert but it seems to me that you could be more specific here.

***Going into too much detail would lengthen the paper, instead we have chosen to use the appropriate key words for graph theory to facilitate easy cross-referencing. We have been more specific as to which elements of the theory we have used and provided more detail where we could.***

Introduction:

- L54: cite also Hunke et al, 2013 ("Sea ice, Albedo, Melt ponds, Ridging, Modeling, Arctic"), Flocco et al, 2012 (10.1029/2012JC008195).

***We have included these references, thank you.***

- L68-L76: Is this really needed ?

***We have removed these sentences, and noted that it now reads better.***

- L80-L146: I am not sure if all this is directly relevant for the present paper and therefore needed ? I understand that it helps set the context of percolation phenomena but here you look at horizontal processes. As such I would more interested to have a more in depth discussion of scaling aspects of your work. For example along the lines of your reference [15]. One question that will arise later in the paper is how the conductivity values that you determine scale with your sample size. I think this kind of discussion would be more useful than a general discussion on percolation phenomena.

***We feel that this material is important in placing the current manuscript in a larger context of previous works using network and percolation modeling to study sea ice structures and other systems. What distinguishes this manuscript is not only the application area, namely melt ponds, but that we directly developed the imaging methods, algorithm and software here in the melt pond context, which is the focus of this paper.***

***While we certainly appreciate and understand the importance of the scaling issues brought up, we believe that it would be more appropriate to leave any substantive analysis to later work. The research in this manuscript is a first step as part of a larger program to use network modeling to analyze a large sampling of Arctic melt ponds, however the methods needed to be developed and applied in some simple examples first, which turned out to be a very substantial undertaking requiring a number of sub-projects that were spread out over the past 5 years. A next step is to look in much more depth at connecting the idealized networks and parameters computed in this paper to the physics of fluid motion on the surface of sea ice, dependence on scale, etc. (We also note that we do not have a large enough data set that has been analyzed with our network methods to adequately address here scaling with sample size.)***

***Finally, the scaling discussions in [15] (now [16] in the revision) revolve around the transition in fractal dimension, where we had access to thousands of melt ponds with length scales ranging over many orders of magnitude. Such an analysis involving the methods in this paper will require substantial future work.***

- L159: you mention algorithms that helped you in [15] distinguish between melt ponds and open water in leads between floes. I am not sure that you use the same methods in the current paper. I think you should. If you do not explain why.

***We now mention a possible method to distinguish between ponds and open water using the blue channels, we have also added a statement that we have only used images that do not contain open water so for this paper it is not relevant to us. From an image analysis perspective, the methods developed in this paper are far more sophisticated than what was used in [15] (now [16] in the revision).***

- L161-L171: I think a more in depth discussion on scaling of melt ponds geometrical characteristics would be welcome maybe after this paragraph.

***Please see response on scaling from above. Again, while we agree and find these issues very interesting, we believe it is more appropriate to consider them in a more substantive way in the future.***

- Is the daily cycle relevant for your findings. For example if you measure pond characteristics at different times of the day would you expect different thermodynamic forcing and hence different conductivity maps...

***Interesting question, however, we do not have sufficient data available to really investigate this and we believe it is out of the scope of our paper. In fact, obtaining imagery on the same area and melt ponds over any sustained period has been very difficult. Perhaps obtaining imagery over very short times should be possible, although the changes over such short periods are most often quite small (but not always). This paper is primarily focused on general properties of the geometry of the melt ponds over a melt season, in this context daily variations are small. It is also likely that this algorithm would not be able to detect any large changes as we expect daily variations to be small (except during certain periods like initial formation where coverage can change very quickly).***

- L200: should you discuss melt freeze up, melt lid formation a bit more here ?

***This paper is primarily meant to deal with the melt season although we do find this interesting.***

- L205-210: I think you should provide some reference illustrating how transverse flow of water is important, maybe Scott et al, 2009 ("Modelling the evolution of Arctic melt ponds"). How do the timescales of drainage vs horizontal flow compare for example ?

***We have now included the Scott reference and mentioned this type of modeling, but have not discussed the time scales involved (see response above about scaling).***

- L214: do these technique have a name ? Can you give some examples of applications in other fields ?

***We have included an appendix which briefly describes the mathematical morphology techniques used.***

- L219-L221: Scott et al, 2009 tackled some of that

***There we are discussing our future work, and have already included the Scott reference in the context of other approaches to these issues.***

Method:

- L241: Otsu's method, again here I am not sure if you do not mix up melt ponds and open water between floes sometimes. This could in turn affect your values of conductivities.

***We do not have any images with open water, in this way we cannot mix them up.***

- L247-255: not clear here if images are at the same resolution in HOTRAX and SHEBA and even for different days. You should provide the pixel to m conversion value or at least discuss this.

***We mention that for simplicity and initial analysis we restrict ourselves to pixels. We are more interested in the geometry of the image. However, we have included a scale in Figure 1, and discussed the issue in the Method section.***

Section 2.1:

- L264-289: I find your description of erosion + dilation not very clear for someone not familiar with the method. You could offer a schematic with the shape of the mask. For example I do not understand what a circular 3x3 mask looks like ? Also discuss sensitivity of your results to size of mask. For example how are the results for conductivity impacted when your ignore narrow bottlenecks ? Should you ?

***We have elaborated on this and added figures to illustrate the techniques and masks. In the last part of section 2.1, we have explained that the mask should be smaller than the narrowest bottleneck.***

Section 2.2:

- L303-L304: reverse sentence order.

***We have corrected this.***

- L306: maybe say how you obtain connected components (what method you use).

***We have included this information in the appendix.***

- L323: should it read 'minimum' ?

***It should be Maximum, and we have added an explanation as to why.***

- L325-334: I find this paragraph very unclear and qualitative. The reader cannot reproduce your method exactly as you do not provide values and justification of the choices of this ratio.

- On figure 2 you should specify the different ratios used.

***We have changed this section to better explain this concept –and included a new figure. We have included a table in the results section that shows the parameter choices.***

Section 2.3:

- This is by far the most difficult part to reproduce. You must provide some kind of clearer summary of the algorithm.

***We have attempted to provide a new and better explanation. We have also included a flow chart in the paper which summarizes the algorithm.***

- L349-357: unclear. Figure 3 is not clear either and lacks explanations in the legend. Why is Fig 3b the negative of Fig 3a for example ? What are the brown lines in Fig 3b ? Define direct connections between ponds ? Define intermediate connections ? Vague.

***We added information to the legend to clarify this.***

- L358-359: add references for these 2 methods.

***We have added references for these methods.***

- L365: should this be eroded ?

***No this should be dilated (We are trying to undo the erosion step by dilating the image, to determine which ponds were connected earlier.)***

- L365-L373: this seems ad-hoc and is unclear. Explain more clearly with better schematics maybe.

***We have attempted to provide a new and better explanation.***

- L374- ... Line numbers missing here! but this method description is very poorly explained. At times description makes no logical sense: "the distance between unconnected ponds is considered to be an arbitrarily large number, which is larger than the maximum distance between two ponds". How can the distance between 2 ponds be larger than the maximum distance between 2 ponds?! You must provide schematics and a much more detailed description of the "simple clustering approach" and the "graph theory" !

***We have attempted to provide a new and better explanation in the text. We use both the distances between the ponds and the width of the connections to assign weights to eliminate the edges connecting the ponds. The distance here is the geodesic distance between them, i.e., the distance between the ponds through water. If the ponds are unconnected, we just assign a really large number to the distance between them (The distance between unconnected ponds is infinity because the strength of connection between two ponds decreases with increasing distance and an infinite distance corresponds to absence of any connection between ponds).***

***We have already given details about the clustering approach as follows:***

***The center of each melt pond pixel-cluster is located using the mean of the cluster with Euclidean distances.***

***We have explained in more detail about how the nodes and edges in the graph are determined and how the weights are assigned to edges.***

- You use sigma for conductance strength is analogy to work in material science I suspect. Please provide some references of similar work in other fields here.

***We have added two general references on the use of network models in studying transport in composite materials. We have also explained that the equation used is analogous to conductance in an electrical circuit, which is directly proportional to conductivity of the wire and inversely proportional to the length of the wire.***

- Fig 4 mentions dilation in the legend nowhere to be seen on the figure.

***We have corrected the legend to accurately explain the figure.***

- L385: improve description of noodle deletion. Why ratio of 20 chosen, discuss sensitivity of results to that parameter.

***We have attempted to provide a new and better explanation in the text.***

- L390: replace latter by second.

***Changed as suggested.***

- L398: dilation is not shown. It is not clear to me how pond 1 and 6 can become connected.

***This was an oversight. The text has now been modified to accurately reflect the figure.***

Section 2.4:

- L405: you introduce battery nodes in the framework of sea ice which sounds a bit odd. Please say in analogy to...

***This is analogous to an electrical circuit, where the conductivity between two points can be calculated and the flow of current through the circuit depends on the potential drop across battery nodes. It is discussed more clearly in the manuscript now.***

- Lines numbers missing between L420 and L425. Replace "Let the M" by "Let M".

***Changed as suggested.***

- L424: explain equation (6) and provide reference.

***We have included three more references that give the general formulation behind (6) as well as the specific formula.***

- L425-L430: very unclear. What are you trying to express ?

***Removed, not needed with clearer discussion of battery bonds.***

Results:

- L455-L457: unclear. If you look at smaller areas you get faster results. I do not understand.

***Removed this line.***

- L460: reduced resolution of the conductance values ? Why ? Unclear.

***Removed this line.***

- L462: using "graph methods". What are they ? Unclear ? It sounds like you use a package from Matlab and that you ignore its scientific content.

***We have added specifics of the methods used to allow for better cross referencing.***



- L473-L476: unclear.

***We have changed the explanation as follows:***

***However, this choice would be application specific, as even the isolated ponds may be used to study the evolution of networks with time, because they might, at some point further in time join larger interconnected networks.***

- L477-L480: I do not see what kind of ground truth you are talking about here.

***We have supplemented with further explanation.***

- Reorder figures so that Fig 10 (June) is first.

***Changed as suggested.***

- It looks to me that the figures are at a different scale and I expect this to affect the conductivity value. Am I correct ? You cannot compare conductivity at different scales. The scales are important and must be clarified throughout the text.

***In general, the effective conductivity of a statistically homogeneous two phase composite really only depends on the geometry of the mixture and the conductivities of the constituents – it's a property of the material and does not depend on sample size (although there are finite size effects for finite samples). The conductance does depend on the sample size, and in Equation (1) a conductance (which is related to how much total current or fluid flows) is defined, but the "conductivities" that are used in the calculations have been normalized by the largest one in Equation (3). The results we obtain can be used to compare idealized, effective flow through different types of configurations. However, as we have said, careful consideration of relating our networks to actual flow rates across the surface of sea ice will be considered in detail in future work.***

- L486-L492: I do not understand.

***We have added an explanation to the text to clarify.***

- In figures 6 to 10 I do not understand why only a subsample of melt ponds is highlighted ?

***We have added an explanation to clarify. We highlighted only the ponds which were connected to the battery nodes to keep the images free from unnecessary clutter.***

Conclusions:

- The conclusion is far too weak. What are the implications of this work ? Why do we care...?

***We have significantly added to the Conclusions section to address this important point.***