RESPONSES TO REFEREE 2

General Comments:

This is potentially a useful paper based on producing a network model of sea ice brine microstructure. However, I have found it extremely difficult to review. My main criticism being that based on network theory as it is, and with many of the references relating to this (e.g. Newman, 2011; Pierret et al. 2002; Delerue et al. 2003), much of the terminology and techniques will be completely unfamiliar to the general reader of The Cryosphere. I believe therefore that before full publication the manuscript needs to be restructures in a form that will make it much less opaque to readers who are not familiar with the methods presented. Without this I feel that any impact that it might have will be substantially diminished. I give below a series of specific comments which are intended to indicate what I see are some of the major issues and, in part, how they might be addressed. The first three comments relate to what I believe should be a standard introduction to the sampling and presentation of the initial measurements.

We thank Referee #2 for the overall comments and thorough reveiw of the manuscript. We have significantly rewritten the methods section in the revised manuscript to make it more accessible to a wider readership.

Specific Comments:

1. Please describe the ice cores. In other words, in each core, what was the thickness of frazil ice at the top, the thickness of columnar ice beneath, and any indication of platelet ice at the base? This is important in terms of reference for the interpretation of the inferred microstructure.

Full descriptions of the ice cores including frazil, columnar, and platelet fractions were reported in previous papers (Obbard et al., 2016 and Lieb-Lappen et al., 2017). We have added two sentences to the first paragraph of the methods section stating these fractions and referencing the relevant papers. The first paragraph of the methods section now starts as follows:

This work will focus on two of the ice cores extracted from different locations in the Ross Sea, Antarctica during a October - November 2012 *field campaign. The* 1.78 *m Butter Point ice core was collected at* $77°35.133'$ *S and* $164°48.222'$ *E and had a temperature gradient ranging from* $-16.1\ °C$ *at the top to* $-2.5\ °C$ *at the bottom. For this core, the top* 14 *cm was frazil ice, the columnar ice region was from* 14 *cm to* 65 *cm, and platelet ice formed the bottom* 64% *(Obbard et al., 2016). The* 1.89 *m Iceberg Site ice core was located at* $77°7.131'$ *S and* $164°6.031'$ *E and had a temperature gradient ranging from* $-17.7\ °C$ *at the top to* $-2.3\ °C$ *at the bottom. Relative to the Butter Point core, the Iceberg Site core had more frazil ice (*0 *cm to* 30 *cm), more columnar ice (*30 *cm to* 137 *cm) and less platelet ice (*137 *cm to* 189 *cm) (Obbard et al., 2016).*

2. Were the cores sampled on site or after transportation? If the latter then please give details of how the cores were treated between extraction and sampling.

Cores were imaged after transportation and storaged in a 33 °C cold room. We have added the following sentences to the first paragraph of the methods section in the revised manuscript:

Immediately following core extraction, we recorded the temperature profile at 10*-cm intervals, and stored the cores in a* $20\ °C$ *freezer at McMurdo station prior to shipping. We then transported the cores at a constant temperature of* $20\ °C$ *back to Thayer School of Engineerings Ice Research Laboratory at Dartmouth College, and stored them in a* $33\ °C$ *cold room prior to analysis.*

3. In section 3, with reference to Figures 2 and 3, please explain what the different parameters plotted are, what you might expect them to show, and how they relate to each other. For example, what is expected to be the relationship between brine volume fraction and specific surface area (Spor). In investigating permeability in sandstone samples Zhang and Weller (2014)* have demonstrated that there is a relationship between fractal dimension and Spor. Would any such relationship be expected here? Explain the Euler number for those unfamiliar with it. How is the degree of anisotropy derived? Given that the lower parts of the cores are explained to have a significant degree of uncertainty associated with

the measurements (quantify this?) does it make sense for the scales for Euler number and connectivity to be dictated by the lowermost sampes? *Zhang & Weller, 2014. Geophysics, 79, D377-D387. The above comments are in fact relatively introductory and indicate the need for a clear explanation of the background to the study, how the initial sampling was carried out, and what the initial measurements show. Unfortunately I find that from this point onwards the manuscript becomes confusing and is not at all well explained or illustrated for the more general reader.

In the revised manuscript we decided to remove the Euler number, connectivity, and fractal dimension. Thus, we were able to condense Fig. 2 and Fig. 3 into a single figure in the revised manuscript. Additionally, although full descriptions of all metrics were referenced (Lieb-Lappen et al., 2017), we revised the second paragraph of the results section to include clearer explanation of these metrics in this manuscript as well. This paragraph now reads as follows in the revised manuscript:

Since the cooling stage did not significantly warm samples beyond $-7\,^{\circ}C$*, we were not surprised that general trends shown in Fig. 2 for all metrics did not differ significantly from the same samples scanned isothermally and presented in Lieb-Lappen et al. (2017) as the percolation threshold was not crossed. As in Lieb-Lappen et al. (2017), we used the structure model index (*$SMI = 6\left(\frac{S' \times V}{S^2}\right)$*, where* S' *is the derivative of the change in surface area after a one pixel dilation,* V *is the initial volume, and* S^2 *is the initial surface area) to quantify the similarity of the brine phase to plates, rods, or spheres. To quantify size, we calculated a structure thickness by first identifying the medial axes of all brine structures and then fit the largest possible sphere at all points along said axes. The structure thickness is defined as the mean diameter of all spheres over the entire volume. The structure separation is the inverse metric, providing a measurement on the spacing between individual objects. We then calculated the degree of anisotropy by finding the mean intercept length for a large number of line directions, and forming an ellipsoid with boundaries defined by these lengths. The eigenvalues for the matrix defining this ellipsoid are calculated, and correspond to the lengths of the semi-major and semi-minor axes. The ratio of the largest to smallest eigenvalues then provides a metric for the degree of anisotropy, with* 0 *representing a perfectly isotropic object and* 1 *representing a completely anisotropic* *object. We observed that the brine phase specific surface area increased with depth, structure model index was roughly* 3 *(indicative of cylindrical objects), structure thickness decreased, structure separation increased, and the degree of anisotropy increased thoughout the middle of the core (Fig. 2). From the metrics above, we conclude that brine channels are primarily cylindrical in shape with more branches at lower depths, consistent with previous observations (Lieb-Lappen et al., 2017).*

4. I find section 4.2 extremely confusing, including the figures that accompany it. Figures 5 and 6 ostensibly show the 5 "largest" brine channels from each of the two cores. I assume that one row represents 1 brine channel shown as a sequence of samples through the core in depth order. However, the colour scale suggests that the throat size goes to zero at many points i.e. a pore terminates. I find this hard to understand in the context of the fact that a single row represents a "large" brine channel. Please clarify. The discussion on branches, with reference to Figure 7, is similarly very confusing. In Figure 7 what is the horizontal scale for each separate line representing a brine channel? What is the significance of the fact that one brine channel appears to pass almost right through a sample but the others do not? I cannot at all understand the significance of Figures 8 and 9.

We thank Referee #2 for noting this potentially confusing section. In fact, there is not a connection from the 5 brine channels selected at one depth to the 5 brine channels selected at the next depth. The reasoning is that we did not scan the entire length of the ice core. Even if we had, we would not have been able to fully track a brine channel from one sample to the next. We have added the sentence below alerting readers of this fact to avoid further confusion. Referee #2 is correct in observing that many of the selected brine channels do terminate and do not continue to the next depth. Further, we have removed the confusing Figure 7 from the revised manuscript in part due to the suggestion in the next comment and in part because it is not essential to the presented work. Fig. 8 and 9 (now Fig. 6 and 7 in the revised manuscript) are directed to the visual learners to illustrate both the magnitude and distribution of throat sizes. We have previously revised the captions to these Figures to make them clearer in response to Referee #1.

We note that since the entire length of the cores were not scanned, there is no correlation between the five brine channels selected from one subsample (e.g. 20*-cm depth) to to the next (e.g.* 30*-cm depth).*

5. Similar comments apply to sections 4.3, 4.4 and 4.5, and their associated Figures. An excellent example of network terminology that will be unfamiliar to most is the statement ". . .treated the network as a directed graph. . ." etc. In essence therefore, although I believe that the work presented is ultimately publishable, to be so requires considerable restructuring of the manuscript and I urge the authors to do this. There needs to be a much clearer explanation of the techniques, probably a reduction in the number of figures including clear explanations of what they represent. A somewhat broader review of previous work on looking at the interconnectness of brine channels in sea ice would also not be remiss.

In the revised manuscript we have completely rewritten the methods section and have provided better description of the network terminology. We feel as though this will help clarify the confusion in sections 4.3, 4.4, and 4.5. However, we have also added a reminder to the reader in section 4.5 that a directed graph in our model is one that allows fluid to flow downwards from node to node but not upwards. Throughout these sections, we have reduced the use of network terminology and/or provided better explanations in these instances. In regards to the number of figures, we have cut Fig. 3 and Fig. 7 from the original submission. Finally, we have added the following paragraph to the introduction in the revised manuscript.

Network models have successfully been employed in a variety of fields to describe complex phenomena and predict future behaviour, in particular fluid flow in porous media (e.g., Golden et al. , 1997, Berkowitz and Balberg, 1992, and Fatt, 1956). Specific to sea ice, Freitag (1999) utilized a Lattice-Boltzmann model to model fluid flow through sea ice. Meanwhile, Golden (1998) examined critical percolation thresholds in their network model of sea ice. More recently, Zhu et al. (2006) used a two-dimensional pipe network model to simulate fluid flow through sea ice using a fast multigrid method. This network compared well with lab data for porosity above 0.15*, but overestimated permeability at lower porosities Golden (Golden2007). The majority of these models generate connectivity networks based on bulk brine proper-*

ties. Here we derive finer-grained statistics empirically, allowing for models to more closely align with the physical properties of sea ice.