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Interactive comment on "Quantifying meltwater refreezing along a transect of sites on the Greenland Icesheet" *by* C. Cox et al.

Anonymous Referee #4

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This paper discusses a novel method to quantify the amount of refrozen meltwater in the western part of the Greenland ice sheet. Thermistor strings were placed along a east-west transect to measure the change in heat content of the firn and used to calculate the amount of refreezing between 1 and 10 m depth. The found values are compared with PDD estimates of snow melt and a MAR model simulation. The paper is well written and organiser, relevant toThe Cryosphere and it method is a welcome addition to the field of firn hydrology. However, I have one major remark that should be addressed before the manuscript is suitable for publication. At the end some small remarks are included.

The major comment regards the presentation of the results. Basically, the whole manuscript is based on one figure (Figure 3), presenting the obtained annual refreez-

ing values, as well as the comparison with other values. With only this sole figure presenting the core results, the reader is left with the feeling that there is more data to be presented. What about time series of refreezing (when and at what depth) or vertical temperature profiles? Moreover, the comparison with the PDD approach and MAR simulation is weak, both in the figure and the text. In the figure, there is low agreement between the methods and in the text these differences are not well discussed. The results and discussion section are written in a style that suggests that the PDD and MAR method are likely correct, attributing the differences to uncertanties in the here-described method. I find it more likely that the opposite is true.

Compared with the MAR model the differences are large; i) there is a 50-500% overestimation of refreezing at all locations and ii) there is no clear relation between decreasing elevation and increasing refreezing. These results suggest that the MAR model is not able to correctly simulate the refreezing of surface melt water in this region of the Greenland ice sheet. These differences are likely related to the physical parameterisation in MAR and/or the horizontal resolution of 25 km. The authors should look into the MAR data to find possible reasons for this mismatch. Another possibility could be to look into a similar model, for example RACMO (Ettema et al., 2009 (GRL)).

For the PDD method, scaled temperatures from the highest site CP are used. By doing so, it is assumed that the climate at all locations is similar to this point, apart from its elevation. However, it is highly likely that the albedo change on lower elevation is larger than at CP, thereby influencing the energy balance and subsequently the temperature and melt amount. This should be discussed in more detail and -if possible- corrected for.

Next to the annual refreezing values, it would be very interesting to show when and at what depth liquid water refreezes. A time series of refreezing would greatly increase the impact of the manuscript. Figure 2a shows a time series of the amount of energy available for refreezing, if those are available, why are they not shown in the manuscript? Vertical temperature profiles of different times could also show where

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heat is added, i.e. where meltwater is refreezing.

Short comments:

Personally, I have a preference to list multiple literature references at the end of a sentence chronologically.

Throughout the manuscript, different units for accumulation and refreezing amounts are used ([m] snow accumulation and [cm] refreezing). It would add clarity to the manuscript if all mass fluxes are given in the same unit, preferably mm w.e. (water equivalent).

Title: "Ice Sheet"

p5488, l26: Is this statement outdated with the recent high-melt summers of 2010 and 2012?

p5491, l1-5: Does this measure differ from site to site? The measurement locations vary from the accumulation zone to the runoff zone, spanning many different percolation and refreezing regimes, potentially leading to different inter-pipe distances.

p5491, line8: Here the authors assume no change in density over time. However, due to the refreezing of meltwater firn density does change. Clarify what the influence of this density change on the eventual calculated refreezing rates is. A constant density approximation may hold for the bottom heat flux, but not for the top one.

p5493, line16: Increased from what?

p5494, line1: Introduce used abbreviations; SD.

p5494, line3: A density uncertainty estimate of 20 kg m-3 is very conservative. 50 kg m-3 is more common

p5495, line18: How was it determined that 2007 was a high melt year? Please add a reference. From the MAR results (Figure 3) this is not evident.

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p5496, line18: This is a questionable statement. In early summer, the firn pack is quite cold and it is likely that the first summer melt will refreeze in the upper 1 m, thereby warming the firn with latent heat release.

p5498, line16: The higher values in H2, H165 and H3 would indicate a lot of lateral water flow, too high in my opinion. How does the surrounding topography look, are these measurements taken in a topographical low? It could also mean that the temperature strings work as a preferential flow path themselves.

p5498, line18: From Forster et al., 2013 and Kuipers Munneke et al., 2014 it is unlikely that firn aquifers are present in this region of the Greenland ice sheet.

p5499, line 20-22: This is only true when also vertical profiles are presented. For snow hydrological models it is indeed important to know how much melt water refreezes in the firn pack, but this information needs to be accompanied by vertical profiles that states where and when this liquid water refreezes.

Figure 2a: What is the physical meaning of the drop in Q in early July?

Figure 4: Different colours for the different lines would enhance the clarity, especially in A).

Interactive comment on The Cryosphere Discuss., 8, 5485, 2014.