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Interactive comment on "The impact of ice layers on gas transport through firn" *by* K. Keegan et al.

Anonymous Referee #3

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Keegan et al. describe the properties of 2 melt layers encountered in the NEEM firn column, and discuss the influence of said layers on gas transport. The authors show that the layers do not significantly impact the permeability of the firn, in agreement with observations from firn air pumping at the same site. The observations are sound, and the brevity of the work is refreshing. However, I recommend that the discussion, as well as the abstract/conclusions are rewritten for improved clarity.

The current discussion contains some misconceptions, and leaves it unclear as to what, if any, the effect of the meltlayer is.

The authors conclude that "Nevertheless, ice layers ultimately should not affect the steady-state gas concentration profile in the firn. In shallow firn, however, ice layers may affect the concentration profile of fast-diffusing species in non-steady-state diffusion conditions" I do not agree with the idea that a distinction should be made between

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gases that are somehow in “steady state” (presumably, this refers to tracers like d15N), and gases in non-steady-state conditions (presumably things like anthropogenic trace gases). Diffusion of all gases should be affected equally by melt layers. The gravitational enrichment signal of all gases is maintained through diffusion, and consequently an impermeable layer would affect both. Case in point is the lock-in depth, where molecular diffusivity vanishes and d15N enrichment ceases. This shows impermeable layers affect all gases, as all gases and their isotopes experience gravitational enrichment. I recommend the discussion at page 1101 is rewritten along the same lines.

The abstract and conclusion are more confusing than they need to be, much of which comes from the repeated use of the word “significantly”. The ice layers are “significantly less permeable”, they “significantly bias age estimates”, yet they do “not significantly bias firn air concentrations”. They “need not be accounted in gas transport models”, yet they could “significantly bias ice core records”. The reader is left to wonder whether the layers matter or not.

Melt layers can influence gas records in many different ways, and in the manuscript the different mechanisms are conflated to some degree. The subtleties are easily lost on a reader not intimately familiar with firn air studies, and I would advocate a more clearly structured discussion to bring this out.

The layer can alter gas records in three distinct ways:

1) Its influence on GAS TRANSPORT IN THE OPEN PORES * The layers reduce permeability: this will impact macroscopic/bulk air movement in response to pressure gradients (e.g. convective mixing in upper firn due to wind pumping). * The layers reduce diffusivity: this will impact (microscopic) diffusive fluxes of ALL gases; it reduces the gravitational enrichment of gases, and the propagation of transient atmospheric signals into the deeper firn. The layers at NEEM appear to not have much effect on the open pore gas transport.

2) Its influence of BUBBLE TRAPPING (i.e. closed pores) * Anomalous amounts of air

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are trapped high up in the firn column; when reaching the bottom of the firn column this air is anomalously old compared to regularly trapped air.

3) The presence of a LIQUID PHASE. * this can alter the concentration in the bubbles through gas dissolution and possibly biological activity.

While the authors discuss points 1 and 2 in the manuscript, I feel that e.g. explicitly numbering the effects would help the reader distinguish the effects better, making for improved clarity in the discussion.

I think it would be worth considering introducing a separate discussion section after the observations to have a discussion of all these effects together in one place, once the reader is familiar with all observations. Alternatively, at the beginning of section 3 a short subsection could be introduced in which these different mechanisms are clearly explained.

Further comments:

P1096 L19: remove "events"

L21: change "column" to "layer" (2x)

L24: change "firn column" to "diffusive zone of the firn column"

Section 2.2: is permeability measured in the lateral or vertical direction, and do these differ?

P1099 L20: remove "depths" (you use the word depth twice)

P1100 L10: the NEEM ice age scale is published as Sigl et al 2013: A new bipolar ice core record of volcanism from WAIS Divide and NEEM and implications for climate forcing of the last 2000âĂŁyears.

P1101 L16-20: I don't understand why you compare to seasonal snow packs. There is no connection. Why not compare to prior work and parameterizations on firn per-

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meability, such as: Schwander et al. 1989 and Freitag et al. 2002 or Courville et al. 2011

P1102 L6: “representing the layers seen visually (Fig. 1)”

P1102 L15-21: These numbers mean nothing without an estimate of scale. What does 0.2% mean? 0.2% percent of the porosity of the entire sample? Or of the depth range associated with the melt layer? If you look at a small enough scale (i.e. that of single bubbles) the anomalous signal is actually 100% of porosity! Also, the porosity changes very much with depth, so it is not a very good absolute reference. Perhaps you can express it as a percentage of porosity in a mature sample? This allows a better comparison of both layers.

P1102 L28: concentration of 0.0001 permil?? This makes no sense to me. Where does that number come from, and why is a concentration given in permil?

P1103 L7: it is not clear what the connection is between the calculations on d15N, and the statement that the air is older. d15N is not an age marker.

discussion: Another impact on gas records is through solubility of gases, and possibly enhanced biological activity. I would encourage the authors to briefly discuss the findings from the recent NEEM community paper (repeated melting at NEEM during MIS5e, as seem by high CH4 and low air content) in light of their new findings.

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