

Author replies to referee comment RC2

We thank very much Zoe Courville for her comments that help improving the manuscript. Please find below our point-by-point replies in green color.

The manuscript presents an improved method for defining transport properties in snow and firn through the examination of microstructural parameters derived from micro CT results and numerically derived values of permeability and diffusivity. The authors propose a simple yet elegant concept of rescaled porosity which accounts for the effects of pore closure on transport values in denser/deeper firn. This approach has promise to improve prediction in firn over previous methods using open porosity of the firn. The fact that the approach improves regression models over a wide range of density values at different polar locations with different conditions also suggests the method is a promising step in developing a generalized snow permeability and diffusivity model.

There are some mostly minor technical edits that should be addressed that are listed by line number below. In addition, I have included suggestions to clarify some of the labeling and description of the figures,

Abstract: As written, it is not clear what was done as part of this research and what was past work (need to make the tense of the sentences consistent throughout). I.e., on line 1, “To this end, different regressions were proposed to estimate the effective coefficient of diffusion and permeability of firn.” When I read this, I get the sense that this is part of the work that is being presented. I think it could be written as (just a suggestion), “To this end, different regressions have been proposed in the past to estimate the effective coefficient of diffusion and permeability of firn,”
The sentence was modified as suggested.

Line 3 (and example of shifting tense): “were little evaluated as data of these properties are scarce” could be written, “have not been evaluated very often as data of these properties are scarce”
The sentence was modified as follows: L3: “These regressions are often valid for specific depth or porosity ranges only. Also, they constitute a source of uncertain as evaluations have been limited by the lack of reliable data of firn transport properties.”

Line 10: “by including snow data.” What snow data does this refer to? The micro-CT data? Or are you referring to surface snow vs. firn at depth?
We refer to a previously published data of diffusion coefficient and permeability for snow samples from Calonne et al. 2019. The sentence was modified to be clearer: L10 “Next, we investigate the relationship of the transport properties with density over the firn density range (550 – 850 kg m⁻³) as well as over the entire density range encountered in ice sheets (100 – 850 kg m⁻³) by extending the datasets with transport properties of alpine and artificial snow from previous studies”

Line 11: “Classical analytical models and regressions from literature are evaluated.” Evaluated compared to what?
The sentence was modified as follows: L13: “Classical analytical models and regressions from literature are evaluated against the estimates from pore-scale simulations.”

Line 15 “with ϕ_{off} the close-off porosity.” Should be “with ϕ_{off} equal to the close-off porosity.” Or something similar since with “ ϕ_{off} the close-off porosity” is not a complete phrase.
The sentence was modified as follows: L18: “where ϕ_{off} is the close-off porosity.”

Line 20: Air entrapped in the closed pores of ice preserved past atmospheric air, from couple of thousands to few millions of years old, providing invaluable data on past Earth's environment. Couple of suggestions: "preserved" should be "is preserved" or "preserves" "from couple of thousands to few millions of years" should be "on the order of a few thousand years to a few million years old" or "thousands to millions of years old"

We agree with the reviewer and modified the sentence as: L22 "Air entrapped in the closed pores of ice preserves past atmospheric air, thousands to millions of years old, providing invaluable data on past Earth's environment".

Line 23: "Among others challenges" should be "Among other challenges"

The correction was made accordingly.

Line 29: "til" should be "until"

The correction was made accordingly.

Line 48: "Only few parameterizations are based on measurements or modeling over the entire firn column (Adolph and Albert, 2014), limiting their range of validity (Tab. 1)." is slightly confusing, suggest rewriting as "Few parameterizations are based on measurements or modeling..."

The correction was made accordingly.

Line 49: "Especially, it is crucial to describe well air transport properties in the lock-in zone from the beginning of the pore closure to the close-off." should be: It is especially crucial to describe air transport properties well in the lock-in zone

The correction was made accordingly.

Line 59: "plus few data of Vostok" should be "in addition to a few data from Vostok"

It would be helpful to explain here what those data are, since it starts to get confusing in the results section and in Figure 1 about what data from Vostok were used. I.e., it seems like it was density, SSA, diffusivity and permeability from 80 m depth. Maybe it makes sense to say that, i.e., "in addition, density, SSA and diffusivity and permeability from 80 m depth from Vostok were used."

We agree with the reviewer and add the following sentence L61: "Properties of a firn sample from 80 m depth at Vostok, Antarctica, are also presented for additional comparisons".

Line 62: "allowing to assess the anisotropy of properties and compare lateral to vertical gas transport"

Line 63: "A variety of parameter to characterize firn microstructure was also estimated from images" should be "A variety of parameters to characterize..."

The sentence was modified as follows: L65 "In addition to transport properties, a variety of parameters to characterize the firn microstructure was computed from the images."

Line 75: til should be until

The correction was made accordingly.

Line 76: "controlled conditions in cold-laboratory" should be "controlled conditions in a cold-laboratory" or r controlled conditions in the cold-laboratory

The correction was made accordingly.

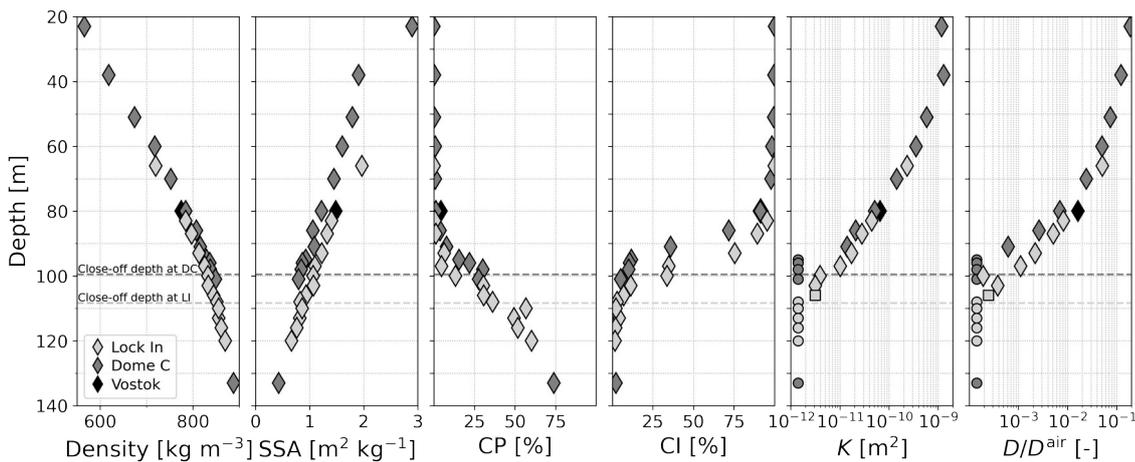
Line 106: "This index allows to describe more accurately the pore closure in firn and bubbly ice than the classical closed-to-total porosity ratio, the latter being sensitive to the sample size (Burr et al., 2018)." Should be "This index allows the pore closure in firn and bubbly ice to be more accurately described than..."

The correction was made accordingly.

Figure 1: The circles are hard to see in the figure for diffusivity and permeability because they show up as half circles in the figures and resemble the diamonds. Is there another symbol that can be used to make it clearer? Also, the square symbols are very hard to see. Could they be black instead of grey so that they show up better? I also cannot see the black diamond indicated the Vostok values for CP and CI, but again, this is unclear if this was calculated for the Vostok core. It's also hard, but not impossible, to see the Vostok value indicated by the black diamond on the Density graph. Not sure if there is a way to make the black diamond more visible? Can it be layered on top of the other sites' data points?

Last thing, it would be helpful if the two dashed lines that indicate the close-off depths were either listed in the legend (i.e., if the difference between the two shades of grey were designated), or if there was a label on the figure that indicated which dashed line designated the Dome C close-off depth and which line designates the Lock In close-off depth. If that makes the figure too cluttered, perhaps that can at least be specified in the figure legend.

Figure 1 was modified to address the reviewer comments. The revised version is shown below. Especially, the Vostok values for CP and CI were missing and were thus added in the new version. The two dashed lines indicating the close-off depth were labeled directly on the figure. The legend was also modified such as “Dashed lines show the close-off depth at Dome C (dark grey) and Lock In (light grey)”.



Line 124: evolves should be evolve
The correction was made accordingly.

Line 129: value should be values
The correction was made accordingly.

Line 152: “Both figures show dimensionless permeability values, i.e. permeability values K divided by the equivalent sphere radius $r = 3/(SSA \times \pi)$ to the square.” I’m not sure what “to the square” refers to. Is it that the squares in the figure denote the dimensionless permeability? That could be written as “as designated by the squares in Figure 2.”

By “the equivalent sphere radius to the square” we meant the squared equivalent sphere radius. To clarify, we reformulate the sentence as follows: L156 “Both figures show dimensionless permeability values, i.e. permeability values K divided by the squared equivalent sphere radius $r^2 = (3/(SSA \times \pi))^2$ ”.

Figure 2: What do the T symbols pointing up or down indicate? Are they in different directions just so that they show up differentiated from one another when they overlap, or is there a physical significance? Also, should the rescaled porosity be defined earlier in the paper so that the inset in the figure is better defined? As it is, the definition doesn't come for another couple pages.

The "T" symbols correspond to our computation results and allow to assess the anisotropy of the property with the tip of the "T" symbols being the vertical property component and the horizontal bar of the "T" symbols being the horizontal component. The legend and description in the paper of Figure 2 have been modified to clarify the meaning of the "T" symbols. L175: "The T-shaped symbols in both figures are our computed property values and the tips and horizontal bars indicate the vertical and horizontal component of the property, respectively."

Line 173: "Those extremes values" should be "extreme values"
The correction was made accordingly.

Line 196: "a assemblage" should be "an assemblage"
The correction was made accordingly.

Figure 4 caption: What do the dotted lines represent in the right-hand figures?
We included the following sentence in the caption of Fig 4: "Dotted lines indicate 1:1 lines."

Table 1: This table is a very nice summary of the available relationships for permeability and diffusivity.

Line 225: "To provide a satisfactory estimates of diffusion coefficient" should be "To provide satisfactory estimates of diffusion coefficient"
The correction was made accordingly.

Line 232: "Figure 5 allows comparing the computed data" should be "Figure 5 compares the computed data"
The correction was made accordingly.

Line 245: "Permeability predicted by the regressions of Freitag 2002 and Adolph 2014 match overall well our data." should be "Overall, permeability predicted by the regressions of Freitag 2002 and Adolph 2014 match our data well."
The correction was made accordingly.

Line 279: "although their dataset originate" should be "although their datasets originate"
The correction was made accordingly.