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Interactive comment on "Impact of water vapor diffusion and latent heat on the effective thermal conductivity of snow" *by* Kévin Fourteau et al.

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Please find attached a brief Supplement addressing two topics. First, in my previous comment on this Discussion Paper, I showed where the authors' derivation of the diffusion coefficient for a layered ice/humid air microstructure is mathematically and physical flawed. Here, I provide additional comments that are much more specific as to the nature of the error in their development.

Second, I am providing an appendix for addition to the Technical Note that should lay to rest any further debate on the role of hand-to-hand vapor transport in the diffusion coefficient for a layered ice/humid air microstructure. It is interesting in that, after all the mind-bending exercises on complex equations, the entire discussion can be distilled down to just a few sketches with some supporting, relatively simple, equations.

In brief, the surface flux across the boundaries of a unit cell of a layered ice/humid air microstructure is known analytically and not in dispute. This surface flux is, indeed, the mass flux for the system–mass leaving one unit cell enters the adjacent unit cell and so on. As this process is occurring in every unit cell, this is clearly the mass transfer moving through the system.

The authors wish to argue that their volume averaged mass flux represents the mass flux of the macroscale. This is simply not true. Directly to the point, the volume averaged mass flux must agree with the known surface flux and their formulation does not bear this out.

The reason the authors volume averaged mass flux is in error is due to the omission of the hand-to-hand diffusion mechanism in their formulation. As shown in the Appendix, once this correction is made, the volume average of the mass flux falls into perfect agreement with the known surface flux across the unit cell.

In discussing hand-to hand vapor transport the authors have often used the term non-physical to describe this mass transport mechanism, e.g., "The reliance on the hand-to-hand mechanism that instantly transports water molecules through the ice phase, which is not a real physical phenomenon." On the contrary, what is truly nonphysical, and non-mathematical, is to have the volume average mass flux of a unit cell and the surface mass flux across a unit cell boundary in disagreement.

Finally, I think it is important to provide a brief discussion as to why the layered ice/humid air microstructure is so valuable to the study of snow. There are 3 important reasons: First, the layered microstructure provides a true upper bound on the diffusion coefficient for snow (de Quervain, 1963; Hansen, 2019). This upper bound is quite useful at low ice volume fractions as the upper bound for the normalized diffusion coefficient lies quite close to one (see Hansen, 2019 for a plot of this upper bound).

Secondly, for very low-density snow, the layered microstructure provides a stunningly accurate prediction of the thermal conductivity in snow. For example, a plot of the thermal conductivity for the layered microstructure shows a near exact correlation with the thermal conductivity for snow for ice volume fractions up to 0.15. I will argue that the layered microstructure is also an excellent predictor of mass transfer in low density snow but that is for another time.

Finally, and more importantly, the layered microstructure is a critical heat transfer mechanism that is on full display throughout the complex topology of snow through the hand-to-hand diffusion process across ice grains. This fact was recognized by de Quervain (1963) who provided a very nice description of the mass transfer process.

In addition to the layered microstructure, de Quervain introduced a second simple one-dimensional microstructure he termed a "pore microstructure" that has continuous columnar pores through an ice block. This microstructure represents a lower bound on water vapor diffusion in snow. de Quervain writes: "The real conditions encountered in the snow structure may be found in between the two models. There are vapor currents passing through as well as short-range currents originating and ending in the structure and corresponding to Yosida's 'hand to hand delivery'." Armed with this description, Foslien (1994) added information from quantitative stereology to arrive at his thermal conductivity and diffusion models.

Of course, all of this information runs counter to the authors' narrative that the diffusion coefficient in the layered ice/humid air microstructure and, by extension, the diffusion coefficient in snow is less than one (Fourteau, 2021). The physics and mathematics simply do not support their view. Hand to hand diffusion must be accounted for in the diffusion coefficient.

When hand-to-hand diffusion is properly accounted for, numerical evidence points toward a slight enhancement in the effective diffusion coefficient for snow. These include the works of Christon (1994), remarkable for the time period, and Pinzer

(2012). Moreover, these numerical calculations are remarkably consistent with the diffusion model of Foslien (1994). Finally, as I pointed out in my original comment of their work, the authors' present calculations of the diffusion coefficient will likely show the same slight enhancement in the normalized diffusion coefficient for snow when hand-to-hand diffusion is properly accounted for.

Please also note the supplement to this comment:
https://tc.copernicus.org/preprints/tc-2020-317/tc-2020-317-SC3-supplement.pdf

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