**Response to Charles Fierz on tc-2020-317**

We are thankful to Charles Fierz for reviewing and commenting our manuscript.

We have copied his comments in blue. Our corresponding responses are available in black below each comment, with proposed modifications to the text written in *highlighted italics*.

We have also copied the comments in the pdf manuscript annotated by the reviewer below, with our responses in black.
The comments on typos and direct reformulation will be implemented.

Best Regards,
Kévin Fourteau on behalf of all co-authors

Following a recent publication by the same authors showing that the macroscopic water vapor diffusion is not enhanced in snow (Fourteau et al., 2021), this paper presents a thorough, self-consistent and well written study of the impacts of the kinetics of the sublimation and deposition of water vapor onto ice in snow. It describes the inextricable coupling of heat conduction and water vapor transport in snow considering two limiting cases, slow and fast kinetics. After a detailed but nevertheless concise theoretical part, the authors present a numerical exercise on quite a few measured snow microstructures. This all leads to new parameterizations of thermal conductivity as a function of density at fixed temperatures and to new insights into the influence of water vapor transport on the effective thermal conductivity of low density snow and near the melting point of ice.

Nevertheless, let me comment on two issues I had while reading the paper. First, the authors state in the abstract (lines 9-11), "Comparison of our numerical simulations with literature data suggests that the fast kinetics hypothesis could be a reasonable assumption to model snow physical properties.", which is re-iterated in the discussion at lines 385-386 and in the conclusions at lines 428-429. On the other hand, on lines 386-388, the authors state, "That being said, further work is required before robustly assessing whether mass and heat transport in snow should be treated using the slow kinetics hypothesis, the fast kinetics hypothesis, or an intermediate case.". The author should clarify that inconsistency, stating what they really mean, and adapting abstract and conclusions accordingly. Indeed, I cannot imagine that the slow kinetics – and intermediate cases – are not applicable to snow. At the same time, not all physical and mechanical properties of snow will depend on these findings, do they?
Our point of view is that at the moment, only the fast kinetics assumption is able to explain some of the observed behaviors of snow (large increase of thermal conductivity of light snow with temperature, and relatively high diffusion coefficient). The slow kinetics hypothesis predicts a decrease of thermal conductivity with temperature, and is thus non-satisfactory. Unfortunately, a general intermediate kinetics model has not been derived yet. It is therefore not possible to compare it to experimental data and verify whether it performs better than a simple infinitely fast kinetics assumption.

While current available data suggests a good agreement with the infinitely fast kinetics, one has to admit that the available data remain sparse. We thus think that the infinitely fast kinetics is a promising assumption, but that it should be backed by more data. That is why we used a conditional framing in the abstract and conclusion ("*suggests*", "*could be a reasonable*") and invite further work to be done on the subject.

We will modify the text **L372** to clearly indicate that the slow kinetics assumption does not reproduce the temperature dependence of the thermal conductivity:

“These measurements, displayed in Figure 7 of Sturm and Johnson (1992), clearly indicate an exponential-like increase of thermal conductivity with temperature, consistent with the fast kinetics hypothesis but not with the slow kinetics hypothesis.”

We propose to modify the concluding paragraph of Section 4.1 to better explain our point of view **L385**:
*“All the above reasons suggest that the effective thermal conductivity and diffusion coefficient of water vapor in snow could be well represented under the fast kinetics hypothesis, at least during temperature gradient metamorphism. Further experimental work should be performed to confirm that the fast kinetics assumption generally applies for modeling mass and heat transport in snow and to highlight its potential limitations. Also, the derivation of a theoretical model able to describe heat and mass transfer with arbitrary surface kinetics would allow to investigate intermediary kinetics, in an effort to ultimately select the best modeling assumptions for snow. At the same time, this model could be formulated to explicitly take into account macroscopic convection, as this phenomenon has been observed in sub-artic shallow snowpacks (Trabant and Benson, 1972, Sturm and Johnson, 1991). Its derivation could be achieved using standard homogenization methods, such as the two-scale asymptotic expansion (e.g. Municchi and Icardi, 2020) or volume averaging methods (e.g. Whitaker, 1977).”*

Second, while I welcome “These new data and parametrizations [that] are primarily meant to be used by detailed snow physics model.” (see Eq. 17 on line 340), I am not sure how I would do this easily as each parameterization is given for a fixed temperature only. Could the authors comment on this and make a corresponding note in the text?
There are two ways to extend our parametrization to other temperatures:
- Construct a parametrization of the polynomial coefficients with temperature. We tried this approach, but it was not clear which laws should be used to relate the coefficients to the temperature, and it resulted in an overall degradation of the fits.
- Interpolate the thermal conductivity values obtained at a given density as a function of temperature. This approach is straight forward and gives reasonable results.

We will add to the text **L344**:
*“This parametrization can be extended to other temperatures by first computing the thermal conductivity at the desired density for the 5 proposed temperatures and then performing an interpolation to the desired temperature.”*

I therefore recommend accepting the paper after the authors addressed this issue and consider doing the minor editorial revisions as suggested in the uploaded PDF-file.
Finally I apologize to the authors for my belated review, mostly due to other urgent commitments.

## Comments in the annotated manuscript

L64 – Is this an assumption or an ascertained fact?
Here we assert that snow can reasonably be considered as transverse isotropic. We will modify the test **L64**:
*“However, snow can be considered as a transverse isotropic material (e.g., Löwe et al., 2013), and this tensor is thus fully characterized [...] ”*

Note that in the case where snow is not transverse isotropic, the overall results of the article would be the same, except that more than two scalar values would be needed to fully characterize the thermal conductivity tensor.

L 126 - What do you mean? Is 'reduces' the proper term here? I feel there is a need for a more accurate formulation here.
I understand you say that c=csat and thus c - csat = 0, isn't it? Accordingly, the r.h.s of the Hertz-Knudsen equation is equal to zero, correct? Why do you need to let $\alpha \rightarrow \infty$ then?
We meant that in the case of infinitely fast kinetics, the Hertz-Knudsen equation simplifies to the simple equality of the vapor concentration with the saturation value.
Having $c=c_{sat}$ does not imply that the RHS of the Hertz-Knudsen equation is zero, as $\alpha \rightarrow \infty$. While $\alpha$ diverges to infinity c converges to $c_{sat}$ and the product $\alpha$ (c- $c_{sat}$) remains finite and non-zero.

We will modify the text **L126**:
*"[…] and the Hertz-Knudsen equation is replaced by the saturation of vapor at the ice/air interface."*

L266 - Could be an equation on its own, i.e., Eq. 17 ?
We will make it its own equation, and add **L265** that:
*"We have by construction … Eq. 17"*

Fig 8 - Are you sure this symbolic representation with ⊤ and ⊥ is clear enough without further explanation in the text?
We will modify the caption to:
*"**Figure 8.** Effective thermal conductivity of snow as a function of density, under the fast kinetics assumption at 263K. The horizontal bar of a symbol marks the horizontal effective thermal conductivity value of a snow sample, while the tip of the vertical bar marks its vertical value."*

L345 - May be, but not very obvious, at least to me.
"Flattening" was not the best choice of words. What we meant is that the slope of slopes decreases with density. We will modify L**345**:
*"[…] show a decrease of the slopes of the thermal conductivity versus density curves with increasing temperatures."*

L371 - Why? maybe a sentence saying "support the …" would be more appropriate here.
The bias of the needle probe method is likely to arise from microstructural damages and too short duration of the experiments. The experiments performed by Sturm and Johnson (1992) were performed on similar snow samples and simply varying the temperature of the snow. Thus, even though the precise thermal conductivity values are biased, the overall trend (i.e. thermal conductivity increases with temperature) should be preserved.

We will add **L371**:
*"Even though recent studies have highlighted a potential bias of the needle probe method when used with snow (Calonne et al., 2011; Riche and Schneebeli, 2013), this reported bias does not impact the trend of thermal conductivity measured at different temperature in similar snow samples, as performed by Sturn and Johnson (1992). These data can thus be expected to reflect the variation of the effective thermal conductivity with temperature."*

L395 - Rewording is needed here! What about, "but considering the microscopic thermal gradients and the associated transport of latent heat by water vapor."
We want to emphasize that the pure conduction part should be computed by taking the actual microscopic thermal gradients, that are influenced by the presence of water vapor.

We propose to reformulate **L395** to:
*"[…] should be clarified to emphasize that $K^{cond}$ corresponds to the pure conduction occurring through the ice and pore spaces, but in response to the actual microscopic thermal gradients that are influenced by latent heat effects."*

## REFERENCES


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