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Geoscientific Instrumentation Methods and Data Systems Discussions

Interactive comment on "An instrumented sample holder for time-lapse micro-tomography measurements of snow under advective airflow" *by* P. P. Ebner et al.

P. P. Ebner et al.

ebnerp@ethz.ch

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We thank the reviewer C96 for the constructive comments. We agree with all his comment, and answer them as follows.

Comment 1: The article is well organized and well written. In general, the concept of the setup could be introduced more clearly, because for readers unfamiliar with the Scanco device, the situation is hard to imagine. A simple sketch with a disk of snow and intended flow configuration would do the job. Introduction of a coordinate system would be beneficial; after all, the authors refer to the z-direction on several occasions

(e.g. "z-stage" page 356, derivative w.r.t. z on page 360, ...) A coordinate system would also help to describe the orientation of the slices in Fig. 5. A crucial piece of information is missing in the description of the sample holder: The dimensions of the sample. In Section 2.1, general numbers are given: "up to 50 mm diameters and 140mm height". Looking at Figure 2, the height of the sample in the proposed setup is probably around 30mm.

Response: We will add the following sentences in the revised manuscript

On page 356, line 3: "A modified μ-CT80 (Scanco Medical) was used for the time-lapse tomography measurements, as described by Schneebeli and Sokratov (2004) and Pinzer et al. (2012)."

A coordinate system will be incorporated into Figure 2, 3 and 5 and the caption of Figure 2 will be changed to:

On page 370: "Schematic of the sample holder design for flow across the snow sample (left) and for flow over the snow surface (right). The dimension of the analyzed snow sample for both setups is 50 mm diameter and 30 mm height."

and caption of Figure 5 to:

On page 373: "Raw constructed μ-CT signal of one scan and the corresponding segmented images and 3-D renderings at (left) t = 0 days, (middle) t = 2 days, and (right) t = 4 days. The dimensions of the displayed images are (3 mm)^2 and the 3-D renderings are (1.5 mm)^3. The images were taken perpendicular to the flow direction (z-axis). The bright phase corresponds to ice and the dark phase corresponds to air."

Comment 2: Regarding the results of the CFD simulations, I would like see some more discussion. In Fig. 3, the scale is logarithmic (spanning 5 orders of magnitude) and hence one cannot estimate the typical fluctuations inside the sample chamber. (a) How strong does the flow vary across the slice depicted in the lower part? (b) What is the FOV of the CT in relation to the sample holder? (c) Is the flow within the

FOV constant enough to deduce quantitative conclusions from the CT images? For a detailed (quantitative) interpretation of the CT images, an inhomogeneous flow field should be taken into account.

Response: We reply to the three questions as follows

a) Figure 3 and the caption will be modified:

Caption Fig. 3: "Vertical cross-section of CFD simulated airflow streamline and velocity simulations for flow in the empty sample holder. A horizontal cross-section of the scan area with the field of view (FOV) of the μ-CT is shown below."

b) A detailed description of the scan parameters will be given in section "2.1 Micro-computed tomography"

On page 355, line 5: "The equipment incorporated a microfocus X-ray source, operated at 30–70 kV acceleration voltage with a maximum nominal resolution of 10 μm. The sample was scanned with 1000 projections per 180° in high resolution setting, with typical adjustable integration time of 200–600 ms per projection. The field of view (FOV) of the scan area is 36.9 mm of the total 53 mm diameter and subsamples with a dimension of $7.2 \times 7.2 \times 7.2$ mm^3 were extracted for further processing."

c) A direct numerical simulation with a porous material is included, was numerical too difficult. However, we found that in a homogenous snow sample of permeability K ($K = 3.45 \cdot 10^{-9} m^{-2}$) the pressure drop is higher along the snow sample compared to the pressure drop at the outlet due to sudden contraction

$$\frac{\Delta p_{\text{snow}}}{\Delta p_{\text{contraction}}} = \frac{-\frac{\mu_{\text{air}}}{K} u_{\text{D}}}{\frac{\rho_{\text{air}}}{2} u_1^2 \left(1 - \left(\frac{A_1}{A_2}\right)^2\right) - \frac{\rho_{\text{air}}}{2} \zeta u_1^2 \left(\frac{A_1}{A_2}\right)^2} > 10$$

where u_1 is the outlet velocity of the air at the snow sample, A_1 the cross-section area of the sample holder, A_2 the cross-section area of the outlet tube, and $\zeta \approx 0.45$ is a coefficient of contraction. Thus, a uniform and homogeneous flow inside the sample

will be ensured.

Comment 3: Throughout the paper, the authors claim to be able to establish a controlled temperature gradient by heating the incoming air flow. Without any calculations or thermal simulations, it is hard to believe that there will be a significant and well defined temperature gradient in the snow. A typical flow rate of 2l/min corresponds to a delivered heating power of about 43mW for every degree that the air is warmer than the sample. (rough estimate with typical values for c_{p} and rho of dry air) With this heating power, the air plug-in (connected to the base frame!) will be heated, as well as the snow sample and the aluminum conductor. Hard to tell what the temperature field inside the sample will look like, but I expect an inhomogeneous distribution with bent isotherms. With the CFD simulation already set up, would it be possible to investigate the thermal effects of a warmer air stream? To this end, an FEM model of a snow sample would have to be included, which would of course yield a huge computational model. For the future, I think this would be worth the effort.

Response: We agree that we will have a heating of the device and that it will be hard to tell what the temperature field will be inside. However, first tests showed a well-established temperature gradient inside the snow sample. But we followed the suggestion and modeled a simplified sample holder (see Fig. 4) to simulate the temperature profile inside the snow sample. The following paragraph will be included in "4 Airflow simulations":

"A thermal simulation was performed (CFD, ANSYS, 2010) to model the temperature distribution inside the sample holder. To reduce the complexity of the simulations, only the snow sample and the device cover were considered (Fig. 4). The boundary conditions were: uniform inlet velocity, temperature and outlet pressure, no-slip at the solid-fluid interface, fix wall temperature, and perfect contact between the different components. The resulting temperature distribution inside the snow sample is shown in Fig. 4. In fact of that the aluminum cylinder serves as a heat conductor to stabilize the applied temperature gradient, an inhomogeneous distribution with bent isotherms can be observed. This inhomogeneity in the temperature distribution has to be taken into account for temperature gradients experiment leading to additional mass fluxes to the side."

and insert a new Figure 4 with the following:

Caption Fig. 4: "Cross section of the 3D thermal simulation of the temperature gradient inside the snow sample. Only the snow sample and the device cover were considered to reduce the complexity of the simulation."

Comment 4: In the experimental setup, section 2.1, I am missing a summary of the imaging parameters. While later in the text the voxel size is mentioned to be 18 um, the tube energy, number of projections, and reconstruction algorithm are not mentioned. The size of the field of view (FOV) would also be very interesting. These are important parameters for repeating such an experiment.

Response: Agreed, a detail summary will be included in section "2.1 Micro-computed tomography":

On page 355, line 5: "The equipment incorporated a microfocus X-ray source, operated at 30–70 kV acceleration voltage with a maximum nominal resolution of 10 μm. The sample was scanned with 1000 projections per 180° in high resolution setting, with typical adjustable integration time of 200–600 ms per projection. The field of view (FOV) of the scan area is 36.9 mm of the total 53 mm diameter and subsamples with a dimension of $7.2 \times 7.2 \times 7.2$ mm^3 were extracted for further processing."

Comment 5: In section 2.2, the authors say that they used POM "to save weight and to ensure good thermal decoupling from the environment". How can this be justified? What's the density of POM, and what would be the alternatives? Why does POM provide good thermal decoupling? And what are the X-ray properties?

Response: The density of POM is 1400 kg m^{-3} and the thermal conductivity is 0.33 W K^{-1} m^{-1}. We could not find X-ray properties for POM in the literature, however

various tests in the μ-CT showed low absorption of X-rays. POM provides good thermal decoupling because combined with the microporous foam it has a lower total thermal conductivity compared to the existing sample holder (Pinzer and Schneebeli, 2009a). An alternative will be to use other thermoplastics as they are light, easy to machine, and has a lower thermal conductivity than aluminum.

We will mention the POM properties in section "2.2 Sample holder design"

On page 356, line 22: "They were made out of Polyoxymethylene (POM) to save weight ($\rho_{\text{POM}} = 1400$ kg m^{-3}) and to ensure good thermal decoupling ($k_{\text{POM}} = 0.33$ W K^{-1}m^{-1}) from the environment with minimal influence on the CT image quality within the field of view."

Comment 6: page 360, equation 5: many people recognize this phenomenon under the name "Kelvin effect"

Response: We will mention it in:

On page 360, line 5: "However, the saturation vapor pressure of snow increases over a curved surface relative to a flat surface due to the curvature effect as molecules desorb more readily (Kelvin effect)."

Comment 7: In Fig. 5, the reader should be informed that the bright phase in the segmented images corresponds to ice, and the dark phase corresponds to air. Similarly for the raw images, which are proportional to the absorption coefficient of the material. The 3Drenderings are too dense, the authors should consider to zoom in such that the reader can distinguish a few details. The caption should also mention that the samples were exposed to convective flow.

Response: We will change Fig. 5 and the caption:

On page 373: "Raw constructed μ-CT signal of one scan and the corresponding segmented images and 3-D renderings at (left) t = 0 days, (middle) t = 2 days, and (right) t = 4 days. The dimensions of the displayed images are (3 mm)^2 and the 3-D renderings are (1.5 mm)^3 The images were taken perpendicular to the flow direction (z-axis). The bright phase corresponds to ice and the dark phase corresponds to air."

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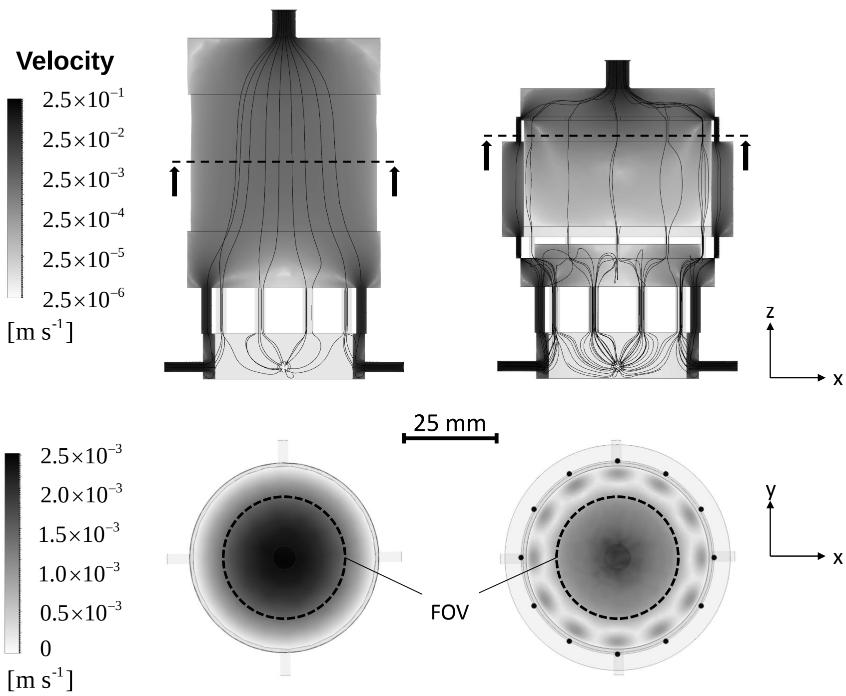

Fig. 1. Modified Fig. 3 in the discussion paper

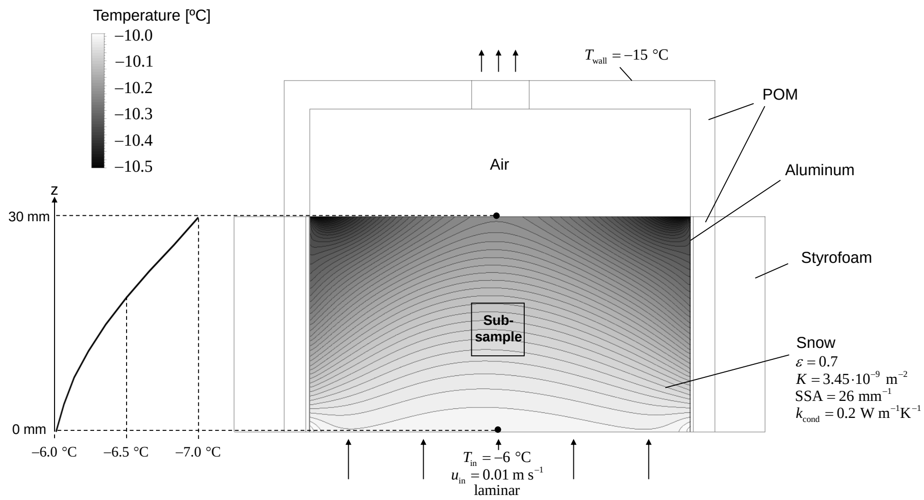

Fig. 2. New Figure between Fig. 3 and Fig. 4 in the discussion paper

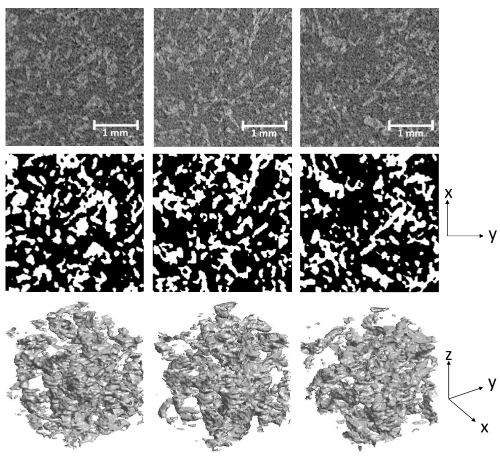

Fig. 3. Modified Fig. 5 in the discussion paper