Review of manuscript "Isotopic Stratification and Non-Equilibrium Processes in a sub-Arctic Snowpack

Authors: Dar et al.

Submitted to Cryosphere.

The manuscript argues that diffusion and wind ventilation cause non-equilibrium fractionation, which reshapes the water isotopic composition within the snowpack in both the vapor and the snow on hourly to seasonal timescales.

The argument is based on a comprehensive dataset of water vapor isotope observations from both above and within the snowpack, combined with snowpack isotope profiles and direct temperature measurements.

The authors support their conclusions based on the finding that their measurements of the water vapor isotopic composition show that the pore-space vapor is rarely in isotopic equilibrium with the surrounding ice.

Their experimental setup consists of two inlets, located respectively 5 and 15 cm above the ground, which are buried by snow deposited throughout the season. At the beginning of the campaign, the 15 cm inlet is 45 cm below the snow surface, while at the end of the campaign, it is 65 cm below the snow surface.

The target question of the manuscript is crucial for understanding the physical processes that affect the climate signal recorded in the stable isotopic composition stored in the ice crystals that comprise the snowpack. Since the early work of Waddington et al., who hypothesized that wind pumping is important for driving the isotopic composition in the snow, discussions and attempts have been made to quantify the vapor transport within the snowpack through direct measurements.

Unfortunately, it is this reviewer's view that the authors make similar mistakes as previous attempts to measure interstitial water vapor, in that they disregard the influence of their measurements on the medium they are trying to measure, i.e., the interstitial water vapor.

Contrary to the statement on line 640, "However, the small volume of vapor extracted relative to total pore-space vapor produced no systematic artifacts," I will argue below that the volume of vapor extracted in fact is producing artifacts, which prevent the authors from reaching a robust conclusion.

The fundamental problem with their setup is that the authors remove air from the snowpack continuously:

L 149 “The three inactive sampling lines were continuously flushed by a single pump at a total flow rate of 100 ml/min, yielding approximately 33 ml/min through each inactive line”

L152 “The active line connected to the analyzer was sampled at the instrument´s internal flow rate of approximately 40 ml/min.

This means that a constant flow through each inlet line buried in the snow is 33-40 ml/min. As the air for the inlet lines in the snowpack cannot come from the ground, it must come from the atmosphere above the snowpack. This means that a total of 66-80 sccm of air will flow to the combined inlets in the snow. See Figure 1 below as a sketch of the setup.

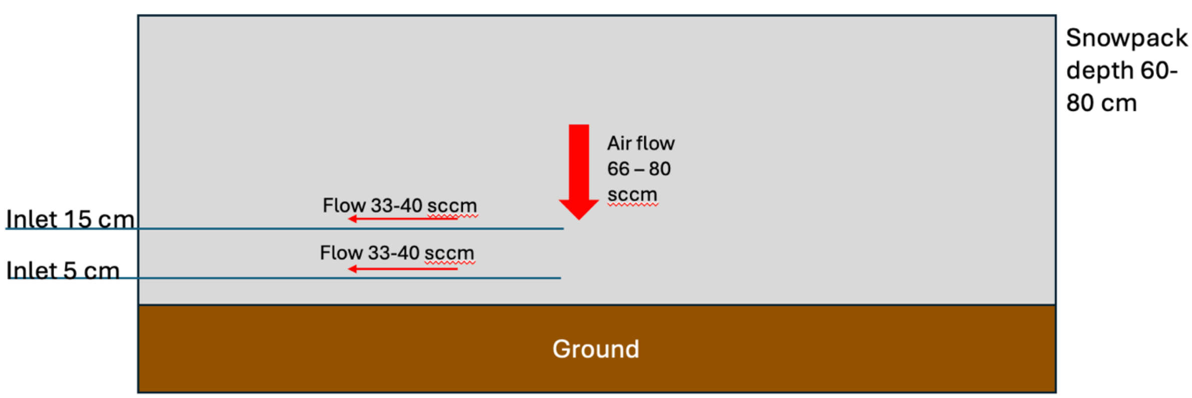

Figure 1: Sketch of setup

The fundamental question that then arises is, where does the air come from? It must be such that the air will follow a path of the smallest integrated resistance. This means that the air cannot come from infinity. On the other side, it also seems unlikely that the air follows a tube flow straight from the surface through a path with a diameter of 6 mm equal to the inlet ID.

Below I therefore consider two situations:

Conservative option 1: The air enters the snowpack through an area with a diameter of twice the depth of the inlet (90 cm beginning of season and 130 cm end of season) and travels through a semi-sphere of the snowpack. See figure 2 for a sketch of the setup.

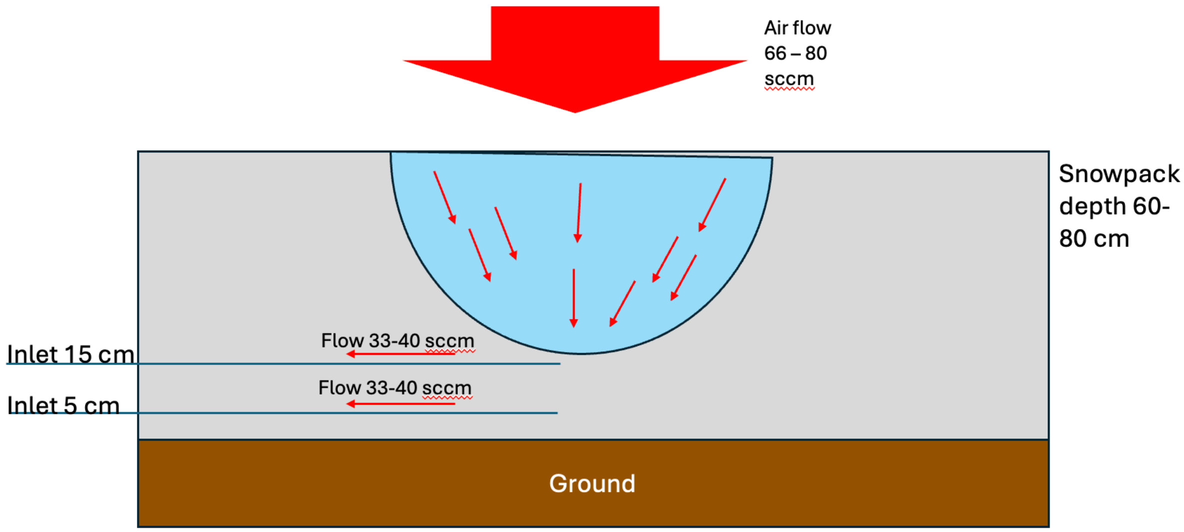

Figure 2: Sketch of a conservative thought experiment of how the air travels through the snowpack.

Making the following assumption that the density of the snow is 500 kg/m3 based on the information in the text that the authors observed compaction during periods of no precipitation and the relatively high temperatures at the field site.

For the calculations of snow depth at 60 cm:

The volume of the semi-sphere is 190e3 cm^3. This means that the volume of air is 95e3 cm^3. With a flow rate of respectively 33 or 40 sccm per inlet, this would mean that all the interstitial air will be replaced every 20 to 24 hours.

Even for this relatively conservative estimate, I will therefore argue that the author's argument on line 640, "However, the small volume of vapor extracted relative to total pore-space vapor produced no systematic artifacts," does not hold.

A more realistic flow field through the snowpack would probably be better described by a column flow with a diameter of 40 cm from the top of the snowpack down to the inlet. Figure 3 illustrates perhaps a more realistic flow field through the snowpack.

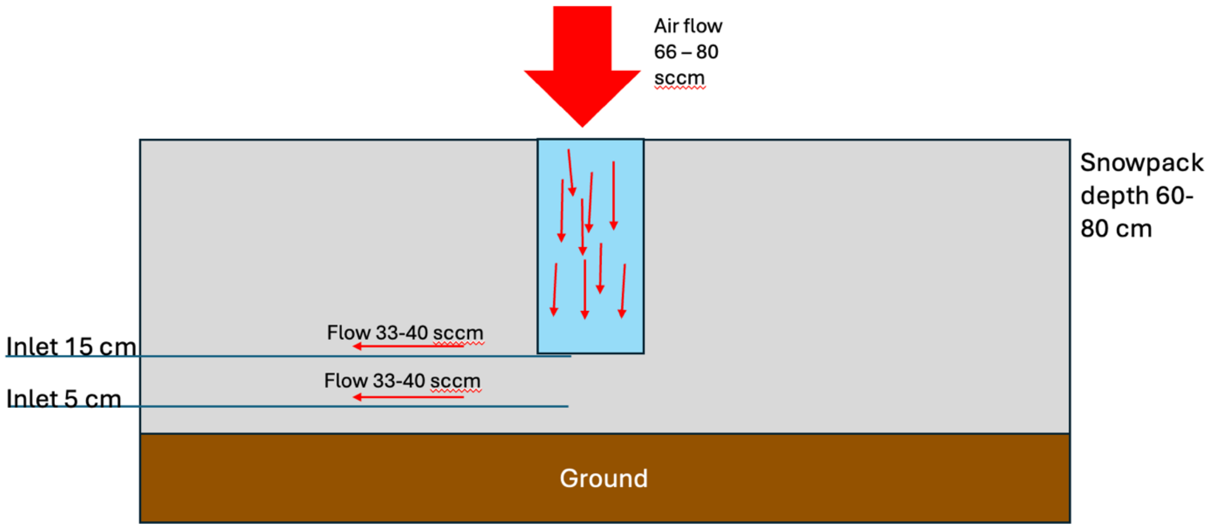

Figure 3: Illustration of a perhaps more realistic flow field through snowpack.

Again, carrying out the calculations for a snow depth of 60 cm.

In this case, the volume of the column is 56e3 cm^3 and the total volume of the interstitial air is 28 cm^3. For the given flow rates through the inlet lines, this would mean that the air in the snow column is replaced every 6 to 7 hours.

Based on these calculations, I believe that the effect on the interstitial vapor isotopic composition, which the authors attribute to diffusion and wind ventilation, is a result of the forced transport of atmospheric air through the snowpack.

Further support for my conclusion is provided by the authors in the observed snowpack temperature at the depth of the inlet and the observed diurnal variations in humidity of the interstitial vapor:

Figure S2 shows that no diurnal variation in snowpack temperature is observed at the 5 and 15 cm inlet

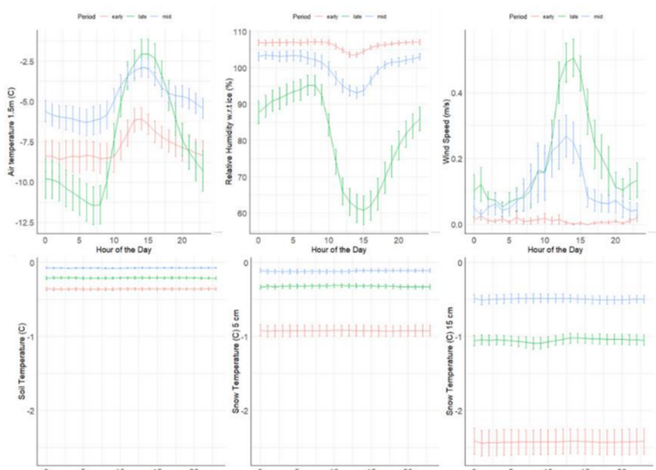

Figure S2 Plots depicting diurnal patterns in ambient air temperature (C), relative humidity w.r.t. ice (%), wind speed (m/s), and soil and snow temperatures (5cm and 15cm) depth, measured over three distinct periods: early, mid, and late.

However, the authors also demonstrate clear diurnal variations in the observed humidity at the inlets, as shown in Figure 3.

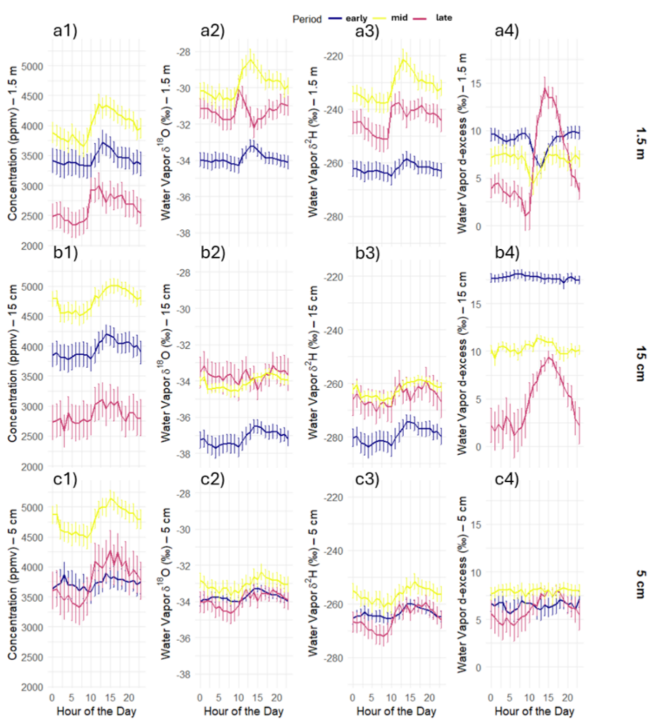

Figure 3 Plots depicting diurnal variations in water vapor concentration (1) and isotopic compositions (*$\delta^{18}O$ (2), $\delta^{2}H$ (3), d-excess (4)*) in ambient air (1.5 m) (a) and at 5cm (c), 15 cm (b) within a snowpack and across three distinct periods: blue-early, yellow-mid and magenta-late.

Following the findings of Neumann et al. 2009 (Sublimation rate and the mass-transfer coefficient for snow sublimation): *"Our data (e.g. Fig. 4) suggest that the snow sublimates* *rapidly, and that for snow samples with thickness 1 cm or greater, pore spaces in snow are typically saturated with vapor, as other investigators have assumed [5]"*

This means that the snow at the 5 and 15 cm inlet must have a diurnal variation in temperature in order to create a diurnal variation in humidity. As the temperature at 5 and 15 cm does not show any diurnal temperature variation, this means that the flow of air into the inlets must influence the temperature in the vicinity of the inlets, but not be recorded by the temperature observations. Hence, one might conclude that even the "*perhaps more realistic flow field in the snowpack*" is in fact still too conservative, and the flow from the surface to the inlet follows an even narrower corridor through the snowpack.

Based on my above argument, I therefore believe that the setup in the manuscript of Dar et al. does not allow the authors to reach the presented conclusions.