Review of EGU-2025-2724: “Isotopic Stratification and Non-Equilibrium Processes in a Sub-Arctic Snowpack”

This study presents the first continuous field measurements of water vapor isotopes inside a snowpack, along with air and snow core data influenced by both maritime and continental climatic factors. The results show that vapor inside the snowpack is usually not in equilibrium with the surrounding ice, and this imbalance changes with depth and season. The author concluded that in cold, stable conditions, diffusion controls vapor exchange, while in warmer, windier late-winter conditions, ventilation by wind becomes more important. These late-winter conditions also caused strong daily swings in vapor and isotopic values, linked to sublimation and rapid mixing with the atmosphere.

The authors provide an extensive analysis of the data and provided some detailed interpretation on processes affecting the isotopic signal inside the snowpack. The findings highlight that snowpack isotopes are strongly influenced by short-term environmental changes, and models must include these processes to avoid errors in hydrology and climate reconstructions. However, I have some drawbacks about the correctness of the measurement and the results of the vapor inside the snowpack or I misinterpreted the data wrong, see my comments below.

In conclusion, this paper is well written and the subject is appropriate for Cryosphere but I recommend major revisions to improve the reliability of the data.

Major comment:

I'm a bit concerned about the correctness of the measurement looking at the data in Figure 2 and 3. Your temperature measurement inside the snowpack (Figure 2) shows a minimum of around -4 degrees (corresponding to a saturation vapor concentration of around 4300 ppmv) but your concentration measurements with the Picarro (Figure 3) show a minimum of around 2700 ppmv. This would indicate that you have a relative humidity of only 65% inside the pore space of the snow pack which is not possible. Do you have an explanation for this?

The same for the ambient measurement, you measured the lowest temperature at 1.5m of

around -20 degrees (corresponding to a saturation vapor concentration of around 1500 ppmv) but your lowest measured concentration was around 2500 ppmv. This would indicate that your ambient air was sometimes oversaturated. Or could it be that your Picarro sucked in ice/water particles or is the Campbell Scientific AP200 intake also used for the isotope vapor? Maybe you could provide a picture of the system in the supplement materials.

You claimed that the pore spaces of the snowpack was at saturation but I could not find any evidence in the data. Therefore, it seems like that either your setup was not leak-tight or there is an offset in the humidity measurement of your Picarro.

General comments:

- Sometimes you are talking about that vapor measurements were taken at 5 or 15 cm depth. This is a bit misleading because when you are talking about the depth some readers will see it as the distance from the surface into the snowpack. I would suggest to skip the 'depth' or call it 'height' to improve the readiness.
- I'm missing important information to get a better understanding of the setup and to interpret the results. How did you check that your system is leak-tight and did you perform a humidity correction of the Picarro?
- I'm a bit concern about your comparison of your results between the three different periods (early, mid and late) because the snow depth is not constant and is changing up to 30 cm during the campaign. I would suggest to provide an explanation why you can still compare the different periods (especially about the data of the two intakes within the snowpack) with each other.
- How do you justify that 15 cm is a mid-snowpack position for a snowpack depth of 90 cm?
- I questioning the wind pumping effect on the isotope signal without knowing your spatial density profile of your snowpack. In addition, based on Figure 2 you measured a max. wind speed of 2 m/s and you are intakes are between 0.4m and 0.8m below the snowpack surface. For this condition I would not expect any significant ventilation inside the snow pack (see Colbeck et al., 1989). But without knowing your density profile of your snowpack it is hard to make a conclusion.

Specific comments:

2) Methods

- Line 115: Did you check your system for leaks? And did you do a humidity correction of the Picarro? It seems like that either your setup was not leak-tight or there is an offset in the humidity measurement of your Picarro. See major comments.
- Line 115: In Figure 2 you showed the snow depth. I would suggest to quickly mention it here with all the other parameters.

- Line 115: Is there a specific reason why you measured the isotopic composition at 5cm, 15cm and 1.5m above ground? I would suggest to provide a reason for it.
- Line 135-136: How did you make sure that the sensors did not get frozen during the measurements, especially your humidity sensor?
- Line 141-142: How did you make sure that the intakes are not sucking in small ice/water particles?
- Line 145-147: Could you provide a bit more explanation how you buried the last 0.5m inside the snow. Were the last 0.5m directly horizontally inside the snow? If not, how did you make sure that the temperature gradient inside the snowpack does not have an impact on condensation inside the tube?
- Line 146: '... and minimizing the risk of condensation': It is hard to understand what you want to say here. I assume the reason why you didn't heat the last 0.5m is because you could have potential heating up/melting of the snow at the intake. Why is there then a risk of condensation? Could you elaborate a bit more.
- Line 148-149: How far was the valve actuator away from the intakes?
- Line 149: '... the three inactive sampling lines...' How can you have three inactive sampling lines when you have only three sampling lines. Why do you have a fourth one? Is it relevant to have a fourth one? Please provide more information.
- Line 149: '... continuously flushed': Please specific mention it that it continuously flush the line with the vapor of the pore space (I assume this is what you did).
- Line 154: I don't see a reason why you should discharge the last 2 minutes before switching the valve. Did you see any impact on the signal in the last 2 minutes? If yes, why do you think that it has to do something with the valve? Could you elaborate a bit more?
- Line 155-156: I would delete this sentences because it confuses a bit. Actually, you measured one intake twice during one hour.
- Line 158-161: I'm questioning your explanation about water percolation. Looking at Figure 2 I don't see a reason why you should have water percolation into the snowpack. The ambient temperature was far below zero and also the temperature at 15cm shows value below zero. Could it not be that the Picarro sucked in ice crystals which melted in the heated tube? How do you prevent that ice particles can enter the intakes?
- Line 170: 'Humidity corrections were applied...': I assume it is not a humidity correction but a humidity-isotope correction.
- Line 177: '... minimal drift over time': At what humidity level did you perform your drift measurement? Close to the humidity levels of the intakes inside the snowpack?
- Line 181-182: You indicate that 10% of your vapor concentration measurements inside the snow were below 2000 ppmv. I doubt that this is realistic for a snowpack where the lowest temperature was around -4 degrees. Could you check what was the snowpack temperature when you measured vapor concentration below 2000 ppmv.
- Line 195-196: Could you elaborate a bit more why you didn't include sample measuring above 20 cm from ground level? Such measurements would help to get a better idea

how the signal changed with depth and why there was a potential disequilibrium at the intakes.

- Line 202: '... using a Picarro CRDS system.' Could you mention which model e.g. L2120, L2130 or L2140?
- Line 216: I assume that the relative humidity was measured at 1.5 m. Please mention it.
- Line 231: 'Relative humidity within the snowpack remained saturated ...': I can't find any evidence that your data shows saturated conditions inside the snowpack. See comments above.

3) Results

- Figure 2: How did you measure the snow depth and what was the resolution of it?
- Figure 3: Could you also add the temperature profile to see whether the concentration (ppmv) is following the temperature profile or not.
- Figure 3: Is it possible to extract a time-shift between the measured atmosphere data and inside the two snowpack locations? If yes, would it be possible to compare this time-shift with the diffusion time ($\Delta t = L^2/D$) from the snowpack surface to the intake locations (maybe include a tortuosity factor for the diffusion length inside the snowpack) to check whether it is consistent.
- Figure 4: I would suggest to change the colour of the '0-5 cm' and 5-10 cm' snow data points. It is hard to distinguish it.
- Figure S4: How do you explain that you measured a vapor concentration below 1900 ppmv inside the snow pack but your temperature is only around -4 degrees? I'm also surprised that the vapor concentration inside the snowpack is almost the same as the 1.5m measurement.

4) Discussion

- Line 459-460: '... at different snowpack heights (5 cm, 15 cm, and 1.5 m)...' -> please rewrite this part because 1.5m does not belong to the snowpack but to the atmosphere.
- Line 487-488: '... than in ambient air, Within the ...': I assume that the sentence ends after 'ambient air.'
- Line 527: I questioning this paragraph without knowing your spatial density profile of your snowpack. In addition, based on Figure 2 you measured a max. wind speed of 2 m/s and you are intakes are between 0.4m and 0.8m below the snowpack surface. For this condition I would not expect any significant ventilation inside the snow pack (see Colbeck et al., 1989). But without knowing your density profile of your snowpack it is hard to make a conclusion. I would suggest that you provide more evidence to support your hypothesis. Maybe you could provide an estimation about what wind speed inside the snowpack would be needed to transport the atmospheric vapor into the snowpack. E.g you could try to extract a time-shift between the measured atmosphere data and inside the two snowpack locations and calculate a wind speed needed to transport the signal into the snowpack.

- Line 608: '... in the mid-snowpack (around 10-15 cm).': How do you justify that 15 cm is a mid-snowpack position for a snowpack depth of 90 cm?
- Line 606 and 610: Would it be possible to provide an explanation that first 'In early winter, the snowpack behaved as a closed system...' and afterwards the snowpack is not closed anymore and wind-pumping and '... ventilation became the primary transport mode...'? Looking at your snow depth data on Figure 2 I would expect that your two intakes locations inside the snowpack are even more decoupled from the atmosphere because the snowpack is rising by additional 20-30cm.
- Line 636-637: Could you elaborate this a bit more? What do you mean '... buried well below its intended mid-snowpack position during an early-season snowstorm'? Didn't you want to keep the intake locations constant at 5 cm and 15 cm above ground? Or what was your intended mid-snowpack position? And how do you justify that 15 cm is a mid-snowpack position for a snowpack depth of 90 cm?

5) Conclusion

- Line 692: The link is not working. Please correct it.

S1) Supplement material

- Line 4: '... fluctuations in water vapor com concentrations.' -> remove 'com'
- Line 7: '... relative humidity at the four inlets, a HOBO...': I think there is a type. You are talking about four inlets but based on your experimental setup you have only three (5cm, 15cm and 1.5m).

Technical comments:

- Line 255: '... the snowpack slightly enriched than the ...' Typo -> '... the snowpack was slightly more enriched than the ...'
- Line 339: 'The 5-10 cm layer shows a steeper slope ...' Typo -> 'The 5-10 cm layer showed a steeper slope ...'
- Line 354: '... vapor was negatively correlated ...' Typo -> '... vapor were negatively correlated ...'
- Line 678: 'Our data set ...' -> 'Our dataset ...'
- Remove redundant commas in citations (e.g., “Bailey et al., (2019)” → “Bailey et al. (2019)”)