The Cryosphere Discussions

The Cryosphere Discuss., referee comment RC3
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Comment on tc-2021-87

Anonymous Referee #3

Referee comment on "The role of sublimation as a driver of climate signals in the water isotope content of surface snow: laboratory and field experimental results" by Abigail G. Hughes et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-87-RC3, 2021

General Comments:

The new, impressive, and labor intensive field measurements from East Greenland on snow-water vapor exchange, as well as laboratory measurements, are a valuable dataset which provides much needed insights on the effects of sublimation on the isotopic content of surface snow, and constraints on the post-depositional processes affecting the evolution of the isotopic composition of surface snow and atmosphere water vapor. The findings clearly show that sublimation does indeed impart an isotopic signal to the surface snow that propagates downward 1-2 cm over the period of 4-6 days during periods of clear skies. A simple box model is utilized to help understand the relatively isotopically enriched surface snow due to solid-vapor phase changes (i.e., sublimation) for $d^{18}O$ and the concomitant decrease in d_{excess}. The box model helps to understand and explain the combined effects of surface sublimation and diffusion of the signal observed at depth in the homogenous lab-based snowpack.

The comparison between field samples, field box samples, and laboratory experiments provides a good test of how large an isotopic effect sublimation has in a controlled environment (albeit extremely dry compared to field conditions). It also helps to identify certain environmental parameters that may be causing unexpected changes in the isotopic composition of field samples, like synoptic whether variations altering atmospheric vapor $d^{18}O$ over hourly timescales or if the snow surface composition is driving the vapor $d^{18}O$ due to deeper snow layers influencing the surface snow by internal diffusion between grains.

The authors highlight one of the key findings: “A key finding from field experiments is that both sublimation and vapor deposition influence the surface snow on an hourly timescale; this is supported by laboratory experiments and model results, demonstrating that sublimation has the ability to influence the mean surface snow isotopic composition in the top 2-3 cm of the snowpack during precipitation-free periods. These changes are occurring faster than the average recurrence of precipitation events, and ***could*** *produce substantial* *changes in the mean isotopic composition of the upper several cm of the snowpack over a long precipitation-free period*. *This suggests that effects from sublimation and vapor deposition* ***may*** *be superimposed on the precipitation signal*, resulting in a snowpack record more indicative of atmospheric conditions and water vapor isotopic composition than condensation temperature (i.e. $d^{18}O$) or precipitation source region conditions (i.e. d-excess). The extent to which this occurs is dependent on the accumulation rate at the ice core site, as these processes primarily influence the top few cm of the snow column."

Although the authors do an excellent job documenting the hourly changes to the surface snowpack in the field sample experiments (FS1-4), the question remains: what is the net effect to the snow pack isotopic composition over a weekly or monthly time period that is precipitation free? If sublimation enriches the snow surface and thus the overlying vapor isotopic composition, and then at night during negative LHF, equilibrium fractionation during vapor deposition should redeposit more $\delta^{18}O$ negative water vapor onto the snow surface, and thus the net change is a minimal enrichment over weekly periods. For example, the initial FS2 0-0.5 cm values shown in Fig. 5 appear to have a mean value of ~−24 ‰ on July 7th and by July 9th the mean value is ~−22 ‰, smaller in magnitude than the $\delta^{18}O$ increases observed in the FB 2-4 samples that were shaded/covered. However, by July 18th the mean value is −23.5 ‰ and then drops down to −32 ‰ (*"likely due to a precipitation event preceding FS4 which may have deposited surface snow with anomalously low $d^{18}O$"*), but the point is that over the ~3 week period the sublimation signal that should be slowly increasing $\delta^{18}O$ is overwhelmed by either fresh precipitation or more depleted $\delta^{18}O$ atmospheric water vapor from elsewhere. The sublimation of the surface snow on day-to-day timescales appears to be less important to the overall seasonal isotopic composition of the surface snow in regions like Greenland with more frequent synoptic systems and advection of water vapor from marine sources (e.g. Baffin Bay, Arctic Ocean or North Atlantic).

On the other hand the laboratory experiments are excellent demonstrators of intense sublimation over prolonged periods (using a continuous LHF equivalent to the max daily LHF in the field) and use a humidity level about 30-40x less than the atmospheric values found during the field experiments, which produces a very strong sublimation signal in the surface snow for L1-L8. The extreme sublimation rates make it a bit harder to draw comparisons to the field experiments, but provides an upper bound for the impact on isotopic enrichment of surface snow $d^{18}O$ and d_{excess} depletion during summer months. The smaller impact in the FS experiments shows that sublimation is still an important factor on diurnal timescales (daytime vs nighttime), but it remains unclear what the cumulative impact would be on the snowpack isotopic composition if at the end of the summer season a snow pit was sampled at 1cm increments would the sublimation changes be detectable or swamped by other post-depositional process (wind redeposition), synoptic scale atmospheric vapor imprints, or new precipitation events bringing in low $d^{18}O$ snowfall? Clearly sublimation (and vapor deposition) is an important factor on the diurnal timescales during accumulation intermittency, but as the authors acknowledge: *"Whether the magnitude of the mean isotope change due to sublimation and snow-vapor exchange outweighs the effects of snow redistribution, accumulation bias, and diffusion has yet to be determined."*

The authors make a strong case that sublimation/vapor deposition changes do occur to the surface snow pack (~1-2cm for the FS snow surface samples) on sub-diurnal timescales. They argue that *"These changes are occurring faster than the average* *recurrence of precipitation events, and [therefore]* ***could*** *produce substantial changes in the mean isotopic composition of the upper several cm of the snowpack over a long precipitation-free period."* The authors then speculate that effects from sublimation and vapor deposition MAY be superimposed on the precipitation signal, "*resulting in a snowpack record more indicative of atmospheric conditions and water vapor isotopic composition than condensation temperature (i.e. $d^{18}O$) or precipitation source region conditions (i.e. d-excess)*." Although this is a reasonable speculation their data is not sufficient to support such conclusions about the monthly or seasonal timescale impacts of the two-way exchange driven by sublimation/condensation. Thus, it is not appropriate to for them to assess the relevance of their results to the scale of the seasonal amplitude in the isotope signal for a firn core from the Renland Ice Cap. The changes observed in the FS field experiments (mean of ~1.8‰ for FS1-4 $d^{18}O$ range based on Table 2) occur on short (multi-day) timescales but in order to compare the cumulative impact of these processes to the seasonal amplitude, they would need to have sampled a nearby snow pit at the start of the field campaign in early July and again at the end of the month to determine the net effect, and ideally throughout the entire summer (apparently new data will be available from Wahl et al., in review). The authors do acknowledge that "*In order to fully understand the implications of sublimation and snow-vapor isotope exchange on the ice core record, it is necessary to quantify the effects of these processes over the course of a full year"* and while that is not within the scope of this paper they go on to make concluding statements that the results support their hypothesis "*that rapid change occurs in a natural setting and propagates into the snowpack**, substantially** altering the initial precipitation isotope signal."* Although true on short timescales (sub-diurnal to diurnal) the results do not provide enough information to make definitive conclusions about the relative magnitude of sublimation/vapor deposition on longer timescales (i.e. years to decades) relevant to ice core interpretations.

I agree strongly with the authors that further research is needed over seasonal and annual timescales and that their results "*suggest that these variables contribute to a combined isotope signal, in which $d^{18}O$ and d-excess in ice core records likely incorporate individual precipitation events (i.e. condensation temperature and moisture source region conditions, respectively), surface redistribution (i.e. wind drift and erosion), and a post-depositional alteration signal reflecting atmospheric conditions at the ice core site."* Their suggestion that "*Snow isotope models such as CROCUSiso (Touzeau et al., 2018), the Community Firn Model (Stevens et al., 2020), and isotope-enabled climate models" would therefore be improved through the incorporation of isotope fractionation during sublimation, snow-vapor isotope exchange, and snow metamorphosis."* is certainly justified by their findings from both the laboratory and field experiments and results from such modeling efforts may help to interpret the relative contributions of the aforementioned processes affecting post-depositional changes.

Based on the above assessment, I would recommend **acceptance with minor revisions** but with a primary focus on revising the Discussion and Conclusion sections regarding the broader application of their findings to seasonal and yearly timescales, speculation on the cumulative effect (monthly, seasonal, or yearly) of short-term sublimation/vapor deposition isotopic changes to surface snow, and their assessment of relevance to the interpretation of annual ice core records (e.g. Renland) is not yet supported by the four separate 2-4 day field data expermients.

Specific Comments:

Note: Please see the line by line comments in the commented pdf. Their repetition here is duplicative, although I have pulled out some of key comments below:

Line 187: If this is the case, are you suggesting the results from the field experiments are only affected at the snow surface by sublimation as well, and the rest of the signal at depth is diffusion (below 0.5cm)?

Line 284: It would be useful to run the snow isotope model with some of the field observations and input values and show how that compares to the model results from L5, which has a very high LHF that is continuous versus much lower mean LHF for FB or FS.

Line 288: Worth noting here that in the FS experiments depth propagation is only 1-2cm (max)

Line 299: See comment from Line 284, and run the isotope box model with more realistic field conditions so in the discussion one can comment on the degree of sublimation impact in the field.

Line 325: This one of the key questions, as the long term (weekly/monthly) result may not cause a significant deviation from the original snow-pack precipitation if the daytime sublimation and nighttime condensation of vapor balance each other out. What is the NET change of the isotopic content over the entire month of July for the surface snow? Include in the Discussion.

Line 350: The authors have not demonstrated that this is the case, as their field snow surface experiments on only on the order of 2-4 days, and they do not provide data from a snowpit at the end of the ~3 week sampling period that can support this statement. It may or may not be superimposed on the precipitation signal, and therefore its an assumption that the "resulting snowpack record would be more indicative of atmospheric conditions..."

Figure A15. Include the RMSE or 2 sigma stdev for the FS1-4 data, and error bar on each graph, so that readers can view the uncertainty around the fit.

Technical Corrections:

Figure 8 caption. The color appears to be brown in the image. Change “FS surface snow 0-0.5 cm values are shown in dark orange” to brown

Line 329: “In general, the box samples experience less decrease (should be increase) in $d^{18}O$ than associated FS samples due to minimized vapor deposition, and greater decrease in d-excess due to increased sublimation”

Figure A13. Figure label says 2.5-4.5 cm (yellow), need to be consistent with Figure caption that states “2.5-4cm below the surface”.

Please also note the supplement to this comment:
https://tc.copernicus.org/preprints/tc-2021-87/tc-2021-87-RC3-supplement.pdf