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The Cryosphere
Discussions

Interactive comment on "The influence of layering and barometric pumping on firn air transport in a 2D model" *by* Benjamin Birner et al.

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Manuscript: The influence of layering and barometric pumping on firn air transport in a 2D model

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Reviewer: Stephen Drake

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Overview

This manuscript addresses firn air mixing stimulated by barometric pumping. The authors have developed a 2D model that simulates advection, convection, dispersion, and diffusion of air through firn that has discontinuous, low-permeability layers. They apply this model to investigate the relative impacts of diffusion and dispersion with depth for several noble gas isotopologues. Improved understanding of firn air mixing will enable more accurate assessments of ancient atmospheric composition and climate change chronology derived from firn and ice cores.

I recommend this manuscript for publication once the following items have been addressed.

General Comments

A result of Buizert and Severinghaus (2016) is that pressure changes above the snowpack manifest with full amplitude down to the lock-in zone after $\sim$ 1 hr. This one hour timescale means that mesoscale and diurnal pressure variations may also influence firn air mixing. Synoptic pressure changes have more spectral power than mesoscale and diurnal pressure changes, however, mesoscale and diurnal pressure changes are more frequent. So, there is an interplay between frequency and amplitude that was not addressed in either this manuscript or in Buizert and Severinghaus (2016). Also, it is relevant to note that synoptic pressure changes do not always yield storms. These complicating factors perhaps would have been better addressed in Buizert and Severinghaus (2016). I leave it to the editor to decide whether they should be addressed in this (already substantial) manuscript.

The authors did not attempt to assess the error that could be attributed to barometric pumping when dating the composition of the atmosphere using ice cores. It would be instructive to a broader audience if they speculate as to what other information is

needed to bound this problem.

Clarity

Overuse of “here” especially to begin a sentence.

It would be helpful if, rather than intermixing “impermeable” and “(near-) impermeable”, the authors choose one term, define its meaning in the introduction and use it throughout the text (with the exception of the references to model layers, which are explicitly and accurately defined as impermeable).

Throughout most of the manuscript, the vertical dimension is referred to as “depth”. But on pages 14 and 15 it is referred to as “height”. I prefer that they use “depth” throughout.

The authors and others have demonstrated that interstitial air mixing near the snow surface is driven both convectively (by temperature gradients) and dynamically (through pressure changes). This is an opportunity to rename the upper layer as a “mixed” zone (or some-such) rather than “convective” zone so as not to perpetuate the overly-simplistic convective zone terminology.

It is easier to parse the history of scientific discovery when multiple references are listed chronologically in the manuscript.

Specific Comments

Page 1

Line 9: “impermeable” do you mean low permeability?

Line 16: “Moreover, we find that . . .” This is a confusing sentence, consider re-wording. Do you mean: As observed in nature, simulated barometric pumping does not substantially change the differential fractionation of fast and slow moving gases?

Line 18: “This suggests that . . .” what is “This” ?

Page 2

Figure 1: consider brightening/enhancing this image so the layers are easier to distinguish

Page 3

Line 11: “. . . smoothing out any concentration gradients . . .” As shown in Drake et al. (The Cryosphere, 2017) snow inhomogeneities provide preferred pathways for airflow. So, remove the “out any”.

Line 13: “Such convective mixing . . . “ The authors are convolving convection with a non-convective pressure-driven process.

Fig 2a: This idealized medium is not non-dispersive. The streamlines, as drawn, are not realistic. Airflow around one sphere has close to an equal chance of going around the next sphere on either side with the net effect that particles will spread out both in the streamwise and transverse directions.

Page 4

Line 3: Why do the pressure-induced air flows need to be fast? Are you suggesting turbulent mixing? How fast is fast?

Line 5: “. . . emergent macroscale phenomenon . . .” what is emergent about dispersion?

Line 7: is dispersion added to the governing equation or is it rather not removed from a simplified form of the governing equation?

Line 18: “. . . hindering effect. . .” how about “diminishing effects”?

Page 5

Line 10: “Most current 1D firn air models. . .” does Buizert et al. (2012) contain a review of other 1D firn air models?

Line 17: "... discontinuous layers of zero diffusivity and barometric pumping" how about, "...by barometric pumping and discontinuous layers that have nominal diffusivity"?

Line 21: "the driving force for gravitational settling is effectively zero during horizontal transport ..." need to reword because the gravitational force is not zero regardless of horizontal transport

Page 6

It would be more complete to also define the term on the LHS of Eq (2).

Fig 4c: Why is the maximum in barometric pumping at $\sim$ 15m depth?

Page 7

Line 5: "... assuming a constant snow and ice mass flux at all depths" How does this assumption bias your results (if at all)?

Page 8

Line 13: "... barometric pumping in the more tortuous, deep firn" barometric pumping occurs throughout the firn column, not just in deep firn

Page 9

Line 3: "... longitudinal to-flow and transverse to-flow" how about "streamwise and cross-stream"?

Page 10

Line 5: Is there a quantifiable basis for the assumption of 10x difference between horizontal and vertical molecular diffusivities?

Page 11

Fig 7. Comment on two CO2 (diamond) anomalies as it appears they are ignored in

the curve fits.

Page 12

Line 2: "In line with observations, ..." the authors previously indicated an anthropogenic signal in CO2 and CH4 that could be repeated here for clarity

Fig. 8: what do error bars with missing end caps mean relative to the error bars that have end caps?

Page 14

Line 20: "A lack of alternative pathways" could be stated as "Fewer alternative pathways" or "Limited number of alternative pathways" or similar

Line 32: If thermal effects are neglected then why is it called the convective zone? Perhaps rephrase sentences in lines 31 and 32.

Page 15

Line 11: "Constraining the convective zone ... much larger than at the more recently sampled WAIS site." need citations

Page 16

Fig 11: Do the 2D simulations include impermeable layers? What is the meaning of missing error bar caps?

Page 17

Line 9: "Advection and mass-independent mixing..." is this the authors' theory or is a citation needed?

Page 18

Line 7: "Therefore, ratios of heavier elements are more susceptible to kinetic fractionation." This sentence needs unpacking/rephrasing.

Page 19

Eq 13: Since this is not strictly a Péclet number you could reference it as a modified (enhanced?, dispersive?) Péclet number.

Page 20

Line 20: how are these values chosen?

Page 22

Lines 21-22: " Downward advection . . ." It should be clarified that these two sentences are based on previously reported results rather than new insights derived from this investigation. For example, "Previous studies (citations) have shown that . . ."

Page 23

Line 2: explicitly specify the correction or explain the correction in more detail

Line 20: source for the solution found in Eq (A3) to Eq (A2)?

Page 24

Line 2: "Nevertheless . . ." Need citation or rationale for why Eq (A2) can be used to calculate δ^15 N

Technical Corrections

Page 1

Line 14: "supresses" → suppresses

Page 2

Line 2: " . . . unconsolidated snow . . ." I think of firn as consolidated snow.

Line 10: "processes which" → processes, which

Line 14: "high resolution" → high-resolution

Page 3

Line 15: remove "the same amount of"

Page 4

Line 1: "Last" → Lastly

Line 3: "gradients and induce" → gradients that induce

Line 17: "DZ but the effective" → DZ but effective

Page 9

Line 7: change " becomes" to "simplifies to" (even though you already have "simplifies to" in the text just above)

Page 11

Line 6: "Kawamura (unpublished)"âĂĺ - might as well leave this out since you have another citation

Page 12

Line 4: "In the following we" → In the following discussion we

Page 13

Line 9: "Isotopes ratios are higher" → Simulated isotope ratios are higher

Page 15

Line 1: "the dispersivity" → dispersivity

Line 4: "estimate is within" → estimate of 2.8 m is within

Page 17

Line 17: ". . . 2013)as" → . . . 2013) as

Page 20

Line 13: “the isotopologues” → remove the “the”

Page 21

Line 20: ”at WAIS Divide” → at the WAIS Divide

Line 23: “75.9% almost” → 75.9%, almost

Page 22

Line 22: remove the “This”

Line 23: remove “clearly”

Page 23

Line 1: “these relationships” → these scaling relationships

Page 26

Line 10: “Movment” → Movement

Line 11: “seperation” → separation

Technical Corrections for Supplement

Page 2

Line 2: “q is a Nx1 vectors” → q is an Nx1 vector

Line 5: “off diagonals” → off-diagonals

Page 5

Line 1: “at all depth” → at all depths

Page 4

Fig S3: Does this figure indicate that there is a $\sim$ 35 year delay in the response of the

δˆ15 N profile due to the 3-day time step relative to the 3 day/5 $\sim$ 14 hr time step?

Page 6

Line 3: “Eularian” → Eulerian

Page 9

Fig S6: “Plot is shown at reduced grid resolution for clarity.” Is this plot in reduced grid resolution or is it a subset of the domain at the original resolution (or both)?

Page 11

Note: there is a gap in the text partway down the page

Page 12

Line 4: “firnf”?

Line 6: is there a reference for equation S28?

Page 13

Line 1: “serval harmonic”?

Table S1: for the WAIS Divide the daily pressure change is 5hPa. Does this mean that for a 3-day time step the pressure change is 15hPa? Or is the 3-day pressure change no more than 15hPa and is quasi-randomly attenuated to match a red-shifted spectra? Or ?

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