Editor / Review 3

In addition to the posted two reviews I have a comment from another reviewer, Jeff Severinghaus, which I will paste below as there was a complication getting this in the system. This review is very positive and just makes some minor comments for the authors to consider.

Review of “Combining traditional and novel techniques to increase our understanding of the lock-in depth of atmospheric gases in polar ice cores – results from the EastGRIP region”

Authors: J. Westhoff et al. March 20, 2024

This manuscript presents a novel and very interesting new method of determining the depth in an ice core at which air bubbles are effectively closed off, taking advantage of the optical properties of bubbles and ice. In polar settings, slow densification of the firn (porous ice) typically leads to formation of ice with trapped air bubbles after several hundred years.

In detail, the authors show that “bright spots” appear in the optical images around 61 m depth, very close to the depth that is found via classical methods for finding the depth of the bubble close-off. The authors make a convincing case that these “bright spots” have a mechanistic linkage to the ice properties at around 61 m depth. With their new optical methods, the authors show persuasively that the “bright spots” record a critical change in the firn geometry and structure.

They proposed that the “bright spots” are due to the creation of bubbles with semi-spherical geometry, which is known to produce bright reflections As such, the “bright spots” are shown to have a mechanistic and meaningful origin that can be further probed in the future. The authors also use traditional methods such as density measurements to verify the closure of bubbles at this depth. Overall, this is an excellent contribution to our understanding of the firn-to-ice transition in polar ice sheets, and represents a new and valuable metric of where the “classical bubble close-off depth” happens. I recommend that this work be published with only minor edits, as spelled out below.

Jeff Severinghaus, reviewer

Thank you for your very positive review. We will include your comments and suggestions for changes throughout the manuscript.

Minor and editorial comments:

Line 56 this would be made clearer for the reader by writing "inserted an inflatable rubber bladder"
We will add the suggestion for more clarity.

Line 57 perhaps this should be ¼ inch, not 1.4 inch? Normally the purge line is about 3/8" to ½" in diameter, and the air sampling line is ¼"
Thanks for pointing this out, yes it is ¼ inch. We will correct this.

Line 59 say "were monitored on-site during pumping to detect contamination issues…"
This will be changed.

Line 64 "and diffusive mixing in the vertical direction essentially stops" [This is an important distinction because many studies have shown that horizontal diffusion and advection can remain prevalent due to horizontal high-permeability layers (typically summer layers) even when vertical air flow is completely shut off]
Thanks for the note.

Line 72 "evolution of pore closure"
Will be corrected.

Line 78 for the reader, it might help to cite a ref here at 2), since thermal fractionation isn't widely known in the community. You could cite Severinghaus et al., 1998 Nature
We will include the citation to make it more clear.

Line 79 your interpretation of an extremum in 15N at 12 m from the previous winter's cold is mistaken - in fact the extremum at 12 m is due to the recent summer atmospheric warmth just months before the pumping. The reason is that the atmosphere cannot change its 15N, due to its virtually infinite reservoir, so the nitrogen gas in the top dozen meters of firn (which is colder than the atmosphere in local summer) must become fractionated with the heavy isotope 15N becoming enriched. The signal of the previous winter, on the other hand, shows at 18 m, with a slightly depleted 15N. See Severinghaus et al. 2001 (G Cubed) for a more complete explanation of the phenomenon, including a wintertime firn air sampling at South Pole along with the usual summertime sampling of firn air. As expected, the top 12 meters

of firn shows very negative 15N in winter (because the atmosphere is so much colder than the air in the firn).
Thermal fractionation of air in polar firn by seasonal temperature gradients – G-Cubed J. P. Severinghaus, A. Grachev, M. Battle 2001
Thank you for the correction and for pointing this out. We will add the reference and adjust the text accordingly.

Line 84 The slight decrease of 15N with increasing depth within the lock-in zone is well known to be due to global warming and resulting firn thermal fractionation over the past 4 to 5 decades, not to contamination. This effect has been extensively documented by Orsi et al., 2017. You should cite her work: *The recent warming trend in North Greenland , Geophysical Research Letters, AJ Orsi et al., 2017*
Thank you also for this input. We will adjust the text accordingly and include the correction and reference.

Line 91 Check your calculation of "almost 400 years of snow accumulation" in 66 m. It's probably more like 330 years. You have to take account of the fact that annual layers are quite thick in the upper part of the firn, with snow densities of only 0.35 to 0.55 kg per liter, in comparison to snow densities of 0.83 to 0.84 kg per liter in the lock-in zone.
The age at 66 m depth is 385 years b2k (Mojtabavi et al. 2020). We will add the reference to the age.

Line 109 Fix the statement "around 66 m the bubbles are essentially closed off". This is not consistent nor accurate, since the same sentence states that "layers with not fully closed pores can be found down to 71.5 m".
Will be changed to: "Layers with not fully closed pores can be found down to 71.5 m although many pores are already closed at 66 m depth."

Line 135 "11 cm annual layer thickness" This doesn't seem right – please check
According to Mojtabavi et al. (2020) one bag (55cm) in depth contains 5 years, which is roughly 11 cm layer thickness.

Line 213 It would be helpful to include a reference here on "percolation transitions" – which some readers might not be familiar with.
A reference will be added and a short explanation: the percolation transition is the transition of small and disconnected clusters merging into larger and connected clusters (Li et al., 2021).

Line 235 please provide a reference to “strangulation” – it is the first time this word is used in the paper, and many readers will not know what this means.

Thank you for noticing, we will clarify this, e.g.: ”...strangulation, reduction of gas exchange between layers, ...”