Review 2

General review:

The article addresses the intricacies surrounding bubbles and LIZ formation within the firn layer of the Greenland ice sheet, employing both traditional and innovative optical methodologies. This research holds significant importance in advancing our understanding of gas ages and their associated smoothing effects. However, the previous conventional methods fell short in capturing the the subtle intricacies of LIZ formation. The authors have introduced a novel term, the optical lock-in depth (OLID), and conducted a comparative analysis with conventional approaches. These novel findings significantly augment our understanding, and the interpretations offered are judicious. Nonetheless, the methods elucidated poses challenges in comprehension, necessitating structural and terminological refinements to enhance clarity. Editorial revisions are imperative prior to publication.

Thank you for the review of our paper. We do not have any objections to any of the review comments and will implement them into the new version of the manuscript.

Specific comments:

Line 20: What does $\delta^{15}N$ signify? Is it $\delta^{15}N$ of N_2? Please specify.

We will add information to lines 19-20 to increase clarification: Blunier et al. (2000) describe three zones derived from the gravitational settling of δ15N of N2: an upper convection zone, a diffusive zone, and a lock-in zone (LIZ).

Page 2, Move '1.3 Motivation' before '1.2 Site Locations' for better flow.

Will be done and the text adjusted. We will also combine the sections "variations between cores" and "site locations" for better readability.

Page 2, In section 1.1 or 1.3, describe the issues with previous conventional methods.

We will enhance the emphasis on the new method and its relevance:
New direct experimental constraints are especially useful for a complex site that challenges model limitations. The EGRIP site is affected by strong horizontal ice flow influencing firn densification and structure, as well as climate change further inducing time variations in firn temperature and snow accumulation.

Line 32: Can you provide coordinates for the S2 location?

Will be provided for the revised manuscript.

Figure 1c caption: why is the photo from Little Dome C shown? Did you use the same equipment? Please clarify this choice.
Yes, the same equipment was used. We will clarify this in the text.

Lines 48 and 50: should not be broken into separate paragraphs.
This will be changed.

Line 59: Specify what you mean by "issues".
Will be added: … issues, such as leakages in the system or sucking air from other stratigraphic layers, …

Line 81: absence of gravitational enrichment => absence of further gravitational enrichment?
Correct – will be changed accordingly.

Figure 2b caption: transition depth of '58 m'? It is not likely to be about 60 m. Refer to text at Line 96.
58 m is the change of slope, between the two values.

Figure 2f caption: Witrant et al. 2012) => Witrant et al. (2012)
This will be corrected.

Line 96: Explain why the top of the LID is differently defined using data of $\delta^{15}N\text{-}N_2$ and CO_2 concentration.
This difference is illustrated in a multi-sites perspective in Table 2 of Witrant et al. (2012). In terms of gas transport, on one hand CO_2 is more affected by diffusion than gravitation due to its important atmospheric time trend which induces a strong concentration gradient between the top and the bottom of the firn that diffusion tends to reduce. On the other hand $\delta^{15}N\text{-}N_2$ is more weakly affected by diffusion due to the absence of atmospheric time trend and relatively more affected by gravitation as well as advection due to the sinking of firn layers. Together with the site-dependent abruptness of gas transport reduction around the LID, differences in the behaviors of CO_2 and $\delta^{15}N\text{-}N_2$ may occur. They may also respond differently to time variations in firn temperature or snow accumulation.

Line 104~107: Add more reference. Similar features were reported also in Mitchell et al. (2015) and Jang et al. (2019)
References will be added.

Line 108: Erase '(fig. 2c)'
We will erase the double mentioning of figure 2c.

Line 127: Even the green line in fig. 2d does not well matched with the CH4 concentrations in high density layers (minima of CH_4 concentration). The authors may suggest plausible reasons.
The model limitations for simulating the complex EGRIP site and influence of the open/closed porosity parameterization will be further discussed (see also answers to first review).

Line 156-158: Mention other definitions of the close-off zone. Consider citing Martinerie et al. (1992).
Thank you for suggesting this, we will add the citation.

Line 161: Between 55 and… => Between 50(?) and…
That is correct and we will correct the value.

Line 165-174: Specify that details of observations are described in Appendix C.
Will be explained in the main text and we will point towards appendix C.

Figure 4 caption & Line 181: please define 'pixel value'
Thank you for noticing. This is clearly missing and will be explained.

Figure 5a caption: please address Appendix B if it is related to the method.
The relation will be established.

Line 221: Define 'percolation transition'
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 227: Specify 'clusters'
Clusters of bubbles (will be added)

Line 231: add Jang et al. (2019) to the references
Will be done

Line 241: Define 'maximum pixel value'
Reference to "maximum" in fig. 2a will be added for clarification and a short comment included. .

Line 273-274: Address 'Appendix D' where the 'pixel values above 20' are described.
We will address the appendix and include more of it in the main text.

Line 281: 55 to 58 m depth => 55 to 58 m depth?
Correct, "55 to 60" will be changed to "55 to 58".

Line 298-299: Change 'agree very well' to 'agree well'. We see a difference in the LIDs defined by CO_2 and $\delta^{15}N\text{-}N_2$
Will be changed.

Line 325-336: Relocate and shorten 'Appendix A' in the main text's site description section.
We will include Appendix A into the main text.

Figure D1b: Specify the meaning of 'gray value' on the y-axis label? Is it the pixel value?
Will be changed to pixel value for consistency.

Line 432: Erase 'Appenix:'
Will be erased

Refercence:

Martinerie, P., Raynaud, D., Etheridge, D. M., Barnola, J. M., and Mazaudier, D.: Physical and Climatic Parameters which Influence the Air Content in Polar Ice, ***Earth Planet. Sc. Lett***., 112, 1–13, https://doi.org/10.1016/0012-821X(92)90002-D, (1992)

Mitchell, L., Christo Buizert, Edward Brook, Daniel Breton, John Fegyveresi, Daniel Baggenstos, Anais Orsi, Jeffrey Severinghaus, Richard B. Alley, Mary Albert, Rachael H. Rhodes, Joseph R. McConnell, Michael Sigl, Olivia Maselli, Stephanie Gregory and Jinho Ahn. Observing and modelling the influence of layering on bubble trapping in polar firn, **Journal of Geophysical Research**, 120, doi:10.1002/2014JD022766 (2015)

Youngjoon Jang, Sang Bum Hong, Christo Buizert, Hun-Gyu Lee, Sang-young Han, Ji-Woong Yang, Yoshinori Iizuka, Akira Hori, Yeongcheol Han, Seong Joon Jun, Pieter Tans, Taejin Choi, Seong-Joong Kim, Soon Do Hur and Jinho Ahn, Very old firn air linked to strong density layering at Styx Glacier, coastal Victoria Land, East Antarctica, ***The Cryosphere, 13, 2407-2419*** (2019)