Review for *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* by Westhoff et al.

General Comments:

The authors present and interpret new optical data to investigate the LID and bubble close-off in an EastGRIP ice core. The method is novel, and the data could be the basis for a strong paper. Nonetheless, I have significant concerns about both the organization and the strength/clarity of the scientific reasoning presented in the manuscript.

One major concern is that the manuscript focuses primarily on the OLID, but the scientific motivation for determining a specific OLID is not clear. The results plotted in Figure 2d and f and Figure 7 have more importance in the broader scientific context of understanding bubble close-off and delta age, given the obvious shortcomings of the Goujon/Barnola parameterization. If the OLID is not the actual motivation, the authors might consider broadening the focus to the depth-range of bubble close-off and the associated implications for delta age.

A second major concern is that the exact methodology for finding the OLID and the "bubble proxy" is poorly explained. As the authors state, this is a new methodology, and it needs to be very clear to the reader. Sections 3.2-3.3 are spent describing and interpreting data from a new method, which the reader has no way of understanding. The information in section 3.4 and Appendices A-D should be given before the data is presented and interpreted.

Specific Comments:

Section 1: The scientific motivation and larger context for this study are poorly defined. Namely, why pursue an optical method for determining the LID? Or, stated another way, what do we learn from 58.3 m that we didn't learn from 58-61 m? Does it provide more precise information about the delta age? If so, more time should be spent discussing the importance of delta age and the physical site characteristics that control it. Section 1.3 is labeled "Motivation," but it summarizes the paper rather than providing scientific motivation.

Section 2.1: This section should be combined with 1.2 and should probably come after the Introduction.

It's not clear which sites are affected by compaction due to flow.

An additional note: Here and throughout the paper, EastGRIP and S6 seem to be used interchangeably. (For example, Figure 2e is labeled EastGRIP open porosity, but I assume it is the same firn air pumping campaign from S6 that is plotted in 2a and 2b). Please clarify throughout the paper

Figure 2: please comment on the data gap between 72 and 75 m in 2c and 2d.

Section 2.3.4: Did the authors consider trying the Mitchell et al., 2015 parameterization, which has a more gradual bubble close-off? How realistic is the modified porosity profile relative to other measurements and parameterizations? The tracers used to tune the model should also be clarified.

Section 3: Overall, the clarity of the scientific reasoning in this section needs improvement.

Section 3.1: It is not clear whether these measurements were made as a part of this research or if they are previously published. If they are previously published measurements, they should be cited.

Section 3.2.1-3.3: The information in section 3.4 and Appendices B-C is necessary to understand these sections. Please reorganize.

The geometry of the 1x5 cm^2 relative to the 165 cm slab is not clear. A figure similar to 2h in Westhoff et al. (2020) would be clarifying.

The "bubble proxy" is not explained:

1) Does one bright spot correspond to one bubble?
2) How is a "bright spot?" defined? Why use one pixel cutoff value versus another?
3) Can a single bright spot be more than one pixel?
4) Can a bubble be more than one pixel?
5) Is the proxy qualitative or quantitative?
6) Is the basis of the proxy empirical or theoretical? If theoretical, section 3.4 needs additional details.

Figure 5b: please explain the different pixel cutoff values. It appears that the results are quite sensitive to the choice of 60.

3.3 is labeled "Density and Visual Stratigraphy derived lock-in depth," and the authors seem to infer that the density measurements suggest the LID is the 58.3 m layer but L162 states: "Between 55 and approximately 67 m depth, density values lie between 790kg/m3 and 830kg/m3, suggesting this to be the LIZ." Please clarify.

Section 3.4: This section is the crux of the methodology/proxy and therefore needs more scientific justification. It also needs citations. It is not enough to draw a picture of what may be happening without explaining the underlying optical physics:

1) Why is it only closed spherical bubbles that make bright spots? What about mostly spherical pores that aren't completely closed off? It seems like any curved air/ice interface could potentially act as focusing lens if it is oriented correctly?
2) Section 3.2.1 describes light "reflection, refraction, and scattering" but Figure 6 shows light refracting and focusing. Please clarify.
3) What is happening with the closed pores between 50 and 58.3 m? Are the closed pores in that depth interval "odd shaped" and they ultimately evolve towards spherical?
4) What is the evidence for closed pores at 50 m? It does not appear to be from the line scan data.

It seems like a melt layer such as the one mentioned in 3.1 would make an effective impermeable layer, potentially preventing diffusion without producing any bright spots. Please address this.

Section 3.5:

The relationship between layering, bubble close-off, and the LID Is not clearly explained. Please clarify.

The text implies that the presence of a single bright spot is evidence that a layer is impermeable. But, if a single bright spot corresponds to a single bubble, that does not make sense. Please clarify.

"Some layers have bright spots, while others appear darker (d), going hand in hand with the number of bubbles we find (e)."- e) only shows number of bright spots… please explain what is meant by "number of bubbles you find" Is it just the number of bright spots? Do the maximums in pixel value correlate to maximums in bright spots? If so, please make a plot that shows the covariance or do a statistical test because it is not obvious from Figure 5d-e. Please clarify.

Section 3.6.1- The information in appendix D is necessary to understand this section. Please reorganize.

It needs to be mentioned these calculations are done using closed porosity from parameterizations, not data here.

Section 3.6.2

This section is potentially useful for improving understanding of delta age and the age distribution of air trapped in polar ice. I recommend a more detailed discussion here.

Can you show the Mitchell parameterization of Figure 7? Or even better implement it in the firn air model?

Section 3.7

The authors state that there is a correlation between closed pore space and image brightness, but it is not clear where the information about closed pore-space is coming from unless it is the image brightness. Please clarify.

Section 4

This should just be "10-50" years, not "± 10-50 years." Moreover, the mixing delay should be easy to calculate with the firn air model. Why not use that instead of Schwander's "typical number?"

Additionally, the authors state earlier in the paper that some closed porosity forms as shallow as 50 m. This is not accounted for in paragraph 2. Please address.

Section 5- please rephrase this first sentence “It is important to…”

Other stylistic notes:

Phrases like “hand in hand” (L243) and “has been around for a long time” (L230) are not appropriate for a scientific manuscript. I suggest something like “Layering in the LIZ can influence bubble closure (Blunier et al., 2000; Fourteau et al., 2019)” and “The maximum pixel brightness covaries with the number of bright spots” at those lines.

In general, please carefully proofread the grammar and give some careful thought to phrasing. There are many opportunities to make the writing clearer and more concise. For example, L296-297 could be revised to:

“All the data presented in this work indicate that the transition between the diffusive and non-diffusive zone in the EastGRIP area occurs between 58 m and 61 m.”

And line 283-284

“Density measurements and visual stratigraphy data can reveal more details about the firn-ice transition.”

Please clean up figure axes and axes labels. Some labels are left justified, and some are centered. Centered is best throughout.