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Interactive comment on "Very old firn air linked to strong density layering at Styx Glacier, coastal Victoria Land, East Antarctica" *by* Youngjoon Jang et al.

Anonymous Referee #2

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The manuscript presents a fairly large new dataset allowing to characterize the gas transport and trapping at a new firn air pumping site: Styx glacier. It is a very interesting site, with very old air (∼90 years) in the open porosity of the deep firn. The few previously documented sites with similarly old air undergo lower accumulation rates. The manuscript provides an overall convincing interpretation relating the older than usual ages to a wider than usual lock-in zone with a larger density variability possibly related to a wind effect on snow metamorphism.

General comments

I am surprised to see no convective zone in δ^{15}N data of this windy site (Figure

3d). A check with the barometric equation (Equation 3 in Sowers et al. (1992), cited by the authors) confirmed it. Could the authors comment the absence of a large convective zone? An overestimation by the firn model of both CO_2 and CH_4 data at the two deepest levels suggests that the diffusivity and/or dispersion used may not be optimal, and the resulting gas ages too young (see also comment on line 183), this point should be checked and the adjustment method for diffusivity and dispersion should be described. The gas age distribution width in deep firn should be shown and commented (see also comment on l197-199). The authors sometimes used ancient but not the oldest bibliographic references or recent but not the most recent in a somewhat surprising way (see suggestions below). There are instances of clumsy drafting (see technical corrections) sometimes making the text difficult to understand (see for example comments on lines 145, 225-226, 287-288), a careful reading by a native English speaker should help improving the manuscript.

Specific comments

l28-30: This sentence could apply to DE08 which shows distinct layering (Martinerie et al., 1992, cited in the manuscript) but very young air in the open porosity due to its high accumulation, please reformulate.
l37: I would also quote Schwander et al., 1993 (cited elsewhere in the manuscript) that reports the first firn air pumping operation.
l45-46: gas trapping in ice is still an active area of research (e.g. Schaller et al., 2017, cited by the authors), thus the expression "the typical close-off density" without a clear definition should be avoided. Here the authors could simply quote a range of density values for example.
l49-50: age distributions are also shown in Schwander et al. (1993).
l63: use consistent terminology: the full close-off depth Zcod (as p5 l130).
l64-72: this section uses a common term "COD" for different evaluation methods of different firn properties. For example, some concepts refer to a mean bubble closure level, and other to complete bubble closure. It should be clarified and/or shortened.

l73-75: this is not entirely true. Buizert et al. (2012a, cited by the authors) showed that all models in the intercomparison study need a non-zero diffusivity in the lock-in zone to simulate the reference gas profiles at NEEM (see for example the abstract or conclusion), which means that the gas transport speed remains different from the surrounding ice advection.
l120-121: I am surprised to see that no co-author is affiliated to SCRIPPS and SCRIPPS personnel is not mentioned in the acknowledgements although the manuscript includes new δ^{15}N data measured at SCRIPPS (Fig. 3d).
l132: I did not understand which other variables are presented in Table 1.
l145: does the standard air used for calibration originate from NOAA?
l152 and 156: δD data are not shown or commented, thus the corresponding equation and precision should be suppressed.
l149: the δ^{18}O results shown (Fig. 2) are near surface measurements (surface to 1.6 meters depth) rather than deep firn data, thus this introductory sentence should be modified.
l172-173: I don't see a clear correlation between hardness and density in Figure 2b. However, the processes producing snow layering are complex and these parameters are not necessarily correlated. For example, a recent study of a wind event concludes that sintering is not the dominating hardening process and that hardness variability could not be adequately explained (Sommer et al., 2018).
l181: the references of the up-to-date Australian and French models should be preferred to ancient versions in this context (Trudinger et al., 2013; Witrant et al., 2012).
l183: at the two deepest firn sampling levels, the model overestimates both the CO_2 and CH_4 concentrations while SF_6 has already dropped to zero. It thus seems that reduced diffusivity and/or dispersion in deep firn would improve the results and increase gas ages, the effect of using a slightly different accumulation rate could also be investigated. As gas age in deep firn is a major conclusion of the manuscript, this discrepancy should be investigated.

l197-199: a high accumulation also tends to reduce the gas age distribution widths, and thus provide stronger constraints for atmospheric trend reconstructions. Therefore age distributions in Styx glacier deep firn should be shown and the comparison with Megadunes (Severinghaus et al., 2010, Supplementary Figure A3) and South Pole (Trudinger et al., 2013, Figure 13) commented.
l205: the density layering effect was already shown by Stauffer et al. (1985).
l209-210 and Section 3.3: the importance heterogeneities in gas records at Styx compared to other sites is difficult to appreciate as no quantitative comparison is performed. This could be improved for example by comparing the Styx results with WAISD (Figure 2 in Mitchell et al., 2015), where a very similar methodology was used.
l214 and Figure 5: the scale of Figure 5a is inappropriate to properly appreciate the correlation between CH_4 and air content, it could be enlarged in order to use the full page width.
l239 and elsewhere: replace "COD" with full COD or FCOD each time it refers to the approximate level of complete bubble closure.
l248-249: Witrant et al., 2012 (cited in the manuscript) also reported LIZ thicknesses at different sites (see their Figure 9), this should be mentioned. Moreover, they report reduced diffusivities (and thus older air ages) at a site with another kind of heterogeneities: numerous refrozen melt layers, this Devon Island site could be mentioned too.
l255-257: this relationship was updated in Martinerie et al. (1994), it should be mentioned although I expect the impact on the ρ_{crit} estimates to be small.
l259-260: a parameterization of the lock-in density was proposed by Bréant et al., 2018 (Equation 10).
l265-267: I am not convinced that σ_p/A is a good indicator of air ages because the site having the second highest σ_p/A after Styx is Dome C which undergoes a narrow LIZ, small accumulation and young air ages (Table 1). Thus I suggest to suppress the last column in Table 2 and related comments.
l287-288: I did not understand if westerly winds prevail during or between blizzard

events, and what is meant by “particles of snow can be sorted”.
l475: critical porosity thresholds (see Section 3.4).

Figures 2c and 2d: a scale should be provided on the pictures.
Figure 4 shows CO_2 age data versus depth at 8 other sites than Styx without methodological indications or references. Either references or a methodological description (for new data) should be provided (possibly in a Supplement).
Figure 7: it is obvious in this figure that ρ_{crit} and the air content related definition of the COD is different from the full COD where all the porosity is closed. This is why it would be less ambiguous to use the term full COD or FCOD than COD in the manuscript when it refers to complete porosity closure.
Table 1 column 4: indicate which gas is used for the age estimation.

Technical corrections
l35: suppress “those”
l52: into three zones:
l56-57: molecular diffusion is the dominant mechanism of trace gas transport in interstitial air
l77: remove “-”
l88: composition
l90: resolution, composition
l105: suppress “that of”
l135: in the firn was measured
l135-136: University using a thawing and refreezing air extraction method
l136-137: discrete firn samples
l140-141: in the flask placed in a cooled
l172: depth hoar
l217: content

l218: and the variability is reduced in deeper layers
l225-226: can induce inhomogeneous records and help constraining the gas age distribution in ice
l227: Fourteau et al. (2017) is not in the list of references
l235: shallowest depth where
l264: (Hörhold et al., 2011; Fig. 7 and Table 2)
l280: Using a snow accumulation rate of
l286: blizzards occur
l299 and 304: variations in the LIZ
l433-435: incomplete reference

References not cited in the manuscript
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