Dear editor,
Thanks for your comments. We followed all your suggestions. Please find in the following our respective responses to the comments (in blue) and our proposed changes for a potential revised manuscript (in blue and in italic).
Sincerely
Susanne Preunkert

Response to the editor comments

Editor:
Your manuscript has now received two detailed peer reviews that highlight the strengths and shortcomings of the manuscript. The reviews were constructive and supportive of your work. They each identified specific issues that would need to be addressed in a revised version of the manuscript in order for potential future publication in The Cryosphere. Thank you for your Author Comment responses to these reviews. I find your responses, proposed changes, and already modified drafts of figures to be promising. As you no doubt noted while preparing your responses, both reviewers (as well as myself) felt muddled in finding the story and sequence of events that the crevasse went through in order to generate the situations observed in the three boreholes. I believe that clarifying this will be an important component of your revision.

I have a number of comments, in no particular order, that originated as I read the reviews, responses, and the manuscript again. Please take these, as well as your Author Comment responses, into account in your revision.

- The proposed revisions to Figure 5 are helpful. I would benefit from seeing the approximate time (e.g. 1995-2000, or whatever you estimate) marked on each schematic (b-c) or noted in the caption.

Thanks for this comment, these dates are now added in the figure caption (see below).

- I would reiterate both reviewers' requests that the sequence of events that the crevasse went through be reported more clearly. This should not involve parenthetical ties to the data, as you currently propose in the revision. Rather, give the narrative story that you propose for the crevasse up front, and then in subsequent paragraphs, explain how the data support that story uniquely. One way to achieve this would be to move Figure 5 to appear much earlier in the manuscript, perhaps as Figure 2. This would give your readers an early encounter of what you propose and would allow their understanding to develop as they read your data. My understanding of your manuscript is that the crevasse story is the primary takeaway, and the new datasets (210Pb, nitrate, etc.) are also new scientific contributions, but they are secondary and are in support of the crevasse idea. Thus, they should appear as later figures than the crevasse figure.

Thanks for your comment. We understand your concern and the concern of the reviewers about this point, which we have tried to address in what we hope is a suitable compromise. We followed your idea to present the crevasse in more details at the beginning of the manuscript. To do so, we introduced the crevasse clearly in Section 2 and moved Figure 5 (now Figure 2) just after Figure 1. With that, the reader will indeed be aware of the crevasse location with respect to the drill site, the fact that it changed over time and the effect of 222Rn and 210Pb accumulation in the crevasse under sealed conditions. However, we believe that we cannot discuss further the evolution of crevasse before adequately discussing all data presented in Section 3. Only through the data presented here the magnitude and temporal extent of this effect becomes evident, which is the basis for discussion the evolution of the crevasse. Therefore, we think that the detailed discussion about the crevasse should stay in Section 4, constituting the synthesis part of the manuscript.
The proposed respective paragraph added to Section 2 would read as following in the revised manuscript.

"...Ice flow, firn compaction and thermal regime have been modeled in three dimensions by Gilbert et al. (2014), allowing particle back-tracking and flow-based estimation of the depth-age relationship for the drilling site.
Recent visual observations made on the CDD glacier attest to the presence of crevasse(s) upstream the CDD drill sites (Fig. 1). Comparing photos taken in 2012 (Fig. 1a) and in 1999 (Fig.1b), shows an enlargement and horizontal propagation of the crevasse to the east from 1999 to 2012. Whereas in 2012, the crevasse is visible clearly as a snow-covered depression on the surface slope, the crevasse appeared to be limited to the southwestern flank of the drill site catchment area in 1999. Following Fig. 1, the crevasse is situated ~100-150 m upstream of the drill site of C10, CDK, and CDM. Figure 2a shows the CDD glacier thickness changes between 1993 and 2017 overlayed with the modelled flow line indicating the calculated arrival depths at the drill site of C10, CDK, and CDM (Gilbert et al., 2014). Crevasses open and close constantly during their lifecycle (Colgan et al., 2016). Fig. 2b and c represent vertical cross sections along the modelled flow line of Fig. 2a overlayed by sketches of the upstream crevasse visible in Fig.1, in two temporal states of the crevasse from the 1960ties to the 1980ties, as concluded in Section 4 on the basis of C10, CDK and CDM ice core data presented in Section 3.
.."

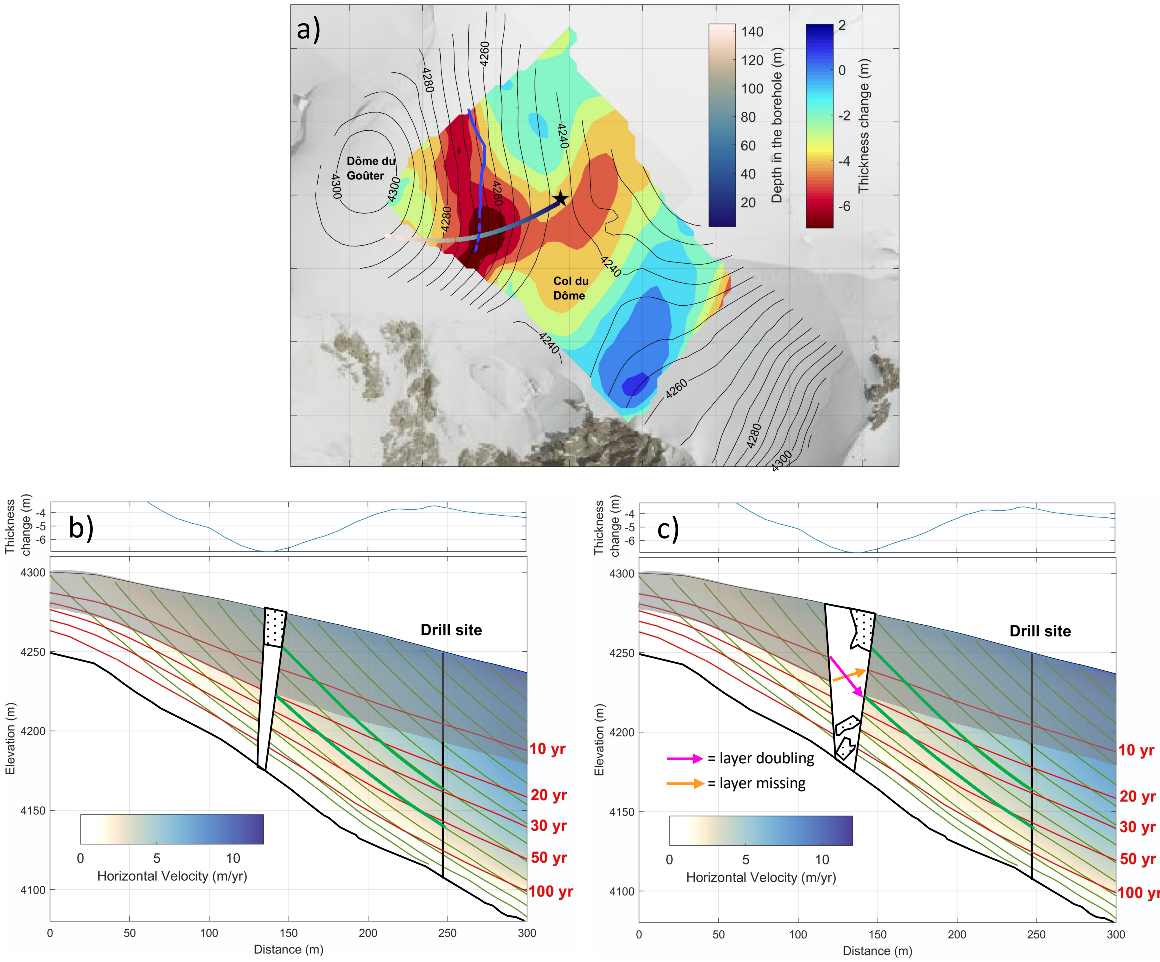

Figure 2: (a) Thickness changes between 1993 and 2017. The contour lines of surface topography correspond to the 1993 surface (adapted from Vincent et al., 2020) overlain by a modelled flow line (color scale on top) which reports the calculated arrival depth at the drill site of C10, CDK, and CDM (black star) (Gilbert et al., 2014). The crevasse location (blue line) is based on the 30^{th} June 2004 aerial photo from IGNF (see Fig.1) (b and c) Schematic representation of the origin of the ^{210}Pb anomalies found at the drill site following the ice flow model of Gilbert et al., 2014, extracted along the flow path reaching the drill site. Isochrones are marked in red, flowlines in green (see also Section 4). The grey shaded zone indicates firn, the dotted zone indicates the snow bridge over the crevasse. Concluded from ice core data of C10, CDK and CDM (see Section 3 and 4), two states of the crevasse are reported: (b) in the years ~1965-1970 (i.e. ~ 25-30 years before the C10 drilling) the crevasse is open to the bedrock but sealed from the atmosphere by a snow bridge. In this state ^{222}Rn and ^{210}Pb accumulate to reach concentrations well above atmospheric conditions in the crevasse and the surrounding firn (c) after ~1975 and at least until ~1990 (i.e. ~ 25-30 years before the CDK and CDM drilling), the crevasse is at least partly open to the atmosphere. In this state ^{222}Rn and ^{210}Pb concentrations in the crevasse and the surrounding firn are strongly reduced compared to (b). The formation of missing or doubling ice layers is indicated by the orange and pink arrows.

- It is not clear to me how the addition of two new samples to the Vincent et al. (1997) record would explain the significantly greater 210Pb activity peaks in the new C10 data. Please clarify your proposed revision in response to Reviewer 2's question about these peaks.

We apologize for the confusion related to the fact that our data differ from those in Vincent et al. (1997) but since the data were measured such a long time ago, we have forgotten that there were the differences of the two peaks in the two data sets. Sorry for that.

For your information, in the year after the study of Vincent et al. (1997) was published, a few further 210Pb spot checks measurements were made at LGGE on the C10 ice core using ice core samples instead of drilling chips this time, to confirm (or not) the enhanced 210Pb levels found in C10 and measured on the drilling chips. These additional measurements included also the C10 core depth sections for which Vincent et al. (1997) did not assign values since the high 210Pb values raised at a first-time doubt of contamination. Since the second measurements confirmed however the results of the first sample measurements, we kept the two 210Pb peaking samples (from94.8 to 97.3 m and 101.3 to 104.7 m) in the data set.
This is the main difference between the Vincent et al. (1997) and our dataset. We revised our proposed revision of this point in Section 2 and give now more details about the two samples which are included in our data but not included in the original dataset of Vincent et al. (1997).

"Note that, the dataset from Vincent et al. (1997) was complemented by two additional samples for which ^{210}Pb analysis and quality control were not available in 1997. Initially suspected to be contaminated, these two samples, containing 760 and 460 mBq kg^{-1}of ^{210}Pb, were not included in the dataset reported by Vincent et al., 1997. Re-measurements of the respective ice core sections using samples extracted from the inner of the core confirmed however the initially measured values, hence they must be considered as valid and were included in the data set of this study.

To avoid further confusion, we re-compared our data set directly with the data given in Fig. 5 in Vincent et al. (1997). All data points have the same ^{210}Pb level except the data point between 97.3 to 101.3 m. This sample indicated an excess of 50 mBq kg^{-1} compared to our data set probably due to the second series measurements made after 1997. To keep (except the two added samples) one unique data set in literature, this data point was aligned in our series to match now with the ones given by Vincent et al. (1997).

- The decay chain leading to 210Pb should be better described in the Introduction or Methods (perhaps Section 3.2, where 210Pb is described extensively). The proposed change, to mention this parenthetically in Section 4, would not be helpful enough. This needs to be more prominent and upfront.

Thanks for this comment, the decay chain of ^{210}Pb is now detailed at the beginning of Section 3.2. Our proposition for the revised manuscript is:

"..Figure 5 reports the ^{210}Pb (half-life of 22.3 years) depth profiles of C10, CDK and CDM. ^{210}Pb is produced through radioactive decay from the noble *gas ^{222}Rn (half-life of 3.8 days), which is an intermediate product in the normal radioactive decay chain of thorium and uranium, and emitted from the ground. ^{222}Rn is almost entirely produced from Radium in soils, in particular when granitic rocks are present. ^{222}Rn is released from soils into the atmosphere (Dörr and Münnich, 1990; Turekian et al., 1977), and its atmospheric sink consists in its radioactive decay producing ^{210}Pb, which becomes immediately attached to submicron aerosol particles (Whittlestone, 1990; Sanak et al., 1981). "*
"

- I very much like the proposed Figure S2, which shows the 210Pb records for both C10 and C11 cores. Rather than adding a supplement, I would suggest that this simply be swapped in for panel c on Figure 4.

Ok, we swapped Figure S2 in Figure 4c (will be Figure 5c) in the revised manuscript.

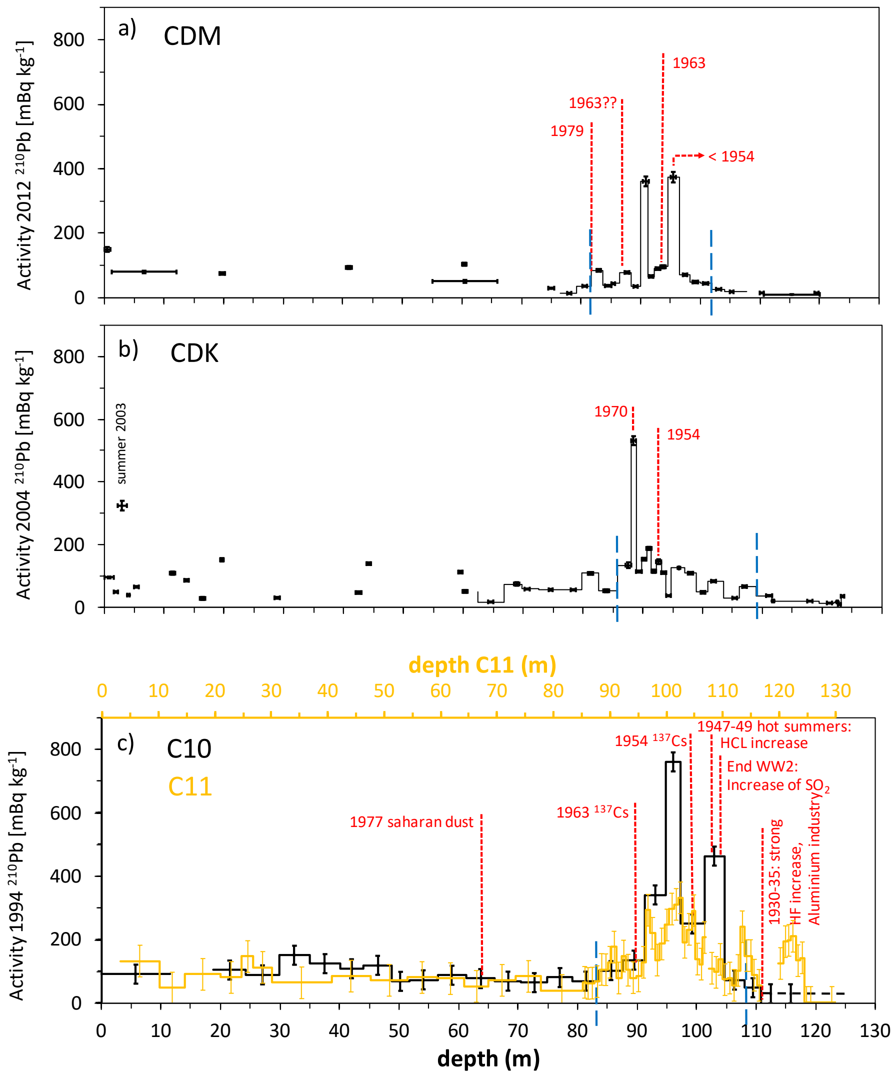

Figure 5: ^{210}Pb profiles of the three CDD ice cores. The decay-corrected ^{210}Pb activity is shown using the drilling year of the respective ice cores as reference. For CDK (a) and CDM (b) the depths covered by the samples are plotted with thick black lines, whereas the thin integrating lines are given to guide the eye and were used to calculate the ^{210}Pb inventories. C10 ^{210}Pb data (c) (lower x-axis, black) from Vincent et al. (1997) and this study are compared to the ones of a 140 m long ice core extracted 30 m away from C10 in 1994 (Vincent et al., 1997, denoted here as C11, upper x-axis in c, orange). The depth scale of C11 was matched to achieve an overlay of the depths in 1963 and 1954 obtained from the respective ^{137}Cs signals. Blue dashed vertical lines indicate the approximate boundaries of the anomaly. When available, absolute time markers detected over the ^{210}Pb perturbed depth zones are also reported.

Response to reviewer

We thank referee#1 for reviewing our manuscript and we much appreciate his suggestions which helped improve the manuscript. Please find in the attached pdf our responses to the comments (in blue) and our proposed changes to a potential revised manuscript (in blue and in italic):

RC1: 'Comment on tc-2022-259', Anonymous Referee #1, 28 Feb 2023 reply

Review of Preunkert et al." Impact of subsurface crevassing on the depth-age relationship of high alpine ice cores extracted at Col du Dome between 1994 and 2012

Preunkert et al. compare the records of three ice cores drilled at Col du Dome, near Mont Blanc in 1994, 2004, and 2012. The age scale appears intact in the 1994 core (C10) while the age scales are disturbed in the 2004 (CDK) and 2012 (CDM) cores in the time period of the 1950s and 1960s. The dating is primarily established by annual layer interpretation of ammonia, but the disturbances are primarily identified by the complexity of the H3 and C137 records. They ascribe the disturbances to the presence of a crevasse upstream. The crevasse, which is sealed near the surface by a snow/ice bridge, allows the accumulation of Pb210 due to the granitic bedrock. I believe the primary argument is that the dated ice in the 1994 core originated when the crevasse was smaller and did not yet intersect the flow path reaching the ice core site. The 2004 and 2012 were disturbed, however, because the crevasse had enlarged and intersected the flow path.

Preunkert et al. present high quality measurements of a large variety parameters and provide a plausible explanation for the disturbed stratigraphy in the two later cores. The use of the bomb horizons to evaluate disturbances is an interesting application. The primary conclusion that care must be taken in interpreting alpine ice core timescales is well supported. The mechanisms of layer skipping and layer doubling is well established. I have a few suggestions to improve the manuscript and make the argument more convincing.

The extension of the crevasse through time should be presented in more detail. A plan view of the extension would be very helpful. The photos in Figure 1, particularly 1b, is quite poor. Given the popularity of Mt. Blanc, it seems like a long record of photographs exists to validate the hypothesis of crevasse extension. Mapping of the crevasse through time would significantly improve the plausibility of the proposed mechanism.

Thanks a lot for this comment and the good idea concerning the mapping of the crevasse over time. Unfortunately, it was not possible to find photos showing precisely that view on the Dome du Gouter and the crevasse. Given the high accumulation at the site (around 2 mwe per year, i.e. 4-6 m of snow per year at the location of the crevasse), it is not surprising that it is partly and temporarily closed and hard to see on the photo.

We checked on the web, and found many photos showing the slope which rises to the Vallot Observatory (and the photogenic ridge rising at the Mt Blanc), but hardly any from Vallot showing the Dome. We asked colleagues, and we rechecked our own collection of photos from the site, but the one that was included is the best we found from the period around the year 2000 or earlier. Therefore, we have to stay with the original photo.

A plan view of the crevasse is assigned in Figs. 1 and 5 on the basis of an aerial photo (from 2004) from the Institut national de l'information géographique et forestière (IGNF). In this database, we found one photo among many in which one could at least imagine the crevasse. In the original manuscript the line was however drawn too thin. This is changed now and in both Figs. the plan view of the crevasse is better indicated.

I found the discussion of Pb210 and Rn222 to be rather confusing. I didn't see any data on Rn222 presented and am unclear how this fits into the Pb210 and crevasse story.
As stated in the introduction of the manuscript, 222Rn (half-life of 3.8 days) is emitted from bedrock, especially from granite. 222Rn is the radioactive gaseous precursor of 210Pb (half-life of 22.3 years). Thus, 222Rn is the source of 210Pb which is produced through radioactive decay. This important relation will be emphasized in the beginning Section 4: "*Furthermore, since the ^{210}Pb anomalies are restricted to a specific depth zone in the cores, we assume that exchange of the gaseous ^{222}Rn (i.e., the radioactive precursor of ^{210}Pb) with the atmosphere is restricted or eliminated at the top by the presence of a snow-bridge containing horizontal summer ice layers such as ….*"

The authors also reference Pb210 record from 30m away, but this is not shown. It would be helpful to see how this compares to the C10 record and strengthen the arguments.
A comparison of the 210Pb record of the C11 ice core drilled 30 m away with the C10 record will be shown in Fig. S2 of the Supplement:

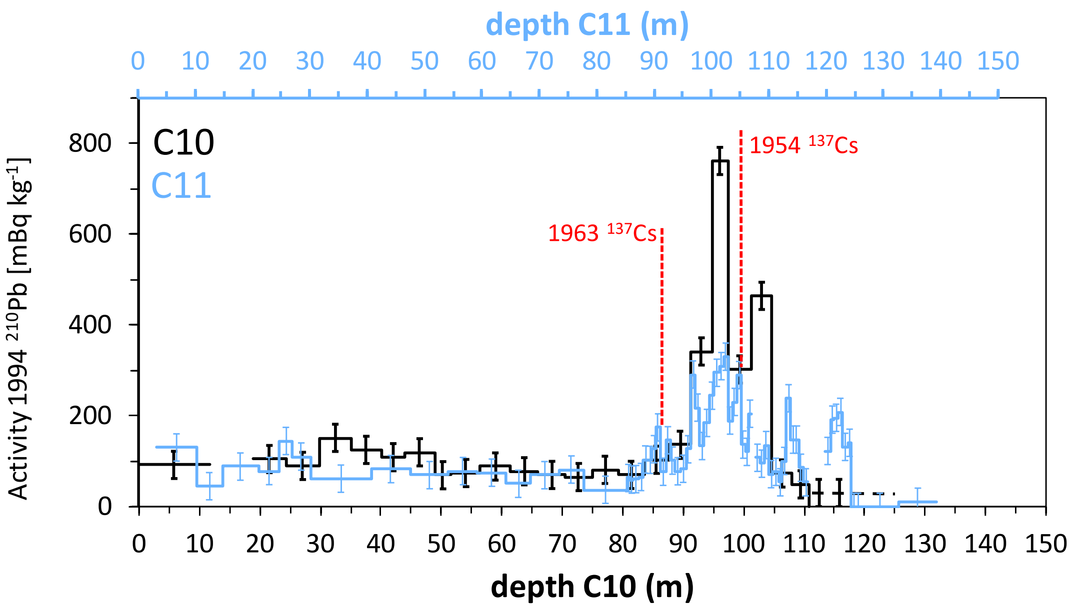

***Figure S1:** ^{210}Pb profiles of the CC10 (lower x-axis, black) compared to the one of a 140 m long ice core extracted 30 m away from C10 in 1994 (Vincent et al., 1997, denoted here as C11, upper x-axis, blue). The decay-corrected ^{210}Pb activity is shown using the drilling year of the two cores as reference. The depth scales of both cores were matched to achieve an overlay of the depths in 1963 and 1954 obtained from the respective ^{137}Cs signals. C10 and C11data are from Vincent et al., 1997. C10 data were completed in this study.*
.

But mainly I remain unclear on why C10 is more enriched in Pb210 if the ice did not intersect the crevasse.

As mentioned above, the point is that the source of 210Pb is the noble gas 222Rn which is an intermediate product in the normal radioactive decay chain of thorium and uranium, and emitted from the ground. 222Rn (half life of 3.8 days) can diffuse in porous snow and firn material and decay to become 210Pb there (half life 22.3 years). The layers enriched in 210Pb would them become part of the ice column and be transported by ice flow. Therefore, 210Pb can be enriched without a direct intersection of the crevasse with the ice core.

We will clarify this point in in the beginning Section 4:

"*Furthermore, since the ^{210}Pb anomalies are restricted to a specific depth zone in the cores, we assume that exchange of the gaseous ^{222}Rn (i.e., the radioactive precursor of ^{210}Pb) with the atmosphere is restricted or eliminated at the top by the presence of a snow-bridge containing horizontal summer ice layers such as ….*"

This is a complex system which necessitates temporal variations in the crevasse as well as coverage of the crevasse with a snowbridge and the firn/ice transition. A schematic showing different crevasse and firn configurations and the resulting Pb210 anomalies would be very helpful.

We fully agree about the complexity of this system. Essentially there are two states of the crevasse. One for which the crevasse is open to bedrock and sealed by a snow bridge, and a second in which it is at least partly open to the atmosphere. Whereas in the first state the 222Rn emitted from the granite in the bedrock will accumulate, diffuse into the surrounding firn and produce 210Pb in excess there (this would correspond to what is observed in C10), in the second state the excess 222Rn gas can escape from the crevasse to the atmosphere, thus 210Pb production will be strongly limited (this would correspond to what is observed in CDK and CDM). As you suggested these two states are now reported in Fig 5b and 5c.

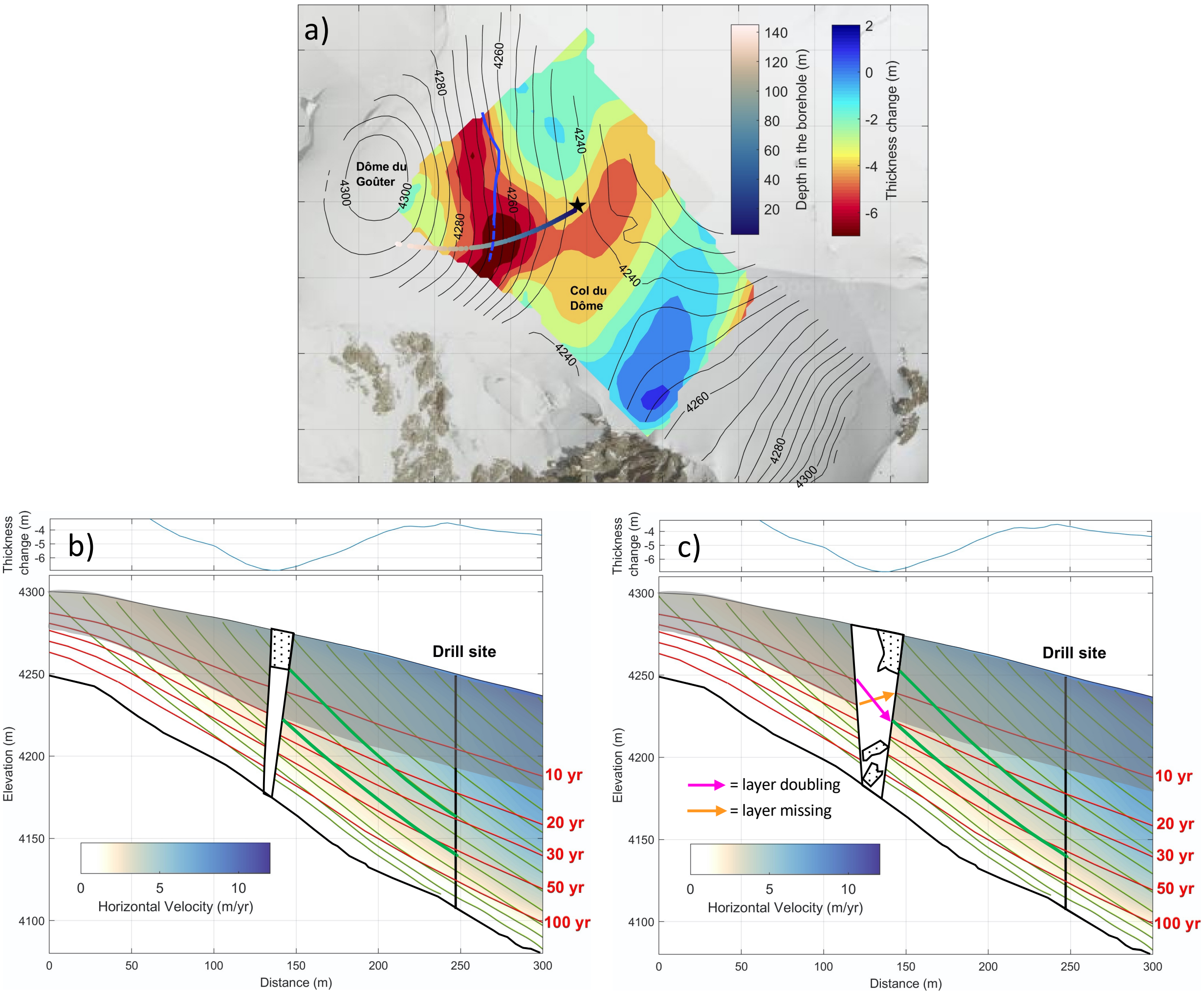

Figure 5: (a) Thickness changes between 1993 and 2017. The contour lines of surface topography correspond to the 1993 surface (adapted from Vincent et al., 2020) overlain by a modelled flow line (color scale on top) which reports the calculated arrival depth at the drill site of C10, CDK, and CDM (black star) (Gilbert et al., 2014). The crevasse location (blue line) is based on the 30th June 2004 aerial photo from IGNF (see Fig.1) (b and c) Schematic representation of the origin of the ^{210}Pb anomalies found at the drill site following the ice flow model of Gilbert et al., 2014, extracted along the flow path reaching the drill site. Isochrones are marked in red, flowlines in green (see also Section 4). The grey shaded zone indicates firn, the dotted zone indicates the snow bridge over the crevasse. *Two states of the crevasse are reported: (b) the crevasse is open to the bedrock but sealed from the atmosphere by a snow bridge. In this state ^{222}Rn and ^{210}Pb accumulate to reach concentrations well above atmospheric conditions in the crevasse and the surrounding firn (c) the crevasse is at least partly open to the atmosphere. In this state ^{222}Rn and ^{210}Pb concentrations in the crevasse and the surrounding firn are strongly reduced compared to (b). The formation of missing or doubling ice layers is indicated by the orange and pink arrows.*

In addition we will reword the discussion of this point in Section 4 in the following way:
"… A partial opening of the crevasse to the atmosphere would allow the bedrock-derived ^{222}Rn in the crevasse to mix with the much lower atmospheric ^{222}Rn concentrations (Pourchet et al., 2000). This would have led to a strong reduction of additional ^{222}Rn accumulation and ^{210}Pb production in the crevasse and in the snow and firn around the crevasse, starting from the moment of the opening to the atmosphere. This would explain ^{210}Pb inventories of 70 and 55% in CDK and CDM compared to C10, because of the radioactive decay of ^{210}Pb accumulated before the opening of the crevasse to the atmosphere, over 10 and 18 years, respectively……"

A few additional minor comments and/or questions:
L266 – "reach"
ok done

Have cores been drilled on Dome de Gouter? The ice thickness may be less and the accumulation lower, but couldn't these cores provide good benchmarks to compare the records collected at Col du Dome?
There was one core drilled on Dome du Gouter, however processing of the core and the data is not finished and there are no 210Pb data available. Furthermore, it is very likely that a full seasonal cycle of snow accumulation will not be well preserved there (due to preferential wind erosion in winter) rendering more delicate the use of the chemical ice-core record for atmospheric chemistry.

Figure 2 – is there an a priori expectation for the H3 and C137 profiles that could be plotted behind the measurements?
The 3H and 137Cs signals found in Alpine glaciers are related to the atmospheric nuclear tests conducted from 1954 (the beginning of atmospheric fall-out) to 1974. It is well established that the maximum radioactivity in precipitation in the Northern hemisphere was in 1963. Among the long-lived products from these events are 137 Cs (half-life of 30.15 years), 90 Sr (28.15 years) and 3 H (12.34) years.

Considering that the information conveyed in Fig. 2 is already very dense, we decided to add this information to the text in Section 3.1:
"…and radiometric analyses aimed at detecting fallout from atmospheric thermonuclear bomb testing via ^{3}H (Legrand et al., 2013 for CDK and this study for CDM) and ^{137}Cs (Vincent et al., 1997) for C10, as already done for other Alpine ice cores records (e.g. Schotterer et al., 1998). Fallout from atmospheric thermonuclear bomb testing typically leads to elevated ^{137}Cs and ^{3}H levels from 1954 to about 1975, with maxima in 1963 if the depth-age relationship is well preserved. The ^{210}Pb depth …"

and in Section 3.1.1:
"The dating of the C10 core was found to be in excellent agreement with several outstanding atmospheric changes or events that occurred during the 20th century such as the ^{137}Cs peak caused by nuclear weapons testing fallout (Vincent et al. 1997), the well-marked increase of fluoride after 1930 ….."

Figure 2 – it would be helpful to have the annual layers marked, at least on the CDM profile
Ok this is done, for the upper part of CDM (back to 1981) which could be dated reliably.

Figure 4 – please make the y-axes the same on all plots so that the differences in magnitude – which I believe is the primary point – stands out more clearly. And please include the results from the core 30m away

Ok this is done, y-axes are changed and the core from 30m away will be reported together with C10 in Fig. S2 (see also our comment above).

Figure 5 – make the bedrock a thicker line and different color
Ok done (see above).

Response to reviewer

We would like to thank referee#2 for the detailed review of our manuscript. The comments made by the referee were appreciated and helped improve the manuscript. Please find in the attached pdf our responses to the comments (in blue) and our proposed changes to a potential revised manuscript (in blue and in italic):

RC2: 'Comment on tc-2022-259', Anonymous Referee #2, 22 Mar 2023 reply

The manuscript presents nitrate records obtained from three different ice cores collected at nearly the same location on Col du Dome, Mont Blanc in the years in 1994, 2004 and 2012. Using the records of nitrate and the radionuclides 3H and 210Pb together with a 3D ice flow model the authors argue that there are discontinuities in the depth-age relation of the ice cores drilled in 2004 and 2012, which were caused by the presence of an upstream crevasse. This is an interesting hypothesis. Although it is common knowledge that areas with upstream crevasses should be avoided as ice core drilling sites, it could be valuable to demonstrate what the effects of such a crevasse are. However, I find the argumentation rather speculative and not well supported by the data, which are often inconclusive. Further, I miss in some part scientific rigorousness as outlined below. Considering all my concerns as outlined below, this manuscript requires major revisions.

Major comments

210Pb data presented in Fig. 4 have very different time resolution. It is scientifically not sound to compare such data. For instance, the peak at 1970 in CDK would disappear if the same averaging period as in the upper part of the record would be applied. This peak is most likely due to the strong 210Pb seasonality (Eichler et al., 2000). When using the same temporal averaging the postulated anomaly in the 1960s and 1970s in the CDK and CDM cores will be much smaller and may be due to an increased input of 210Pb in the 1970s. Such an increase has been observed already at other glaciers in the Alps, e.g. at Silvretta and Adamello (Festi et al., 2021), at Colle Gnifetti (Gäggeler et al., 1983) and at Grenzgletscher (Eichler et al., 2000) and was attributed to enhanced vertical transport related to the maximum in sulphate aerosol particles acting as transport vehicles (Eichler et al., 2000).

We regret the ambiguity in the presentation of the original version of Fig. 4. Since we were focused on the depth range corresponding to the depth-age anomaly which was sampled in relative high resolution, we only sampled the upper part for of CDK and CDM at lower frequency and interpolated the measurements. This will be changed in the revised version (showing raw data). Samples of CDK and CDM now are shown in Fig, 4 as measured and the depth intervals of the individual measurements (typically 0.7 to 1 m) are assigned clearly. In addition, as requested, we discuss whether or not the re-increase of 210Pb in the 1970s in CDK and CDM might be of atmospheric origin.

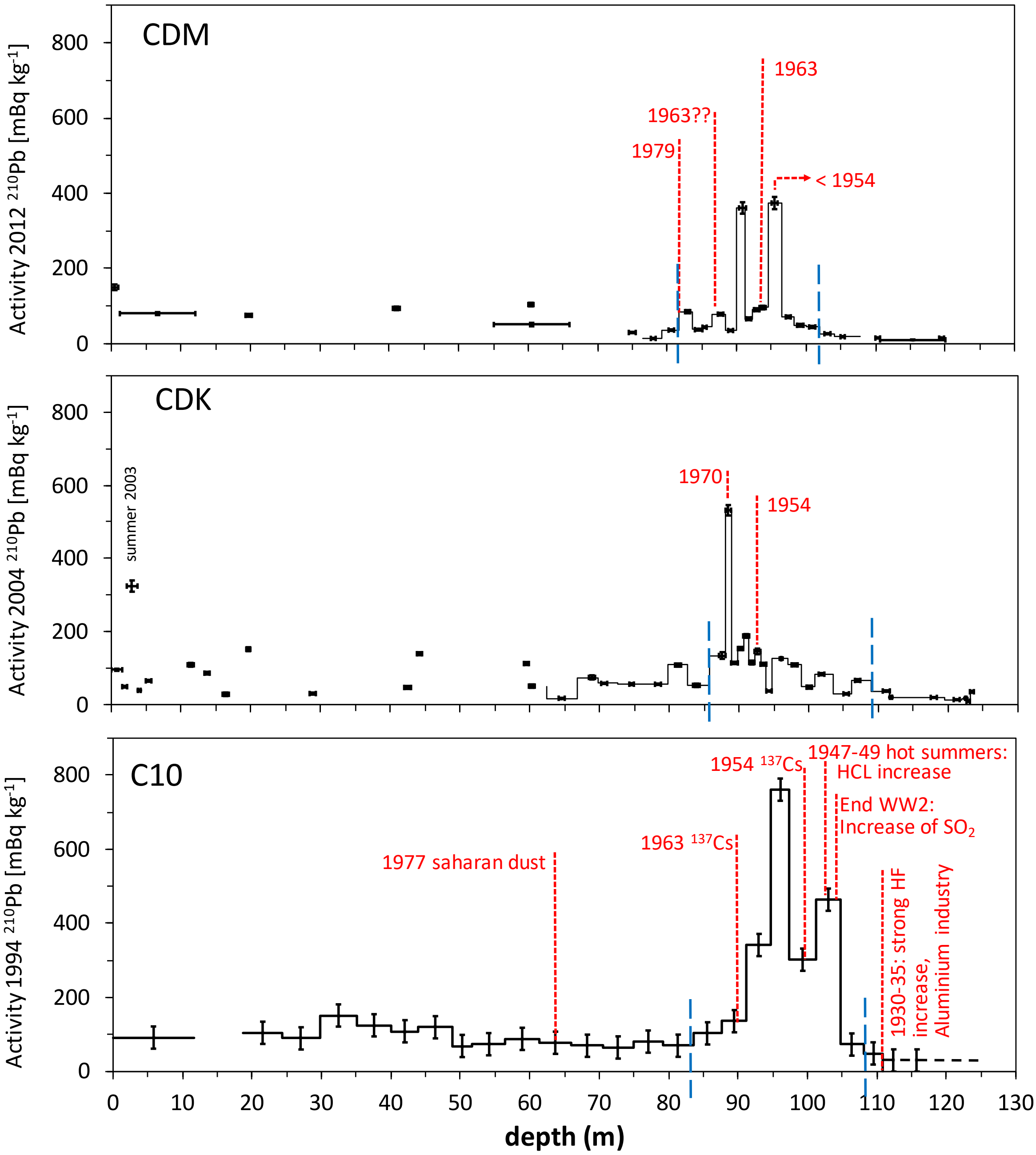

Figure 4: ^{210}Pb profiles of the three CDD ice cores. The decay-corrected ^{210}Pb activity is shown using the drilling year of the respective ice cores as reference. ***For CDK and CDM the depths covered by the samples are plotted with thick black lines, whereas the thin integrating line is given to guide the eye and was used to calculate the ^{210}Pb inventories.*** **Blue dashed vertical lines indicate the approximate boundaries of the anomaly. Where available, absolute time markers detected over the ^{210}Pb perturbed depth zones are also reported.** ***C10 data are from Vincent et al. (1997) and this study.***

The discussion whether or not the re-increase of 210Pb in the 1970s in CDK and CDM might be of atmospheric origin was revised as follows in Section 3.2:

" As a consequence, a strong seasonal cycle with ^{210}Pb concentrations three to four times higher in summer than in winter is observed at high altitude Alpine sites. As expected, this also is observed in the snow deposition at CDD and shown in Fig S1 of the Supplement for summer 2004 and the outstanding hot summer 2003, for which an extremely enhanced upward transport was already reported previously (Legrand et al., 2005). Whereas in 2004 a summer

to winter ^{210}Pb ratio of 2 was found, this ratio reached a factor of 7 in 2003. Together with the systematic decrease of the winter to summer layer thickness ratio with increasing core depth at the drill site (see Section 3 and Preunkert et al., 2000), this pronounced ^{210}Pb seasonality counteracts the expected ^{210}Pb decrease from radioactive decay.

Second, a well-marked anomaly characterized by ^{210}Pb enhancements (including ^{210}Pb peaks up to 10 times higher ^{210}Pb than expected from atmospheric deposition) is observed in the three cores. The anomaly extends from ~83 to 108 m depth (i.e., ~26 to 54 years) in C10, ~85 to 108 m (i.e., ~32 to 70 years) in CDK, and ~82 to 102 m (i.e., ~33 to more than 58 years) in CDM ice. The ^{210}Pb re-increase observed in CDK and CDM, however, is less pronounced than in C10. In addition, the starting depths of the CDK and CDM ^{210}Pb re-increases correspond to the 1970s, for which ^{210}Pb enhancements have been reported at other ice core sites (Eichler et al.,2000) and attributed to an enhanced vertical transport related to the temporal maximum of atmospheric sulfate aerosol acting as transport vehicle. To check whether these atmospheric conditions also could be responsible for the enhancement seen in CDK and CDM, we report exemplarily the CDK ^{210}Pb activity, corrected for its respective deposition date together with the corresponding sulfate concentration in Fig. S1 of the Supplement. As mentioned above, a strong seasonality was detected in the uppermost part of the CDK core for a few years where ^{210}Pb samples are available in seasonal resolution (Fig. S1a of the Supplement). If atmospherically derived, mean ^{210}Pb concentrations of ice layers from 60 to 85 m depth (i.e., from 1988 to 1972), i.e., in the period for which the sulfate aerosol maximum was observed at CDD (Preunkert et al., 2001), would correspond to around 130 ± 60 mB kg^{-1}of ^{210}Pb in freshly deposited snow, which is comparable to the atmospherically derived ^{210}Pb further upward in the core. However, from 85 to 108 m depth, this connection between sulfate levels and ^{210}Pb activity no longer holds. Whereas sulfate concentrations strongly decrease, ^{210}Pb at the time of deposition (decay-corrected) would be strongly enhanced (mean of 600 mBq kg^{-1}) and far above what is expected from atmospheric ^{210}Pb contributions. Thus, the mechanism proposed by Eichler et al. (2000) cannot be invoked in this part of the CDD core. For CDM (not shown) a similar picture appears. While from 80 to 90 m surface decay-corrected ^{210}Pb (160 ± 70 mBq kg^{-1}) would not have been significantly enhanced compared to the atmospherically derived ^{210}Pb concentrations seen further up in the CDM core, this is not the case between 90 and 103 m depth. As for CDK, mean values at the time of deposition would have been around 650 mBq kg^{-1} and thus far too high to what would be expected from atmospheric transport.

Third, below the anomaly, a decrease ….

Revised Fig. S1 of the Supplement now is as follows:

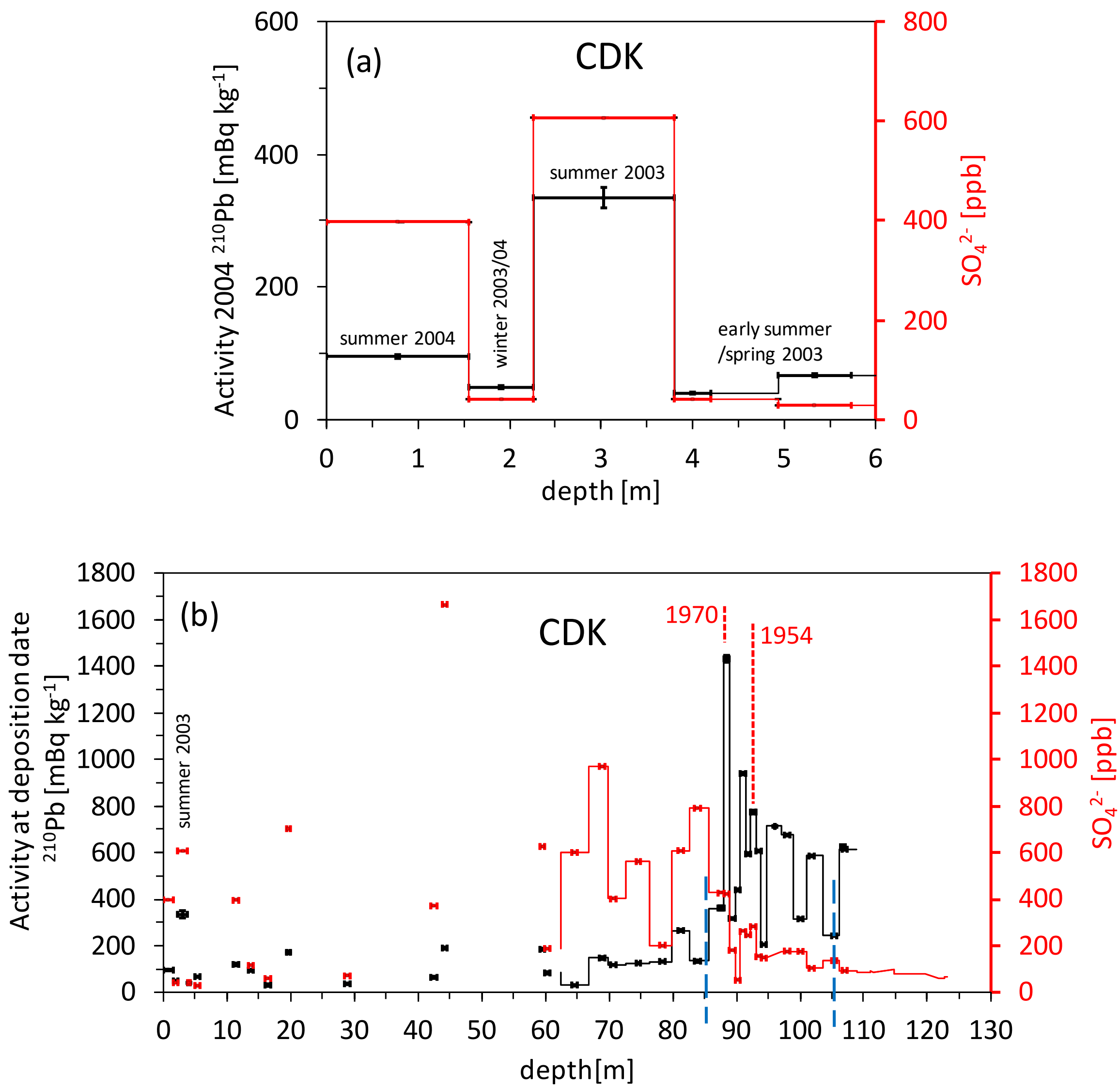

Figure S1: 210Pb profiles of the CDK ice cores (left y-axis, black) together with corresponding SO42- concentrations (right y-axis, red). The decay-corrected 210Pb activity is shown using the from the ice core chronology estimated snow deposition date. A thin integrating line is given to guide the eye, whereas the depths covered by the samples are assigned with thick lines. The blue dashed vertical lines in (b) indicate the approximate boundaries of the anomaly.

The entire depth records of 210Pb should be shown and not only the interval between 40 and 130 m in Fig. 4. Without the upper part, it is impossible to see if there is a decrease of 210Pb with depth at all and if the surface activity is in the range expected for glaciers in the Alps.
Done. The full records will be shown in revised Fig. 4 (see above).

In the C10 core, 210Pb was determined by gamma-spectrometry (Vincent et al., 1997), whereas for the CDK and CDM cores 210Pb was analyzed by alpha-spectrometry of its decay product 210Po after chemical enrichment, which is the much more sensitive method. Gamma-spectrometry is rather insensitive due to the high conversion of the low energy gamma-line at 46 keV (96% in the form of electron and only 4% in the form of gamma-emission) and the rather low efficiency of gamma-detectors. This method is normally used for samples with high activity concentrations of 210Pb, e.g. from lake sediments. For low-activity ice samples, the uncertainty is high (more than 50%, Vimeux et al., 2008). Especially in the region, where the anomaly was observed in the C10 core, also 137Cs activity concentrations are high due to the fallout from nuclear tests. This must have resulted in a high background in the gamma-spectrum. These uncertainties need to be discussed.

Thanks for this comment. The uncertainties of the gamma spectrometry used will be now discussed in the manuscript and respective error bars of the 210Pb data are reported. In fact, this specific gamma spectrometry method was developed at the Laboratoire de Glaciologie et Géophysique de l'Environnement, now Institut des Géosciences de l'Environnement (Delmas and Pourchet [1977], Pinglot and Pourchet, 1995) and applied in the past for many ice core studies in the Alps, sub-Arctic, South America, and also at polar sites (see e.g. Pourchet et al., 2000, Pinglot et al., 2003, Vimeux et al., 2008, Pourchet et al 2003).
Note that, since the energy of the 210Pb (46.54 keV) and the 137Cs (661 keV) is rather different (resolution of the detector is between 1.3 and 1.7 keV) we assume that the radioactive fallout from the nuclear tests should not have led to significant downgrading of the quality of the 210Pb measurements. Anyway, the adopted detection limit for C10 was assigned originally for ice core measurements which included also the time period in which 137Cs activities were high.

The following text will be added in section 2:
"" Previously reported ^{210}Pb measurements in C10 ice (Vincent et al. 1997) analyzed at the Laboratoire de Glaciologie et Géophysique de l'Environnement, now Institut des Géosciences de l'Environnement (IGE),were complemented by two samples measured for this study. The analytical technique was high-resolution gamma-ray spectrometry, designed to detect very low levels of radioactivity using a 20% high-purity Ge (N-type) detector, with an anti-Compton scintillation detector (Pinglot and Pourchet,1995) for which snow and ice samples were filtered previously through ion-exchange papers (Delmas and Pourchet,1977). This method is less sensitive than α-spectrometry and Vincent et al. (1997) did not assign uncertainties to their analyses. Here we estimate the uncertainty based on what has been reported in other studies using this detection method developed at IGE. Pinglot et al., 2003 reported a detection level of 10 mBq at a 97.5% confidence level for 3 days of counting on ice core samples with a typical ^{210}Pb activity of 20 – 50 mBq kg^{-1}. These measurements included Chernobyl fallout in sub-Arctic glacier sites, and the levels were similar in range to the background activities of 50-100 mBq/kg found in our cores. On the other hand, detection levels of 13 and 25 mBq were calculated at 97.5 % confidence when peak interferences where neglected or considered, respectively, for a 10 g sediment sample containing 1000 times higher ^{210}Pb activities as found in ice cores (~70 Bq kg^{-1}) that was measured for 63 hours (Pinglot and Pourchet, 1995). Vimeux et al. (2008) reported a lower detection limit of 4 mBq kg^{-1} for ^{210}Pb measurements (activities between 20 and 100 mBq kg^{-1}) on relatively small (150-250 g) ice core samples from Patagonia. The ^{210}Pb activities in C10 ranged from 50 – 700 mBq kg^{-1}, with the measurements done on the C10 drilling chips merged over 3 to 5 m, allowing to obtain sample weights of up to ~ 3 to 5 kg. Since these sample masses, type (ice core sample) and geometry (filter) are comparable to those used in the Pinglot et al. (2003) study but are very different from the sediment sample in Pinglot and Pourchet (1995), we assume in the following a detection level of 10 mBq and an uncertainty of 30 mBq for the C10 ^{210}Pb measurements. Note that, the dataset from Vincent et al. (1997) was supplemented by two additional samples for which ^{210}Pb analysis and quality control were not yet finished in 1997.

….”

It is unclear, which 210Pb decay correction was made. In Fig. 4 it is stated that for the C10 core the 1994 activity is shown. However, 210Pb activity concentration are much higher than in the original publication (Vincent et al., 1997). For a comparison between the cores, the activity should be corrected to the same reference date.

Thanks for this comment. In Fig 4, the same reference date (1994) is applied for C10 as in Vincent et al., 1997. C10 data seem to be higher in our Fig. 4 compared to the one from Vincent et al., 1997, since two additional samples were added to the data set in our study. C10 data from Vincent et al., 1997 were complemented with two additional samples for which additional measurements and quality check were done after 1997. This will be stated in the revised manuscript in section 2:

"…*Note that, the dataset from Vincent et al. (1997) was supplemented by two additional samples for which ^{210}Pb analysis and quality control were not yet finished in 1997.* …..”

I cannot follow the argument how the presence of the crevasse caused such a large 210Pb anomaly in the C10 core, but did not affect the stratigraphy, while in the other two cores the stratigraphy was disturbed, but the 210Pb anomaly was much smaller if present at all. This is a contradiction to me.

Essentially there are two states of the crevasse – one for which the crevasse is open to bedrock and sealed by a snow bridge, and a second in which it is at least partly open to the atmosphere. Whereas in the first state the 222Rn emitted from the granite in the bedrock will accumulate, diffuse in the surrounding firn and produce 210Pb in excess (this would correspond to what is observed in C10), in the second state the excess 222Rn gas can escape from the crevasse to the atmosphere, thus 210Pb production will be strongly limited (this would correspond to what is observed in CDK and CDM). To clarify that, these two states will be reported in Fig 5b and 5c in the revised manuscript.

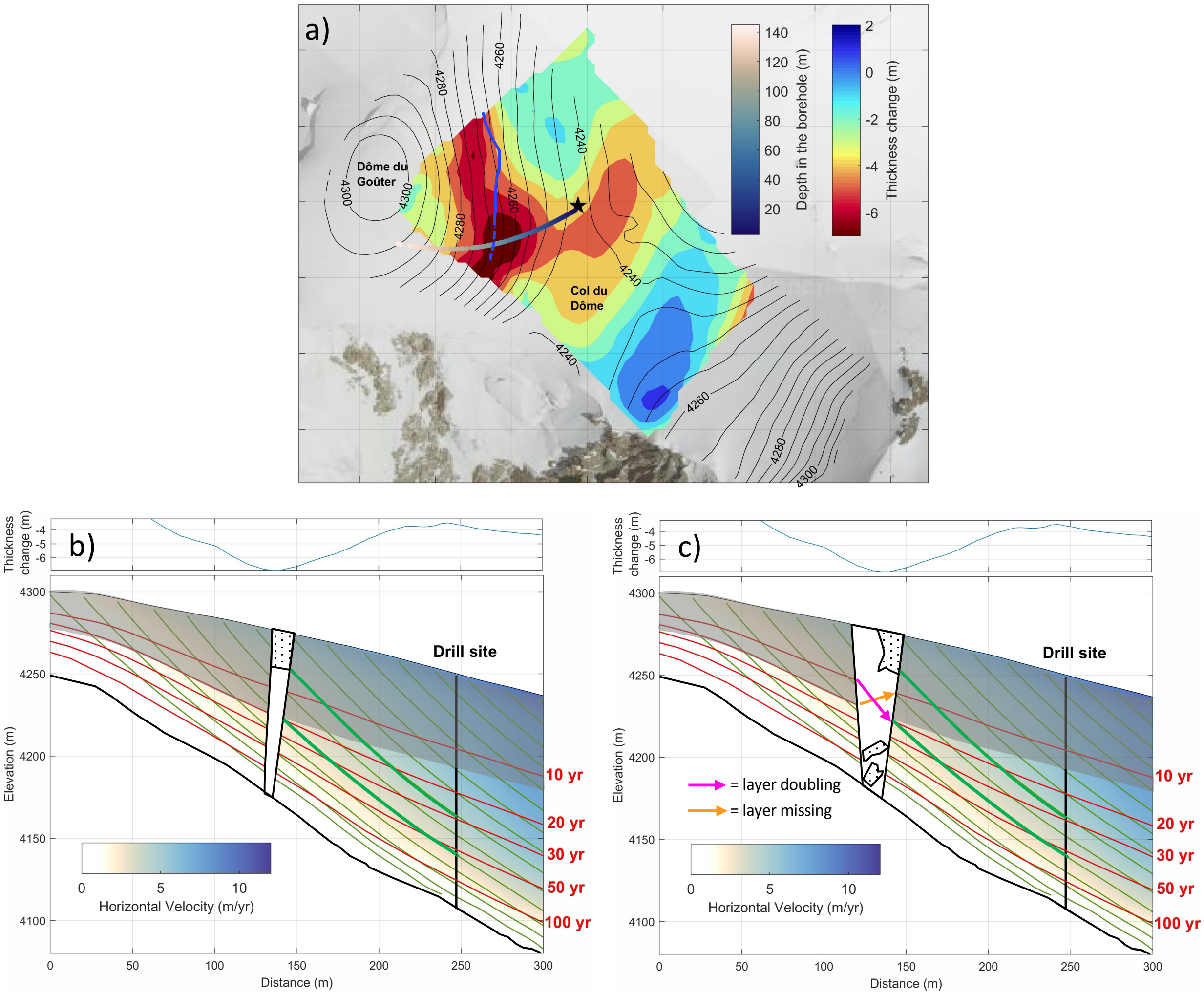

Figure 5: (a) Thickness changes between 1993 and 2017. The contour lines of surface topography correspond to the 1993 surface (adapted from Vincent et al., 2020) overlain by a modelled flow line (color scale on top) which reports the calculated arrival depth at the drill site of C10, CDK, and CDM (black star) (Gilbert et al., 2014). The crevasse location (blue line) is based on the 30^{th} June 2004 aerial photo from IGNF (see Fig.1) (b and c) Schematic representation of the origin of the ^{210}Pb anomalies found at the drill site following the ice flow model of Gilbert et al., 2014, extracted along the flow path reaching the drill site. Isochrones are marked in red, flowlines in green (see also Section 4). The grey shaded zone indicates firn, the dotted zone indicates the snow bridge over the crevasse. ***Two states of the crevasse are reported: (b) the crevasse is open to the bedrock but sealed from the atmosphere by a snow bridge. In this state ^{222}Rn and ^{210}Pb accumulate to reach concentrations well above atmospheric conditions in the crevasse and the surrounding firn (c) the crevasse is at least partly open to the atmosphere. In this state ^{222}Rn and ^{210}Pb concentrations in the crevasse and the surrounding firn are strongly reduced compared to (b). The formation of missing or doubling ice layers is indicated by the orange and pink arrows.***

In addition, we will reword the discussion of this point in Section 4 as follows:

"… "… A partial opening of the crevasse to the atmosphere would allow the bedrock-derived ^{222}Rn in the crevasse to mix with the much lower atmospheric ^{222}Rn concentrations (Pourchet et al., 2000). This would have led to a strong reduction of additional ^{222}Rn accumulation and ^{210}Pb production in the crevasse and in the snow and firn around the crevasse, starting from the moment of the opening to the atmosphere. This would explain ^{210}Pb inventories of 70 and 55% in CDK and CDM compared to C10, because of the radioactive decay of ^{210}Pb accumulated before the opening of the crevasse to the atmosphere, over 10 and 18 years, respectively….."

The agreement between the nitrate records obtained at a nearly identical location (please add coordinates to support this statement) is not as good as I would expect. Maybe plotting them against a m water equivalent scale would make it easier to identify common features. Generally, I find Fig. 2 difficult and confusing. What are the 250 ppb and 400 ppb levels?
The GPS coordinates of the ice cores were checked. Differences are at most 10m distance. We will provide the mean GPS coordinates of the three cores in the Introduction:
"…Underpinning these efforts are three ice cores all drilled to bedrock within maximal 10 m of each other (mean geographic location of 45.842195° N, 6.84675° E) in 1994 …"

The fact that the agreement of the NO3 depth profile is not as good as expected by the reviewer is likely due to the fact that the corresponding layers were not deposited at the same location along the flowline since the cores were not drilled at the same time. E.g., the layer of 1990 is in C10 at 25 m depth and in CDM at 67 m depth. As shown in Fig. 5a, the deposition locations were different by around 50 m. Taking in account the changing accumulation and winter to summer deposition ratio upstream the core (see section 3) this would result in stratigraphic differences in the NO3 (and all ion) depth profiles.
To point this out we added in the caption of Fig. 2 the following sentence:
"…Note that the chronological changes of the NO3 concentrations are offset in depth relative to each other due to the different years the cores were drilled."

We prefer to keep m scale in Fig. 2 since with that the reader can directly compare the depths in the core with the modelled surface deposition sites of the ice layers (see Fig. 5a). In any case, since ice core sections reported in Fig. 2 (except for the upper part of C10) are below the close off, which is around 50 m depth at the drill site, overplotting the m water equivalent scale would not change the picture.
The bars of 250 and 400 ppb were removed in Fig. 2 since they are not used in the discussion.

What is also puzzling is that 14% of the nitrate values (and even 30% of the ammonium data) were discarded. What is the basis for that? Which criteria did you use to identify contaminated values?
Thanks for this remark. After careful consideration we found that we made an error in the original manuscript. In fact much less data were discarded due to contamination. This is explained now in more detail.
In section 2 it will read:
"….Despite the undersized core section available for the CFA analyses at CEP, 86% of the ice core could be analyzed. The nitrate profile obtained at DRI and CEP (covering 97% in this depth range), were compared from 45 to 86 m depth. Both datasets are in very good agreement (Fig. 2). After having additionally discarded very high peaks in NO_3^- values (1.5% of CEP data), which were not present in the DRI dataset and could be attributed easily to contamination, mean NO_3^- values from 45.3-86.0 m were 263 ppb (CEP) and 255 ppb (DRI). The agreement is somewhat weaker for NH_4^+ likely because only 80% of the depth range is covered by the CEP measurements. After discarding additionally 8 % of the CEP NH_4^+ data consisting of high NH_4^+ peaks which were not present in the DRI dataset, the mean NH_4^+ values of 101 ppb (CEP) and 95 ppb (DRI) were in good agreement. ….."

Why are the tritium records not continuous? With a discontinuous record it is difficult to identify the 1963 maximum. In the case of the CDK core the maximum might be at 86 m.
The CDK and CDM records were mainly dated first using the depth stratigraphy of major ions and by comparison with C10, and only the depth range over which the 3H bomb test maximum was expected was analyzed for tritium. This is common approach when searching the 1963 bomb maximum since the rest of the 3H depth profile is rather uninteresting scientifically.
In the case of CDK, ice layers at 86m depth could be clearly assigned to the years 1970 (see Legrand et al., 2013 and Figs. 2 and 3). Thus, in our opinion there is no reason to search for the 1963 bomb horizon at this core depth.

Minor comments
Bachelor thesis's cited (Waldner, Zipf) are not publicly available. Include information in supplement.
The references for the two Bachelor thesis were initially put to credit the work of the two students, but finally both became co-authors. The references were deleted, and their work (analyses of the samples) will be credited in the author contribution section. Analytical details on measurements are already published and referenced in the manuscript (see Section 2). The detection limit appropriate to the method used in the CDK and CDM 210Pb analyses will be given Section 2 in the revised manuscript:
"*^{210}Pb samples of CDK and CDM ice were analyzed at IUP by α-spectrometry for its decay product ^{210}Po. Typical blank values of (5.7 ± 2.5) 10^{-5} Bq for ^{210}Po and (3.8 ± 1.6) 10^{-5} Bq for ^{209}Po were subtracted from the sample counts (see Stanzick, 2001, and Elsässer et al., 2011 for further working analytical conditions)*."
Thus, we feel that no supplement information is necessary.

103: Despite the undersized core section available at CEP, the nitrate profile obtained at DRI and IUP are in very good agreement (Fig. 2). Do you mean DRI and CEP?
Thanks, CEP was meant, this was corrected.

177: How was the winter to summer layer thickness ratio obtained?
The winter to summer layer thickness ratio was calculated on the basis of the NH4 depth stratigraphy. Details can be found in Preunkert et al., 2000. This now is assigned clearly in the revised manuscript when the term "winter to summer layer thickness" first appears (Section 3.1).

"…and the winter to summer layer thickness ratio, calculated on the basis of the ammonium depth stratigraphy (see details in Preunkert et al., 2000), decreases from 1 at the surface to 0.5 at 100m depth. "

216: Result of annual layer counting, what do you mean with that?
Thanks for this remark, we clarified this sentence in section 3.1.

".... As a consequence, annual layer thicknesses of only 0.7 and 0.2 mwe are observed at 100 m and 118 m depth (Preunkert et al., 2000) and the winter to summer layer thickness ratio, calculated on the basis of the ammonium depth stratigraphy (see details in Preunkert et al., 2000), decreases from 1 at the surface to 0.5 at 100 m depth….."

239: For 210Pb seasonality include reference Eichler et al., 2000.
ok done
"…CDM ^{210}Pb re-increases correspond to the 1970s, for which ^{210}Pb enhancements have been reported at other ice core sites (Eichler et al.,2000) and attributed to an enhanced vertical transport related to the temporal maximum of atmospheric sulfate aerosol acting as transport vehicle..;"

245-250: A zero 210Pb level can only be seen if the values are blank corrected and if the ice does not contain any supported 210Pb from mineral dust (see e.g. Gäggeler et al., 2020). Did you do a blank correction and what was the blank?
Thanks for your remark, the data are blank corrected. The "non-zero" term will be changed in "above detection limit" and the detection limit will be added in the manuscript in Section 2.
" ^{210}Pb samples of CDK and CDM ice were analyzed at IUP by α-spectrometry for its decay product ^{210}Po. Typical blank values of (5.7 ± 2.5) 10^{-5} Bq for ^{210}Po and (3.8 ± 1.6) 10^{-5} Bq for ^{209}Po were subtracted from the sample counts (see Stanzick, 2001, and Elsässer et al., 2011 for further working analytical conditions)…."

and in Section 3.2 it will read:
"..However, it is worth noting that, especially in the case of the CDM and CDK cores, ^{210}Pb activity (after blank correction) is above detection limits even in the bottommost core sections, while in C10 levels are below the detection limit…"

Figure 3: C10 was drilled in 1994. Why do the records of annual layer thickness and nitrate concentration continue to the year 2000?
Thanks for this remark. We agree that the Fig. and caption needed improvement. C10 and CDM annual layer thickness data are shifted in time to compensate for the different drilling dates of the three ice cores. The revised Fig. 3 is as follows:

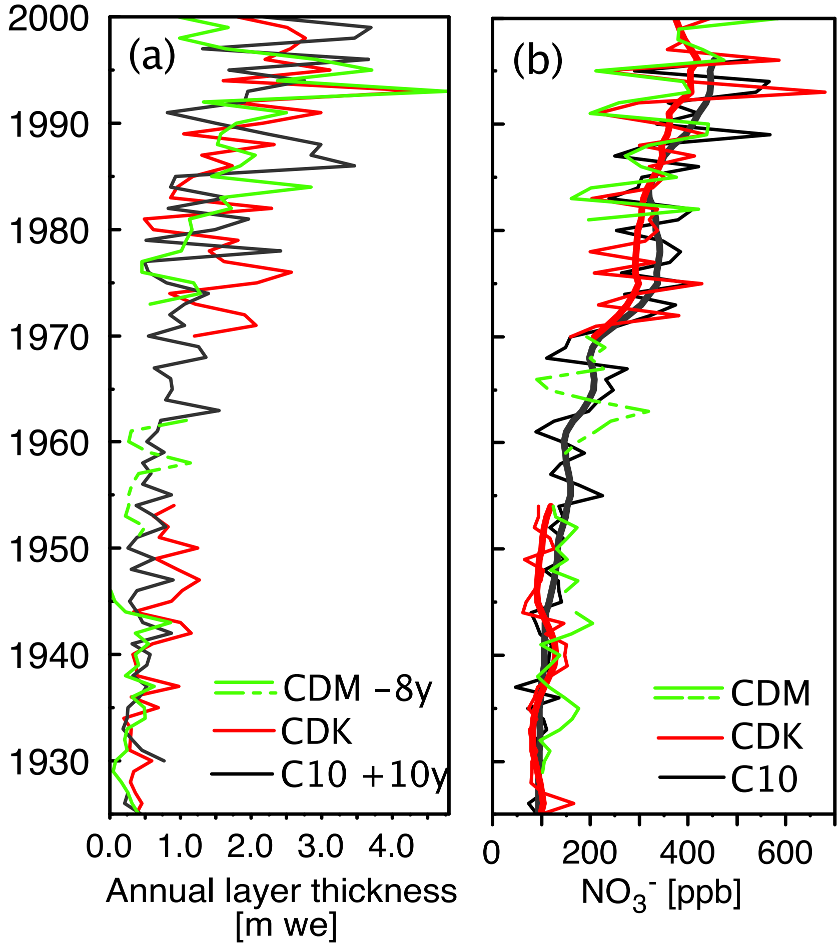

Figure 3: (a) Annual layer thickness of C10 (Preunkert et al. 2000) and CDK (Legrand et al., 2013) compared to CDM. To compensate for the different drilling dates of the three cores, annual layer thickness data of C10 and CDM were shifted for +10 and -8 years, respectively. For CDM, the annual layer thickness is estimated via the ammonium stratigraphy back to 1980 and via the nitrate (and ammonium) stratigraphy further back in time (Section 3.1.3). (b) comparison of nitrate summer half-year means of C10 (Preunkert et al., 2003), and CDK (Legrand et al., 2013) with CDM. The thick solid lines for C10 and CDK refer to the smoothed profile (single spectrum analysis, see Legrand et al., 2013). CDM depth intervals for which the dating is uncertain (Section 3.1.3), are marked with dashed lines.

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