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:

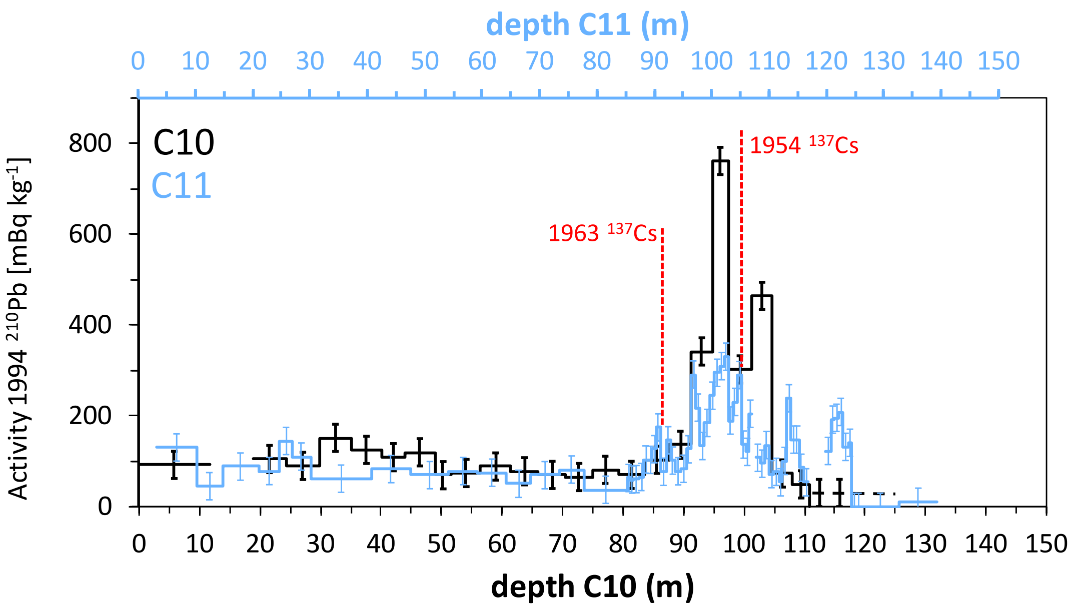

***Figure S1:** ^{210}Pb profiles of the CC10 (lower x-axis, black) compared to the one of a 140 m long ice core extracted 30 m away from C10 in 1994 (Vincent et al., 1997, denoted here as C11, upper x-axis, blue). The decay-corrected ^{210}Pb activity is shown using the drilling year of the two cores 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.

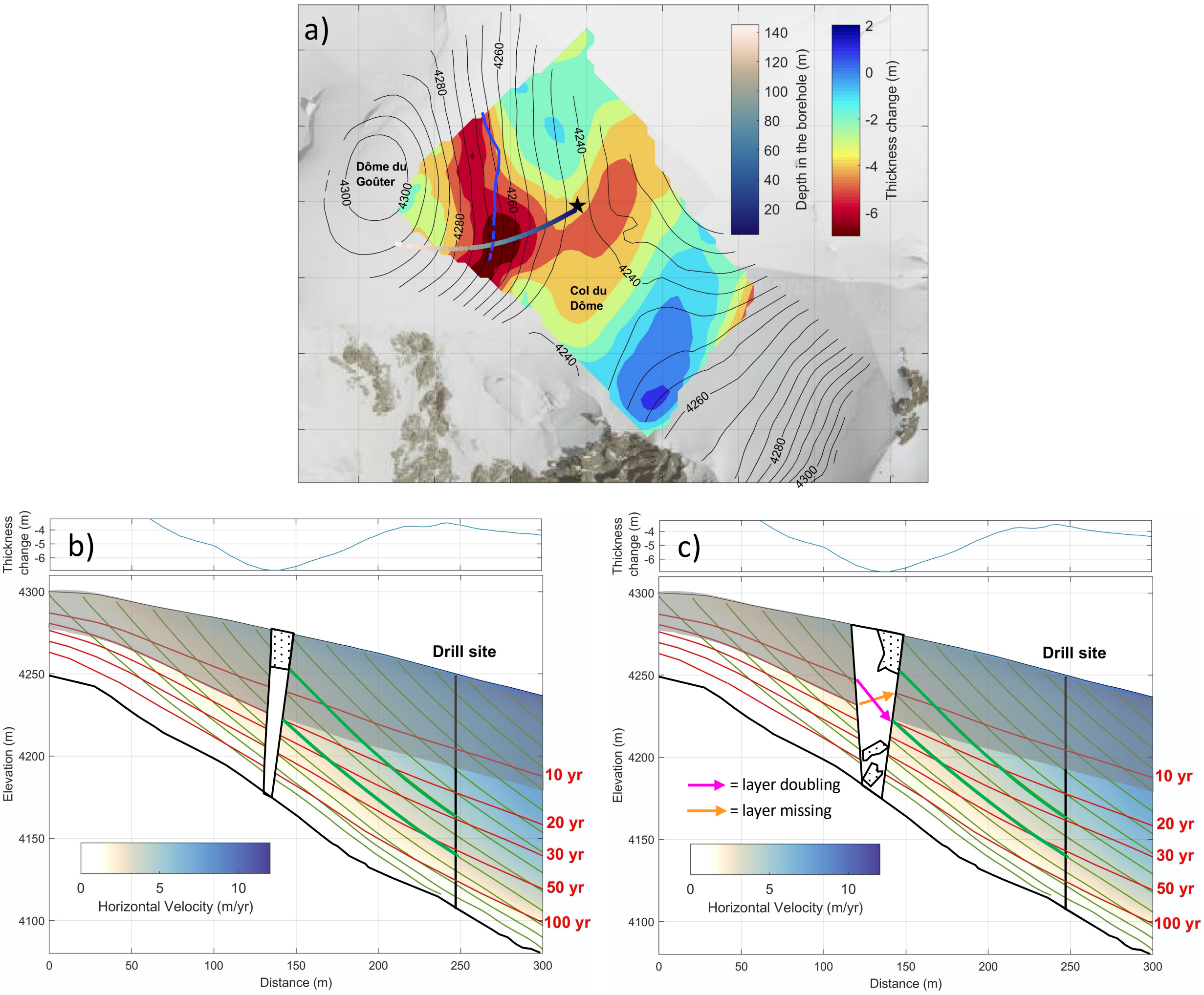

Figure 5: (a) Thickness changes between 1993 and 2017. The contour lines of surface topography correspond to the 1993 surface (adapted from Vincent et al., 2020) overlain by a modelled flow line (color scale on top) which reports the calculated arrival depth at the drill site of C10, CDK, and CDM (black 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).