Minor changes in the revised version:

- ➔ Changes in the affiliations (new lines 3 to 26 “all revision mode”)
- ➔ Line 36. (“years” by “yr”)
- ➔ Line 38. “data from A294” by “of A294 cave”
- ➔ Line 47. “the rise in” by “more”, “seasons” by “season” and “the” by “a”
- ➔ Line 56. “an” by “a recent”
- ➔ Line 64. “systems” by “system”
- ➔ We added a new sentence about a recent review paper on ice caves (Lines 68-70)

  “In recent years, the growing scientific interest on ice caves—driven by their rapid degradation—has led to a notable increase in interdisciplinary research efforts (e.g. Barabach and Stasiewicz, 2025).”

- ➔ Lines 72-73. “data” by “proxy information”
- ➔ Line 113. We added “some”
- ➔ Line 123-124. “Weather Station” by “weather station” and “Fig” by “Figs”
- ➔ Figure 1 caption: “Weather Station” by “weather station”
- ➔ Line 138. “high” by “deep”
- ➔ Line 144. We added “ ” to chimmey effect
- ➔ Line 146. We added “the”
- ➔ Figure 2 caption. “The location of temperature sensors is indicated in red rectangles” by “The locations of the temperature sensors are indicated by small red rectangles”
- ➔ Figure 3 caption: “from” by “based on” and “corner” by “Corner”. We have homogenized all “corner” by “Corner” along the text.
- ➔ Line 215. “(approximately mid-October to April) (Tuhkanen, 1980)” by “(approximately mid-October to April - Tuhkanen, 1980)”
- ➔ Line 216. Similarly, the “Thaw Index, (TI),” by “Similarly, the Thaw Index (TI)”
- ➔ Line 217. We moved “(Fig. 4)” to line 219.
- ➔ Line 221. “thermal open phases begin” by “thermally open phase begins”
- ➔ Line 230. “Wheather Staion” by “weather station”
- ➔ Line 234. We added “i.e.,”
- ➔ Line 238. We deleted “a”
- ➔ Line 241. “in case” by “when”
- ➔ Line 246. We added “pendant” “data logger”
- ➔ Line 247. ”(Pendant UA-003-64)” by “(UA-003-64)”
- ➔ Line 253-254. “using” by “applying”
- ➔ Figure 4 caption. “Wheather station” by “weather station”. We added “data” and “short”
- ➔ Line 258. We deleted “primarily”, we added “mainly”, and changed “has” by “had”
- ➔ Line 264. “Fig.” by “Figs.”
- ➔ Line 269. We added spaces between dates and changed “years ago” by “yr cal BP”
- ➔ Line 272. “years ago” by “yr cal BP”
- ➔ Figure 5 caption. “detail of ice” by “details of the ice”
- ➔ Line 276. We added “(Fig. S4)”
- ➔ Line 278. We added “and Fig. S4”
- ➔ Line 281. “cal yr BP” by “yr cal BP”
- ➔ Line 284. “cal yr BP” by “yr cal BP”
- ➔ Table 1. ““cal yr BP” by “yr cal BP”
- ➔ Figure 6 caption. We added “and” and “see also Fig. S3”
- ➔ Line 292-293. “indicated” by “indicates”
- ➔ Line 299. “Weather station” by “weather station”.

- **Figure 7 caption. “Weather station” by “weather station”, “Indexes” by “indexes”, we added “the” and change “study” by “monitoring”**
- **Line 327. We deleted “considerable”**
- **Line 332. We removed “a remarkable”.**
- **Line 333. “cumulated” by “annual”**
- **Line 339. “early” by “Beginning of”. We deleted “in” and “in”**
- **Line 342. We deleted “meteorological”**
- **Lines 344-345 “stands out with” by “was characterised by”**
- **Line 360. “Fig. S4” by “Fig. S5”**
- **Line 374. “indicates” by “indicate”**
- **Line 377. “Fig. S5” by “Fig. S6”**
- **Line 380. “(Fig. 9))” by “(Fig. 9)”**
- **Line 390. “(Figs. 3c and 10a, b, c, d, e, f)” by “(Figs. 3c and 10 a, b, c, d, e, f)”**
- **Line 399. “(Fig. 9a, b, c)” by “(Figs. 9a, b, c)”**
- **Line 401. “Eastern wall” by “East wall”**
- **Figure 9 caption. “indicates” by “shows”**
- **Line 404. “(Fig. 9c, d)” by “(Figs. 9c, d)”**
- **Line 405. “(see Fig. 9e, f)” by “(see Figs. 9e, f)”**
- **Line 406. “(retreat rate of ~166 cm a^{-1} n=3, 2015-2019)” by “(retreat rate ~166 cm a^{-1}, n=3, 2015-2019)”.**
- **Line 409: “(Sancho et al., 2018; Leunda et al., 2019;, Fig. S3)” by “(Sancho et al., 2018; Leunda et al., 2019; Fig. S3)”**
- **Line 427. “(e.g. Luetscher…)” by “(e.g., Luetscher…)”**
- **Line 439.”in” by “with”**
- **Line 441. “winters” by “winters,”**
- **Line 444. “of” by “in”**
- **Line 449. We deleted “climate”**
- **Line 450. “4ºC” by “-4ºC”**
- **Line 460. We added “start to”**
- **Line 472. We added “in the Pyrenees”**
- **Figure 11 caption. We added “obtained from the Basa de la Mora lake in the study area”, and “5 year running average”, “grey”**
- **Line 480. We deleted “formed”**
- **Line 481. “year cal BP” by “yr cal BP”**
- **Line 490. “year cal BP” by “yr cal BP”**
- **Line 491. We added spaces between the ages**
- **Line 494. We added “^{36}Cl”**
- **Lines 502-503. “years ago” by “yr cal BP”**
- **Line 504. “-rings” by “ring data”**
- **Line 505. “Century” by “century”**
- **Line 507. “year cal BP” by “yr cal BP”**
- **Line 511. We deleted “away”**
- **Line 524 “about the past ice mass balance” by “about past ice accumulation rates”**
- **Line 531. We deleted “the”**
- **Line 533. “(e.g. López-Moreno et al., 2016, 2019; Vidaller et al., 2021, 2023)” by “(e.g., López-Moreno et al., 2016, 2019; Vidaller et al., 2021, 2023)”**
- **Line 547. We added spaces between dates.**
- **Line 549. “smaller” by “small”**
- **Line 555. We deleted “monitoring” and “have”**
- **Line 559. We deleted “dashed rectagle”**
- **Line 570. “on” by “of”**
- **Line 572. We deleted “was”**
- **Line 576. We added “h”, and we changed “e.g. Luetscher et al., 2005; Kern and Perşoiu, 2013; Serrano et al., 2018; Colucci and Guglielmin, 2019; Perşoiu et al.,**

2021,)" by "e.g., Luetscher et al., 2005; Kern and Perşoiu, 2013; Serrano et al., 2018; Colucci and Guglielmin, 2019; Perşoiu et al., 2021, Obleitner et al., 2024". We added a new reference here, and also to the reference list.

- ➔ Line 595. "an cleear" by "a clear". We added "rapid"
- ➔ Line 599. "this" by "these", "archive" by "archives", "is" by "are"
- ➔ Line 606. We added "regional", we deleted "in the area"
- ➔ Lines 611-612. "through dripping points" by "via seepage water"
- ➔ Line 614. "elevated" by "rising"
- ➔ Line 616. We added ","
- ➔ Line 617. We added "~"
- ➔ Lines 621-622. We added "regional" and we deleted "in the area" and "older"
- ➔ Line 625. We deleted "current"
- ➔ Line 637. "sensor download and maintenance and a cave survey in 2019" by "maintained the sensors, and surveyed the cave in 2019."
- ➔ Line 640. We delete "all" and "s"
- ➔ Line 647. We deleted "In memory of Carlos Sancho"
- ➔ Line 652. "foe" by "for"
- ➔ Line 654. We added "We would like to thank the two anonymous reviewers for their thorough and constructive comments, which helped to improve the clarity and quality of the manuscript."
- ➔ Lines 661-664. We added "CGL2016-77479-R, INTERREG-POCTEFA OPCC2 (ref. EFA082/15), ADAPYR (2019-2022) ref. EFA346/19 and P4CLIMA "Towards a climate resilient cross-border mountain community in the Pyrenees" (ref. LIFE22-IPC-ES-LIFE PYRENEES4CLIMA,101104957)."

Minor changes the text in the figures.

Figure 1: "treshold" by "threshold"

Figure 2: we moved "scale" in panel B over the scale bar, and we change "90s" by "1990s", we put in singular the legend.

Figure 3: Changes made are described later in this text

Figure 6: "year cal BP" by "yr cal BP"

Minor changes the supplementary material.

Referee 1

1) The temperature reconstruction method using quantile-based gap-filling should include a validation step against external datasets beyond Góriz and La Renclusa stations.

The authors consider it unnecessary to test additional stations beyond those used in this study, given the very low percentage of missing data in the series (<1%) and the strong performance observed during the independent validation period. In fact, Barca et al. (2024) emphasized that the method used to fill temperature gaps has a minimal impact when data gaps are below 5%, even in analyses of extreme events.

- ➔ No changes were made, as the gaps are minimal, as previously indicated.

2) More details on uncertainties associated with ice retreat rates would be helpful. For example, specifying potential sources of error in survey comparisons (e.g., instrument precision, human factors) would strengthen confidence in the retreat estimates.

In the case of the speleological survey from 2019, the precision associated with each measurement (n=68) is ±1.5 mm (Leica Disto X310). In contrast to clean congelation ice, where the laser can penetrate the ice over several meters (e.g., Bartolomé et al., 2023) our measurements indicate this is not the case in firn. The points from which the measurements were taken are well identified in the field, but potential errors may arise from the inclination of the laser line when taking the measurement. Normally, several measurements are taken to ensure that there are no major variations. This human error could result in inaccuracies of up to 5 cm, which, for distances greater than 10 m, would represent less than 0.5% error (measurements from Northern (1) and Ice Front (3), Fig. 3d in the manuscript), and slightly more for Rock Corner (2).

Luetscher et al. (2005) used a comparison of historical surveys to highlight changes over time, as it is a simple method to observe ice changes. Of course, surveys carried out by different individuals may vary slightly depending on the level of detail, the skill of the surveyor, and human measurement error. In fact, in the 1974 topography, we noticed an error in the orientation of the north arrow. However, the ice loss is so evident that even when considering only a rough outline of the cave, the measurements taken in successive surveys are consistent with those reported by Belmonte et al. and with the ice retreat measured in this study. We will add some sentences about the uncertainties of measurements.

> **→ We have included sentences addressing the uncertainties of the measurements. New lines (155 to 204)**

"The ice retreat was assessed on the basis of cave surveys from different years (1978, 2012, 2019, Figs. 3a, b, c, d). Following Luetscher et al. (2005) we use a comparison of historical surveys to highlight changes over time, as it is a simple method to observe ice changes. The surveys of 1978 (Grupo de Espeleología Cataluña Aragón, G.E.C.A.) and 2012 (Belmonte-Ribas et al., 2014) were carried out with a compass and clinometer. The North arrow in the original 1978 survey was not correctly positioned, and the crevasse between ice and bedrock is questionable, as in 2008 the old ice on the southern wall was in contact with the bedrock (Fig. S2). The crevasse must have been small, because the new gallery (called Gallery 90s) was found during the 1990s after the ice had retreated (Fig. 2). The survey in 2019 (Fig. 2) was conducted using a Leica DistoX2 (X310) modified with an electronic base plate to measure the direction and dip (Heeb, 2014). The precision associated with each measurement is ±1.5 mm. A total of 68 points were measured emphasizing the cave morphology and the ice perimeter. To determine the horizontal retreat of the ice body, the ice perimeter was determined at three reference points/sectors defined and well identified in the field (Fig. 3 (number 1 to 3)). Potential errors may arise from the inclination of the

laser line when taking the measurement. Several measurements were taken to ensure that there are no major variations. This human error could result in inaccuracies of up to 5 cm, which, for distances greater than 10 m, would represent less than 0.5% error (measurements from the Northern wall (1) and the Ice front (3), (Fig. 3d), and slightly more for the Rock Corner (2). Errors in topographic comparisons depend on the level of detail, the surveyor's expertise, and inherent human measurement inaccuracies. However, the extent of ice loss is so pronounced that even when using only a rough outline of the cave, the measurements obtained from successive surveys are consistent with those reported by Belmonte et al. (2014). Complementary field measurements using fixed reference points (blocks, walls, dripping points) together with several photographs taken between 2008 and 2023 were also used to reconstruct the changes in size of the ice body. For the Northern wall (1), the three cave surveys were compared. In contrast, for the Rock Corner (2) and the Ice front (3), the data consisted of a combination of cave surveys comparisons and field measurements.

To evaluate vertical changes of the ice body during the monitored period, two stratigraphic logs were made (Sancho et al., 2018; Leunda et al., 2019) (Fig. S3). In 2011, when the deposit was first sampled, the ice was 9.25 m thick and decreased to 7.90 m in 2015 when the second stratigraphic log was prepared. The internal structure of the ice sequence also changed between 2011 and 2015 (Leunda et al., 2019) as shown by the cross-stratified ice beds formed during snow deposition. Nevertheless, the identification of a same detrital layer (observed at 165 cm depth from the top in 2015 and at 240 cm depth in 2011) allows correlating the depth-age models for both years (Fig. S3). The spatio-temporal reproducibility of the depth-age models together with the good correspondence between two independently dated terrestrial plant macrofossil remains reveals that, although decadal-scale melting periods may have occurred repeatedly, the macrofossil remains preserved in the detrital layers did not suffer significant movements within the ice deposit.

"

3) Some sections, particularly those discussing temperature trends and ice retreat, could benefit from a clearer distinction between observed data and modeled inferences. For instance, in section 5.1, the link between external temperature anomalies and ice melting rates could be more explicitly quantified. Including R-squared values or additional statistical measures would strengthen the argument.

We agree on this point; however, due to the resolution of the measurements and the comparison of surveys (n=3), it was difficult to obtain the same year-by-year resolution for melt rates and the increase in temperature/precipitation. This limits our ability to perform correlations similar to those established with other parameters derived from the weather station and the cave's internal sensors. In this sense, the discussion on this topic could only be linked to what is addressed between lines 416 and 426 of the manuscript, in section 5.1, regarding melting rates depending on the sector of the cave. Without consistent resolution in both measurements and environmental parameters, it is challenging to establish any correlation beyond indicating that melting rates have increased in recent years. We will add a few lines in the Methods section specifying which annual rates were inferred from cave surveys and which were obtained from direct measurements inside the cave.

→ We have added a sentence pointing out this issue: "For the Northern sector (1), the three cave surveys were compared. In contrast, for Rock Corner (2) and Ice Front (3), the data consisted of a combination of cave surveys comparisons and field measurements." Lines (184 to 187). This was added between the lines 155-204 such we show in the previos response.

4) Linking the cave's ice retreat to regional hydrology or ecosystem impacts could provide further relevance beyond cryosphere studies.

Thank you for this suggestion. However, the retreat or even the complete disappearance of this or all ice caves in the Pyrenees, would not have a significant impact on the local and regional hydrology. In fact, López-Moreno et al., (2020) calculated the water storage capacity of Pyrenean glaciers (Rico et al., 2017) and estimated that their contribution represents only 0.02% of the 3000 hm^3 storage capacity of the 13 major dams built in the Central Pyrenees (López-Moreno et al., 2008); 0.04% of the 1500 hm^3 annual average of water stored as snow in the Central Spanish Pyrenees; and less than 0.01% of the 7300 hm^3 long-term mean annual runoff (1950–2006) from the main Pyrenean tributaries (López-Moreno et al., 2011). Thus, the hydrological contribution of Pyrenean glaciers is minimal, and their disappearance would not impose a significant additional pressure on water resources. Ice caves represent only a very small percentage of the cryosphere in the Pyrenees.

Regarding the ecological impact, it primarily occurs at the cave ecosystem level. Ruiz-Blas et al. (2023) identified the prokaryotic and eukaryotic microbial communities inhabiting the ice in A294 at different ages of ice deposition. This study simulated the in vivo effects of climate change, examining how a 4°C temperature increase would affect microbial populations. The results revealed molecular modifications, identified several proteins and enzymes associated with cellular adaptation to higher temperatures, documented the influence of temperature rise on biogeochemical cycles, and detected proteins expressed at elevated temperatures that could serve as climate change indicators. All this information will be briefly included in Section 5.3 of the manuscript.

Done. Lines 580-594. "In terms of hydrological and environmental impacts, the contribution to the local and regional hydrology of the melting of all the ice in A294 and all the subterranean ice in the Pyrenees would be negligible, similar to the contribution of water if all Pyrenean glaciers melt, as calculated by López-Moreno et al., (2020). The ecological impact would primarily occur at the level of individual cave ecosystems. Ruiz-Blas et al. (2023) investigated prokaryotic and eukaryotic microbial communities within the ice in cave A294 across different depositional layers. By simulating temperature increases, the study mimicked in vivo climate

change effects to assess microbial responses. The results revealed molecular modifications associated with cellular adaptation under warmer conditions. "

Figures & visual presentation

Figure 3: The cave survey should have clearer legends to indicate differences in retreat rates across different sectors of the cave. In panel (d) the ice limit for 2011 is shown but not for 2012. Why there are no plan views for all ice deposit limits shown in (d)?

We outline this suggestion below.

"The cave survey should have clearer legends to indicate differences in retreat rates across different sectors of the cave."

We will enlarge the legend and add more information. Additionally, in the topographic maps, we will enlarge the red lines that indicate the measured points.

→ Done

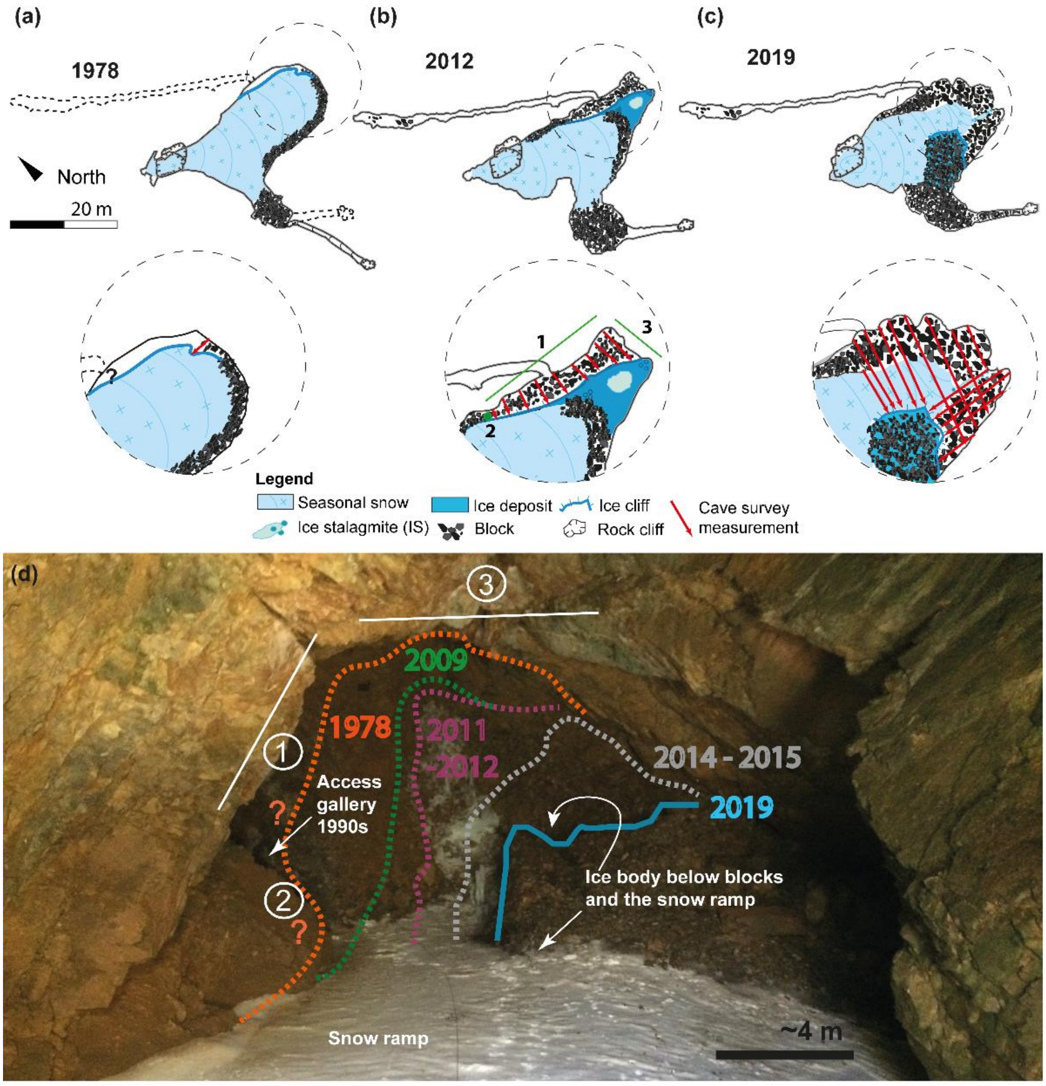
"In panel (d) the ice limit for 2011 is shown but not for 2012."

The positions in Figure 3d have been approximately reconstructed based on the topographic surveys conducted in 1974, 2012, and 2019, as well as photographic sequences. To avoid overcrowding the figure with additional lines, and given that the position of the deposit in 2011 and 2012 was very similar, we will add a label "2011–2012" to the pink line.

→ Done

"Why there are no plan views for all ice deposit limits shown in (d)?"

No additional topographic surveys were carried out during these monitoring years; only those from 1974, 2012, and the most recent one from 2019 exist. We conducted the 2019 survey after learning about the existence of the 1974 topography, considering it would be valuable to have a new survey for comparison purposes.



➔ **We changed "survery" by "survey", and "90s" by "1990s"**

Figure 4: I suggest using "Twelve years …" instead of "12 years…"

We will change 12 years by twelve years

➔ **Done**

Figure 8: (a) The caption is unclear. Light blue bars are visible in other months than April to November. The dark blue lines are intended to represent the number of rainy days (April to November), but the curve includes data from months outside this period. The same applies to the total rainfall. Why are the Y-axes titled "April-November" when the plots show wider intervals? Are the last two plots (nr of rainy days and total rainfall) depicted in Fig. 8a necessary, given that they are also shown in Fig. 8b and in panel (a) there is a lack of correlation?

We will clarify the footnote. We will add dashed vertical lines in the figure to clearly separate the April–November periods, and we will double-check the dates for both series.

Regarding the second point, we plotted both curves together with the temperature during the closed phase and the Thaw Index, to visually show the increase in temperature (closed phase), and the rise in both the amount and frequency of precipitation during the monitored period. Given the inflow of liquid water into the cave during the closed phase is the main mechanism driving ice melt and the increase in cave temperature, we would like to keep the figure as it was.

➔ **We have added vertical dashed lines, the dates were checked and corrected, and the figure caption was clarified. The final figure is below. The part "b" of the figure is the same as we discussed above.**

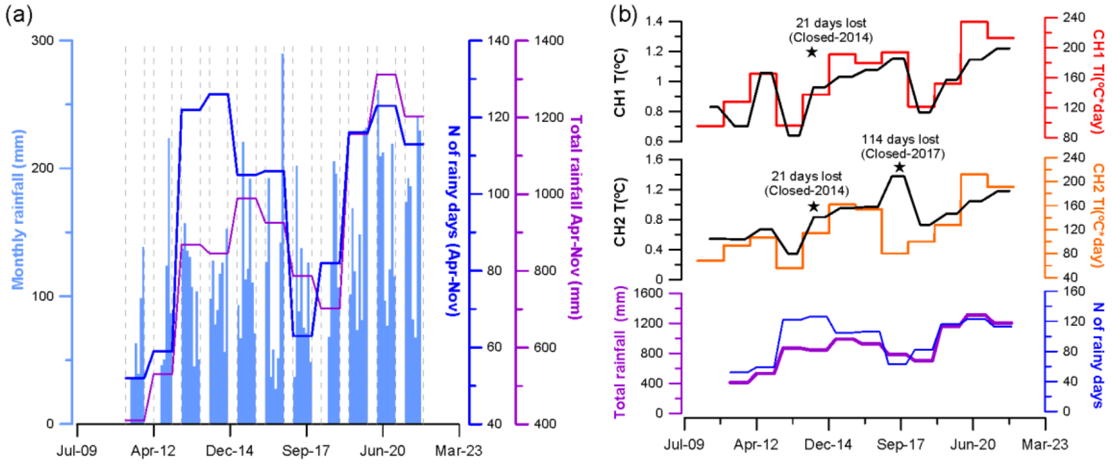


Figure 8: a) Monthly rainfall (light blue vertical bars) and the number of rainy days (dark blue line) and total rainfall (purple line) from April to November (grey dashed lines). b) Mean cave air temperature and Thaw Index (TI) during the closed phase measured by sensors CH1 and CH2 compared to the number of rainy days (dark blue line) and total rainfall (purple line).

Figure 9: Enhance text visibility in panels (e) and (f) by employing larger white font.

We will increase the font size of the text in figures (e) and (f).

➔ **Done**

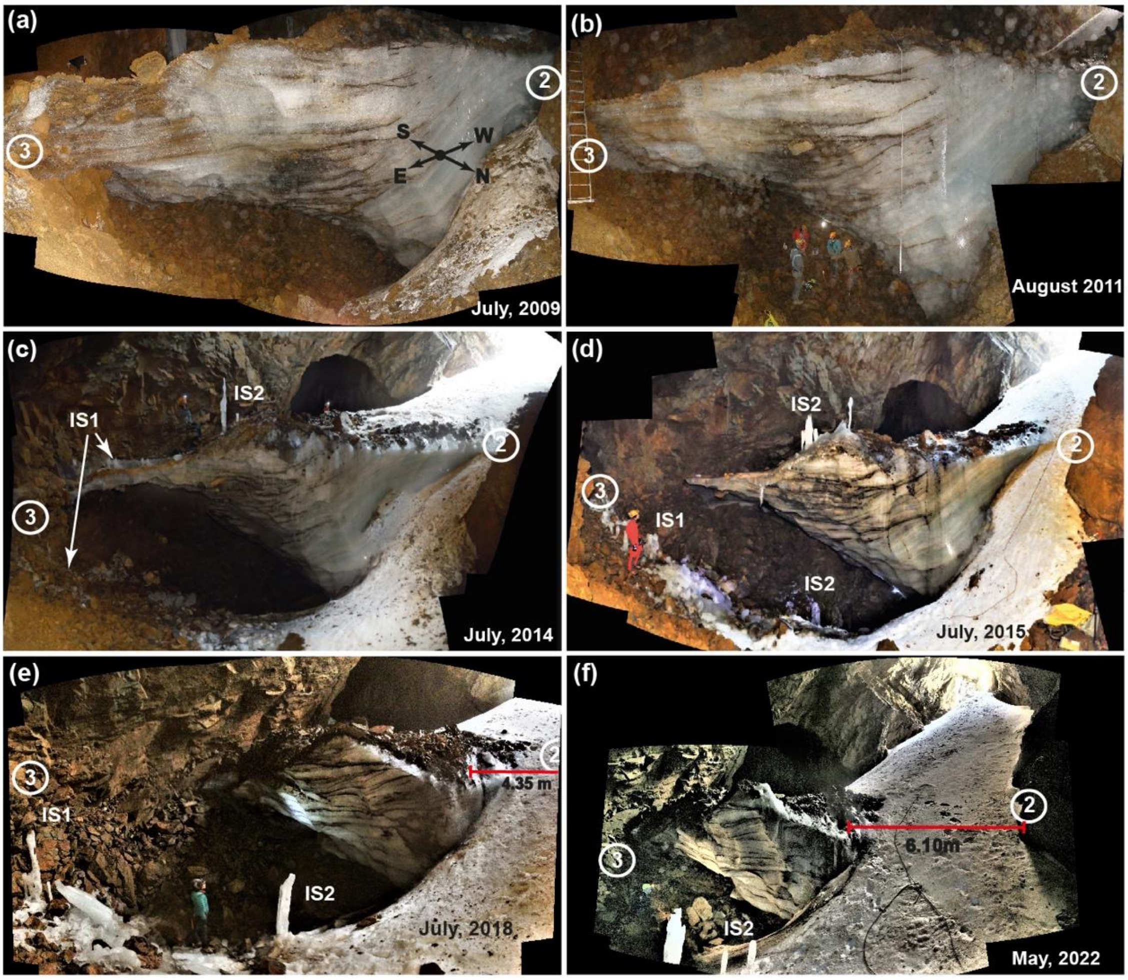


Figure 11 is highly informative, but it is quite dense. Can you think of some changes that might improve readability? For (h), orange (Fall) is not the best color as is almost impossible distinguish from red.

We will adjust the colors for fall, summer, and annual in Fig. 11h to enhance readability. To simplify and reduce the number of curves, only the moving averages will be retained in Fig. 11f.

- ➔ **Done. We have kept the 5-year running average in Fig. 11h, changed the color of total precipitation to grey, and added a background to the summer and autumn bars. We have adapted the figure caption to this.**

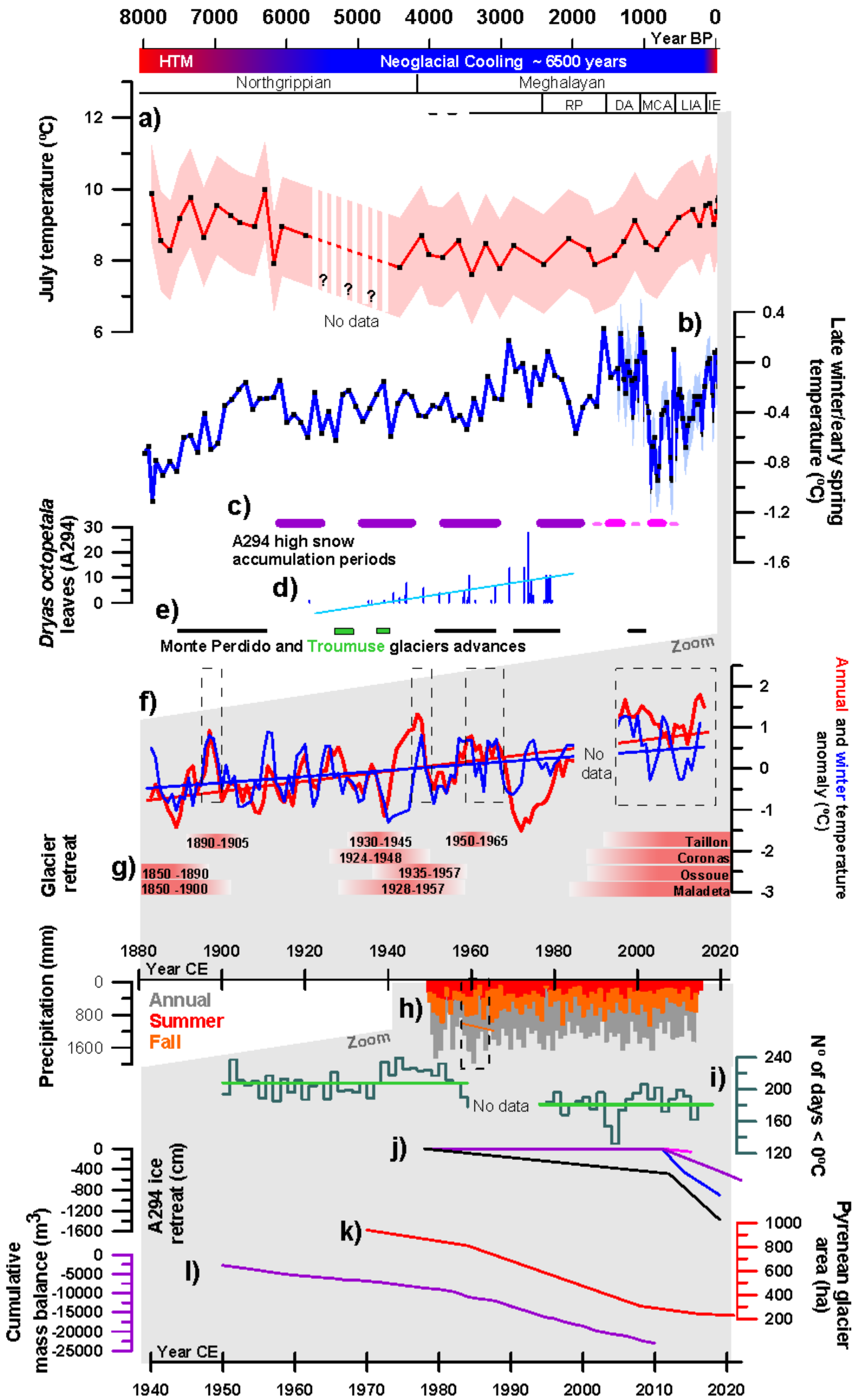


Figure 11: a) July temperatures reconstructed from chironomids obtained from the Basa de la Mora lake in the study area (Tarrats et al., 2018). b) Winter-spring temperatures reconstructed from chrysophyte cysts in Lake Redón (Pla and Catalan, 2005). c) High snow accumulation in A294: purple from Sancho et al. (2018), pink from this study. d) Number of *Dryas octopetala* macrofossils in the A294 ice body

(Leunda et al., 2019). e) Advances of Monte Perdido and Troumouse glaciers (Gellatly et al., 1992; García-Ruiz et al., 2014, 2020). f) Mean annual temperature (red) and winter anomaly (blue) 5 year running average from Pic du Midi de Bigorre (period 1882-2008) weather station (2860 m a.s.l., Bücher and Dessens, 1991; Dessens and Bücher, 1995). g) Glacier retreat in the Central Pyrenees (Marti et al., 2015). h) Annual precipitation (grey), summer (red), and fall (orange) from a Torla weather station located 39 km NW of A294 at 1053 m a.s.l. i) Evolution of freezing days calculated from the Pic du Midi de Bigorre weather station. j) Ice loss (cm) in A294: lines show vertical loss (pink), Rock Corner (blue, point 2), East wall (purple, point 3), and North wall (black, point 1). k) Changes in Pyrenean glacier area (ha) (Rico et al., 2017; Vidaller et al., 2021). l) Global cave ice loss - cumulative mass balance (m^3) of ice caves (Kern and Perşoiu, 2013).

Minor editorial issues:

Lines 80-82: Several additional factors influence cave temperature during the "closed" phase, not solely the heat exchange during winter. The sentence requires revision for clarity, considering the information provided in lines 82-85.

We will rephrase the lines 80-82 taking into account the lines 82-85

We have rephrased the paragraph: (new lines 78-101)

"In static (i.e., sag-type) ice caves, cold and dense air enters the cave during the winter season (open phase), cooling the cave environment. During the warm season (closed phase), the cave acts as a thermal trap, largely isolating the interior from external temperature fluctuations (Luetscher et al., 2008). However, although external temperatures have minimal direct influence during the closed phase, the thermal state of the cave is still affected by the heat exchange that occurred during the preceding open phase (Wind et al., 2022). This residual heat influences the cave's internal temperature and, consequently, the rate of ice melting. Additionally, increased rainfall and extreme precipitation events during the closed phase contribute to ice loss, as infiltrating water releases heat into the cave environment (Luetscher et al., 2008; Perşoiu et al., 2021). Overall, ice retreat in these caves is primarily driven

by reduced winter precipitation, rising winter temperatures, and the thermal effects of water infiltration during warmer months (Luetscher et al., 2005, 2008).”

Line 183: The (dd/mm/aa) format is used, but at line 187, authors use the (dd/mm/yy) format. Choose and maintain one format consistently.

We will check the consistency along the text and we will homogenize the format

- ➔ **Done. We have standardized them as dd/mm/yy.**
  New line (221)

Line 594 (Acknowledgements): should be "... foe for .." or it should only be "for"

We will delete "foe"

- ➔ **Done. We have changed "foe" by "for"**

References: There are minor formatting inconsistencies in the list, which should be checked for uniformity.

We will correct the inconsistencies in the reference list.

- ➔ **Done. We have reviewed the reference list as specified by the journal and have added the new reference introduced in the introduction**

Referee 2

We thank referee #2 for the revisions. Below we respond to the comments (text in green).

In this paper, the authors indicate, based on several sets of data, observations and inferences, that cave ice melt in the central Pyrenees (Spain) is unprecedented over the past ~6000 years. The "message" of the paper can be broken down into two sections: 1) melting of ice during the past decades and 2) unprecedented melting during the Holocene. The authors use cave climate monitoring data to decipher the main factors responsible for ice melting (and/or accumulation) and use these in combination with mapping of the extent of ice during the past ~45 years to reconstruct the general retreat of ice. Further, the authors combine these observations with data from previous studies (aided by two additional ^{14}C ages) to show that the melting that occurred in modern times is unique in the history of the ice cave. I find the first part well supported by data, measurements and associated discussions, but cannot say the dame about the second part. Support for this thesis is given mainly by circumstantial observations, mostly at the end of section 5.2. As the manuscript stands now, the title and conclusions are not supported by the data and the discussions. I suggest the authors restrict their analysis to the modern (i.e., post 1978 melting) – there findings fit well with similar data from the Alps and the Balkans and give strong support to the usage of cave ice as indicators of melting cryosphere. The part dealing with the Holocene, however, is not well constrained and would require much better support to be considered for publications. I will restrict my comments to this section, as it is the one where most of the criticism would go.

So, first, reconstructing the extent of past ablation in a sedimentary sequence is difficult, as it implies usage of an equation with two unknowns: accumulation and ablation. It is impossible to derive a well-constrained (age-wise) melting period, based on observations of what is left behind.

> Obviously, reconstructing the mass balance is not possible, and we agree with the reviewer on the difficulty of reconstructing the melting periods from an ice sequence in a cave. However, we would like to clarify that at no point has this study attempted to reconstruct the ice mass balance in the strict sense, as defined by the equation:
>
> $$\Delta mice = m_{new\_ice} - m_{melted\_ice}$$
>
> where, mass variations (Δm_{ice}) in subsurface ice accumulations result from a difference between seasonal ice accumulation (m_{new_ice}) and annual melting (m_{melted_ice}). It is impossible to determine how much ice melted in the past (e.g., in m or m^3). However, there are sedimentary structures in this deposit that indicate the occurrence of ablation phases. Sancho et al. (2018) provide a detailed description of the deposit's stratigraphy — summarized in our manuscript (Results, 4.a) — including variations in accumulation rates inferred from radiocarbon dating, as well as the interpretation of the unconformities within the deposit. The term "mass balance" appears in two instances throughout the text. The first is in line 482, and although it is not possible to provide a precise value, the available data suggest — and it seems reasonable to infer — a clearly negative mass balance, as stated in the manuscript. The second instance refers to the stratigraphy of the deposit. To avoid potential confusion, we will remove the term in that context and replace it with "ice accumulation rate" in this second case.

➔ **Done. As indicated above, we have changed the "mass balance" by "accumulation rate" in the second case. New line 524**

The authors say that no periods of extended melting occurred in the past, based on the putative absence of debris layers, but these are clearly identifiable in the figures and also the same authors (Sancho et al., 2018) identified several such periods based on the presence of unconformities in the ice deposit (mentioned also in lines 224-228 in the current manuscript).

➔ At no point in the manuscript do we state that extended melting did not occur in the past, nor do we claim that debris layers are absent. In fact, we explicitly mention the presence of debris layers (referred to as *detrital layers*). Furthermore, we identified (lines 219–233) three periods of reduced ice accumulation between the main unconformities recognized in the stratigraphy — which are interpreted as associated with ablation phases — and provide an interpretation of these features. In fact, we say that if a similar phase of retreat to the one currently observed had occurred in the past, the stratigraphy we see today in the deposit would be completely different, with truncated strata and high-angle unconformities formed by the accommodation of subsequent snow that would adapt to the geometry of the unconformities.

This is also indicated in the current manuscript (lines 155-156), the authors identifying changes in the internal structure of the ice sequence (which would contradict their later statements).

➔ The response to this comment is discussed further below in this document.

While it is not clearly stated in the manuscript, it seems, based on the photos, that while the ice filled most of the cavity, the current retreat happens in a series of steps that combine lateral melting (retreat from the walls) followed by collapse of the overhanging flat surface, and again retreat.

➔ We respectfully disagree with this comment. These aspects are addressed multiple times throughout the manuscript. First, the 1978 topographic survey indicates that ice filled the cave up to the elevations recorded at that time. In fact, Figures 3A and 3D (reconstruction of the cave's ice extent in plan view based on topographic data and field observations) show that the ice occupied the entire floor of the cave. This is explicitly stated in lines 253–255 of the manuscript. Second, regarding the current retreat, Section 4.4 discusses the recent melting and lateral retreat of the ice, including the collapse of an overhanging sector (lines 364–365), as well as the most recent retreat of the ice.

This retreat (10+) would have definitely destroyed possible layers indicating melting that would have formed in the past.

➔ We do not agree with this comment. As can be observed, the lateral retreat is not altering the stratigraphy of the layers, since the direction of retreat is perpendicular to the exposed surface of the ice body. In fact, its preservation over time is evident when comparing the two age models (2011 and 2015). These age models support the extent of the main unconformities that affected the deposit in a similar way. Of course, there are minor discrepancies in the ice thickness between these unconformities and/or detrital layers, but the phases of higher and lower accumulation are consistent (cf. supplementary material). The thickness of ice between the unconformities is not constant, since the newly accumulated snow adapted to the morphology of the previously ablated surface. Additionally, since snow entered the cave from the ramp down to the bottom, it is coherent to find slightly greater thicknesses in the central part of the deposit compared to the snow accumulated above the unconformities towards the ramp, where it could taper out.

Second, the new 14C ages seems to be derived from layered ice deposit located 15 m above the main one. It is not clear what relationship exists between the two, but if they belong to the same ice mass, 15 m of missing ice must have melted away sometimes in the past, thus far exceeding the current melting.

➔ We do not agree with the reviewer on this point. We have observed that the ice deposit continues above and is stratigraphically connected to the sequence previously described by Sancho et al. (2018). The new radiocarbon ages obtained are in correct stratigraphic order and consistent with the previous ones.
Below, we provide a photograph showing the continuity of the newly exposed ice deposit, revealed after the complete melting of the seasonal snow cover. These details are discussed in lines 235 and 245 of the manuscript. We can include this photo, or a selection of them, in the supplementary material if deemed necessary.

→ Done. We have included this figure in the supplementary material, figure caption was added and the numbers of supplementary figures were modified, as well as in the principal manuscript.

Figure S4: General view of the ice deposit (upper image) and detail of the ice ramp (red square, lower image) after the snow had disappeared, and location of the ablation pit hole (green square, top left image) where the A294 R-Mid sample was taken for ^{14}C dating.

Another support for the unprecedented of the melting is given by the comparison of the two age models. It is not clear how this data supports the hypothesis (and why is tucked away in the supplementary material). The two sedimentary logs look quite different so it is difficult to understand what the authors wanted to say – perhaps that there is no vertical unconformity (lines 485-487) inside the ice mass? This is just absence of evidence.

➔ We do not agree with the reviewer's comment. At no point in the manuscript do we use the comparison of age models to claim that the current melting is unprecedented. The comparison of the age models is used to estimate the centimeters of ice lost due to the vertical retreat of the deposit (lines 151–156), and to discuss the retreat rates observed at different locations within the cave (Section 5.1).

Nowhere do we state that a vertical unconformity exists within the ice deposit. In lines 483 to 485, we indicate that if a past retreat event similar to the current one had occurred, the present-day ice stratigraphy would show truncated strata and large unconformities — features that are absent in the observed stratigraphy of the deposit. Therefore, we firmly believe that the available field evidence supports our conclusion that the current cave ice melt is unprecedented in the last 6100 years.

Minor changes in the revised version (supplementary material):

→Lines 4 – 59. We actualised the affiliations

→Line 64. We deleted "period"

→Line 73. We delete ";" and added ","

→Line 74. We delete "Limestone"

→Figure 1 caption. We added "Rios et al., (1982)", we changed "Robador-Moreno et al. (1999) and López-Mier et al. (2015)" by "Robadoret al. (1999) and López-Mir et al., (2015)". We deleted "along the", "t" and "the". We added "." at the end of the phase.

→Figure 2 and caption. We changed "Gallerie discovered in 90s" by "Gallery discovered in the 1990s". We changed "arrow" by "orientation". We changed "probably" by "probable"

→Figure 3 and caption. In the figure we changed "proflile" by "profile" (right axe in green). We added "stratigraphic" in the caption.

→Figure 4 and caption. We changed "4" by "5" and we changed "The lost data corresponds to recording failures in the sensors due to low battery power" by "The lost data correspond to sensor failures."

→Figure 5 and caption. We changed "5" by "6" and changed " " Example of extreme rainfalls (>80 mm) recorded by the Armeña Weather Station and delayed increases in cave air temperatures in A294. Red line is the external temperature, while green and blue lines represent the cave temperature variations recoreded of the CH1 and CH2 sensors, respectively. Dark blue vertical bars represent precipitation events"

by

"Example of extreme rainfall (>80 mm) recorded by the Armeña weather station and delayed increases in cave air temperature in A294. Red line is the external temperature, while green and blue lines represent the cave temperature variations recorded by the CH1 and CH2 sensors, respectively. Dark blue vertical bars represent precipitation events."

→Reference list (lines 91-153). We adapted the list to the journal citation type.