Responses to Anonymous 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.

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.

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.