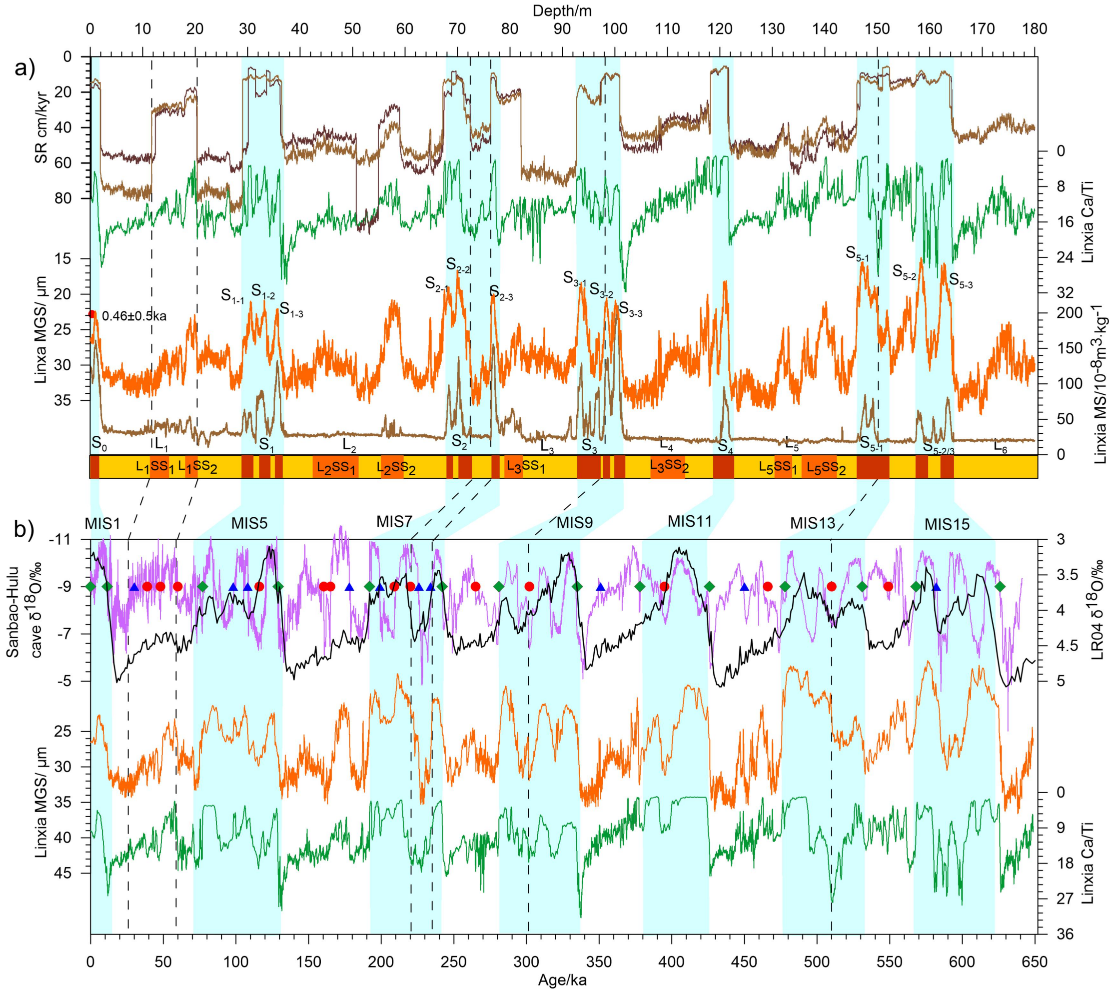
The paper by Guo et al. submitted to CP is based on a new East Asian Summer Monsoon rainfall reconstruction from the northwest Chinese loess plateau over the last 650 ka.

In this study the authors address the following questions: i) is there a reliable proxy for East Asian summer monsoon (EASM) rainfall at the millennial timescale and ii) what are the factors modulating the millennial monsoon variability (MMV)? Overall the manuscript is clearly structured, well written and both topic and objectives are suitable for Climate of the Past.

First of all as I am not a specialist in "wavelet analysis" I will leave the evaluation of this approach to reviewers more familiar with statistical methods. On the other hand, as a geologist working on Loess-Palaeosol Sequences (LPS) for a long time, I am surprised (not to say displeased) by the complete absence of data presenting the loess and palaeosol record on which is based the present study.

Re: Thanks for reminding us of adding the basic information for stratum lithology of Linxia loess section to evaluate our age model. We would like to revise Figure 2 in our manuscript and add relative information in result section. See the following figure.



Revised Figure 2 in manuscript, a) Strata and down-core variations of mean grain size, magnetic susceptibility, Ca/Ti and sedimentation rate against depth (brown in grain size based age model and dark brown in loess-cave comparison based age model). Brown red, orange and yellow rectangles represent palaeosol layers, weakly pedogenic palaeosol in loess layers and loess layers, respectively. The timing of dash line and glacial-interglacial transition are control points of grain size based chronology; b) variations of mean grain size, Ca/Ti over last 650 ka and age model of Linxia loess section. Comparison of mean grain size and Ca/Ti in Linxia section with Sanbao-Hulu (Cheng et al., 2009, 2016) and benthic $\delta^{18}O$ stack (Lisiecki and Raymo, 2005). The dark brown squares, blue triangles and red dots represent the first (glacial-interglacial transition), second (precession cycles) and third (millennial-scale events) class age control points at the corresponding position of cave record, respectively (Sun et al., 2021a). Light blue bands donate the interglacial times.

This is a main concern and that alone would be for me a matter to reject this contribution. Indeed, this is the starting point of the study: before presenting and interpreting the variation in Ti/Ca ratio and grain size parameters along the 182 m of the Linxia record, the LPS itself should be exposed with a reasonable level of information. Even if the Linxia LPS was previously published in another paper by Guo et al in Catena (2021) this information should be provided in the present contribution because it is very important for the evaluation of the “age model” on which all the conclusions of the study are based.

Re: Yes, I total understand your concern about our new age model. Because we did not detailedly explain the errors and differences of our new age model in method section. We have already published the age model and stratum lithology of Linxia section in Sun et al.,’s paper (Sun et al., 2021, ESR). We did not make this very clearly in our paper. In Sun et al,,’s, five high-sedimentation-rate loess records including Linxia loess section on the Chinese Loess Plateau are investigated to assess East Asian monsoon variability at orbital and millennial timescales (Figure 1). The independent speleothem-based chronology for Chinese loess-paleosol sequences over the past 640 ka is established by correlating loess grain size (a winter monsoon proxy) to speleothem $\delta^{18}O$ (a summer monsoon proxy). We would like to revise Figure 2 in our manuscript and show these information.

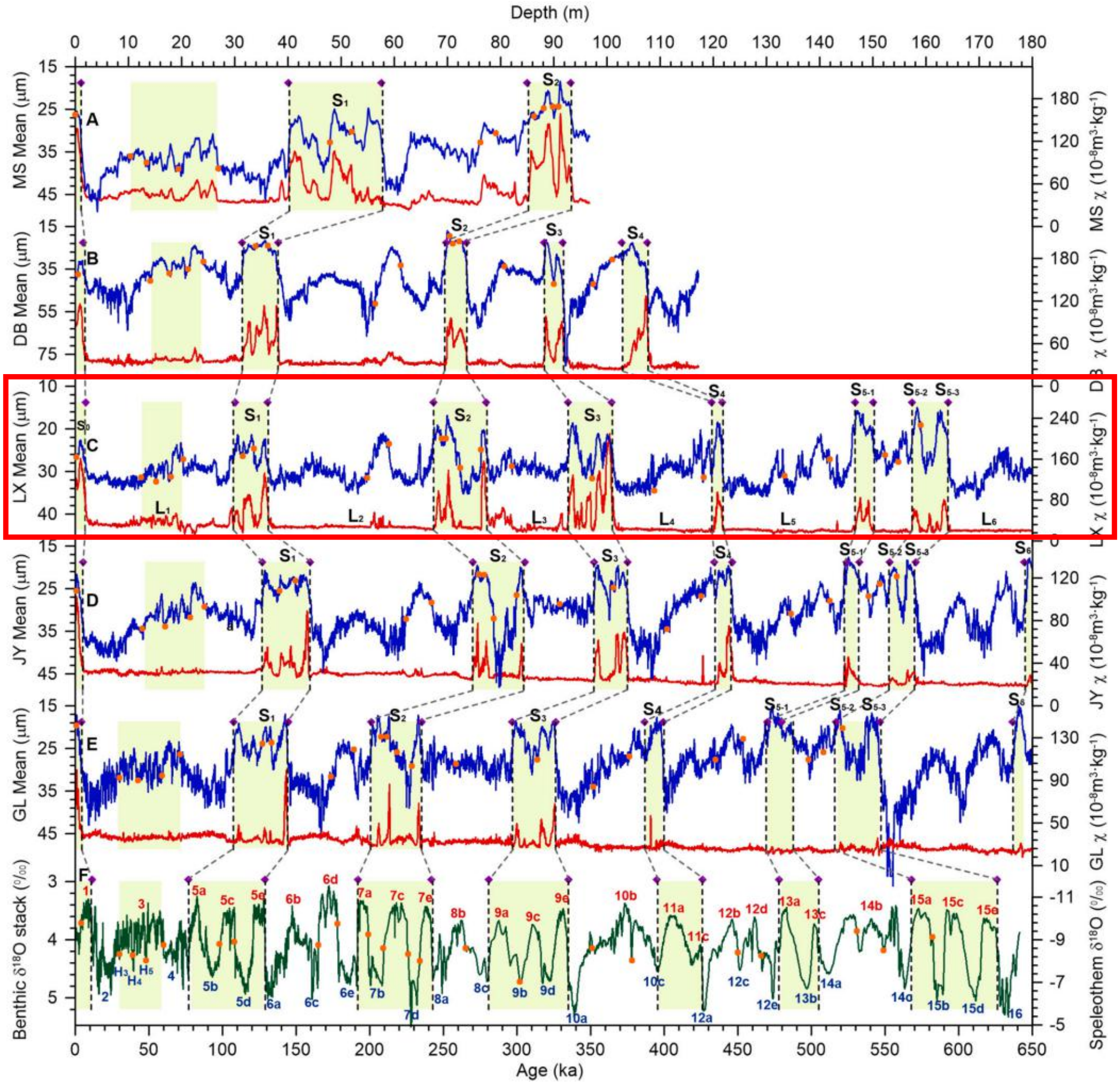


Figure 1. Comparison of loess proxies (χ-red lines, mean-blue lines) with speleothem $\delta^{18}O$ (purple). From top to bottom: (A) Mangshan (MS) (Wang et al., 2020); (B) Dingbian (DB); (C) Linxia (LX); (D) Gulang (GL); (E) Jingyuan (JY) (Sun et al., 2019; this study); and (F) Speleothem $\delta^{18}O$ from Hulu and Dongge caves (Wang et al., 2008; Cheng et al., 2016). Light green bars denote interglacial stages (1-15). Dashed lines and purple diamonds (first-order time controls) denote correlations between loess/paleosol boundaries and glacial/interglacial transitions. Orange dots indicate the second-order time controls adopted for matching abrupt changes between loess mean and speleothem $\delta^{18}O$.

The second main concern is indeed the "age model". As Reviewer 1 I will ask: what is the implication of the age model errors for the wavelet coherence correlations that authors conducted (against GHG, ETP, Insolation and benthic d18O on Figure 4) and for the millennial-scale component extraction.

Re:We should take the influence of age model error into consideration in method section. We assessed the this kind of influence and add the result in method parts. We isolated the millennial-scale components of loess Ca/Ti at the different age model for comparison (Figure 2).

The age model difference of millennial-scale variability is 1-3 kyr. We applied Ca/Ti on grain size based age model to calculate the MMV and conduct wavelet coherence analysis, showing almost the same correlation and phase at the orbital frequency bands (Figure 3) as that of WTC results at loess-cave comparison based age model (manuscript Figure 4).

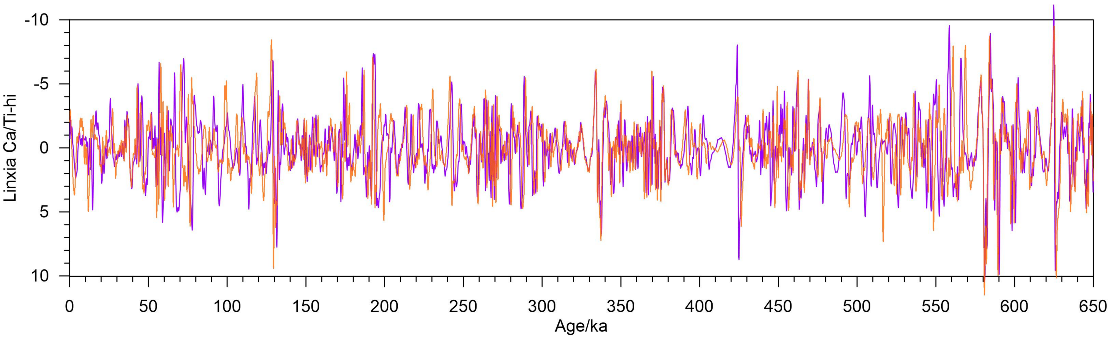


Figure 2 The comparison of millennial-scale loess Ca/Ti variations on grain size based age model (purple line) and loess-cave comparison based age model (orange line).

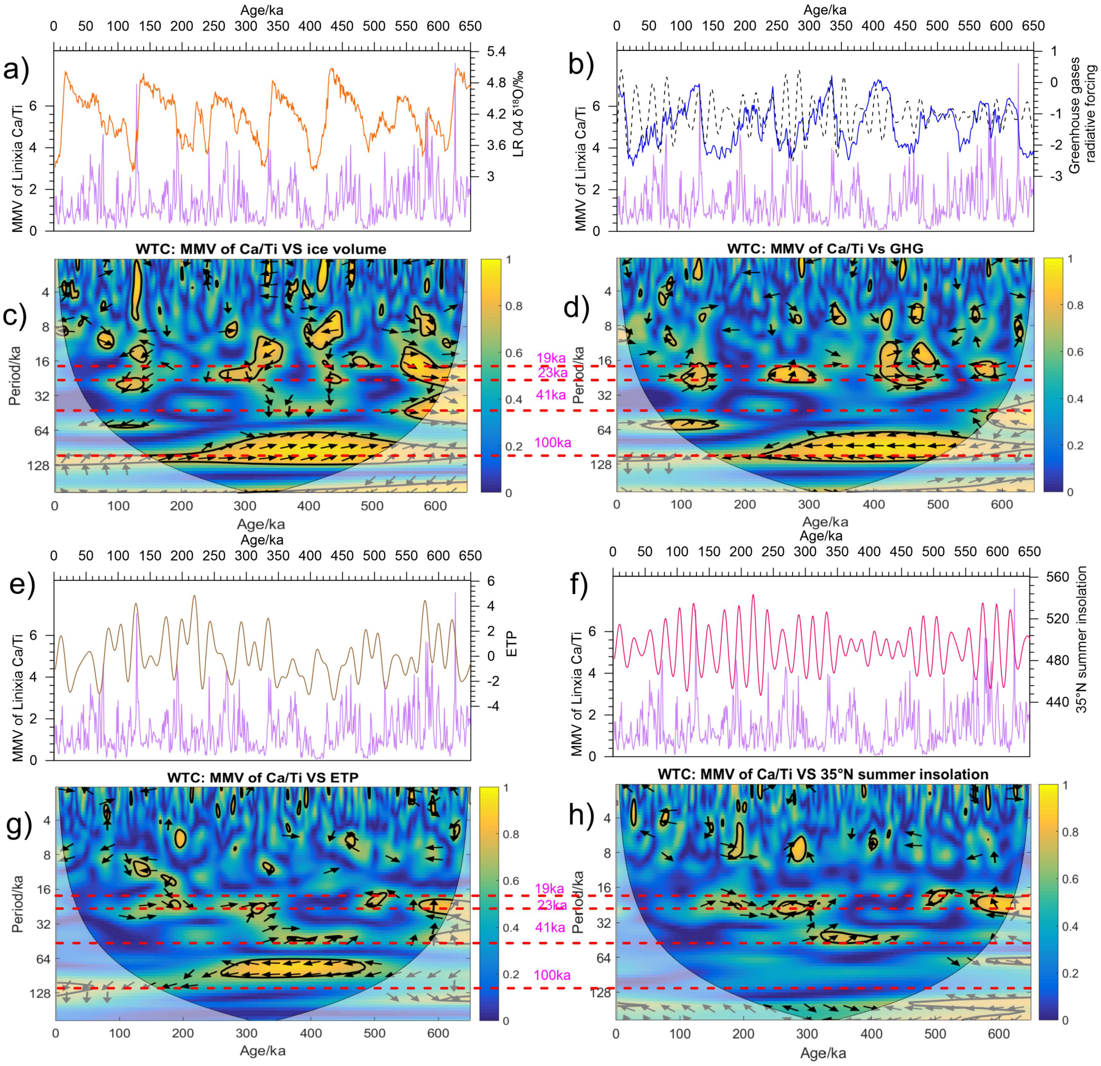


Figure 3 Comparison of a) ice volume, b) GHG forcing, c) ETP and d) local summer insolation with MMV of loess Ca/Ti over the past 650 ka at the grain size based age model.

Before to present and age model you should provide variations curves of climate proxies considered here regarding to depth (Ca/Ti and loess mean grain size). The age model proposed in the present contribution is directly extracted from the one published by Guo et al., 2021. Looking to Fig. 3 of this paper I can agree with the age-depth relation proposed for the last 60 ka where OSL dating are available but concerning the part of the record older than the Last Glacial no absolute data are provided and the age model is thus highly speculative.

Re: Yes, I agree with you. We know that ^{14}C and OSL dating method could provide us absolute dating results for loess record over past 130 ka. For older glacial periods extending back B/M boundaries, there is no good dating method to obtain absolute dates. In East Asian monsoon region, high-precision dated stalagmites from the Hulu and Sanbao caves offer high-resolution δ^{18}O records reflecting orbital-to-millennial Asian monsoon variability over the past 640 ka (Wang et al., 2001, 2008; Cheng et al., 2009, 2016). Since most of the U-Th dating errors are less than 2 ka for the last 450 ka and increase to 4-8 ka before 450 ka, the composite cave δ^{18}O record has been used as an important benchmark for regional-to-global synchronization of abrupt climate changes. During past two decades, optical simulated luminance (OSL) dating has been successfully applied for reconstructing an independent chronology of the last glacial loess deposits (e.g., Lu et al., 2007; Lai et al., 2007; Stevens et al., 2008). Abrupt changes in two OSL-dated loess grain-size time series match well with millennial-scale climate events recorded by stalagmites, marine and ice cores (NGIP), implying that all abrupt events during the last glaciation are coupled among these records (Sun et al., 2012; Wang et al., 2020). Proxy-model comparisons suggest that abrupt changes of the winter and summer monsoon events are anti-correlated at millennial and centennial timescales in response to the meltwater forcing and the resulting change in the Atlantic meridional overturning circulation (Sun et al., 2012; Wen et al., 2016). At glacial-interglacial time scale, numerous loess proxies have demonstrated that during glacial terminations remarkable strengthening of the summer monsoon was associated with synchronous weakening of the winter monsoon (e.g., Liu and Ding, 1998; Xiao et al., 1995; An, 2000). Therefore, an independent loess chronology can be generated by matching rapid changes in loess grain-size (a winter monsoon indicator) with abrupt shifts of the cave δ^{18}O record (a summer monsoon proxy) at times of glacial/interglacial transitions. We could make a comparison between the typical grain size based model and our new speleothem-based age model and evaluate the accuracy of this new speleothem-based age model. The high-precision dated stalagmites are proven to be successive. The comparison of the millennial-scale signals among loess, speleothem, marine records could also check whether erosion hiatus occur in the loess record. The abrupt climate events are well recorded by loess MGS. The magnitude of millennial-scale abrupt climate events in loess MGS are equal or more than that of cave δ^{18}O.

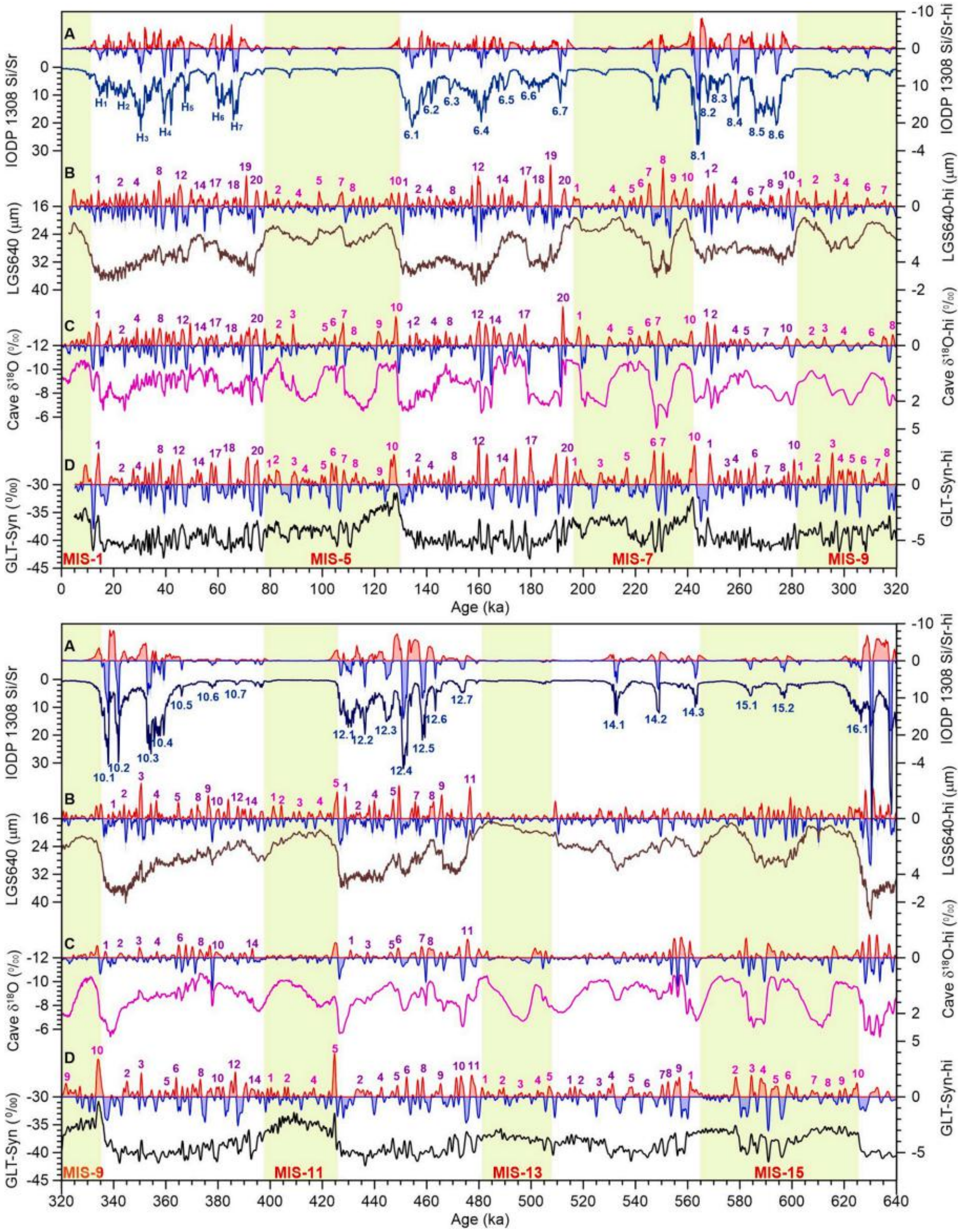


Figure 4 Correlation of abrupt climate events in terrestrial, marine and ice-core records. (A) Si/Sr ratio and its high-frequency components of IODP site 1308 (Hodell et al., 2008); (B) LGS640 and its millennial component; (C) Cave $\delta^{18}O$ and its millennial variability (Wang et al., 2008; Cheng et al., 2016); and (D) A synthetic Greenland temperature (GLT) and its high-frequency component (Barker et al., 2011). Abrupt climate events are recognized based upon their amplitude (>average deviation) and duration (>0.8 ka) of high-frequency components of these records. Purple and pink numbers above red curves indicate the warm DO-like events during each glacial and interglacial.

Deep blue numbers below the IODP 1308 Si/Sr curve denote the Heinrich-like events. (Sun et al., 2021, ESR, manuscript Figure 8).

The age-model is classically build using “tie points” that can be selected by “matching the loess (L)/paleosol (S) boundaries to the glacial/interglacial transitions. This is the classical approach but they should know that it is only reliable if: 1) the sedimentation rates are more or less regular through time during each glacial period and 2) no erosion hiatus occur in the record. This is not the case for the Linxia LPS according to Fig. 3 published by Guo et al. 2021.

For example it is strange to note that the sharp boundary in MGS and MS data occurring at the base of L2SS2 soil (-60m) has no counterpart in MIS stratigraphy. Following the correlation methodology exposed above (tie points) this major limit would rather have been correlated to the base of MIS 7 interglacial and thus dated at about 220 ka and not at about 175 ka according to the present scheme. In addition why the Last interglacial (MIS 5e) is only marked by a short and relatively not intense peak in both MGS and Ca/Ti curves (SISS3) whereas it is generally represented by a thick and well developed soil horizon in LPS?.

Re: Yes, it is strange. I think it is because of proxy sensitivity difference to climate factors forcing. As to LR04 record (mostly ice volume forcing), it is a good target to provide the glacial-interglacial age control points. The precession scale variations are not obvious as that preserved in Cave $\delta^{18}O$ record (mainly strong summer insolation forcing), especially during the glacial times. Due to weak pedogenesis and high sedimentation rates, precession- to millennial-scale oscillations are well preserved in the western and northwestern Chinese Loess Plateau (CLP) over the past glacial cycles (Sun et al., 2012, 2021a; Ma et al., 2017; Guo et al., 2021, Figure 5). However, these signals are not clear in middle and southern CLP. For example, the precession-scale variations are evident in Linxia Ca/Ti, but not in that of Galang Ca/Ti during MIS3 and MIS 6, which is caused by precipitation difference across the CLP. During the MIS 5e, the prevalent stronger East Asian monsoon results in intensified precipitation and leaching effect associated with flat low Ca/Ti value (low Ca/Ti reflecting stronger precipitation-induced leching, such MIS 11c,d and MIS 13a). While weaker winter monsoon leads to deposition of smaller particle size corresponding to low value of MGS.

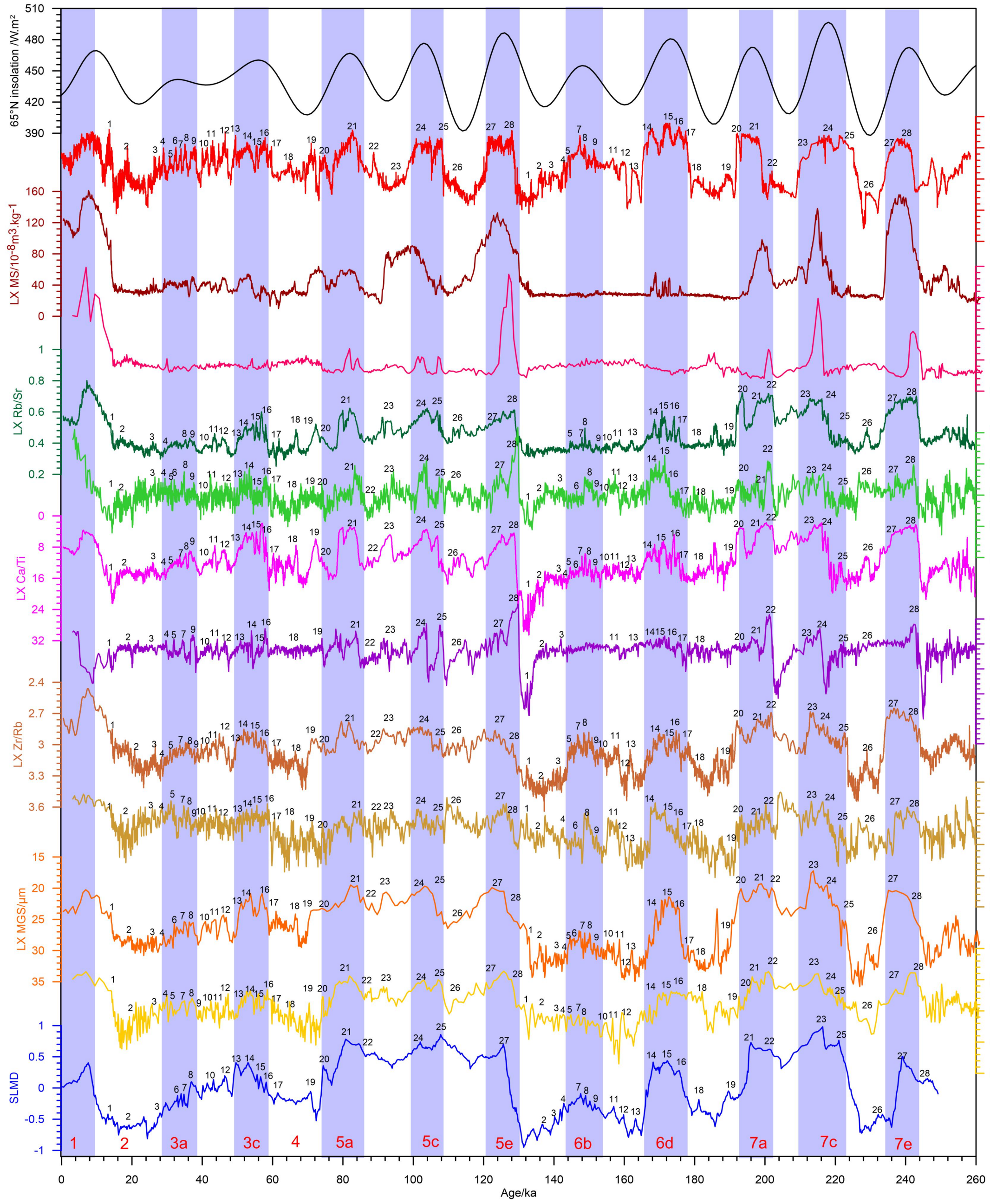


Figure 5 Comparison of records of Ca/Ti, Rb/Sr and Zr/Rb determined by the CXRF method, magnetic susceptibility (MS), and mean grain size (MGS) for the Linxia (LX) and Gulang (GL, Sun et al., 2016) sections with the Chinese Sanbao-Hulu speleothem $\delta^{18}O$ (Wang et al., 2008; Cheng et al., 2009, 2016) and the normalized stack loess median diameter (SLMD) records (Yang and Ding, 2014). Light blue bars indicate precessional cycles of different proxies corresponding to to July insolation maxima (Berger, 1978). Black numbers are DO (warming) events.

In addition the period corresponding to MIS 3 (± 60-30ka) exhibits only two weakly developed soil horizons (L1 SS1 and L1 SS2). These soils are likely corresponding to composite (upbuilding) soils developed over quite long periods (± 40-26 ka for L1SS1 and 60-45 ka for L1SS2) and thus including numerous DO events. So, the response to millennial timescale climate variations is clearly not recorded in the stratigraphic signal. In addition many of the peaks in proxies are so thin and of so small amplitude (MGS variation ≤ to 3 mm) that interpreting them as the result of a DO event is very difficult to support.

Re: Yes, these two sub-paleosoil are formed during MIS 3. If we just take the absolute value of millennial-scale MGS variations into consideration, the value is not large. The absolute value of glacial-interglacial MGS variations varies from 7 to 10 μm. 2-4 μm fluctuations of millennial-scale MGS relative to orbital-scale variations are pretty large. Abrupt climate change is commonly defined as a transition in the Earth's climate system whose duration is short relative to the duration of the preceding or subsequent state (Overpeck and Cole, 2006). The high-pass filtering (10 kyr) components of MGS presented in Figure 2 are well correlated with abrupt climate events in Cave $\delta^{18}O$ and synthetic Greenland temperature (GLT) record (Figure 4). The amplitude of some abrupt climate events are relative small in MGS record, but it is clear.

Finally the authors seem to ignore that millennial time-scale climate variations have been evidenced for more than 20 years in European loess series (e.g. Antoine et al., 2001 (QI), 2009 (QSR); Moine et al., 2008 (QI); Rousseau et al, 2002 (QSR), 2017 (QSR); 2020, (CP); 2021 (QSR) and that they have been definitely dated and correlated with NGIP record using ^{14}C dating (Moine et al., 2017(PNAS) and Ujvary et al., 2017 (PNAS).

Re: Thanks for minding us of millennial time-scale climate variations recorded in European loess sequences. They are good articles and worthy of reading. Our group will constantly pay attention to loess research in Europe. These researches confirmed that millennial-scale climate variations could be well preserved in high resolution eolian loess record of Europe and China. They are synchronous with abrupt climate events documented in high latitude ice core and marine records.

Conclusion: The authors must answer to the major comments exposed above to demonstrate that the main conclusions of their paper can be fully supported by data before publication.

Re: Thanks for giving useful suggestion to improve our manuscript and let reader knows more about this special geological archive. Any further advice and question are welcomed.