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Climate of the Past Discussions

Interactive comment on "Stable isotope and trace element investigation of two contemporaneous annually-laminated stalagmites from northeastern China surrounding the "8.2 ka event"" *by* J. Y. Wu et al.

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I. General comment: The paper submitted by Wu et al. addresses the impact and characteristics of the climate variations during the 8.2ka event recorded in two speleothems from North-Eastern China (Nuanhe Cave). Both stalagmites were appropriately analysed for the palaeo-climate purpose. Good dating results accompanied by high resolution δ18O, δ13C and Ba/Ca records offer the possibility to investigate the effect of the 8.2 ka event closely regarding seasonal differences. In addition, the study offers the chance to enhance the understanding of the coupling mechanisms between North

Atlantic climate and the Indian/Asian monsoon systems. The authors suggest that the δ13C and Ba/Ca signal are influenced mainly by the climate conditions of the winter season while the δ18O variations are ruled by the summer monsoon regime. This leads to the effect that the 8.2ka event reflects only in the Ba/Ca and δ13C signal but not in the δ18O. The submitted paper is very well suited for the scope of CP. Nevertheless, the manuscript would benefit from a more detailed and structured discussion of the proxy records. First, some introductive comments on the atmospheric circulation patterns influencing the cave might facilitate to follow the conclusions the authors draw. Second, the authors could give more weight to the discussion of the correlation between climate and climate proxy (δ18O, δ13C, Ba/Ca) in general. Third, the final synthesis contains important insights to the seasonal circulation patterns and climate conditions at 8.2ka B.P. and highlights the value of the study, but should be stated more precisely. The manuscript would benefit from a clearer explanation by the authors. In some cases an interpretation is hinted but not clearly and in details explained, which might be them weakness of this manuscript (e.g. monsoon regimes, influence of seasons on different proxies). However, the multi-proxy records presented here are excellent and highly suitable for discussing the effect of the 8.2ka event in Northern China. With some further discussion the manuscript could be a profound investigation of the complex climate conditions and trends between 8.6 ka and 7.8 ka before present. To conclude, the submitted paper should be published with major/minor revisions. The specific comments are listed below.

Reply: We appreciated the constructive suggestions and comments from Wackerbarth and understand his (her) concern that our interpretations for the speleothem proxies and climate mechanisms were weak. Due to lack of monitoring data for the cave and the presence of multi-interpretations for the geochemical proxies concerned here, the revised version of the manuscript could not address the weakness completely but we strived to incorporated the reviewer's comments one by one. In addition, we added new Ba/Ca data measured for Sample NH6 to enhance interpretation of the geochemical proxy and its relations to the δ13C profile. We put more weight to the discussion of the monsoon dynamics and its global linkage, including the winter and summer monsoon circulation patterns that exert different influences on the cave. Furthermore, we made more precise conclusions as suggested by the reviewer.

II. Specific comments Section 3.2 - Page 1596 - Lines 13-22 The discussion regarding the correlation of the δ18O records from NH33 and NH6 in the different intervals would benefit from adding correlation coefficients for each. In addition, the important frequency of 20 years should be proven by a frequency analysis or preferably a wavelet analysis. Probably the reasons for the high frequency variation in the records should be commented.

Reply: We calculated the correlation coefficients of the δ18O records from NH33 and NH6 different time intervals. The correlation coefficient is much higher (r=0.6) for the well-matched interval that for the remainder of the entire record (r=0.15). We used a wavelet analysis (Fig 7, in revised paper) to reveal the main frequency of 20 years and made detailed interpretations for the high frequency in section 4.2. The $\sim$20-year quasi-periodicity is analogous to modern rainfall variability.

Section 3.2 - Page 1596 - Line 27 In the case of kinetic fractionation a relationship between δ18Odrip and δ18Ocalcite exists although the description requires more complex models (Dreybrodt, 2008; Scholz et al., 2009). These should be mentioned. Other parameters like temperature, cave air ventilation or pCO2 of cave air should be named which complicate an interpretation of the δ18Ocalcite as a climate signal.

Reply: We discussed the models presented in Dreybrodt (2008) and Scholz et al (2009), as well as other factors mentioned by the reviewer. Although the two δ18O records have a small offset during the youngest part, we cannot rule out the effect of kinetic fractionation caused by a unique combination of flow path, CO2 partial pressure, residence time, concentration of solutes and degassing history. Even though replicated well, kinetic fractionations may exist, but their net effect of kinetic fractionation on δ18Ocalcite must have been the same. In addition, we discussed a relationship

between δ18O and growth rate for testing kinetic fractionations, although this does not include all parameters into consideration.

Section 3.2 - Page 1597 - Lines 3-7. The authors state that if the δ18O largely reflects changes in the δ18O of meteoric precipitation, the observed variations likely relate to the proportion of summer monsoon to the annual total. However, it is not clear and no test is shown if the δ18O value indeed fulfils this requirement. Is this supported by the cave monitoring or other observed values? In this context the reader might appreciate a general comment on the climate influence on the δ18Oprec signal at the specific location (Lachniet, 2009; Mook, 2006). At the cave site 60% of annual precipitation occurs from June to September. For the authors this is the reason why the variations of drip water δ18O value reflect the proportion of summer monsoon precipitation to the annual total. However, this statement must be handled with care, because precipitation occurring during the summer month is partially lost due to evapotranspiration. Hence, although the summer monsoon precipitation has a high contribution to the annual amount of precipitation, it is possible that it contributes less than initially assumed to the annual amount of infiltration water forming the drip water in the cave. This fact must be considered and in the best case tested with monitoring data from the cave or data available from other caves in the region. Equation like that of Thornthwaite and Mather (1957) can help to evaluate the amount of evapotranspiration (or more sophisticated Penman (1948)). It is possible that due to the high humidity during summer monsoon evaporation is highly reduced and summer monsoon contributes largely to the annual amount of cave drip water. The second question arising here is, if the precipitation from the remaining months shows a rather stable behaviour compared to the monsoon driven summer precipitation. Only then, the assumption is valid, that the δ18O variations of the cave drip water reflect the proportion of summer monsoon to the annual precipitation. Maybe the authors could also discuss in this context the influence on the δ18O signal of the drip water of varying contributions winter precipitation.

Reply: Yes, we discussed the climate influence on the δ18Oprec signal at the specific location (Lachniet, 2009; Mook, 2006). As we did not monitor hydrological processes of drip water in the cave, we restricted our discussion on how annual rainfall reflects changes in summer monsoon from the modern meteorological data. Based on the atmosphere circulation pattern, the summer monsoon rainfall occurs between June to September and its peak falls within July-August when the summer monsoon rain-belt reaches the cave site. The meteorological data from the nearby Benxi Station (Source from http://isohis.iaea.org, 1956∼2000 A.D.) shows that rainfall amounts during the summer seasons (June∼September) make up 60%∼85% of annual totals, and display a strong correlation with the annual totals (correlative coefficient r=0.903) for the past 50 years. This implicates that the amount of winter precipitation remains relative stable during this period.

The second issue is how much the rainfall becomes filtration water. If taking the evaporation into consideration, summer monsoon contributes more largely to the annual amount of cave dripping water. As illustrated in Fig. 1 (monthly averaged data for 1960∼1990 A.D., sourced from Local Chronicles of Huanren County where the cave is located), large evaporation (here measured as open water evaporation not natural one) occurs between April and June while relative humidity reaches the largest during July to Sept. Due to the high humidity during summer monsoon period (possibly including densely covered vegetation), evaporation is highly reduced, thus contributes largely to the annual amount of cave drip water.

Section 3.2 - Page 1597 - Lines 11-19 A short comment on the reasons why higher δ13C values relate to lower biological activity (fractionation during plant respiration) could be enlightening to a reader who is not familiar with the δ13C system. The authors discuss the increasing trend towards 8.2ka before present and link it to lower biological activity. However, after this time the records show severe discrepancies which need discussion. What could be the origin for the different behaviour, since this cannot be linked to climate?

Reply: we added a short comment to explain why higher δ13C values relate to lower

biological activity, as follows: It has been demonstrated that in most temperate caves between 80 and 90% of the speleothem carbon comes from the soil CO2 (Genty et al., 2001). The δ13C variation is mainly controlled by the soil biogenic production (plant root respiration and microbial activity of the soil and the epikarst zone), which is linked to climatic factors such as temperature and humidity (Genty et al., 2003). In general, high temperature and humidity triggers the microbial activity in the soil above the cave, and allows vegetation to develop, both phenomena producing a CO2 depleted in 13C and leading to a decrease in the speleothem δ13C. Conversely, a climate degradation induces the reduction of plant and soil activity, the δ13C of the dissolved CO2 will be much less influenced by biogenic CO2 and more by atmospheric CO2, leading to an increase in the speleothem δ13C (Genty et al., 2006).

However, the speleothems δ13C is also affected by the other sources of CO2 dissolving in the groundwater (the bedrock) (Hendy, 1971) and different local conditions in the same cave, such as prior calcite precipitation in the vadose zone (Baker et al., 1997) and the extent of degassing of CO2 from the dripping water (Spötl et al., 2005; Mattey et al., 2008). We cannot rule out the possibility that the two δ13C records were imprinted by these non-climate factors that resulted in a discrepancy between the two records after 8.2 ka. A key test for the climate interpretation of speleothem δ13C comes from the measured data of Ba/Ca which is generally considered to be relevant to the soil processes as cited in the Ref. (Hellstrom and McCulloch, 2000). As suggested by the two reviewers, we measured the Ba/Ca ratios for Sample NH6. The two time-series of Ba/Ca could not cover the whole profile as long as the stable isotope data due to sampling pits existing on the polished sections. As shown in Fig.2, The two trace element records matched very well during the contemporaneous intervals. Because of being comparable with the Ba/Ca records in terms of their timing and transitional pattern, the δ13C time series from NH33 could be selected as a true climate signal.

Section 3.2 - Page 1597 - Line 17 It should be explained once what is meant by “climate deterioration”, because this expression has different connotation depending on the respective climate zones and regions.

Reply: We define "climate deterioration" as the condition of decreased precipitation and temperature.

Section 4.1 - Page 1598 - Line 14 The term "Permafrost" is used here. Per definition permafrost is soil which is frozen for two or more years. If this is the case stalagmite growths is not possible. Maybe a different term should be used. It should also be discussed, if the dripping ceases completely or is reduced during this time. Are these information derived from cave monitoring? (December to February are three months (four were written accidentally).

Reply: We used "seasonally frozen ground" to replace "permafrost". We investigated the cave several times since Feb, 2008, and observed no drip water at the sampling site during winter months (December to March, should be four months).

Section 4.1 - Page 1598 - Line 19 Do the authors mean "growth axis" as written or "growth rate"? A short explanation of "steady hydrological state" could clarify if the water characteristics or the flow path or something different are indicated by this.

Reply: We changed this statement as follows: if the growth axis keeps perpendicular to the growth surface as we observed from the two samples, it can be inferred that the flow path remains unchanged during the whole growth period.

Section 4.1 - Page 1599 - Line 13 Same case as in Section 3.2 - Page 1597 - Line 1

Reply: Please see the reply to question "Section 3.2 - Page 1597 - Line 1".

Section 4.2 - Page 1599 - Line 21 and following the δ18O records from Nuanhe are in this section compared to records from Dongge Cave and Qunf Cave both showing the 8.2ka event more clearly. However, as stated by the authors both caves are influenced by the regime of the Indian monsoon. There are some other caves and speleothems which probably could be suited for comparison in this study. These stalagmites are HS4 from Heshang Cave (Hu et al. 2008), C996-1 from Jiuxian Cave (Cai et al. 2010)

or SB10 from Shanbao Cave (Shao et al. 2008) showing a less comparable change in the signal as recorded in Greenland or Dongge/Qunf. Hu et al. (2010) approach the 8.2ka event in their study. It could also be enlightening to include the COMNISPA record from Vollweiler et al. (2006) from the Alps which also lacks the 8.2ka peak (discussed in the respective paper) although it is directly influenced by North Atlantic climate. The interpretation is offered that Nuanhe Cave is influenced by the East Asian summer monsoon while Dongge and Qunf Cave are influenced by the Indian monsoon. The reader would appreciate further discussion why the Indian monsoon reflects the 8.2ka event while the EASM does not (maybe including information about the stability of the two monsoon systems).

Reply: Well-dated and highly-resolved record is prerequisite to capture the 8.2 ka event, such as those from Dongge and Qunf Cave which were carefully re-dated by Cheng et al (2009) (quite different from the firstly published records surrounding the event). However, it is difficult to say if the 8.2 ka event exists in other speleothem records mentioned here (Heshang, Jiuxian and Shanbao Cave) due to the limitation in resolution and dating. We cannot assess if the COMNISPA record is suitable for discussing the 8.2ka event, so that we restrict our discussion on the reason why the Indian monsoon reflects the 8.2ka event while the EASM does not. On the basis of a simulation result from Pausata et al (2011), monsoon precipitation over the northern Indian Ocean and subcontinent was directly linked to changes in North Atlantic sea-ice extent during the Heinrich Event 1. As a consequence, vapor transported from the northern Indian basin into China both directly and indirectly through recycling over the India subcontinent has a heavier δ18O composition. At present, water vapors from Indian Ocean transport as far as 33°N, including middle and lower beach of Yangtze River, but does not reach the Northeastern China where the Nuanhe Cave is situated. This could explain why Dongge and Qunf records have a profound effect of the 8.2 ka event. For the region typically influenced by the EASM, the blocking highs in mid- and high-latitudes of Eurasian continents and the subtropical high over the western Pacific play a more important role, which is quite different from the condition for the Indian monsoon (Ding et al, 2005). In particular, different sources of water vapor from the Northwest Pacific and from South China Sea contribute to the EASM precipitation and its δ18O, leading to the mixed vapor signal of high- and low- Pacific at the 8.2 ka.

Section 4.2 - Page 1600 - Lines 19-21. The authors could describe more clearly why only the δ13C record from NH33 is selected as the true climate signal. It should be discussed before why NH6 does not show the same signal decrease after the 8.2ka event and why this cannot be the true climate signal.

Reply: Thanks for the suggestion, your points of why the Sample NH33 was selected as climate signal are well taken (see our reply to Section 3.2 - Page 1597, Lines 11-19). We selected this profile to do the wavelet analysis and correlative coefficient with the Greenland climate records for the following two reasons: (i) higher resolution of the NH33 record; (ii) Compared to the NH6 δ13C record, Sample NH33 has little effect of kinetic fractionation, and more similar to the Ba/Ca records from the two stalagmites.

Section 4.2 - Page 1601 - Line 1 The Ba/Ca ratio is only shown for NH33. Was it measured also for NH6? If yes, it could be also shown and discussed. Maybe the Ba/Ca ratio helps to explain the differences in the δ13C record from NH6 compared to NH33.

Reply: We added the new Ba/Ca data for Sample NH6 measured by the same XRF meter. The two Ba/Ca time series replicate well during the same period. The results and discussions are given in section 3.2.

Section 4.2 - Page 1601 - Line 5 The term "prior calcite precipitation" can help here to clarify the discussion.

Reply: We used the term "prior calcite precipitation" to clarify our discussion.

Section 4.2 - Page 1601 - Line 27 The linking mechanism between EAWM and North Atlantic climate could be discussed more closely. The westerlies are suggested as the coupling element, however, this need further discussion. Throughout the discussion

section the interpretation could be stated more clearly why Ba/Ca and δ13C are influenced mainly by the winter climate (although dripping ceases during winter) and less by summer climate.

Reply: The climate change in East Asian is characterized by seasonal alternations of summer and winter monsoon circulations, which are formed as a result of thermal differences between the Asian landmass and the Pacific Ocean, and is further enhanced by the thermal and dynamic effect of the Tibetan Plateau. In the summer season, warm and humid air originating from the low latitude oceans migrates north along with the seasonal changes of planetary scale circulations, and is further driven by the east/west pressure gradient in East Asia. Warm and humid air can extend northwesterly into China's interior as far as the China-Mongolia border, leading to intensive rainfall from June through September, which contributes 60% of the mean annual precipitation at the site (between 800 mm and 900 mm). While in the winter season, dry and cold air from high latitudes is controlled by the continental high-pressure system, and propagates southward along the eastern margin of the Tibetan Plateau to form the strongest northerly dry winter monsoon (An et al, 2000). The EAWM produces a dry and cold winter season from November until February at the cave site.

In the revised version we used the conclusion of Sun et al. (2011) from both geological evidence and modelling results to strengthen our discussion on this viewpoint. As shown in previous studies (Yanase & Abe-Ouchi, 2007; Wu et al., 2008; Nagashima et al., 2011), Atlantic Meridional Overturning Circulation (AMOC) is a driver of abrupt change in the East Asian winter and summer monsoon systems. Sun et al. (2011) gave more confidence level for that the northern westerly play a role in transmitting this signal from the North Atlantic to the Asian monsoon regions. The rapid climate change in the North Atlantic region (for example, Heinrich and DO events) can result in variability in the strength and position of the westerly jet, influencing northern hemisphere climate, including East Asia. As AMOC slows, global northward ocean heat transport is reduced at all latitudes, including a 60% reduction north of $\sim$40°N. This is partially, but not completely, offset by an increase in atmospheric heat transport. Consequently, temperatures in the northern hemisphere decrease, with the largest cooling during the winter associated with areas of sea-ice expansion in both the North Pacific and North Atlantic. The increase in the meridional (latitudinal) temperature gradient leads to stronger westerly winds in the mid-latitudes and strengthened winter wind speed above the northwestern China.

Both temperature (winter monsoon) and rainfall (summer monsoon) play an important role in changing soil environment. Indeed, the soil-dominated proxies of Ba/Ca and δ13C show a resemblance in terms of timing, general pattern and transition. Changes in the two proxy records were considered to be more related to temperature changes (i.e. winter monsoon), not simply because of their dramatic difference from the summer monsoon proxy of δ18O, but also because of the geochemical behaviors of the proxies in the soil zone and specific climate conditions at the cave site. The carbon isotopic variations may changes from both temperature-driven changes in the intensity of soil microbial activity and humidity-driven changes in the extent of degassing of drip waters (Moreno et al, 2011) and the prior calcite precipitation (PCP) (Fairchild et al, 2009). During the 8.2 ka event, the δ13C rise may be caused by the decreased temperature and the decreased precipitation. However, the δ18O did not show a distinctly weakening trend in the intensity of the EASM. Furthermore, if the PCP is important, the Ba/Ca would increase, contradicting with the observed data.

The different response of the summer/winter monsoon strength to the high-northern latitude cold event, as recorded in the Huanhe Cave, stems from the difference in the forcing mechanism. Two internal factors are important for driving EASM circulation: (1) different sensible heat between the tropical Pacific and Asian continent and (2) latent heat collected from the tropical Pacific Ocean and released over Asia during precipitation. On the other hand, changes in the winter monsoon strength, as discussed above, are coupled with climates in the high northern latitude and associated with extent of continental and sea ice cover, summer monsoon strength will subdue due to the large

thermal inertia in the tropical ocean from which water vapor transport to inner-land over the East Asia. However, a change in winter monsoon circulation is fast-responding variable to the high-latitude climate via atmospheric circulations. This tele-connection should be more direct, resulting in a good match of Greenland temperature and the cave Ba/Ca and δ13C records.

Section 4.2 - Page 1601 - Line 27 to Page 1602 - Line 14 The synthesis can be clarified. Several questions arise (some named earlier): 1. Did summer monsoon change little or was it influenced by other hydrological processes? 2. Which is the coupling mechanism between EASM and NADW? 3. Why is only winter climate influencing Ba/Ca and δ13C? 4. Why is the Indian summer monsoon more stable than the EASM?

Reply: We clarified the synthesis based on the 4 questions that the referee mentioned here. The first question could be seen in the reply to “Section 4.2 - Page 1599 - Line 21”. The second question could be explained as changes in AMOC. Simulation results indicated that cooling in the North Atlantic associated with the reduction of the AMOC causes a southward shift of the Intertropical Convergence Zone in both the Atlantic and the Pacific, a strengthening of the Walker circulation in the northern tropical Pacific, and a weakening of the EASM (Zhang and Delworth, 2005). The third question could be found in the reply to “Section 4.2 - Page 1601 - Line 274”. And the last question would be answered by the reply to “Section 4.2 - Page 1599 - Line 21”.

Section 5 - Page 1603 Line 5 Please, explain more clearly “reorganisation of lowlatitude atmospheric circulation and hydrological cycles”.

Reply: we added a short comment on the atmospheric circulation patterns influencing the cave in section 2.

III. Technical corrections Section 4.2 – Page 1600 – Line 6 The comma between “δ18O” and “records” can be deleted.

Reply: Thanks, we did.

Section 4.2 - Page 1601 - Line 11 A comma is missing between “soil” and “plant”.

Reply: We added a comma between “soil” and “plant”.

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Figure 1. The monthly averaged precipitation, temperature, evaporation and relative humidity in Huanren County (1960∼1990 A.D.)

Figure 2. Comparison of multi-proxy records between two stalagmites (NH33-blue curves and NH6-orange curves). (A) δ18O records, the gray lines designate average values of δ18O in 3 phases; (B) δ13C records, the gray arrow illustrates the same trend between two δ13C records; (C) Ba/Ca ratio records; (D) annual layer thickness records.

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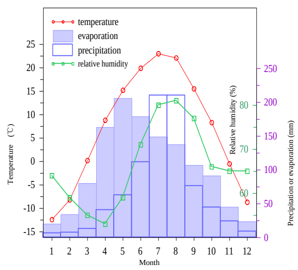

Fig. 1. The monthly averaged precipitation, temperature, evaporation and relative humidity in Huanren County

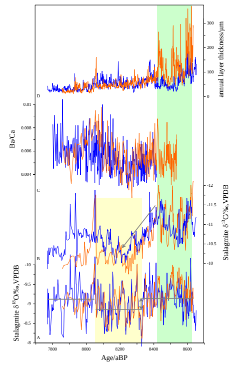

Fig. 2. Comparison of multi-proxy records between two stalagmites