

Interactive comment on “Abrupt climate variability of eastern Anatolia vegetation during the last glacial” by N. Pickarski et al.

L. SADORI (1st Referee)

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This manuscript is quite interesting and provides a high-resolution pollen study with new elements for the knowledge of the paleoclimate of the Near East during last glacial. In my view this is a valuable contribution to the understanding of how a far away region could respond to North-Atlantic changes. I encourage the authors to take into consideration the following general comments and the specific points included in the attached file.

General considerations

Considering the chronology of the record (already established and published in other articles) I wonder about the perfect correspondence existing between PAZ and MIS.

Many papers demonstrated that vegetation phases are not always synchronous with marine isotope stratigraphy. I guess this is due to the criteria used to establish the chronology of the core, that mostly consisted in synchronization of marine lowering/increasing of temperature and terrestrial reduction/expansion of AP. The authors should admit they could not be always in phase. They just discussed it for the (obvious and expected in my opinion) lack of correspondence between the timing of some Dansgaard–Oeschger (DO) events and pollen expansions. We are still far away by obtaining correct chronologies and we have always to admit that lacking of perfect matching could either be due to problems in dating or to time-lag between terrestrial response to ocean changes.

Dear Laura Sadori,

Thank you very much for your insightful suggestions and useful recommendation to improve the quality of this manuscript. I believe that we can make essentially all of the modification easily and it would be our pleasure to do so.

Concerning your question about the perfect match between PAZ and MIS, we admit that our chronology is not independent. It is chronology based on event-stratigraphy. As already discussed and described by Stockhecke et al. (2014), the independent proxy records based on high-resolution XRF measurements (Kwiecien et al., 2014), TOC (Stockhecke et al., 2014), and pollen data (Litt et al., 2014) were used for the age-depth model construction. This proxy record was correlated and finally visual synchronized by using ‘age control points’ to the e.g. NGRIP sequence (to avoid misunderstanding, we add some more information about the construction of the age-depth model in section ‘3.1. Chronology’).

However, the age-depth model of Stockhecke et al. (2014b) is based on tuning with the NGRIP event stratigraphy. The correlation points of the Lake Van sedimentary record have been mainly defined by abiotic proxies (i.e. TOC) caused by a higher time resolution of this data set in comparison to the pollen samples available during that time. Even if we present a high-resolution pollen record in this manuscript, leads and lags between different biotic and abiotic proxies related to climate events have to be taken into account.

‘In any case, we cannot expect a perfect matching between biotic and abiotic proxies related to climate events due to their different response time. In addition, the lack of correspondence between the pollen signal and the timing of some DO events could also be explained by uncertainties in the current age-depth model. Still, as expected from various eastern Mediterranean pollen records, the Lake Van pollen record documents that temperate taxa tend to reach their maxima after the onset of a warming phase and, therefore, lag behind the Ca/K increase, which responds immediately to climate changes (Fig. 5).’

We considered the mismatch between climate changes and vegetation responses and now expand this issue in the discussion.

Page, Line: Comment

Introduction

3344, 1-2: See also the crater lakes from Lazio: Valle di Castiglione, Lagaccione, Lago di Vico, Stracciacappa (e.g. Follieri et al. 1998, Quaternary International) and Lake Prespa (Panagiotopoulos et al. 2014, Climate of the Past. 10: 643-660) and Lake Ohrid (Lezine et al. 2010. Palaeogeography, Palaeoclimatology, Palaeoecology 287, 116-127).

We have added the crater lakes in Italy, Lake Prespa, Lake Ohrid and their related references.

3344, 19-20: Detailed high-resolution pollen analysis for the last interglacial (between ~100 and 800 year) is documented in (Pickarski et al., 2015).

Changed to: ‘A detailed high-resolution pollen analysis (between ~100 and 800 years) for the last interglacial (131.2-111.5 ka BP) is documented in Pickarski et al. (2015).’

Regional setting

3345, 2: ...lake (max. depth > 450 m, surface area ~ 3600m²), situated...

Changed to: ‘... lake (3,574 km²; max. depth >450 m), situated....’.

Material and methods

3347, 12: no previous ones?

Thank you very much for this important hint. We added Reille (1998, 1995).

Results

3349, 15: documented

Changed.

3349, 15: In which types have been oaks divided? What about the abundant semideciduous oaks that can be distinguished by deciduous ones and provide a different climate signal? At Lake Van, we were able to distinguish between deciduous *Quercus* and evergreen *Quercus* (as described in Wick et al., 2003 and Litt et al., 2009). During the last glacial-interglacial cycle mainly deciduous oaks occurred. In this manuscript, evergreen oaks were not presented in the pollen diagram due to their negligibly low percentages during the last interglacial (Pickarski et al., 2015) and their total absent during the last glacial period (this study).

3349, 19: Here charcoal concentration is properly expressed, see my note in fig. 2

Thank you very much for this advice. We corrected the issue with our inconsistent expression throughout the manuscript.

Discussion

3350, 9: do you really think that only temperature was a key-factor? What about humidity?

We added: ‘...and/or too cold or dry to reach the climate optimum....’

3350, 10: and dry

Done.

3350, 21: again, you do not consider the role of wetness

Done.

3351, General comment: the diagram of fig. 3 starts with 5e. Even if I understand why, you should include some comments on it.

The reviewer is fully right. We rewrote the first section of ‘MIS 5e-5a’ and added some more information/comments of the last interglacial stage.

3351, 11: ‘continentality’, again, also for this definition wetness is important

Changed.

3351, 12: ‘In accordance with the last interglacial (MIS 5e),....’, please make it clear, rephrase.

Changed. See reply above.

3351, 17: insert space

Done.

3351, 27: conifers

Changed.

3352, 3: I agree. Most studies pointed out that the available fuel (plant biomass) made the difference in fires (e.g. Vanniere et al. 2011, Holocene; Sadori et al., 2015- Plant Biosystems).

Thank you very much for your comment. We added the publications you mentioned.

3352, 8-10: I agree with this interpretation.

Thank you very much.

3353, 1: present-day

Removed. See reply below.

3353, 1-4: Please say it in a clearer way. You use present-day precipitation to infer past vegetation conditions.

We have revised the entire section “5.2. Abrupt climate changes during 4-2” to place the work more clearly in the context of the existing body of knowledge.

Therefore, we removed the sentences about the present-day precipitation in eastern Anatolia.

3353, 5: why cf.? I wonder with what it could be confused.

This is a very valuable remark, thank you. We changed '*Carpinus cf. betulus*' into '*Carpinus betulus*'.

3353, 7-9: Is this a speculation of yours?

Yes, it was a speculation of ours. We removed this sentence from the manuscript.

3354, 18-19: Can it be a problem of chronology? Which are the tie points used in this period?
Yes, it can be a problem of the chronology. The lower resolution pollen record from Litt et al. (2014) was not used as tie points during the last glacial.

Here, for clarity, we revised this section as follows:

'In general, the abrupt variability of temperate AP from Lake Van and $\delta^{18}\text{O}$ NGRIP values are more or less synchronous (Fig. 4). Leads and lags between the proxy records, illustrated in detail in Fig. 5, are difficult to assess due to their heterogeneous resolution. Here we have to mention again, that the Lake Van pollen record was not directly used for determination of 'tie points' for the chronology of the last glacial due to its low resolution (Litt et al., 2014; Stockhecke et al., 2014a).'

3354, 19: Still, as expected, we recognized

We revised the entire section 5.2., see reply above.

3357, 16-22: Please consider that this is also clear in many pollen records from central Italy (Follieri et al. 1998, Quatern Int 47/48, 3-20). Even if the sequences are plotted only against depths, a number of C14 ages is supporting the existence of a number of significant mesophilous trees expansions.

We added the pollen records from Italy and rephrase this sentence as follows:

'Despite the intensive aridification in eastern Anatolia during glacials, the vegetation composition of Lake Van and the Levantine Basin differs from the terrestrial Mediterranean pollen records. Firstly, drought-sensitive taxa such as *Ulmus*, *Carpinus betulus* and *Fagus* were frequently present in Italy, e.g., at Lago Grande di Monticchio, Valle di Castiglione, Stracciaccappa and Lagaccione (Allen et al., 1999; Follieri et al., 1998) even during stadials. Secondly, the high-resolution Tenaghi Philippon and Ioannina sequences (Müller et al., 2011; Tzedakis et al., 2002) show that thermophilous trees (deciduous *Quercus*) increased rapidly during each interstadial without migrational lags (Fig. 4G, F).'

Figures

Figure 2:

3370: the unit of measure is not cc, but pollen grains/ccX1000. It has to be adjusted also for other taxa.

Changed, see reply above.

Figure 3:

3371: Total oaks?

We changed '*Quercus*' into 'deciduous *Quercus*'.

Anonymous Referee (2nd Referee)

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This is an interesting and important contribution to the existing high resolution archives of vegetation history through the last glaciation and, coming from the region east of the Mediterranean, fills a geographical gap in the existing body of knowledge. It represents a significant increase in resolution relative to previous palynological data generated from Lake Van and as such has the potential to improve our understanding of how terrestrial ecosystems east of the Mediterranean responded to the abrupt climate oscillations that occurred in the North Atlantic during this interval. However, there are a number of weaknesses in the manuscript and, in light of the significance of the data, I'd like to recommend some additions and edits (below) which should help to make the most of this great dataset. In general, the manuscript would be improved by:

- 1) placing the work **more clearly** in the context of the existing body of knowledge,
- 2) **improving** the clarity of **discussions about vegetation and climate change mechanisms** (particularly the **distinction between drivers and responses**, and **between inference and assumption**), and
- 3) providing a **more critical approach to the chronology**, stratigraphic framework and correlations with existing records. There are also **numerous grammatical errors** which need to be corrected for the sake of clarity of the text, the most important of which are also indicated below (though there is not time to mention them all, and the manuscript will need a thorough proof-read).

Thank you very much for your constructive suggestions. We considered all of them and implemented them in the revised manuscript. We rewrote the manuscript more clearly and improved the discussion section, especially, as recommended, the distinction between climate driving forces and vegetation responses. Following suggestion of both reviewers we clarified issues concerning chronology of Lake Van record. Furthermore, we carefully checked our use of English. We think the revisions improved our manuscript significantly, and we hope that our manuscript in its present form will be better suited for publication.

Page, Line: Comment

Abstract

3342, 8: Should read “expansions and contractions of tree populations” (presumably) Changed.

3342, 10: Recognition of the same pattern does not “provide a linkage” – there must also be the suggestion of (and justification for) an underlying mechanism.

Thank you for a thoughtful comment. We removed this section and have revised this sentence as follows: ‘Our high-resolution multi-proxy record shows rapid expansions and contractions of tree populations that reflect variability in temperature and moisture availability. These rapid vegetation and environmental changes can be related to the stadial-interstadial pattern of Dansgaard-Oeschger (DO) events as recorded in the Greenland ice cores’

3342, 11: Are the periods of reduced moisture availability based on the pollen record or some independent measure of climate? Also, on what basis is the correlation with North Atlantic IRD and SST made?

We rephrased this sentence.

3342, 15: “. . . recognised by . . .” does not make sense. Should this be: “explained by”?

Thank you very much. In the revised version we are more careful with our use of English.

3342, 16: You say the expansion of temperate species was “stronger” . . . stronger than what/when?

We revised this sentence in: ‘Influenced by the diverse topography of the Lake Van catchment, more pronounced DO interstadials (e.g., DO 19, 17-16, 14, 12 and 8) show the strongest expansion of temperate species within the last glacial.’

3342, 23: “enables the shed light” doesn’t make sense. “Should be “enables us to shed light”?

Changed.

Introduction

3343, 12: “steadily” should be “steady”, or perhaps “gradual” would be more apt.

We changed ,steadily‘ into ,gradual‘.

3343, 20: “extend” should be “extent”

Changed.

3344, 1: The reference to central and eastern Mediterranean records does not match the presence of western Mediterranean records in the list of references in lines 6 and 7

Thank you very much for this important comment. We rearranged the list of references and removed the references for the western Mediterranean records. Furthermore, we added some new locations and references for the central and eastern Mediterranean records. Please, see also the answer to referee #1.

3344, 17: “has” should be “have”

Changed.

3344, 25: “and its regional response on vegetation” does not make sense. Do you mean “the response OF vegetation” or something else?

We revised this sentence in: ‘Special focus is given to the centennial- to millennial-scale climate variability, as known from Greenland, and the regional response of vegetation to abrupt paleoenvironmental changes in eastern Anatolia.’

Regional setting

3345, 9: Should read either “The present day climate of: : :” or “Present day climatic conditions in: : :”. “Climate condition” as a phrase does not work (it occurs numerous times through the manuscript).

Good remark, thank you very much. In the revised manuscript we changed all phrases of ‘climate condition’ in ‘climatic condition’ or ‘climate of...’.

Material and methods

3346, 10: Please clarify – what is the “lake floor-no event”?

We rewrote this sentence as follows: ‘Here we present data of the uppermost 3.87-41.72 m of the event-corrected composite record (mcb1f-nE; depth scale, which excludes volcanic ash layers and mass flow deposits; Stockhecke et al., 2014a), representing the time span from 9.48 to 111.39 ka BP.’

3347; 2: it would be very helpful to the reader to emphasise here the improvement in resolution that this study represents over existing data.

We revised the sentence. Now it reads: ‘The new high-resolution palynological analyses were performed on 216 sub-samples taken at 10-20 cm intervals. The temporal resolution between each pollen sample, derived from the present age-depth model, is ranging from ~250 years (18.37-21.24 mcblf-nE) to ~500 years (3.87-18.37 and 21.24-41.72 mcblf-nE; Fig. 2).’

Results

3349, 11: “dominating” should be “dominated”

Changed.

3349, 13-14: it is conventional (and clearer) to separate the description of the results from interpretations (i.e. “in response to highly variable climatic conditions” may not belong in this section).

We removed ‘...in response to highly variable climatic conditions’.

3349: General comment about the results section: it struck me as odd that no results appear under the headings of stable isotope analysis or profiling measurements since, although I realise that these are presented in an earlier publication, they do appear in the methods section which is perhaps a bit incongruous.

Thank you for this useful comment. In the first version of the manuscript results of the stable isotope analysis and profiling measurements were presented together with methods – in order to avoid confusion between new and already available data. Now we separated the methods from the results of the stable isotope analysis and profiling measurements.

Discussion

3350, 12-18: Evidently, the abrupt millennial-scale oscillations with which much of this paper is concerned are not directly forced by Milankovitch (orbitally)-driven changes in insolation. Please can you incorporate into this section something about the relationship between millennial-scale (i.e. sub-orbital) climatic change (and its drivers) and orbital-scale climatic change (and its drivers)? As it stands, these lines are extremely confusing.

Thank you very much for your helpful suggestion. We rewrote this section as follows:

‘Variations in the orbital configuration of the Earth are responsible for changes in the climate system from one state to another; on millennial timescales, for glacial-interglacial cycles (Berger, 1978; Berger et al., 2007). However, higher frequency oscillations (e.g., Dansgaard-Oeschger events; Dansgaard et al., 1993) are superimposed on the long-term orbitally-driven climate dynamics. These abrupt changes of the climate system are not directly driven by orbital forcing, but can be interpreted as transitions between two states of the inter-hemispheric Atlantic Ocean circulation driven by large-scale thermal and salinity gradients (e.g., Bond and Lotti, 1995; Cacho et al., 2000, 1999; Chapman and Shackleton, 1999; Hemming, 2004; Hodell et al., 2008; McManus et al., 1999; Rasmussen et al., 2014; Wolff et al., 2010). In particular, changes in the oceanic circulation affected regional and local atmospheric circulation patterns, for example, the strength and position of the westerlies in the Northern Hemisphere, which are responsible for the moisture supply in eastern Anatolia (Akçar and Schlüchter, 2005, Roberts et al., 2008).

According to Jessen and Milthers (1928) and Litt et al. (2014), an interstadial stage is an interval of temporary improved climate within a glacial phase, which has been either too short to permit full expansion of thermophilous trees and/or too cold or dry to reach the climate

optimum of an interglacial period in the same region. In comparison, stadial stages correspond to cold/dry intervals marked not only by global but also by local ice re-advances (Lowe and Walker, 1984).’

3350, 18: Please define “steppe forest”. I am familiar with the term “wooded steppe” from earlier work on biomisation, but what is a steppe forest and how does it differ, if it does?

The oak steppe-forest consists of several deciduous oak species (*Quercus brantii*, *Q. infectoria*, *Q. ithaburensis*, *Q. libani*, *Q. robur*, *Q. petraea*, *Q. boissieri*, *Q. mannifera*) as well as *Pistacia atlantica*, *P. khinjuk*, *Acer monspessulanum*, *Juniperus oxycedrus*, and several more (see Zohary, 1973).

Now, for the better understanding, we only use the term ‘oak steppe-forest’ in the manuscript, because the climax vegetation of the last interglacial, and somehow of pronounced interstadials, is similar to the present interglacial at Lake Van.

3350, 19: Please describe the basis on which “major interstadials” have been identified. Are they chosen (and identified as “major”) on the basis of the pollen record here, or Greenland ice core records, or some other way?

We revised this sentence as follows: ‘Below, we will discuss only the most pronounced interstadials (e.g., MIS 5c and 5a) and Dansgaard-Oeschger interstadials (AP >10%; e.g., DO 19, 17-16, 14, 12, 8 and 1), here identified on the basis of the Lake Van pollen record (see also Litt et al., 2014).’

3350, 21: This sentence is confusing (especially “small compared to the major changes” – difficult to understand since it is not clear how small or major are defined) – please can you reword it to make the meaning clear?

We rewrote the sentence. Now it reads: ‘All other ‘warm/wet’ phases with lower expansion of temperate trees (AP <10%) are not explicitly mentioned in the following section.’

3351 General comment: It would be very helpful to see inserted here (before section 5.1.1 I think) a critical discussion of the chronology and an explanation of the basis for correlation of the pollen record with the Marine Isotope Stratigraphy.

The explanation of the basis for the correlation of the proxy record, which includes the pollen record, is discussed in detail in Stockhecke et al. (2014). Here in this manuscript, we added some more information about the chronology in section ‘Methods and material’. Please, see also reply to reviewer #1.

We tried to make clear that on the stadial-interstadial time scale pollen record – due to its lower resolution – was not used for tuning.

‘However, the age-depth model of Stockhecke et al. (2014b) is based on tuning with the NGRIP event stratigraphy. The correlation points of the Lake Van sedimentary record have been mainly defined by abiotic proxies (i.e. TOC) caused by a higher time resolution of this data set in comparison to the pollen samples available during that time. Even if we present a high-resolution pollen record in this paper, leads and lags between different biotic and abiotic proxies related to climate events have to be taken into account.’

Furthermore, we added ‘In any case, we cannot expect a perfect matching between biotic and abiotic proxies related to climate events due to their different response time. In addition, the lack of correspondence between the pollen signal and the timing of some DO events could also be explained by uncertainties in the current age-depth model. Still, as expected from various eastern Mediterranean pollen records, the Lake Van pollen record documents that temperate taxa tend to reach their maxima after the onset of a warming phase and, therefore,

lag behind the Ca/K increase, which responds immediately to climate changes (Fig. 5).’ in the discussion section.

3351, 4: “indicates low amplitude of temperate taxa” does not make sense. Should this be “correlates with low values for temperate taxa”?

To avoid repetition of the results in the discussion, we generally improved the discussion on the mechanisms of vegetation and climate changes, and therefore, rewrote the section ‘MIS 5e-5a’ and ‘Abrupt climate changes during MIS 4-2’ to distinguish between climate drivers and vegetation responses in a clearer way.

3351, 6: “As a result of insolation: : :” this sentence does not make sense.

We removed this term.

3351, 12-14: Please explain more clearly. You say “In accordance with MIS 5e” but I am not at all sure what is meant by that as later in the paragraph I think you say that 5c is very different to 5e.

We improved the first section of ‘MIS 5e-5a’ and added some more information/comments about the last interglacial stage (MIS 5e). See reply to reviewer #1.

3351, 25: “providing” in this sentence is the wrong word – whole sentence needs to be reworded more clearly.

Changed.

3351, 28: “less” should be “lower”

Changed.

3352, 5: “resolved” should be “resolve”

Changed.

3352, 12: There is a tendency throughout to mix up discussion of patterns in the pollen with inferred patterns in the vegetation. There is an example here: pollen percentage or concentration curves can show low (or high) amplitude change but expansions of grassland across a landscape cannot really be said to have “low amplitude”.

Changed.

3352, 17: Should this read “assumption”? Is it not an inference based on the evidence?

Thank you very much for this useful comment. We rephrased this sentences.

3353, 4-7: This is not strictly correct “the total absence of temperate species: : : “ does not “suggest that woodlands: : : are restricted to refugia”. Their rapid return to the site in response to short-lived warming might suggest this, but their absence does not suggest anything but their absence.

Changed.

3353, 29: Should read “contraction of tree populations”

Changed.

3354, 5-6: This statement does not make sense to me: “From the evidence of the pollen record, we can infer direct influence of global ice sheet volume: : :” and so on. Please explain more clearly.

We revised the entire section ‘5.2. Abrupt climate changes during MIS 4-2’, see reply to reviewer #1.

3354, 18-19: The topic of offsets between the pollen record presented here and the NGRIP sequence needs to be addressed in more detail – please expand on this sentence, perhaps in a dedicated section.

We revised the entire section ‘5.2. Abrupt climate changes during MIS 4-2’, see reply to reviewer #1.

3355, 4-5: Needs an explanation of how this “increased seasonal contrast in insolation” would affect regional climates and vegetation.

We removed this phrase.

3355, 20: I think this section 5.3 should be within the section above.

The reviewer is fully right. To avoid repetition, we included section ‘5.3 Heinrich events’ into section ‘5.2 Abrupt climate changes during MIS 4-2’.

3356, 6: Which region is “this region”? Ambiguous as it stands.

We changed the term ‘this region’ into ‘the Mediterranean region’.

3356, 12-18: I think I see what you mean here, but it is quite confusing as you describe “minor drops in tree pollen” and “massive reduction of tree taxa” seemingly in reference to the same climatic events, in a way which sounds contradictory.

We removed the sentence: ‘Minor drops in tree pollen do not necessarily reflect a minor climatic decline.’

3357, 22: I think the paper would benefit from more discussion (at least description) of the nature of the migrational lags alluded to here. This would be one way in which to make more of the high resolution data set presented here.

Here, we added the following information about migrational lags in the record.

‘Thirdly, both the diversity and the low amplitude of variations in temperate tree taxa (e.g., deciduous *Quercus*) of the eastern Mediterranean pollen records (Lake Van and Levantine Basin; Fig. 4C) indicates greater distances and/or slow migration rates from refugia during the glacial interval. Such areas might be found in the south and south-east Black Sea Mountains (Euxinian vegetation) and the Caucasus mountains (Hyrcanian vegetation), which receive increased atmospheric moisture and higher orographic precipitation from the Black Sea (Bottema, 1986; Leroy and Arpe, 2007; Shumilovskikh et al., 2012). Especially the Black Sea region was characterized by mean winter temperatures close to or above 0°C during the last glacial (Shumilovskikh et al., 2014).’

3357, 25: A grammatical problem here: “: : : as well as due to their geographical location: : :” does not make sense.

We removed this term.

3358, 17: Should read “cannot be clearly distinguished”

Changed.