Interactive comment on "A new high-resolution pollen sequence at Lake Van, Turkey: Insights into penultimate interglacial-glacial climate change on vegetation history" by Nadine Pickarski and Thomas Litt

G. Jiménez Moreno (Referee #3)

This is an interesting article that shows new detailed pollen and oxygen isotope data from the MIS 8-6 part of the Lake Van sedimentary record. The authors interpret the pollen and isotope changes as changes in vegetation and precipitation/evapotranspiration around the lake basin. Vegetation changes between forested-steppe environments can be correlated with climate oscillations (interglacial/interstadials-glacial/stadials) described in the marine isotope records. The paper is well-written and the data support the interpretations/conclusions and thus deserves publication in CP.

However, in my opinion, there are some changes that need to be done before publication and several topics are not very well discussed in the manuscript and need to be clarified.

Below are my comments:

It is not very clear what is really triggering the vegetation changes in the area – is it mostly temperature or precipitation? In some parts of the text temperature is indicated as the main trigger and in some others is precipitation or effective precipitation (supported by the isotope data). A clear example is the Abstract (lines 11-13) where effective precipitation is first introduced as the main trigger and then temperature...and this is very confusing as maximum insolation and thus maximum temperature would reduce the effective precipitation and should not produce the same effect on the vegetation. For example, in line 13 – maximum forest development during stage 7c does not seem to occur during summer insolation maxima…

First of all, each terrestrial temperate interval at Lake Van begins at the time of maximum summer insolation, which is the case during the penultimate interglacial (except for the youngest warm period, MIS 7a), last interglacial, and the current interglacial (see Fig. 4). This can be seen in the changes of abiotic proxies. The vegetation, however, reacts very slowly to climatic changes. The time lag of oak steppe-forest expansion depends mostly on spring/summer-drought conditions and/or by slow migration rates form refugia (This topic is now discussed in the section 'Comparison of past interglacials at Lake Van').

However, the most important trigger for vegetation changes in this semi-arid region is precipitation rates, esp. at the beginning of each terrestrial temperate interval. However, we also have to keep in mind that temperature changes have 'some' influences on the vegetation (in general).

Now, the text at this place is rephrased as follows: 'Integration of all available proxies shows three temperate intervals of high effective soil moisture availability, evidenced by the predominance of open forested landscapes (oak steppe-forest) similar to the present interglacial vegetation in this sensitive semi-arid region between the Black Sea, Caspian Sea, and Mediterranean Sea.

The wettest/warmest stage as indicated by highest temperate tree percentages can be broadly correlated with MIS 7c, while the amplitude of tree population maximum during the penultimate interglacial (MIS 7e) appears to be reduced due to warm but drier climate conditions.' (now line 11-17).

In this area, where precipitation is not very abundant I would think that forest development would be mostly related to precipitation or effective precipitation. I think you should be consistent throughout the text.

You are completely right. To be consistent throughout the manuscript, we paid attention to these phrases.

I also had the feeling that after reading the text and looking at the figures one still lacks of a clear idea of what is the relationship between insolation and plant dynamics in this record. In lines 268-269 it is stated that "…vegetation development (forest?) is clearly controlled by insolation forcing and associated climate regimes (high summer temperature, high winter precipitation)". I understand here that forest development in this area is "clearly" controlled by summer insolation, so in a very simplistic model if we had high summer insolation we would have had high forest development. This is a model that can be applied to several long Mediterranean records (see Tzedakis et al., 2007). However, if we look at figure 3, the major forest development seems to happen during summer insolation minima, so completely the opposite of what it is said in the text. Check stages 7e and 7c. What I understand from this is that forest cannot develop during periods of insolation maxima (and probably precipitation maxima) due to very high evaporation and that would explain the big lag between them. The vaguely mentioned lag in the text (line 315) is not just 2-3 ka…but about 10 ka (ie. stage 7c). This subject should be further explained and clarified in the text.

The maximum oak steppe-forest development occurred during summer insolation minimum, however, the start of forest development is closely associated with the timing of summer insolation peak.

Concerning the time lag between the start of interglacial conditions and the expansion of temperate trees, we have added some additional information (see also comments above, and to Referee#1, line **7 207** and **10 315** and Referee#2). We revised this section as follows:

'…the MIS 8/7e, MIS 7d/7c as well as the MIS 6/5e boundary in the continental, semi-arid Lake Van region recognized a delayed expansion of deciduous oak steppe-forest of c. 5,000 to 2,000 years, comparable to the pollen investigations of the marine sediment cores west of Portugal by Sánchez Goñi et al. (2002, 1999). As already shown in high-resolution Lake Van pollen studies by Wick et al. (2003), Litt et al. (2009), and Pickarski et al. (2015a), a delay in temperate oak steppe-forest refer to the Pleistocene/Holocene boundary as defined in the Greenland ice core from NorthGRIP stratotype (for the Pleistocene/Holocene boundary; Walker et al., 2009) as well as from the speleothem-based synthetic Greenland record ($GL_{T\text{-}syn}$; Barker et al., 2011; Stockhecke et al., 2014) can be recognized. The time lag of oak steppe-forest can be explained by slow migration of deciduous trees from arboreal refugia (probably the Caucasus region) and/or by changes in seasonality of effective precipitation rates (Pickarski et al., 2015a). In particular oak species are strongly dependent on spring precipitation (El-Moslimany, 1986). A reduction of spring rainfall and extension of summer-dry conditions favoured the rapid development of a grass-dominated landscape (mainly *Artemisia*, Poaceae; Fig. 2b) and *Pistacia* shrubs in the very sparsely wooded slopes (Asouti and Kabukcu, 2014; Djamali et al., 2010). Furthermore, high intensity of wildfires of late-summer grasslands, at the beginning of each warm period could be responsible for a delayed re-advance of steppe-forest in eastern Anatolia (Pickarski et al., 2015a; Turner et al., 2010; Wick et al., 2003).'

I am also puzzled about the isotope record from the lake and the comparison with the pollen data. First, if the interpretation of the data is correct (higher values, higher evaporation/dryness), the isotope data do not seem to agree with the summer insolation and it should. Second, if the vegetation was delayed because during summer insolation maxima there was too much evaporation, this would show a delay between the isotope data and the pollen and they basically covariate (except for some periods (stage 7a). Please clarify.

First, you are right. High oxygen isotope values indicate higher evaporation and/or dryness in the Lake Van area. In general, the interpretation of lacustrine stable isotope values at Lake Van is not as simple as in the marine record. It was analyzed from lacustrine bulk sediments, where all complex relationships, which are involved in the lacustrine carbonate precipitation, are not fully understood yet. The isotope signature reflects several regional climatic variables as well as local factors, such as precipitation (rainfall, snow) and evaporation processes. They were also influenced by the water temperature and composition of the lake water. Therefore, the interpretation of stable isotope data at Lake Van is not that easy. Previous studies at Lake Van by Litt et al. (2009) and Wick et al. (2003) have found out that the depleted diluted isotope values at the beginning of terrestrial temperate intervals, esp. at the beginning of the Holocene, mainly reflects freshwater input due to snowmelt from local glaciers in the catchment area. This mechanism was transferred to earlier periods/interglacial onsets by Kwiecien et al. (2014). Unfortunately, at some points, this mechanism does not match (in particular in MIS 7a).

Second, the delay of vegetation depends on local conditions keeping moisture availability below the tolerance threshold for tree growth in the more ecologically stressed areas. In the eastern Mediterranean area, the precipitation is still concentrated in the winter months, while the expansion of deciduous oaks is often hindered due to spring/summer-drought conditions at the beginning of interglacials (see reply above).

The fact that stage 7c shows one of the largest forest development in the record needs to be highlighted in the chapter about "Comparison of past interglacials at Lake Van".
We highlighted that the MIS 7c documents the largest oak steppe-forest development within the penultimate interglacial complex.

It is very confusing to see terms such as "steppe forest landscape" "oak-pine steppe forest" or "oak steppe forest" as these two terms "forest" and "steppe" are quite opposite. Why not calling these forests with AP pollen percentages around 60% "forests" or if you do not agree that they are close forests "open forests"? Also, steppes are mostly characterized in the area by Artemisia and Amaranthaceae, and Poaceae seems to be relatively abundant during the "forest" periods so it would not be quite an "steppe" environment.
According to Zohary (1973), the southern mountain slopes are covered by the Kurdo-Zagrosian oak steppe-forest belt, containing several oak species, *Juniperus excelsa*, and *Pistacia atlantica.* This oak steppe-forest has also been described as 'mixed formation of cold-deciduous broad-leaved montane woodland and xeromorphic dwarf-shrublands' by Frey and Kürschner (1989). Furthermore, several pervious vegetation studies at Lake Van used the term 'oak steppe-forest', see also Zohary (1973); van Zeist and Bottema (1991); van Zeist and Woldring (1978); Wick et al. (2003). We added the definition of oak steppe-forest in the section 'regional setting'. (See also reply Referee #1)

Even though there is certain variability during MIS 6 the forest oscillations are only between 0-10%. I would not call these oscillations "pronounced" as stated in the abstract (line 23). The authors should soften the language regarding these oscillations (section 4.2).
Here, we wanted to say that the early stage (c.193-157 ka BP) oscillates a bit more than the later stage (c. 157-131 ka BP). However, it was probably a bit exaggerated. We replace the phrase 'pronounced oscillations' by 'higher oscillations'.
We also softened the language regarding the 'pronounced' oscillations in section '4.3 The penultimate glacial' as well as in the 'Abstract' and in the 'Conclusion'.

Line 10: "The presented record displays the highest temporal resolution for this interval"? from where? Lake Van? Turkey? The World? Please be specific.
We added 'Lake Van'. Now it reads: 'The presented Lake Van pollen record displays the highest temporal resolution….'.

Pinus has an important role in the observed vegetation changes in this record and probably were important tree taxa regionally as well. Therefore, I think the authors should give some information about Pinus distribution in the area or regionally at Present in "Site description" as later it is mentioned that was transported to the area by the wind (lines 235-238).
Today, the distribution of *Pinus* (probably *P. nigra*) is located in the more continental western and central Anatolia areas. In eastern Anatolia and in the vicinity of Lake Van, *Pinus* is almost absent in the vegetation composition. Therefore, we do not give any further information about the *Pinus* distribution in the section 'Site description' to avoid any confusion.
However, we have added some more information in the discussion section. Now it reads: 'The ensuing ecological succession of the first warm stage is documented by a shift from deciduous oak steppe-forest towards the predominance of dry-tolerant and/or cold-adapted conifer taxa (e.g., *Pinus* and *Juniperus*; c. 237-231 ka). Especially, high percentages of *Pinus* suggest a cooling/drying trend, which occurred during low seasonal contrasts (low summer insolation and high winter insolation; Fig. 3). *Pinus* (probably *Pinus nigra*) as a main arboreal component of the 'Xero-Euxinian steppe-forest' recently occurs in more continental western and central Anatolia, and in the rain shadow of the coastal Pontic mountain range (van Zeist and Bottema, 1991; Zohary, 1973). Compared to the present

distribution of *Pinus nigra* in Anatolia, the Lake Van region was probably more affected by an extended distribution area of pine during the penultimate interglacial as indicated by higher pollen percentages (Holocene below 5%; PAZ Vc2 up to 26%; PAZ Va3 up to 20%; Fig. 4). Holocene pine pollen was mainly transported over several kilometers via wind into the Lake Van basin.' (now line 295-305).

Line 120: Give unit for the "4 cm" size samples - cm3 ?
It was already written '…samples of 4 cm^3….'. (now line 136)

I think the presence of Spiniferites should be better explained as many people would interpret this taxa as marine species. Do they occur in lake environments? Under what circumstances?
We added some further environmental information about the presence of *Spiniferites* spp.. Now it reads: 'Furthermore, we calculated dinoflagellate concentration (probably *Spiniferites bentorii*; cysts cm-3) in order to get additional information about environmental conditions of the lake water (Dale, 2001; Shumilovskikh et al., 2012; Fig. 2a). The occurrence of *Spiniferites* spp. in lacustrine sediments suggests low aquatic bio-productivity (low nutrient level) and hypersaline conditions (Zonneveld and Pospelova, 2015; Zonneveld et al., 2013). In this study, the concentration of dinoflagellate cysts is high (500-2,000 cysts cm-3) during non-forested periods, especially within PAZ IV1, IV3, IV5, Va2, and PAS Vb.' (now line 196-201)

Lines 195-196: "The d18O composition of the lake water becomes progressively more enriched during interglacial/interstadial periods". Not fully true – check stage 7a where the opposite happened. Please be more specific.
We rephrase this sentence as follow: 'At the beginning of major forested phases (e.g., PAZ Vc4, the end of Vb, Va1, and IIIc6), the $\delta^{18}O_{bulk}$ composition of the lake water becomes more depleted (Fig. 3c). According to Kwiecien et al. (2014) and Roberts et al. (2008), negative isotope values document not only enhanced precipitation during winter months but also the significant contribution of depleted (diluted) snow melt/glacier meltwater during the summer months.' (now line 221-225) (see also reply above).

Lines 197-200: 'Termination III (T III at 241.4 ka BP) and at the transition from stadial to pronounced interstadial periods documents not only enhanced precipitation during winter months but also the significant contribution of depleted snow melt/glacier meltwater during the summer months (Kwiecien et al., 2014; Roberts et al., 2008).' – This statement is not clear – in Fig. 3 the isotopic changes are explained and changes in dryness or evapotranspiration, supported by low detritic input in the lake.
See reply above.
Here, enhanced freshwater input and/or precipitation is supported by high detrital input (see also reply below).

The charcoal record is clearly related with forest fuel. Be then more specific in line 217, "..vegetation communities changed towards more forest environemt"?
Changed.

If I am right, the melting of the glaciers mentioned in lines 220-221 are not well supported by the data – this would be shown by high detritic input into the lake during deglaciation, which is not the case (see 7e, highest forest, highest evaporation and lowest detritic input). Not clear…
At the transition from cold to warm periods, the Ca/K ratio shows high detritic input at Lake Van during cold/dry periods (glacials). At the beginning of terrestrial temperate intervals the melting of the glaciers is clearly visible by negative isotope values (up to -4‰ around 240 ka BP suggest low evaporation, high freshwater supply) along with high detrital input into the basin (low Ca/K ratio, ~10, still low forest density).

Lines 239-241: This is not clear – please rephrase.
We removed this section.

Lines 242-245: The vegetation shift towards more Pinus does not seem to be due higher continentality as stated here. Check Fig. 4, where the peak in Pinus seems to be reached during the lowest seasonal contrast (low summer insolation and high winter insolation – cooler summers and warmer winters).
Thank you very much for this very important comment. We revised the section as follows: 'The ensuing ecological succession of the first penultimate interglacial stage is documented by a shift from deciduous oak steppe-forest towards the predominance of dry-tolerant and/or cold-adapted conifer taxa (e.g., *Pinus* and *Juniperus*; c. 237-231 ka BP). Especially, the high percentages of *Pinus* suggest a cooling/drying trend, which occurs during low seasonal contrasts (low summer insolation and high winter insolation; Fig. 3a, f).'

I hope my comments help improving the manuscript.
Yes, it was very helpful.