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Climate of the Past Discussions

Interactive comment on "Synchronizing ^{10}Be in two varved lake sediment records to IntCal13 ^{14}C" *by* Markus Czymzik et al.

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We thank the Anonymous Referee #2 for his thorough comments, which helped to significantly improve the manuscript. In the following, we give a detailed response to all concerns raised, first answering the main point of criticism, followed by a point-by-point reply.

General comments:

This manuscript by Czymzik and co-authors targets to a key issue in paleoclimate records i.e. time-scale uncertainties, which often inhibit the detailed investigation of multiple spatial high resolution climate proxy records. 10Be records from two varved lake sediment sequences from northern Germany and Poland are synchronized with

IntCal13 calibration curve. This methodological approach is a novel attempt to synchronize lake sediment records using 10Be in order to investigate the leads and lags, unwanted but inherent features in all proxy records. Large (and growing) number of the high resolution paleoclimatic studies is published from lacustrine sediments but the detailed comparison of the proxy records suffer from the temporal uncertainties. From this perspective, the manuscript contains interesting ideas and is topical. The text is well written and structured and has illustrations of high quality to support results and interpretations very nicely.

The main point what I miss in this manuscript would be a visual illustration of the sediment composition and composition changes from the two sediment records with SAR, TOC and perhaps Ca, Ti and 10Be variability, at least for the time windows that were more closely inspected. Although the references to original publications are provided, the illustration would greatly help to follow the detailed discussion from two lake records with several proxies and time windows and changes in sedimentation. Overall, this manuscript is suited for the journal of Climate of the Past discussions and can be accepted with minor revision.

Detailed Answer: We visualize changes in sediment composition and accumulation by depicting the original 10Be, TOC, Si, Ca, Ti and SAR records from Lakes Tiefer See and Czechowskie for the inspected three grand solar minima in Figs. 2 (for TSK) and 3 (for JC). In addition, we added the supplementary Fig. S1 to the revised manuscript showing our new 10Be records from Lakes Tiefer See and Czechowskie against core depth.

Specific comments:

Page 2 Line 26: Could it be shortly explained how the non-uniform 10Be depositional patterns are generally taken into account/expected to influence the records?

Non-uniform deposition patterns are presently one of the main uncertainties in 10Be research (Adolphi and Muscheler, 2016, Climate of the Past). However, common

changes of the cosmogenic radionuclides 10Be and 14C in different environmental archives are considered to reflect variations in the cosmogenic radionuclide production rate, due to their same production mechanism and different chemical behavior (Muscheler et al., 2016, Solar Physics). That is one of the reasons why we compare our 10Be time-series from Lakes Tiefer See and Czechowskie to 14C production rates inferred from the IntCal13 calibration curve. To account for the reviewer's comment, we added the following sentence in page 2 lines 27-29 of the revision and provide two references:

'Despite these non-production effects, common changes in 10Be and 14C records are considered to reflect the cosmogenic radionuclide production signal, due to their common production mechanism and different chemical behavior (Lal and Peters, 1967, Muscheler et al., 2016).'

Another way to distinguish and reduce non-production effects in sedimentary 10Be time-series is our here applied approach based on environmental proxy-series from the same archive. Thereby, it is assumed that coinciding changes the environment reflected by proxy time-series might leave an imprint in the 10Be time-series (Czymzik et al., 2016, Quaternary Science Reviews).

Page 3 Line 9: No major inflows, today. Well, were there major inflows previously? What kind of changes in inflow system have occurred and when? Does this influence the sediment composition within the time interval of the study, e.g. the changes in sedimentation rate or sediment composition? If not, this should be mentioned as well.

Very low and rather stable contents of detrital grains in varved Lakes Tiefer See and Czechowskie sediments indicate that no major tributaries existed throughout the investigated three grand solar minima (and the complete Holocene). To include this information to the manuscript we revised the related sentence and provide two references.

'The lake basins are part of subglacial channel systems formed at the end of the last glaciation and had no major inflows during the Holocene (Dräger et al., 2017; Ott et al.,

2016).'

Page 3 Line 20: at 20 year resolution. This is not clear to me; do you mean one sample every 20 years, or a sample comprising 20 years?

We need to be clearer about our sampling strategy. We use continuous series of sediment samples, each comprising about 20 years of sedimentation. Therefore, we changed the related sentence to:

'Continuous series of sediment samples at 20-year resolution were extracted for 10Be measurements from sediment cores TSK11 and JC-20 M2015, based on varve chronologies (Dräger et al., 2017; Ott et al., 2016).'

Page 3 Methods – Page 4 Results: Overall, this section leaves me a bit confused. For a reader I feel I am left with a tenuous grasp on the TSI and CJ records. Although the references are provided it would be helpful to shed light on these previously published varve records that are frequently referred in the text, e.g. where the non-varved sections are located and how the sediment composition changes (in time/depth scale)? An illustration of the records perhaps with some Ti, Ca TOC and even 10Be variation curves would be helpful to quickly get an overall picture of the two records.

See our Detailed Answer on Figs. 2 and 3 showing the original 10Be, Ti, Ca, Si, TOC and SAR data from Lakes Tiefer See and Czechowskie sediments during the investigated three grand solar minima. Moreover, we now add information about non-varved sediment sections in Lake Tiefer See to Fig. 2, by highlighting the respective time-intervals with bars. We describe this new feature in the caption to Fig. 2.

Page 4 Line 27: Although references are provided it would be helpful to mention briefly how environmental and catchment conditions can influence the 10Becon variation in sediment record.

We discuss possible mechanistic linkages between environmental effects and 10Be deposition in Lakes Tiefer See and Czechowskie sediments in detail at the end of

Chapter 5.1, after describing and performing our procedure used for the attribution and correction of these effects. To be clearer about this structure, we added a sentence and reformulated the beginning of Chapter 5.1:

'Environment and catchment conditions can add non-production variations to 10Becon records from varved lake sediments (Berggren et al., 2010; Czymzik et al., 2015). In the following we will, first, describe and perform our approach used for detecting and correcting for possible non-production features in our 10Be time-series and, then, discuss possible mechanisms behind the statistically inferred connections.'

Page 5 Line 12: The correlations could be added in the figure 4 similarly as is done in figures 2 and 3.

Done.

Page 5 Line 19: Could these depositional mechanisms be briefly described?

See our answer to comment 'Page 4, Line 27'.

Page 5 Line 20-21: At this point it does not become clear which correlations are referred. This becomes clear later in the paragraph but text would be easier to follow if the correlations were specified before showing the numbers.

We now mention the correlation between 10Be and TOC before we provide the correlation coefficient and significance level.

Page 6 Line 8-9: Why? Are there indications in the sediments that suggest resuspension of littoral sediments or changes in sediment focusing? The illustration of sediment composition (see general comments) could be helpful here.

See our Detailed Answer. We added more detailed information on the sub-layer of resuspended littoral sediments in JC varves, deposited back to 2800 a BP, in Section 5.3. However, to avoid repetition, we prefer at this point of the text not to go into details and hint more clearly to the later discussion:

'In JC sediments, the 10Becomp excursion from -50 to 0 a BP (AD 2000-1950) without an expression in the group sunspot number record as well as the about 20-year delayed Maunder Minimum response could be explained by transport of 'old' 10Be from the littoral to the coring site (see more details on the sub-layer of resuspended littoral sediments in JC varves back to 2800 a BP in Section 5.3) and/or spatially inhomogeneous 10Be deposition patterns (Fig. 5).'

Page 6 Line 29-30: This (also) would be nicely clarified with the record-descripting illustration (see comment for Page 3-4 Methods-Results).

See our Detailed Answer.

Page 7 Line 1-2: What is this layer? Does this occur at the time interval discussed in this paper at Page 6 Line 6 (from -50 to 0 BP)? If so, this could be mentioned already earlier. This would actually answer partly to the specific comment I made for Page 6 Line 8-9.

This sub-layer was deposited in fall AD 2003. It consists of the same littoral diatoms and patches of calcite deposited in Lake Czechowskie during this season since about 2800 a BP. However, during that year the fall layer was exceptionally thick (3.7 mm), containing comparably high amounts of 'old' 10Be leading to an anomalous 10Be value for that year (Czymzik et al., 2015, Earth and Planetary Science Letters). To account for the reviewer's comment, we added more information about this exceptional sediment sub-layer to the manuscript.

'Comparable influences of sediment resuspension were also found in a sample from an annually resolved 10Be time-series of recent JC sediments covering the period AD 2009-1988 (Czymzik et al., 2015). A varve with an exceptionally thick (3.7 mm) layer of resuspended littoral diatoms and patches of calcite deposited in fall 2003 reveals anomalous 10Be values (Czymzik et al., 2015).'

Figure 4: Why 10Becon and 10Beenvironment are out of phase in Lake Czechowskie

from about 2700 to 3100 BP?

This is an effect of our 'environmental correction' procedure. When the correction is large, the generated signal will look increasingly different from the original 10Becon record. That this looks partly like a phase shift is mere coincidence. We discuss on page 6, lines 11-20, that we do not obtain significant fits between Lake Czechowskie 10Be and IntCal13 14C production during the Homeric Minimum and point out that this is likely due to environmental influences on Lake Czechowskie 10Be, which are challenging to correct for.

Thank you!

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