Rebuttal Anonymous Referee #1

Thank you for your most helpful comments on this manuscript!

This study represent a multi-proxy approach based on a marine sediment core GeoB18308-1, located on the South Coast of South Africa, offshore the Gouritz River, Southern Cape. The study reconstructs approximately the last 4 ka and additionally presents samples inland within the catchment areas of the Gouritz River itself. The authors interpret their data as demonstrating humid conditions in the Gouritz River catchment during the Medieval Climate Anomaly with lower, but highly variable sea surface temperatures in the Mossel Bay area. On the contrary they claim that the Little Ice Age was characterized by relatively warm sea surface temperatures in Mossel Bay and arid climatic conditions favorable to torrential flood events sourced in the Gouritz headlands. I am generally excited about this work as it shows new data from an area missing detailed marine/terrestrial records. I think it is a very detailed and solid approach particularly having material from the Gouritz River catchment for "ground-truthing" in a source to sink approach. I am also okay with the conceptional model explaining the atmospheric circulation system which is based on A.L. Cohen and P.D. Tyson 1995. I am in favour of publication of this record, however would like the authors to respond/check some aspects of the paper which I describe below. My main two concerns are the construction of the age model and the interpretation of the data in the LIA. Age Model First of all, if two labs are used, Poznan and Beta lab in this case, it should be shown that the results are consistent between labs. Has a comparison on an aliquot sample been done which shows that both labs come to the same conclusion?

Unfortunately, no comparative study of the 2 C14 labs has been done and we have no remaining funds to do so. However, both labs have assured us that they follow stringent procedures to ensure the quality and reproducibility of their results.

Table 1 shows all material dated but only Figure 4 caption reveals what was used for the age model thereafter. It should be clarified in table 1, which of the core depths were not part of the age model. As I understand depths 123 cm, 285 cm and the reworked package at 26- 66 cm depth were excluded from the age model.

We have added this information also to Table 1

Hence the levels taken into account are 16.5 cm, 69 cm, 125 cm etc. Core depth 69 cm, TOC measured, gives a calibrated age (median) according to table 1 of 1294 cal. Age BP. The level used thereafter is 125 cm, TOC measured, gives a median of 598 cal. Age BP. Also the two levels below are significantly younger than core depth 69 cm dated. Why were these samples part of the age model and not excluded although they could be equally reworked material?

Sorry there is a mistake in the caption of Figure 4: the reworked package is at 26-69 cm depth and (not 66cm)! The 1294 cal. Age BP age at core depth 69 cm, was removed from the age model as part of the redeposited package.

In fact the TOC sample at 125 cm just plots outside the uncertainty level given by the Baysian age model. Normally this software should give a probability estimate stating how likely this date is part of the age model or not. I somehow also see a mismatch between the table 1 data and Fig. 4. For example the plot shows two TOC point just below the blue shaded area 'reworked package, erosional contact 0 . I believe that this refers to the sample at 60 and 69 cm core depth according to table 1. However, the author writes that samples between 26-66 cm were excluded. So the sample at 60 cm should not be in there. Moreover, 490 cm core depth has a median age of 4720 cal. Age yr BP which is not even part of the axis in Fig. 4. And there are more examples C2 were the cal. age from table 1 does not fit the cal. age on the axis of Fig. 4. If the author could clarify this mismatch and the core depths used and revise.

We thank the reviewer for pointing out these errors! There were errors in Tab 1 and Fig. 4 that were responsible for this mismatch. They have been corrected.

It is not clear to me why one would calibrate with an SHcal and then with the marine 13 in the core intervals below despite high BIT index in that interval? Moreover, the BIT index wasn 0 t even measured on the same samples the TOC was dated.

We understand that this is an unusual approach, it is unfortunately a consequence of working at the marine-terrestrial interface since the TOC in such a nearshore depositional area is bound to be a mix of terrestrial and marine material. This we had to take into account when calibrating our C14 dates. However, we have no way of determining the exact percentage of marine our terrestrial material in each dated TOC sample - our choice of a calibration curve has to be based on interpretations of the available data. Compound specific dating was unfortunately also outside our budget. The solution we offer is therefore relying on the(what we think) best interpretation of the available data: using our various indirect parameters (XRF data, sediment color) and a direct indicator of soil input (the BIT index) we have identified sediment intervals that are marine and other that are fluvial deposits and chosen the calibration curves accordingly. We believe that resulting age model is reliable enough for the scope of this paper, but we are open to suggestions that will help us improve our age-depth estimations!

Why was there no radiocarbon dating conducted on foraminifera from the same material?

Unfortunately, dating foraminifera ages are not available here, because planktic foraminifer do not live at these shallow depths and benthic species are prone to recording the 14C signal of old bottom water masses.

Interpretation of the LIA interval: I am not sure the data during LIA supports the claim made for that interval. The author states that there is missing age control in that period due to re-depositional events. So no data is shown. Instead the author concludes that based on redeposited material which can be characterized as reworked soil, the time frame of the LIA must have had torrential rains and flashfloods on the background of an arid climate. I can 0 t see the evidence for that conclusion

We agree with the review that we draw this conclusion very swiftly – it draws on ideas from the catchment sample analysis 5.1.1. that we neglected to refer to in the discussion of the LIA climate (5.2.3). We hope that the revised version of 5.2.3. (below) presents the evidence for an LIA Arid climate with flashfloods more clear: *Continuous sedimentation at the core site was interrupted at ~650 cal yr BP. One or more erosive event deposits are inferred from the sedimentology (erosive contact at ~60-65 cm; fine sand with intercalated organic layers and lumps from ~30-60 cm) and an age reversal indicated by the 2 radiocarbon dates in this interval (~1,466 cal yr BP at a depth of 31 cm ~640 cal yr BP at a depth of 60 cm and; Fig. 4; Table 1). Due to the discontinuous nature of the deposition we are only able to curtail the timeframe of deposition to having taken place between ~650 cal yr BP (the youngest age in the event deposit) and a post – bomb date ~13.5cm above the redeposited. From the redeposited sediment package 3 samples have been analyzed organic geochemistry (see Table 3). The average values over the possible timeframe of deposition is plotted in Fig.5. The high BIT-index (~0.7) indicates that the redeposited package can be characterized as reworked soil material. The averaged δD_{C31} signature of ~-135‰ is comparable to that of Gouritz river paleoflood deposits described in section 5.1.1. We therefore suggest that the origin of the event-deposited material in core GeoB18308-1 is similar to the origin of these terrestrial paleoflood deposits. Our catchment study (Leaf wax δD_{C31} of paleoflood and soil deposits-see 5.1.1) indicates that paleoflood deposits are primarily induced by an increase in high latitude precipitation i.e. precipitation in the upper parts of the Gouritz catchment. The shift in $\delta^{13}C_{C31}$ towards slightly more depleted values in the event deposited material in core GeoB18308-1 (average in the redeposited unit: ~-28‰VPDB) furthermore indicates that the n-C31 alkanes contained in the event deposit were produced by plants under less water stress (c.f. Collister et al., 1994, Ehleringer and Cooper, 1988) than those deposited before ~650cal yr BP. We therefore infer an increase in upper catchment rainfall inducing floods for the time period of the event deposit(s) (~300-650 cal yr BP). This roughly falls into the timeframe of the so-called "Little Ice Age (LIA)" recorded as humid throughout the South African WRZ (Meadows et al., 1996; Benito et al., 2011; Stager et al., 2011; Weldeab et al., 2013) due to a northward shift of the SHW (Tyson and Preston-Whyte, 2000; Chase and Meadows, 2007). In the uppermost Gouritz catchment (Seweweekspoort site) a major SHW sourced rainfall regime has been documented (Chase et al. 2015). Desmet and Cowling (1999) indicate that despite the general SRZ regime in the Gouritz catchment, the SHW supply additional rainfall in extreme events. We suggest that an increase of these extreme SHW-sourced rainfall events produced large floods during the LIA (~300-650 cal yr BP)….*

neither for the claim, that the SST 0 s in Mossel Bay were warm if there is no TEX data for that core depth presented.

The reviewer is correct; we were not able to calculate SSTs for the LIA timeframe due to the confounding influence of the very high soil content in this interval. The warmer SSTs in the LIA is merely something we suggest as a consequence of applying the Cohen and Tyson model to our findings. We see how this is misleading and have reformulated the abstract accordingly and we have removed the following sentence from the conclusion: ~~*In contrast; a weakened, more northerly SIA (e.g. during LIA conditions) has the opposite effect: the weaker Agulhas current is less liable for upwelling and the more frequent SHW advect warm surface water plumes onto the Agulhas bank in analogy to the modern day winter situation*~~

Moreover, what does the average line for deposit mean for the interval shown in Fig. 5?

The average line for deposit represents the averages of all the measurements made in the redeposited sediments. To make this clearer we have modified Fig. 5 and the caption accordingly. The presentation of the LIA climatic / oceanographic data is difficult due to the lack of age-control in this part of the core. We have however collected data from the redeposited interval that we believe represents the LIA climatic / oceanographic conditions. They can however not be plotted against time in figure 5 since these are not continuous, but event deposits. WE therefore opted for presenting averages of the measured data points in the event deposits. Obviously we have done a bad job in presenting this data. This leads the reviewer to enquire what the average line for deposit means. We hope the modified fig. 5 is easier to read.

The SST conclusion in this paper is with odds of Zinke et al., 2014 (Zinke, J., B. R. Loveday, C. J. C. Reason, W. C. Dullo, and D. Kroon (2014), Madagascar corals track sea surface temperature variability in the Agulhas Current core region over the past 334 years, Sci. Rep., 4. doi: 10.1038/srep04393) who show that Agulhas Current SSTs cooled through the Little Ice Age. How can these opposing findings be explained? Moreover, I think there should be more evidence for that claim presented.

Thank you for this reference. As stated above we have no SST data for the LIA timeframe so unfortunately we have no basis for a discussion.

2) Specific questions/issues: Page 2 line 4: I feel that a more African specific chapter of the IPCC report should be cited here rather than Metz or Kirtman et al : "Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. C3 Urquhart, 2014: Africa. In: Climate Change 2014: Impacts, Adaptation, and Vul- nerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

Done

Page 2 line 20: There are more recent studies by now showing insolation driven responds of Southern Africa climate and should be cited here: (Daniau, A.-L., M. F. Sánchez Goñi, P. Martinez, D. H. Urrego, V. Bout-Roumazeilles, S. Desprat, and J. R. Marlon (2013), Orbital-scale climate forcing of grassland burning in southern Africa, Proceedings of the National Academy of Sciences, 110(13), 5069-5073. doi: 10.1073/pnas.1214292110); (Simon, M. H., M. Ziegler, J. Bosmans, S. Barker, C. J. C. Reason, and I. R. Hall (2015), Eastern South African hydroclimate over the past 270,000 years, Scientific Reports, 5, 18153. doi: 10.1038/srep18153)

We have added Daniau et al. 2013 and Simon et al. 2015

Page 3 Line 1: Biastoch et al., 2009a does not show that strong SHW reduce leakage into the SA and should not be cited here in this respect. This study only shows what effect shifting the SHW to Leakage strength has. It does not evaluate what a change in the strength of the SHW does to leakage variability. In this respect the citation of Durgadoo et al., 2013 in the line below is wrong as in this paper the authors show that an equatorward shift in westerlies increases leakage and not like written in this paper page 3 line 4:" a weakening of the Agulhas Current and the leakage of warm water due to northward displacement of the SHW".

Both references were removed

Page 5 line 21: Not sure how this description of the bathymetry fits into this part of the oceanography. Would suggest shifting that.

The descriptions of the bathymetry have been shifted to be included in the section 3.1.

Page 6 line 29: Is that a valid common method to calibrate XFR scans? I would rather think that taking sub-samples and analyzing for bulk major and trace elements would be the way to do it? One approach could be following the below: “Prediction of Geochemi- cal Composition from XRF Core Scanner Data: A New Multivariate Approach Including Automatic Selection of Calibration Samples and Quantification of Uncertainties By G. J. Weltje, M. R. Bloemsma, R. Tjallingii, D. Heslop, U. Röhl and Ian W. Croudace.”

Yes we did take sub-samples and analyzed them for bulk major and trace elements, it is not expressed clearly in our methods section, but we have added that 28 dried and ground subsamples were analyzed for bulk major and trace elements for calibration purposes.

Page 8 line 19: Why and how was the original method modified? Does the modification have advantages compared to Hopmans protocol? If so that should be stated there.

since the Hopman publication there have been several changes that we describe in the text, describing the advantages of these changes compared to Hopmans protocol would in our eyes be beyond the scope of this study and expand this methods section unnecessarily.

Page 9 line 27: To be statically significant one have to at least count 150 specimens per sample not only 20.

The statistical reliability depends not only on counted numbers but also on proportions of considered taxa. Hence, only taxa exceeding 5% relative abundance and occurring in at least two samples were used for PCA. We agree that there is a large uncertainty for samples with a minimum number, which is 31 individuals in 1 sample and below 100 in three other samples, but, by our opinion, sufficient to figure out the explanatory power of axis 1 (35.1% !) which is used here for simplified representation of microfossil distribution. We hope that you accept our simplified approach of displaying micropaleontological results, because a detailed presentation of microfossil distributions would need much more space.

Page 12: By which evidence sedimentological etc. was a paleosoil and a flood de- posit distinguished? Only by different dD values? That should be better described and presented in the text.

Soil horizons and flood deposits were also distinguished by their sedimentology in the field. We have added the following information to 5.1.1.:”Catchment samples were all taken at lowland locations, however some were identified as soil samples from horizons of darker, finer material while others were identified as flood deposits by their lighter, coarser facies (Fig. 6).”

Page 12 line 10: why would rainfall in the highlands auto- matically lead to flood events?

We do not infer that this is automatically so in every catchment, but it seems to be the case in the Gouritz catchment; the layers that we have identified sedimentologically as flood deposits contain organic material that was synthesized under different conditions than the plant material contained in the soils. The deuterium values of the flood deposits are depleted – this gives an indication of their origin as rainfall becomes deuterium depleted with origin. We hope to have made this chain of thought clearer in the text.

Page 14 line 15: If that is stated then values should be given as well. As the age model was derived from a Baysian approach one can give an uncertainty value here for the age model.

Added: (+/-2σ: 835-1100cal yr BP)

Page 14 line 17: The recent review paper by Should be included in that part of the manuscript. Also Nash, D. J., G. De Cort, B. M. Chase, D. Verschuren, S. E. Nicholson, T. M. Shanahan, A. Asrat, A.-M. Lézine, and S. W. Grab (2016), African hydroclimatic variability during the last 2000 years, Quaternary Science Reviews, 154, 1-

22. doi: http://dx.doi.org/10.1016/j.quascirev.2016.10.012 Woodborne, S., G. Hall, I. Robertson, A. Patrut, M. Rouault, N. J. Loader, and M. Hofmeyr (2015), A 1000-Year Carbon Isotope Rainfall Proxy Record from South African Baobab Trees (<italic>Adansonia digitata</italic> L.), PLoS ONE, 10(5), e0124202. doi: 10.1371/journal.pone.0124202 should be added here as their record also shows the wettest period was c. AD 1075 in the Medieval Warm Period.

Nash et al., 2016; Woodborne et al., 2015 included

Fig. 5: For comparative purposes other regional paleoenvironmental records are plot- ted. How was secured that there are no age model offsets between this study and the other records?

We see the concern of the reviewer – no age model is perfect, but each record is based on a relatively reliable (published) independent age depth model. We do not see how we can improve this.

3) Technical corrections

Fig. 2: page 29 line 5: legend says Carr et al., 2014 in the figures in the map it says Carr et al, 2015

Done

Fig. 5 Could do with more labels on the Y-Axis i.e. at least 500 year tick labels between tick marks.

Done

Page 12 line 12: twice 'mainly used here! Rephrase grammar is wrong in that part of the sentence!

Done

Page 12 line 26: Formatting issues and missing space.

Done

Page 13 line 21. Fig. 5 shows the main record only till 4 ka according to the axis however the text states: " The oldest part of the 18308-1 paleorecord (~ 4880-1150 cal yr BP)

Has been corrected to 4058 cal yr BP

...... where is the rest of the data? Where are the figure captions of the supplement?

I have added these to the bottom of the paper

And what are the dots in SF1? The calibration samples or the subsampling for the organic geochemistry?

No, the discrete measurements (in mg/kg) for calibrating the XRF scans are plotted as squares.

Rebuttal Anonymous Referee #2

The study encompasses an impressive variety of methodologies and of different proxies, and discusses the rich results in a convincing way, especially for what regards the aridity-humidity multi-proxy reconstruction. An undoubtable strength of the approach is the analysis carried out in samples from several places in the Gouritz catchment, which provides decisive supports for the inferences made. I would recommend that the manuscript be published, although prior to that the authors should improve a few aspects of it, and respond to some questions that I detail below.

Thank you for the helpful comments on this manuscript!

General reservations that I have with this work are: 1) a better effort could be made of emphasizing, especially in the abstract and introduction (and potentially also in the title), what the key findings are and what their importance implications of their results is.

We have added the implications of the key findings at the end of the abstract. We have modified the introduction as well, but we thought it best fit to stress the implications of the key findings mainly in the abstract.

As it is it resembles more an account of analyses carried out in a very good setting (whose importance could be made even more clear).

We have added the following to the beginning of the abstract: "In addition to this, it´s location at the interface of Atlantic and Indian Ocean circulation systems makes the southernmost tip of South Africa a climatically extremely sensitive as well as interesting area. Thus far few marine records have been available in order to study the interplay of marine and atmospheric circulation systems. This study of sediment core GeoB18308-1 at the terrestrial-marine interface fills this gap for the time interval of ~4 ka BP."

2) It would be very interesting if the authors could draw more explicitly the implications of their results, and/or of the conceptual model they somehow validate,

To explain better what we mean by validate we have added: "The only SST record published for the area (Cohen and Tyson, 1995) does not include data for the time frame in question."……" The decrease in SSTs recorded in GeoB18308-1 for the interval of increased humidity in the Gouritz River catchment inferred in this study for the time interval of the Medieval Climate Anomaly serves as data to validate the conceptual model by Cohen and Tyson, (1995) for which thus far no Medieval Climate Anomaly data had been available."

for the latitudinal shifts in ITCZ. This is of interest to a larger climatological community, and to projections of what the region may expect with ongoing climate change.

We did not want to include an attempt to make a predictions of future climate that are too speculative. We have however added a suggestion of a future prognosis at the end of the abstract to address this reviewer comment.

3) the paper is very wordy, especially in its sections 2 to 5. The authors should improve readability and really consider refraining from reporting all they have done and all results, and focus of what is of relevance to the new findings discussed. Some records barely matter for the discussion.

We have tried to shorten the complete regional settings section (2) as well as the methods (3) and results (4) to a minimum in particular for the not much used heavy mineral and microfossil proxies. Furthermore we have rewritten large parts of section 5 in order to make it more readable (even if maybe not shorter)

4) Probably because of the vast amount of material presented, the manuscript is sloppy in many parts: odd sentences, mismatches in the wording, punctuation, typos. One would expect that nine authors could proofread the manuscript to a higher quality.

We have reworked the manuscript to fix this.

Main specific points The first sentence of the introduction seems inconsequential and unjustified to me: there is no argument for the importance of South Africa's geographic position. Re- phrase.

We have rephrased the first sentence to make this clearer.

I would suggest to pay more attention to streamlining the introduction chap- ter: as it is it is hard to read, and the main points that the authors wish to make do not come through clearly. What are the main research gaps regarding South African climate? Can you present the evidence for one or the other explanation in a more or- ganized manner?

We have removed some of the surplus information and focused the introduction on the 2 main research questions of the region.

I would recommend an effort to focus section 2. It could be made more concise, and thus the readability of the paper could improve, if you privilege the information that is relevant to the findings of this paper. E.g., the reader doesn't gain insight that are relevant to this Late Holocene paper by your discussing Cretaceous tectonics.

We have removed some of the surplus information, the section now only includes what is relevant for the interpretation of the data.

Fig 4. The LIA follows the MCA, not the other way around.

Changed

Pag 14 line 2 and following. First, from fig 5 one would say that all discussed changes happen from ca. 950 yBP, rather than 1150. Can you clarify whether the figure or the discussion are correct?

The figure is correct I have changed the text

Further, I don't think you can state that anything happens to the SST record around 1150 yBP, at least from the results contained in fig.5. Simply the sampling temporal resolution increases, but I would argue there is no real difference in variability before and after 1150 kBP. If anything, low peaks appear after that time: could you show a real statistical significance between the average SSTs either side of 1150kBP?

None of the SSTs inferred for the period before the MCA are lower than the average SSTs measured for the MCA interval (n=17). However, we will remove all mention of a difference in variability, this may indeed be an artefact of the sampling resolution as the reviewer suggest…

(related to one of the main objections of reviewer 1) You state that age-reversals oc- cur from 650 yBP, but from figure 5 one can see that you take data up to ca. 500 yBP seriously (also the gray band starts at 500): can you clarify?

Sorry, there is a mistake in the caption of Figure 4: the reworked package is at 26-69 cm depth and (not 66cm)! The 1294 cal. Age BP age at core depth 69 cm, was removed from the age model as part of the redeposited package.

Pag 14 ll 27-28. For intensification of Agulhas Current transport, you should check Durgadoo et al (2013), who report, from three ocean models, that northward shifts (and intensification) in at- mospheric features increase Agulhas Current transport contrary to what included in the conceptual model here discussed. This does not mean that ocean models in the above studies hold the truth, but I would suggest you could take the occasion to discuss this contradiction in the literature. (also in the Conclusions) Pag 16 line 10. Future climate change may follow what pattern? You reported two.

We have removed the LIA scenario so it is hopefully clrear now that we are referring to the MCA scenario.

Also, could you provide a reference supporting this? (rephrase anyway, as sentence is confused)

Unfortunately not, this is our suggestion…

Minor comments: The title could be modified to eliminate the present continuous tense – vague – and include any word that reports the results of this "linking"

New title: Southerly anticyclonic circulation drives climatic conditions and sea surface temperatures in southernmost Africa

Abstract: "highly dynamic" and "highly complex" used just one sentence apart, maybe either make more specific or eliminated one

Done

“give information on climatic changes”: it is vague, make more concrete.

Oceanographic and hydrologic changes in specific

The last sentence is unclear: to which processes do you refer, to those in the LIA or in the MCA? Rephrase. Also, probably not appropriate to only refer to a climate model like this at the end of the abstract, where the reader cannot make much out of it: essential information is missing.

We have changed the abstract accordingly

Ll 9-12. This sentence is complicated and doesn’t show a contrast between concepts that one would expect from the use of “while”. Ll 16 ITCZ not explained, maybe avoid abbreviation as never used anymore.

Written out

Ll 16-18 you either use whether, or add a question mark, not both.

Question mark removed

Page 3 line 4. Durgadoo et al 2013 find precisely the opposite, i.e. that Agulhas leakage increases when westerlies move north. I would suggest you deal with this in the introduction.

As also suggested by referee1 the citation was removed

line 6. What is YRZ?

Written out in text

Ll 16-17. Odd phrasing, a sediment core doesn’t aim to anything.

Rephrased to “our work” aims

Line 28. Harmonize the units (use exponential in place of Mm3)

Done

Line 32. What do you mean by mixed summer and winter rainfall? And why this single paleo piece of information in a present-day context?

Removed

Page 6 ll 15-16. Sentence not clear: what is the unit for the numbers in parenthesis, years? (14C should have 14 in the superscript) Dewar et al 2012 is missing from the ref list.

Unit and reference added

Line 17. Why do you inform about the sedimentation rate: this is not further discussed in the paper.

Removed

Line 21. Analyses. Line 24. Change “elemental profiles” in place of “scanning data”.

Done

Line 27. Change “vertical resolution or downcore resolution” in place of depth resolution.

Done

What are 1.2 cm2?

Removed

Line 3. Change “scanning intensities” for a more appropriate term

Changed to peak intergals

Pag 7 ll 4-5. Not clear how the xrf data helped in selecting the samples for organic geochemistry, please reformulate.

Reformulated – a higher resolution is chosen in the upper part….

Methods: try to avoid so many abbreviations, especially those not further used in the paper. In general the manuscript is highly packed with abbreviations, please try to be parsimonious with them.

We tried to stil to this advice throughout the manuscript

Pag 9 line 16. "micropaleontologically" probably not a word.

Changed to microfossil analysis

Pag 10 line 2. "None of the considered taxa was found to correlate".

Changed

Line 4. What do you mean by point counted?

Point counted is a method used instead of grain counting of minerals in order to do justice to the larger size of some minerals – this can be left out…

Line 15. Same reference occurs twice.

Removed

Line 20. Fig S4 does not exist. S3 Pag 14 ll 15-17. The reader gets the impression that the MCA is a Southern African phenomenon, while this is a concept normally applied north Atlantic records. Please rephrase. Also, punctuation is jumbled.

We have clarified that this is a NH trend expressed in South Africa….

Line 30. "serves as data to validate", not really clear, could you reformulate? Rephrased:The decrease in SSTs recorded in GeoB18308-1 for the interval of increased humidity in the Gouritz River catchment inferred in this study for the time interval of the Medieval Climate Anomaly serves as data to validate the conceptual model by Cohen and Tyson, (1995) for which thus far no Medieval Climate Anomaly data had been available.

Pag 15 line 19. An anthropogenic signal shouldn't be expected only for the recent decades, as humans and colonization of South Africa were active (and potentially modifying the vegetation) also during the LIA, please check/reformulate. We see no evidence of anthropogenic impact so I have removed this entirely Conclusions: please reconsider the use of resounding wording like "unique" (twice; surely this is not the only record to report SSTs along with terrestrial proxies), "not only" removed / changed to "advantage" Caption Fig. 4. Explain what the 10,000 iterations are.

Caption modified: the calibrated 14C dates (transparent blue) and the age-depth model (darker greys indicate more likely calendar ages; grey stippled lines show 95% confidence intervals; red curve shows single 'best' model based on the weighted mean age for each depth).

Also, please turn the numbers of the y-axis by 180 degrees

Done

Fig 5. Why no LIA grey block until the right part of the figure? It seem that the last curve to the right extends into the future. MCA and LIA colour references in the caption are wrong. Also, you plot PCA but refer in the text to PC1. In general, check the wording and concordance between caption, figure and what reported in the main text, as there are several mismatches. Since there are many proxies, you should avoid confusing the reader with slightly different wordings.

We have tried to pay attention to this changing Fig. 4 and 5

Fig. S2 contains mistakes: commas instead of points, no units for temperatures, BIT-index instead of BIT.

We have modified the Fig S2 accordingly.

Southern hemisphere anticyclonic circulation drives climatic conditions and sea surface temperatures in southernmost Africa

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Abstract

Due to the high sensitive of southern Africa to climatic change, a reliable understanding of its hydrological system is crucial. Recent studies of the regional climatic system revealed a highly complex interplay of forcing factors on precipitation regimes. This includes the influence of the tropical easterlies, the strength of the Southern Hemispheric Westerlies as well as sea surface temperatures along the coast of the subcontinent. However, very few marine records have been available in order to study the coupling of marine and atmospheric circulation systems. Here we present unique results from a marine sediment core, which could be recovered in shallow waters off the Gouritz River mouth on the south coast of South Africa. Core GeoB18308-1 allows a closer view to the last ~4 ka BP. Climate sensitive organic proxies like the distribution and isotopic composition of plant-wax lipids as well as indicators for sea surface temperatures and soil input give important information on oceanographic and hydrologic changes during the recorded time period. Moreover, the micropaleontology, mineralogical and elemental composition of the sediments reflect the variability of the terrigenous input to the core site. The combination of down-core sediment signatures and a catchment-wide provenance study indicate that the Little Ice Age () was characterized by climatic conditions favourable to torrential flood events. In contrast, the so-called Medieval Climate Anomaly () is expressed by lower sea surface temperatures in the Mossel Bay area and humid conditions in the Gouritz River catchment. These new results suggest very closely that the coincidence of humid conditions and cooler sea surface temperatures along the south coast of South Africa may result from a strengthened and more southerly anticyclonic circulation. Most obviously the transport of moisture from the Indian Ocean by strong subtropical easterlies was coupled with Agulhas Bank upwelling pulses, which are initiated by an increase of the strength of the Agulhas Current.

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1 Introduction

South Africa's regional climate has been discerned as particularly sensitive to future climate change. Over the last five decades mean annual temperatures have increased by at least 1.5 times the observed global average and both extreme rainfall events as well as droughts are anticipated as environmental, social and economic threats (Niang et al. 2014, Ziervogel et al. 2014). It is well known that the precipitation pattern in South Africa is influenced by shifts of the Southern Hemispheric Westerlies (SHW), the strength of the southeast trades, as well as variations in ocean circulation (e.g. Chase and Meadows, 2007; Chase et al., 2011; Marzin and Braconnot, 2009; Schefuß et al., 2011; Fig. 1). The interplay and regional extent of these factors and their relation to global climate forcings at different time scales is, however, far from being understood. The main dispute currently concerns the driving factors behind the easterly rainfall regimes in the southernmost part of Africa. Very probable, shifts of the Intertropical Convergence Zone may be at best of subordinate importance so far to the south. A major question in this context is whether the climate variability in southern Africa is synchronous with northern hemispheric variations or driven by direct insolation changes and thus anti-phased to northern hemispheric signals. It was relatively uncontroversial that long term (glacial-interglacial timescale) climate variations in southernmost Africa are directly forced by local insolation (Daniau et al., 2013; Simon et al., 2015). However, recent studies could not show clear evidence either of direct insolation as mainly responsible for climate variability (Chase et al., 2009, 2010; Dupont et al., 2011) nor for opposing trends (i.e. synchrony with the northern hemisphere) (Tierney et al., 2008; Stager et al., 2011; Truc et al., 2013). Furthermore, on shorter timescales, recent datasets reveal strong indication that the local climate system is much more complex. So, data from Wonderkrater in eastern South Africa (Truc et al., 2013) and regional pollen analyses (Scott et al., 2012) document enhanced and diminished precipitation with respect to the geographical position of the recording archive. A progressive Holocene aridification in northwestern Namibia (Chase et al., 2010), consistent with a proposed cool and dry period in eastern South Africa (Holmgren et al., 1999; Norström et al., 2014) and a regional compilation of pollen records (Chevailier and Chase, 2015) all offer additional evidence for climate variability in phase with the northern hemisphere.

Mechanisms suggested to explain the transmission of the northern hemispheric signal to southern Africa include tele-connections causing a dipole-pattern of rainfall between eastern tropical and southern Africa (Norström et al., 2014) as well as sea surface temperature (SST) changes due to ocean circulation variability (Agulhas strength) (Tierney et al., 2008; Stager et al., 2011; Scott et al., 2012; Truc et al., 2013). The latter can be discerned as a major research gap in southernmost South Africa. Due to the strongly erosive Agulhas current, very few marine records from the Agulhas bank exist and the influence of SSTs on the regional precipitation patterns therefore remains under dispute. On the one hand, it has been suggested that decreased SSTs on the southwestern coast of South Africa lead to decreasing precipitation in southernmost South Africa (Rouault et al., 2003) and positive SST anomalies along the east coast associated with Agulhas strengthening enhance summer precipitation in the eastern South Africa (Jury et al., 1993; Dupont et al., 2011; Scott et al., 2012). On the other hand, the oxygen isotope composition of marine mollusk shells preserved in Nelson Bay archaeological cave deposit indicate that during periods of wetter conditions over the southern African interior, the Agulhas surface water temperatures were actually lower than during arid periods (Cohen and Tyson, 1995). Based on this data in combination with interannual observations a conceptual model relating oceanic and atmospheric circulation systems of southern Africa was proposed in 1995 by Cohen and Tyson. This model predicts that during periods of stronger anticyclonic circulation, the increased alongshore winds caused coastal upwelling off Mossel Bay whereas the increased Agulhas strength drives upwelling over the east coast shelf edge. The database behind this model is however sparse and a large gap exists for the period between 2400 and 650 BP (Tyson and Lindesay, 1992; Cohen and Tyson, 1995).

Our multiproxy study on core GeoB18308-1, located on the South Coast of South Africa, off the mouth of the Gouritz River, 30 km west of the town Mossel Bay, aims to close this gap. In addition to providing a SST reconstruction for the past ~4 ka, this record also holds the potential for a high resolution continental climatic reconstruction. In order to decipher the complexity

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of the terrigenous climatic signal, sediment provenance and transport processes are studied using catchment material in a source to sink approach.

2 Regional setting

2.1 Gouritz River catchment area

The Gouritz River catchment area is divided into four sub-catchments. The first includes the Buffels, Touws and Groot Rivers, the second consists of the Gamka and Dwyka Rivers, the third comprises the Traka, Olifants and Kammanassie Rivers, and the fourth represents the Gouritz River itself (Le Maitre et al., 2009). The mean annual runoff of the sub-catchments was measured to be $105*10^6$ m^3, $206*10^6$ m^3, $229*10^6$ m^3 and $134*10^6$ m^3, respectively. The entire Gouritz River catchment is located within the year-round rainfall zone YRZ (Fig. 1). Le Maitre et al. (2009), however, note that even though observed rainfall patterns in the catchment area show year round precipitation, most of the area mainly receives rainfall during summer and autumn. Measurements by Desmet and Cowling (1999) reveal highly variable mean annual precipitation, but also show somewhat lower rainfall quantities in winter. Several major floods, e.g. in January 1981, March 2003 and in March 2004, caused by extreme rainfall events, are another characteristic of this area (Desmet and Cowling, 1999; Cowling et al., 2004). Despite the relatively small size of the catchment area (approximately 45,715 km^2), the altitudinal gradient is steep as the Swartberg Mountains rise abruptly above 2000 m a.s.l. within 100 km of the coast (Le Maitre et al, 2009).

2.2 Vegetation in the study area

Within the study area three dominant vegetation types are described: Fynbos, Succulent Karoo and the Nama Karoo biomes (Mucina and Rutherford, 2006; see map in Fig. 2). The Fynbos biome is characterized as a Mediterranean-type vegetation (Goldblatt and Manning, 2002). It is found especially along the southern and southwestern coast of South Africa and therefore, receives most of its rainfall during austral winter. The most dominant photosynthetic pathway reported is C_3 (Vogel et al., 1978). The Succulent Karoo biome is described as being better adapted to arid conditions and higher summer temperatures (Carr et al., 2014). Due to the geographic distribution of vegetation, the Succulent Karoo biome gets most of its rainfall during winter but also receives summer precipitation in the eastern part of the catchment (Rundel et al., 1999). The last vegetation type, Nama Karoo, is described to consist mostly of C_4 grasses and due to its occurrence in a north-eastern geographical position, receives dominantly summer rain (Le Maitre et al., 2009). Studies within this region as well as in other areas of Africa revealed that these vegetation types showed differences in their *n*-alkane composition (Rommerskirchen et al., 2006; Vogts et al., 2009; Carr, 2012; 2014; Boom et al., 2014; Herrmann et al. 2016; Fig. 2).

2.3 Geology of the Gouritz River catchment

The distinctive topography of Southern Africa is characterized by a high-relief inland plateau flanked by a low average elevation coastal plain and the Gouritz River catchment drains almost all sequences of the Cape. The oldest 'basement' rocks comprise the Malmesbury Group and the Cape Granite Suite (~550 – 510 Ma) related to Pan African orogenesis during the formation of Gondwana (Rozendaal et al., 1999; Johnson et al., 2006; Milani and de Wit, 2008). Overlying deposits of the Cape Supergroup form a 6 – 10 km thick siliciclastic sequence, divided into the Table Mountain, Bokkeveld and Witteberg Groups (Thamm and Johnson, 2006) and which were deformed ~278 – 230 Ma (Newton et al., 2006). After Deposits of the Karoo Supergroup were laid down in a foreland basin adjacent to this orogen and Karoo sedimentation was terminated by the extrusion and intrusion of the extensive Drakensberg basalts and dolerites at ~183 Ma (Duncan et al., 1997). The southern cape continental shelf and low relief coastal plain comprise the submerged and emergent portions of a continuous feature, the degree of separation being dependent upon the relative sea level at any given time (Cawthra et al., 2015). This broad, shallow plain is mantled with Pleistocene/Holocene deposits. The south coast is characterized by a series of eastward-opening log-

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spiral bays that extend for approximately 20-40 km between adjacent west-east trending rocky headlands. The Gouritz River is associated with a well-developed, stratified, sediment wedge (~10 km wide and 85 km long) (Birch, 1978) that extends predominantly westwards of the river mouth. Offshore, the Gouritz River is associated with a subdued incised valley, running across the continental shelf (Cawthra, 2014).

2.4 Oceanic circulation on the eastern Agulhas Bank

The oceanography of the Agulhas Bank is strongly influenced by the warm, fast-flowing Agulhas Current originating in the Mozambique Channel (Lutjeharms et al., 2001). The inner shelf targeted in this study is influenced by wind-driven coastal upwelling, particularly during summer (cf. Hutchings et al., 1995). Along-coast easterly winds drive these periodic events of short-term surface water cooling of up to 8°C (Schumann et al. 1982, Beckley 1983). During winter, plumes of warm Agulhas Current water have been observed to advect onto the shelf by southwesterly winds (Lutjeharms and van Ballegooyen, 1988).

3 Material and methods

3.1 Sediment coring and catchment samples

Sediment core GeoB18308-1 was taken with a vibrocorer during RV METEOR Cruise M102 in December 2013 from a protected valley fill on the continental shelf near Mossel Bay (34°22.39'S 21°55.75'E) 4 km offshore the Gouritz River mouth. Using multibeam bathymetry and side-scan sonar Cawthra et al. (2015) describe the morphology of the area as a generally smooth, wide continental shelf of low gradient (see location in Fig. 3). The core has a total length of 4.94 m and mainly consists of fine sand and mud. In the interval between ~30 cm and 70 cm an event deposit revealing slumped turbidite facies with an erosive contact was identified. South African sea level reconstructions (Compton, 2006; Ramsay and Cooper, 2002) reveal that the sampling site (located in about 40 m water depth) was not significantly influenced by fluctuations during the last 5 ka. Riverbank, flood deposit and suspension load (obtained by filtering ca. 100 L of water pumped from the rivers' main flow) samples were collected from eight locations along the Gouritz River in March 2015 in order to determine the provenance of the deposited material (see locations in Fig. 2).

3.2 Age model

The age model used in this study is based on fourteen radiocarbon ages (Fig. 4). Ages were estimated from nine total organic carbon (TOC) samples, two shells, two pieces of wood and one crab claw (Table 1). The cleaning procedures as well as the Accelerator Mass Spectrometry (AMS) measurements were carried out in the Poznań Radiocarbon Laboratory, Poland and Beta Analytic Radiocarbon Dating Laboratory Florida, USA. Depending on sediment type (terrestrial or marine identified using all available data) either the Southern Hemisphere calibration curve (SHCal13) (Hogg et al., 2013) or the modelled ocean average curve (Marine13) (Reimer et al., 2013) were used to calibrate the radiocarbon ages. The marine ΔR is assumed to be close to the south west coast ΔR (146 ± 85 ^{14}C years) published in 2012 by Dewar et al. (Meadows et al. in prep./personal communication). The software Bacon (Blaauw and Christen, 2011) was used to calculate an age model. We refer to median age estimations in this paper; please note the associated uncertainty indicated in Fig. 4 and Table 1.

3.3 Inorganic Geochemistry

Inorganic geochemical analyses were performed down-core (2 to 10 cm resolution) as well as on soil, riverbank, flood deposit and suspension load samples collected from eight Gouritz catchment locations (ECT-1 to ECT-8) in March 2015 (Fig. 2, Tab. 2). Elemental profiles were collected using MARUM XRF Core Scanner II (AVAATECH Serial No. 2) equipped with an Oxford Instruments 50W XTF5011 rhodium X-Ray tube, a Canberra X-PIPS Silicon Drift Detector (SDD; Model SXD 15C-150-500) run at a 150 eV resolution and a Canberra Digital Spectrum Analyzer DAS 1000 at the MARUM-University of

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Bremen. The vertical resolution was 1 cm with two generator settings (30 kV, 1 mA, 20 s; 10 kV, 0.2 kV, 20 s) for detection of different elemental groups. For calibration purposes the XRF-spectrometer measurements were completed on 28 selected dried and ground sediment samples using a PANalytical Epsilon3-XL XRF spectrometer. Using these discrete ED-XRF measurements and the procedure proposed by Lyle et al. (2012) we were able to normalize the XRF scanning data (counts). Good correlations (R^2 above 0.7) of XRF scanner and XRF analyses of discrete samples results were found for a variety of elements including Ca and Fe.

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3.4 Organic Geochemistry

The continuous high resolution, XRF scanning dataset (Fig. S1) indicates little variability in the lower half of core GeoB18308-1. Based on this finding sub-samples for biomarker analysis were taken at higher resolution in the upper half of the core.

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3.4.1 Plant-wax analyses

Dried and ground samples were extracted using a DIONEX Accelerated Solvent Extractor (ASE 200) at 100°C, 1000 psi with a 9:1 mixture of dichloromethane (DCM) to methanol for 5 min and 3 extraction cycles. Prior to extraction, squalane and C_{46}-GDGT (glycerol dialkyl glycerol tetraether) were added as internal standards. Asphaltenes were removed from the total lipid extracts using Na_2SO_4 columns and elution with hexane. Extracts were saponified for 2 hours at 85°C in 500 µL of a 0.1 M KOH-solution in methanol (MeOH). Neutral lipids were recovered by liquid-liquid extraction using hexane. Lipid fractions were separated over a silica gel column (10% deactivated) using hexane (hydrocarbons), DCM (ketones), and DCM:MeOH 1:1 (polar fractions). Unsaturated compounds were removed from the hydrocarbon fractions by column chromatography over $AgNO_3$-coated silica using hexane. The saturated hydrocarbon fractions containing *n*-alkanes were injected in splitless mode at 260°C into a Thermo Scientific Focus gas chromatograph equipped with a DB-5ms column (30 m x 0.25 mm, 0.25 µm film thickness, Agilent Technologies, Palo Alto, USA) coupled to a flame ionisation detector (GC-FID). The oven was held at 70°C for 2 min, then heated at a rate of 20°C min^{-1} to 150°C, and after with a rate of 4°C min^{-1} to 320°C, and remained at this temperature for 16.5 min. An external calibration standard containing *n*-alkanes of known concentrations was analysed every six samples. Based on the repeated standard analyses the precision of quantification is calculated to 5%. The ratio between C_{29} and C_{31} *n*-alkanes (Norm31) was calculated using Eq. (1):

$$\text{Norm31} = C_{31}/(C_{29} + C_{31}) \qquad (1)$$

The carbon preference index (CPI) (Bray and Evans, 1961) was calculated according Eq. (2):

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$$CPI_{23-33} = \frac{1}{2}\left\{\left(\frac{C_{23}+C_{25}+C_{27}+C_{29}+C_{31}+C_{33}}{C_{22}+C_{24}+C_{26}+C_{28}+C_{30}+C_{32}}\right) + \left(\frac{C_{23}+C_{25}+C_{27}+C_{29}+C_{31}+C_{33}}{C_{24}+C_{26}+C_{28}+C_{30}+C_{32}+C_{34}}\right)\right\} \qquad (2)$$

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3.4.2 Compound-specific carbon and hydrogen isotope analyses

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The fractions containing *n*-alkanes were used for compound-specific carbon and hydrogen isotope analyses. Compound-specific stable hydrogen isotope measurements were performed on a Trace GC (Thermo FisherScientific, Bremen, Germany) coupled to a MAT 253 IRMS (Finnigan MAT, Bremen, Germany) via a pyrolysis reactor operated at 1420°C. The PTV injector was maintained at 45°C at injection and then heated to 340°C to transfer the sample onto the GC column. Compounds were separated on a Rxi-5ms silica column (30 m x 0.25 mm, 0.25 µm film thickness, Restek, Bellefonte, USA). The GC was maintained at 120°C for 3 min then heated to 200°C with 30°C min^{-1}, then at 4°C min^{-1} to 320°C and held for 24 min. H_2 reference gas was used for isotope calibration. The δD values are expressed in ‰ relative to VSMOW. The H3+ factor varied around 6.12 ± 0.02 ppm nA^{-1}. Long-term repeated analysis of the external standard mixture with 16 *n*-alkanes rendered a precision (1σ) of ± 3 ‰ and an average accuracy of 0 ‰. The internal standard squalene had an accuracy and precision of 0 and 2 ‰, respectively.

Carbon isotope compositions of the *n*-alkanes were analysed on the same type of GC coupled to a MAT 252 IRMS via a modified GC/C III combustion interface operated at 1000°C. Injector and GC setting were similar as for δD analysis. Calibrated CO_2 reference gas was used for isotope calibration. Values are expressed in $\delta^{13}C$ relative to VPDB. Long-term repeated analysis of the external standard mixture with 16 *n*-alkanes rendered a precision (1σ) of ± 0.3 ‰ and an average accuracy of 0.4 ‰. The internal standard squalene had an accuracy and precision of 0.4 and 0.2 ‰, respectively.

3.4.3 Analysis of GDGTs

The concentrations of Glycerol-Dibiphytanyl-Glycerol-Tetraethers (GDGT) were determined at the Department of Geoscience, University of Bremen. Polar fractions containing GDGTs were filtered through a 0.45 µm PTFE filter and weighted before analysis. The instrument used to determine GDGT concentrations was an Agilent 1200 series high performance liquid chromatograph (HPLC) coupled with an atmospheric pressure chemical ionization interface (APCI) to an Agilent 6120 quadrupole mass spectrometer (MS). A detailed description of the method this is based on can be found in e.g. Hopmans et al., 2000. GDGTs were eluted over a Prevail Cyano column (Grace, 3 µm, 150 mm×2.1 mm) maintained at 30°C using a gradient of solvent A (*n*-hexane) and B (5% iosopropanol in *n*-hexane) from 80% solvent A (5 min) followed by a linear increase to 36% solvent B in 40 min. The flow rate was 0.2 mL min^{-1}. GDGTs were detected in positive-ion mode of the APCI-MS and selective ion monitoring (SIM). The APCI spray-chamber specifications were: nebulizer pressure 50 psi, vaporizer temperature 350°C, N_2 drying gas flow 5 L min^{-1} and 350°C, capillary voltage −4kV and corona current +5 µA. Peak areas of the target compounds were used to compute the following proxies: The TetraEther indeX TEX_{86}^{H} was used as a proxy to estimate SSTs (Kim et al. 2010). The TEX_{86}^{H} is based on the ratio between isoprenoidal GDGTs of 86 carbon atoms, containing one, two and three cyclopentane moieties (I, II and III) as well as the regioisomer of crenarchaeol, a GDGT with 4 cyclopentane moiety (V′). These compounds represent membrane constituents of planktonic archaea, which were found to shift in abundance with changing SSTs (Schouten et al., 2002). TEX_{86}^{H} was calculated with Eq. (3) whereas for SST reconstruction Eq. (4) was used (Kim et al., 2010).

$$TEX_{86}^{H} = \log\frac{[II+III+V']}{[I+II+III+V']} \quad (3)$$

$$SST = 68.4 * (TEX_{86}^{H}) + 38.6 \quad (4)$$

The BIT (Eq. 5) was derived from the relative abundance of branched glycerol dialkyl glycerol tetraethers (brGDGTs) and the isoprenoid GDGT crenarchaeol (Hopmans et al., 2004). While brGDGTs are thought to be produced by soil bacteria, crenarchaeol is known to be a biomarker for planktonic archaea. Hence, the index is widely used as a proxy for soil input (Weijers et al., 2014 and references therein).

$$BIT = \frac{[I+II+III]}{[I+II+III]+[V]} \quad (5)$$

A relationship between BIT and the tetraether index TEX_{86}^{H} (Fig. S2) is not evident, ruling out a possible alteration of the TEX_{86}^{H} signal near big river flows as indicated by Weijers et al., (2014). Comparison of core-top TEX_{86}^{H}-based SST estimates from GeoB18308-1 with satellite-derived SSTs (MODIS-A ftp://podaac-ftp.jpl.nasa.gov) reveals similar temperatures (Locarini et al., 2013). Reconstructed SST values are therefore assumed to reflect mean annual values.

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3.5 Grain size

Particle size distribution was obtained by laser diffraction, using a Malvern Mastersizer 2000 fitted with a Hydro 2000G dispersion unit. Scattered light data was recorded from 2000 to 5000 snapshots of 10 µs. A polydisperse mode of analysis and a refractive index of 1.533 with an adsorption of 0.1 were chosen. Size data collection was performed at constant obscuration in the range 10–20%. Visible shell fragments were removed prior to measurement.

3.6 Micropaleontology

Microfossils from sixteen samples from core GeoB18308-1 were analysed. The sample volumes vary between 1 and 9 ml around an average of 5 ml and represent a 1 cm-thick horizon each. After wet sieving, the >200 µm size fraction of the dried residues was picked under a low-power stereomicroscope for all ostracods and foraminifers. Other microfossils or fragments of larger forms were counted on group level and only selected specimens of those were picked as a reference. If possible, all taxa were identified to the species level, relying on Benson and Maddocks (1964), Dingle (1992, 1993, 1994), Dingle and Honigstein (1994) Martens et al. (1996) for Ostracoda, and mainly on Lowry (1987) and Schmidt-Sinns (2008) for Foraminifera. Relative abundances (percentages) are calculated for samples with at least 30 specimens to keep a large number for statistical analysis; samples contain about 100 specimens on average. Statistical analysis was carried out using the program package PAST (Hammer et al. 2001). A Principal Components Analysis (PCA) was used for identifying main factors structuring the changing association composition within the core (Fig. S3). Association data are composed of relative abundance data grouping selected species on the genus level if ecologically reliable. Only taxa occurring in at least two samples and with a proportion of more than 5% in at least one sample are considered. Before running the PCA, a Spearman Rank Correlation was applied for identifying highly correlating taxa, which was not detected.

3.7 Heavy-mineralogy

We have studied the mineralogy of point counted three samples and separated heavy mineral from two additional samples in the same study area at the "Laboratory for Provenance Studies" of Milano-Bicocca. From a quartered aliquot of each bulk sample (5 – 10 g), sediments were wet sieved with a standard 500 µm sieve in steel and with a handmade special tissue net sieves of 15 µm. The fraction >500 µm and <15 µm were dried after sieving and weighted for a quantitative estimation of each granulometric class. Heavy minerals were after separated by centrifuging in sodium polytungstate (density 2.90 g/cm^3) in the 15 – 500 µm size-window and recovered by partial freezing with liquid nitrogen. Heavy minerals after separation were also weighted. An appropriate amount of heavy minerals was split and mounted with Canada balsam (n=1.54), and 200 to 250 transparent heavy-mineral grains were point-counted at suitable regular spacing (100 µm) under a polarizing microscope to obtain real volume percentages (Galehouse, 1971). During point counting we have also studied surface textures on detrital grains by polarizing microscope to estimate chemical dissolution (Andò et al 2012). Dubious grains were checked and properly identified by an inVia Renishaw Raman spectrometer equipped with a green laser 532nm and a 50x LWD objective, in the spectral range (144 – 4000 cm^{-1}) referring to Andò and Garzanti (2013). Heavy-mineral concentration was calculated as the weight percentage of total heavy minerals (HMC) and transparent heavy minerals (tHMC).

4 Results

4.1 On- and offshore samples

4.1.1 Isotope Geochemistry

The CPI of all samples ranged from 7.5 – 14.4 indicating generally fresh, hardly-degraded material. Down-core as well as in the catchment samples (Fig. 5; Fig. 6; Table 2; Table 3) the average relative contributions of the long-chain *n*-alkanes are: *n*-

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C_{29} ~15 – 23%, n-C_{31} ~40 – 50%, and n-C_{33} ~20 – 24%. Together, these compounds accounted for 80 – 90% of the total n-alkanes. The most abundant n-alkane is the n-C_{31} alkane. Due to the consistent and strong predominance of the n-C_{31} alkane further discussion is focused on this compound. $\delta^{13}C$ analyses of the n-C_{31} alkane revealed only minor differences (-28.5 to -26.7‰ VPDB). The precision is 0.1 ‰ on average with maximum 0.3 ‰. Similarly the Norm31 showed values varying only minimally from 0.75 to 0.82. Larger differences (ranging from -143 to -127‰) could be detected in the δD composition of the n- C_{31} alkane. Average precision is 1 ‰ with maximum precision 3 ‰.

4.1.2 Heavy-mineralogy

In the studied samples (Fig. 7), heavy-mineral concentrations in silt and sand fraction (15-500m) range from very poor (<0.5 HMC) or poor (0.5 ≤ HMC < 1) to moderate rich (2 HMC). In Gouritz River catchment sample ECT2-1 clinopyroxenes dominate with subordinate ultrastable zircon, tourmaline, rutile (ZTR), apatite, garnet and titanite, common amphibole and rare orthopyroxene. The samples, from 11.5 cm and 285 cm depth in core GeoB18308-1, have a very similar heavy-mineral assemblage with slightly lower content of clinopyroxene and more epidote, very rare chloritoid and orthopyroxene. Red flowers of hematite are detected and corrosion features of clinopyroxenes are similar to the Gourtiz River assemblage. The sample, from 285 cm depth in Mossel Bay core GeoB18308-1 is very similar in composition to the Gouritz River but hematite is extremely rare.

4.1.3 Microfossil distribution and PCA results

A diverse foraminifer (at least 46 species) and ostracod (60 species) fauna characteristic for a sublittoral environment was found in the studied core. Beside skeletons of marine invertebrates, continental taxa like plant remains, charophyte oospores, insects, fruits and seeds occur as well, but in low numbers. A continental input is also reflected by six freshwater and four brackish water ostracod taxa occurring in several depths but in rather low numbers. Results of the loading plot analysis of the first principal component shows that freshwater ostracods, charophytes as well as fruits and seeds coming from continental waters or even of terrestrial origin are associated with high PC1 values. Microfossil results can thus be summarized in an index for estuarian inflow (based on PC1 which is best explained by fluvial input) (Fig. S3).

4.2 Down-core variations

Results of AMS-^{14}C determination are presented in Table 1. The basal age of core GeoB18308-1 is ~4.100 cal yrs BP (Fig. 4). The continuous high-resolution, XRF scanning dataset (Fig. S1) indicates little variability in the lower half of core GeoB18308-1. However, a time interval of abrupt increase in Fe, clay and silt content (up to 55%) with more estuarine-inflow-related microfossils (increased PC1), higher BIT (from ~0.06 to 0.81) and enriched δD values of the n-C_{31} alkane (up to -127‰) can be observed during the period between 950 and 650 cal yrs BP (Fig. 5). These trends are accompanied by a slight depletion in $\delta^{13}C$ of the n-C_{31} alkane (up to -28.5‰) and to generally lower but highly variable TEX_{86}^{H} (from ~0.49 to 0.41) based SST values (12.2 to 17.1°C) (Fig. 5).

5 Discussion

5.1 Catchment samples-source signatures

5.1.1 Linking catchment depositional processes to rainfall regimes

The catchment samples analyzed for plant wax isotopic composition were all taken at lowland locations. However samples from horizons of darker, finer material identified as soils show distinct δD_{C31} differences (~10‰ VSMOW) relative to samples identified as flood deposits (Fig. 6). As hydrogen used for biosynthesis of plant waxes originates directly from the water taken

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up by the plants, isotope changes measured in these compounds are related to isotope composition of precipitation (Sessions et al., 1999). This indicates that the plant waxes contained in soil horizons were synthesized under conditions distinct from those under which plants waxes contained in flood deposits were synthesized. δD signatures can also give an indication of the respective conditions; in the Gouritz River catchment the extreme elevation difference is most likely the main influence on rainfall δD signatures which becomes deuterium depleted with altitude (ca. 10 – 15 ‰ per 1000 m; Gonfiantini et al. 2001). The relatively deuterium depleted flood deposits (δD_{C31} values of ~-138‰ vs. ~ -127‰ in soil horizons) indicate that all analyzed flood deposits contain a considerable amount of upper-catchment material. Despite the dominant summer rains in most of the catchment area (Le Maitre et al., 2009), SHW related precipitation events in the otherwise arid winters have been described as the main precipitation signal influencing the Seweeweekspoort record in the upper most Gouritz River catchment by Chase et al. (2013). Since plant material synthesized in the upper part of the catchment characterizes the δD signature of paleoflood deposits sampled in the lowlands we suggest that these winterly SHW related precipitation events in the headlands are a main cause for large Gouritz River flood events.

5.1.2 Sediment provenance indicators

5.1.2.1 Leaf wax *n*-alkane distributions and $\delta^{13}C_{C31}$

Different vegetation types show variations in the *n*-alkane distribution of their leaf waxes. In general, it is thought that plants adapted to higher aridity produce longer chain wax components than those in habitats of temperate regions (Gagosian and Peltzer, 1986). Therefore, the distribution of *n*-alkane chain length is widely used as an environmental proxy and the *n*-alkane distribution ratio "Norm31" can indicate changes of the source area (Carr et al., 2014). The stable carbon isotopic composition of organic matter reflects the isotopic composition of the carbon source as well as the discrimination between ^{12}C and ^{13}C during biosynthesis (Collister et al., 1994). In particular, compound specific $\delta^{13}C$ of long chained *n*-alkanes show variations with changes in vegetation type (Collister et al., 1994). In this study, the *n*-C_{31} alkane is the most abundant *n*-alkane of the plant waxes and thus used as an indicator of vegetation type in addition to Norm31 ratios. Carr et al. (2014) show vegetation specific distributions of *n*-alkane homologues within the arid zone South African flora (Fig. 2). In the case of Gouritz River catchment samples and GeoB18308-1 downcore samples, plant waxes indicate a dominant Karoo vegetation signature according to Carr et al. (2014) and Hermann et al. (2016) (Fig. 2). This vegetation type is dominant in the northern parts of the catchment area (see map in Fig. 2). The flood deposits, soil and suspension load samples analyzed in this study, however, indicate that even in the lower catchment area the Karoo vegetation signature is dominant in the flood as well as in the soil deposits (Table 2, Fig. 2). This may be attributed to a) difficulties in attributing vegetation types to *n*-alkane distributions caused by CAM plants existing in South Africa´s southernmost vegetation (Boom et al., 2014), b) presence of succulent and Karoo plants in areas classified as "fynbos biome", c) an overprint of the lower catchment signature by depositional material originating from the upper catchment. Understanding these processes in detail is beyond the scope of this study. Instead, *n*-alkane distributions and their isotopic values are used as provenance indicators. In the Gouritz River catchment as well as in down-core samples both indicators of vegetation type have similar signatures (identical average Norm31 values of 0.79 and average $\delta^{13}C_{C31}$ of -28.5‰ and ~-26.7‰ respectively) and show just minor variations (SD of Norm31 and $\delta^{13}C_{C3}$ down-core = 0.02 and 0.4 respectively; n=27) (Fig. 2, Table 2). We therefore infer that the sediments deposited at the GeoB18308 site originate directly from the Gouritz River catchment area.

5.1.2.2 Heavy-mineralogy

Heavy-mineral analysis represents an independent powerful tool in provenance studies. In the Gouritz River catchment as well as in samples from GeoB18308-1 clinopyroxenes dominate with subordinate ultrastable zircon, tourmaline, rutile (ZTR), apatite, garnet and titanite, common amphibole and rare orthopyroxene. The significant contribution of ultrastable ZTR to the

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heavy mineral assemblages of GeoB18308-1 samples reflects the Gouritz River Cape Supergroup sandstone-dominated geology. The abundance of corroded clinopyroxene indicates weathering of doleritic dikes located only in the uppermost parts of the Gouritz River catchment. Although mineral and organic loads do not necessarily derive from the same source area, when used as provenance indicators both suggest a (upper) Gouritz River catchment provenance for the sediments deposited at the GeoB18308-1 site.

5.2 GeoB18308-1 paleoclimate record

5.2.1 ~4000 – 950 cal yrs BP – stable arid conditions

The oldest part of the 18308-1 paleorecord (~4058 – 950 cal yrs BP) is characterized by a relatively low Fe/Ca ratio and a domination of the sand size fraction (mud and silt content below 20% – 30%). We associate this with winnowing of fine grained material by the strong current field inherent to the coastal Agulhas Bank. Heavy mineral analyses from this part of the core (285 cm) show that hematite is extremely rare, suggesting a dry period without formation of iron oxides in the catchment area. Further afield in South Africa, pollen data from Lake Eteza (South African east coast) reported relative dryness for this period. This was deduced from evidence for decreasing trees and shrubs vegetation accompanied by increasing herbaceous plants (Neumann et al., 2010; Scott et al., 2012). The high resolution XRF records indicate little variability in the composition of the supplied sedimentats. This is in accordance with the relatively stable conditions recorded in the millennia prior to ~1000 cal yr BP in the speleothem layer width from the Cold Air Cave (Holmgren et al., 1999) as well as pollen data from Wonderkrater and Rietvlei Dam (Scott et al., 2012) in southeastern Africa.

5.2.2 ~950 – 650 cal yrs BP – Medieval Climate Anomaly

At ~950 cal yr BP a shift occurred to slightly lower SSTs (Fig. 5) in the study area. At the same time, fluvial deposition became more dominant in the record: there is a strong increase in terrigenous input described by a higher index of fluvial input based on microfossil composition, a higher Fe content, an increased BIT (from ~0.1 to 0.3) as well as a twofold increase of clay and silt content (to 40 – 60%) (Fig. 5a-c, f).This may either indicate a decrease in Agulhas strength, an increase of sediment delivery via the Gouritz River or a combination of both. Simultaneously a shift towards lower $\delta^{13}C_{C31}$ values (to -28.5‰) in the sediment core can be observed. The heavier isotope ^{13}C is more depleted in C3 plants (as opposed to C4) which are less adapted to aridity (Collister et al., 1994). Furthermore, $\delta^{13}C$ values may become more depleted when a plant's water-use efficiency decreases in moister climatic conditions (Pate, 2001; Ehleringer and Cooper, 1988). In either case, $\delta^{13}C$ values of n-C_{31} alkanes exported from the catchment suggest a shift towards more humid conditions on land after 950 cal yrs BP. At the same time, δD values of the leaf wax n-C_{31} alkane shift to -129‰ indicating deuterium-enriched precipitation during this time. This likely indicates a shift to lower altitude source regions. Enriched δD_{C31} values would be an indication for plant material mainly derived from more vegetated lowlands as opposed to plant material derived from the upper catchment during major flood events (see Sec. 5.1.1.). Within the error margin of our age-model, the shift we see at ~950 ±120 cal yrs BP towards a more humid lower Gouritz River catchment is a general eastern South African expression of the northern hemispheric trend termed Medieval Climate Anomaly (MCA) summarized by Tyson and Lindesay (1992), Tyson and Preston-Whyte (2000) and Nash et al (2016). A large array of continental records document this humid period throughout the South African summer rainfall zone (SRZ) (Talma and Vogel, 1992; Holmgren et al., 1999; Thomas and Shaw, 2002) as well as Wonderwerk Cave (Brook et al., 2015), Braamhoek Wetland, Free State (Norström et al., 2009, 2014), Lake Eteza, coastal KwaZulu-Natal (Neumann et al. 2010), Lake Sibaya, KwaZulu-Natal (Stager et al 2013), Blydefontein basin, Kikvorsberge (Scott et al. 2005), Katbakkies Pass, Swartruggens Mountains, southwestern Cape (Chase et al., 2015) and northeastern South African baobab trees (Woodborne et al., 2015). The few existing records of the YRZ record similar trends; a continuous rise in precipitation was found in $\delta^{15}N$ of hyrax middens at Seweweekspoort (Chase et al., 2013) and more evidently in the indirect (TOC-based) humidity record at Groenvlei – a Wilderness lake (Wündsch et al., 2016) (Fig. 5h-j). In contrast to the large array of available

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continental datasets, marine records are rare. The only SST record published for the area (Cohen and Tyson, 1995) does not include data for the time period in question. However, it does provide a conceptual model of ocean-atmospheric interplay to be tested (c.f. Fig. 8). The authors postulate a periodically strengthened and more southerly South Indian Ocean Anticyclone and South Atlantic Anticyclone having an onshore as well as an offshore effect: 1) reinforcing the tropical easterly influence causing extended warm wet spells in the South African Summer Rainfall Zone and 2) increasing the frequency of eastward ridging highs and, thus, along shore winds driving the coastal upwelling on the eastern Agulhas Bank. Additionally, shelf-edge upwelling becomes more frequent when the strong South Indian Ocean Anticyclone increases the Agulhas volume transport. The decrease in SSTs recorded in GeoB18308-1 for the interval of increased humidity in the Gouritz River catchment inferred in this study for the time interval of the Medieval Climate Anomaly serves as data to validate the conceptual model by Cohen and Tyson, (1995) for which thus far no Medieval Climate Anomaly evidence by SST data had been available.

5.2.3 Conditions after ~650 cal yrs BP – Little Ice Age and beyond

Continuous sedimentation at the core site was interrupted at ~650 cal yrs BP. One or more erosive event deposits are inferred from the sedimentology (erosive contact at ~60 – 70 cm; fine sand with intercalated organic layers and lumps from ~30 – 60 cm) and an age reversal indicated by the two radiocarbon dates in this interval (~1,466 cal yrs BP at a depth of 31 cm ~640 cal yrs BP at a depth of 60 cm and; Fig. 4; Table 1). Due to the discontinuous nature of the deposition we are only able to curtail the timeframe of deposition to having taken place between ~650 cal yrs BP (the youngest age in the event deposit) and a post-bomb date ~13.5 cm above the event deposit. From the redeposited sediment package three samples have been analyzed for organic geochemistry (see Table 3). The average values over the possible timeframe of deposition is plotted in Fig. 5. The high BIT (~0.7) indicates that the redeposited package can be characterized as reworked soil material. The averaged δD_{C31} signature of ~-135‰ is comparable to that of Gouritz River paleoflood deposits described in Sec. 5.1.1. We therefore suggest that the origin of the event-deposited material in core GeoB18308-1 is similar to the origin of these terrestrial paleoflood deposits. Our catchment study of plant wax δD in paleoflood versus soil deposits (c.f. Sec 5.1.1) indicates that paleoflood deposits are primarily induced by an increase in high latitude precipitation, i.e. precipitation in the upper parts of the Gouritz catchment. The shift in $\delta^{13}C_{C31}$ towards slightly more depleted values in the event deposited material in core GeoB18308-1 (average in the redeposited unit: ~-28‰VPDB) furthermore indicates that the n-C_{31} alkanes contained in the event deposit were produced by plants under less water stress (c.f. Collister et al., 1994, Ehleringer and Cooper, 1988) than those deposited before ~650 cal yrs BP. We therefore infer an increase in upper catchment rainfall inducing floods for the time period of the event deposit(s) (~300 – 650 cal yrs BP). This roughly falls into the timeframe of the so-called "Little Ice Age (LIA)" recorded as humid phase throughout the South African Winter Rainfall Zone (Meadows et al., 1996; Benito et al., 2011; Stager et al., 2011; Weldeab et al., 2013) due to a northward shift of the SHW (Tyson and Preston-Whyte, 2000; Chase and Meadows, 2007). In the uppermost Gouritz catchment (Seweweekspoort site) a major SHW sourced rainfall regime has been documented (Chase et al. 2015). Desmet and Cowling (1999) indicate that despite the general Summer Rainfall Zone regime in the Gouritz catchment, the SHW supply additional rainfall in extreme events. We suggest that an increase of these extreme SHW-sourced rainfall events produced large floods during the LIA (~300 – 650 cal yrs BP). After ~650 cal yrs BP continuous sedimentation is re-established with sediment properties returning to pre-hiatus conditions. The return to "normal conditions" recorded at the GeoB18308-1 site after the LIA time interval (i.e. after ~300 cal yrs BP) does not indicate any recent major Gouritz River flood events (e.g. the 1983 mega flood documented by Damm et al. in 2010) underlining the magnitude of the LIA events.

6 Conclusion

The unique position of the core site directly offshore the Gouritz River mouth at a central location on the South African South Coast allows for a combined analysis of variability in marine processes as well as terrestrial input at a high temporal resolution.

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In order to reliably reconstruct terrestrial climatic change from an offshore record, measurements were performed down-core, as well as on material from the Gouritz River catchment for ground-truthing in a source to sink approach. Samples from the river and its flood deposits reveal that the sediments at our core site predominantly originate from the Gouritz River catchment. Furthermore, they indicate that paleoflood deposits are sourced from heavy rainfall events in the highlands whereas soil formation processes are more likely linked to regular rainfall in the lowlands. The down-core GeoB18308-1 records stable conditions on land and offshore prior to the so-called Medieval Climate Anomaly (~950 – 650 cal yrs BP), which has been interpreted as humid in the (lowland) region between the eastern SRZ and western WRZ. The Little Ice Age (<~650 cal yrs BP) interval in turn is characterized by major flood events attributed to (SHW) storm tracks influencing the upper catchment area. These paleoclimatic reconstructions correspond to available continental records for the region. The vantage point of this study at the marine-terrestrial interface is the SST record accompanying the terrestrial climatic reconstructions. This first regional SST dataset for the 2,400 – 650 cal yrs BP timeframe allows us to test the conceptual model of oceanic-atmospheric interplay (Cohen and Tyson, 1995) during short term Late Holocene climatic anomalies. In accordance with this model (cf. Fig. 8), our results indicate that variability in South Indian Ocean Anticyclone (SIA) location and strength drives both tropical easterly influence on South African Summer Rainfall Zone climate as well as coastal upwelling on the eastern Agulhas Bank. During a poleward displacement and strengthening of the SIA (e.g. MCA situation) the stronger easterly (alongshore) induce coastal upwelling, common during summer on the eastern Agulhas bank, to become more frequent. Future climate change may follow similar patterns and the scenario could be replicated if similar short-term shifts take place with global warming.

Acknowledgements

This work was financially supported by the Bundesministerium für Bildung und Forschung (BMBF, Germany) within the project "Regional Archives for Integrated Investigations (RAiN)". We also thank the captain, the crew and scientists of the Meteor M102 cruise for facilitating the recovery of the studied material. This study would not have been possible without the support of MARUM. Thanks to all RAiN members as well as the reviewers of this paper for critical discussion and helpful advice for our work progress.

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Ocean circulation patterns have been suggested to influence precipitation in South Africa on both the east and the west coasts.

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.In western South Africa paleoenvironmental reconstructions suggest that strong SHW reduce the leakage of warm, saline Agulhas water into the southern Atlantic, weakening the Benguela upwelling system (Kim et al., 2003; MacKellar et al., 2007; Biastoch et al., 2009a). Modelled data show similar outputs predicting a weakening of the Agulhas Current and the leakage of warm water due to northward displacement of the SHW (MacKellar et al., 2007; Biastoch et al., 2009b; Durgadoo et al., 2013).The coevally decreased SSTs on the south western coast of South Africa may have led to decreasing precipitation in the YRZ (Rouault et al., 2003). In turn, positive SST anomalies along the east coast associated with Agulhas strengthening were suggested to enhance summer precipitation in the east South African SRZ

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Continuous sedimentation at the core site was interrupted at ~650 cal yr BP. One or more erosive event deposits are inferred from the sedimentology (erosive contact at ~60-65 cm; fine sand with intercalated organic layers and lumps from ~30-60 cm) and an age reversal indicated by the 2 radiocarbon dates in this interval (~1,466 cal yr BP at a depth of 31 cm and ~640 cal yr BP at a depth of 60 cm; Fig. 4; Table 1). The redeposited material can be characterized as reworked soil material (high BIT-index: ~0.7) supposedly formed in the upper parts of the catchment (the altitude effect depleting the δD_{C31} signature to ~-135‰) under humid conditions (according to the depleted $\delta^{13}C_{C31}$ of ~-28‰VPDB) (Fig. 5, Table 3). After ~650 cal yr BP continuous sedimentation is re-established with sediment properties returning to pre-hiatus conditions. The increase in torrential rains and flashfloods that may be inferred for the time period of the event deposit(s) (~300-650 cal yr BP) roughly falls into the timeframe of the so-called "Little Ice Age (LIA)" recorded as humid throughout the South African WRZ (Meadows et al., 1996; Benito et al., 2011; Stager et al., 2011; Weldeab et al., 2013) due to a northward shift of the SHW (Tyson and Preston-Whyte, 2000; Chase and Meadows, 2007). Our catchment study (Leaf wax δD_{C31} of paleoflood and soil deposits-see 5.3.1) indicates that paleoflood deposits are primarily induced by an increase in high latitude precipitation. In the uppermost Gouritz catchment (Seweweekspoort site) a major SHW sourced rainfall regime has been documented (Chase et al. 2015). Desmet and Cowling (1999) indicate that despite the general SRZ regime in the Gouritz catchment, the SHW supply additional rainfall in extreme events. The return to "normal flow conditions" recorded at the GeoB18308-1 site after the LIA time interval (i.e. after ~300 cal yr BP)

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related to the intensive herding practiced in the catchment between ~ the 1850s and the 1980s (Meadows et al. 1994; Dean and Macdonald, 1994). The absence of an evident anthropogenic signal in the record underlines the magnitude of the LIA events.