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Interactive comment on "Glacial to interglacial climate variability in the southeastern African subtropics (25–20° S)" *by* Annette Hahn et al.

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Summary

In this article, Hahn et al. report on the analysis of a 958 cm sediment core that was taken in the Delagoa Bight off southeastern Africa. The source of the sediment is argued to be from three nearby river catchments that are relatively small, and as a result of this the environmental information derived from the sediments represents a fairly clean signal (in contrast to nearby cores that sample the Limpopo River catchment which is vast and probably includes multiple climate sensitivities).

The chronology for the core is generated using 12 radiocarbon dates, of which two are beyond the limit of the method, and δ18O values from benthic foraminifera that are

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compared to the LR04 benthic stack. The radiocarbon dates from the upper part of the record overlap with the δ18O values from the lower part of the stack so that one of the tie δ18O tie points has an apriori age assignment. The results of the age model demonstrate a relatively constant deposition over the last 100 000 years.

Ca/Mg ratios on foraminifera are used to reconstruct past sea surface temperature (SST), and this record demonstrates that SST was almost 4°C warmer during interglacials (MIS 5 & 1) that it was during glacials (MIS4-2).

The main substance of the article is the presentation of multiple geochemical tracers of terrestrial climate and the associated vegetation responses in the catchment. These include δ13C C31 (terrestrial plants community indicator), red/blue ratios (organic vs. classic indicators), K/Al (chemical vs. physical weathering), Ca/Fe (terrestrial vs. marine source indicator) and δDC31 values (rainfall amount indicators). The authors identify a coherent pattern in which all of the geochemical tracers vary in concert with one another, and this is coherently argued to reflect hydrological changes in the associated river catchments.

The underlying cause for the alternation between mesic and xeric conditions in the catchment are explored through northern hemisphere forcing in the form of Heinrich Stadials, and southern hemisphere forcing in the form of Antartic ice advances. What emerges is that the forcing during glacials and interglacials differ from one another, and this must be reconciled through synoptic scale changes in the drivers of continental rainfall (rather than insolation variability). The model that is proposed centers on the way in which the two main moisture-bearing systems, the inter-tropical convergence zone (ITCZ) and the southern hemisphere westerlies (SHW), interact and influence the development of the South African high system that is dominant influence on modern rainfall. In essence the argument is that during glacial conditions the SHW migrate northwards because of Antarctic expansion, while the thermal equator (ITCZ) migrates southward because of Arctic expansion, and the South African high system occludes. The extinction of the South African high pressure system during glacials prevents the development of the southern Indian Ocean convergence zone (SIOCZ) and the associated temperate tropical troughs (TTT) that dominate modern summer rainfall (but please note the comment on this subject below). As a result the catchment maintained a relatively constant water balance between glacials and interglacials as the glacial loss of the TTT/SIOCZ was compensated by direct summer rainfall from the ITCZ and/or winter rainfall from the southern hemisphere westerlies (depending on the dominant Arctic vs. Antarctic forcing at the time).

Scientific merit

Notwithstanding the critique that is presented below, this manuscript makes a valuable contribution to climate science in southern Africa. The dynamics of the climate system are relevant to both future projects of climate change, and the interpretation of the rich archaeological heritage of the region. Several archaological sequences of a similar age are in close enough proximity for the climate model to be relevant. Sibudu cave and Border Cave contain evidence of mesic/xeric cycles, and they are also well dated, so there is potential to refine the glacial/interglacial climate model. Key palaeoclimate records, such as the Pretoria Salt Pan have been dated using insolation arguments, and if the climate model proposed by Hahn et al. is correct, then the basis for the age model of the Pretoria Salt Pan is flawed.

The authors have presented their data in supplementary tables, which is going to be very useful for comparing this dataset to others.

Review

The critique of the manuscript is in the form of substantive clarifications, minor issues, and typos.

Substantive clarification

One of the most important contributions of this manuscript is the model for synoptic shifts in the region during glacial periods, and in particular its effect on the SIOCZ.

Clarification is required of exactly what the SIOCZ is. Comparing figure 1 with figure 5 it would appear as if the ITCZ and the SIOCZ are synonymous, but the text line 330 couples the SIOCZ to TTT, and line 334-336 clearly decouples the SIOCZ and the ITCZ. Certainly in the modern system the SIOCZ and TTT systems are distinct from the ITCZ. Since figure 1 includes the ITCZ, the SHW and the circulation patterns, it should also indicate the modern SIOCZ and TTT systems. The text that describes the contribution of ITCZ summer rainfall in the relevant catchment during glacials (lines 343-347) but in figure 5 the source of summer rainfall is indicated as the SIOCZ. This needs to be reconciled.

In the discussion of SST (line 237-240), comparison is between core top SST with modern SST data from Fallet et al. 2012 in order to defend a seasonal interpretation of the G. ruber Mg/Ca values. This argument is flawed in many ways. First, the uppermost Mg/Ca result from the sediment core is from 40.5cm depth in the core, which is approximately 5 000 years old according to the radiocarbon dates. This cannot be compared with the “modern” data from Fallet et al. (2012) which is approximately 1 000 years old. Indeed the age of the youngest Mg/Ca SST value prevents any verification against modern SST values. Second, the satellite data for SST in the Mozambique Channel presented by Fallet et al. (2012), and also the SST data based on Locarnini et al. (2013) presented in figure 1 show a strong thermal gradient in the Mozambique Channel. Correlating the Mg/Ca 27°C SST temperature for the “top” of this sediment core does not take in to account this southward cooling gradient. The inshore location of this core in the Delagoa Bight also implies stronger coastal influences that is associated with warmer SST (also based on data in Fallet et al. 2012). The seasonality of this SST reconstruction is not central to the development of the climate forcing argument, but it will need to be tempered as a stand-alone interpretation.

Minor issues

The age model for the core is very clearly argued, and is sufficiently convincing for the broad-brush stroke assessment of palaeoenvironmental proxies, but close scrutiny of

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the radiocarbon dates indicates some heterogeneity in deposition rates. Rapid deposition is indicated between 300cm and 200 cm, and also between 150cm and 100cm (although the Bacon model produces a parsimonious smoothing that downplays the date from 102cm). Placing more emphasis on the outlier date leads to the possibility of very slow deposition in the 15 000-6 000 year range, and also in the 32 000 -25 000 year range. The Bacon model needs more input data to verify this level of heterogeneity, and so there is possibly an underestimation of the error in the age model around these periods of slow deposition. Similarly only 2 δ18O tie points are used in the chronology for the oldest 60 000 year part of the record. This clearly cannot capture heterogeneity in the deposition rate, and again the age model error estimates are probably too small.

The suite of proxies that reflect wet and dry conditions in the catchment are reported to change in concert with one another, and this is clear in a relative sense but not in an absolute sense. Scrutiny of figure 4, for example, shows clear oscillations in values that are syncronised between proxies, but within proxies these oscillations are really most apparent because of the contrasting peaks and trough values that are immediately older or younger. The absolute values do not hold up to the wet/dry assignations. The K/Al and Ca/Fe ratios in the wet period around 82 000 years ago, for example, have very similar values to the arid values at around 46 000 and 52 000 years ago, and so the absolute values are seemingly not important. Some discussion of the relative nature of these proxies should be presented.

The interpretation of the δ13C record invokes a framework presented by Dupont et al. (2011) in which woodlands and forests with grasslands in the interior during interglacials is contrasted with rivers fringed with gallery forests & sedges in glacials. This scenario may account for the observed trends in the record, but it is a very imprecise science. The entire δ13C variability noted in the 100 000 year record all falls very in the range of C3 plants, and even the maximum values that are interpreted as an increased C4 plant community still fall in the C3 range. As much as this represents an integrated

C3/C4 environmental shift, it could just as well represent a xeric/mesic environment with exactly the same C3 plant communities. The part of the equation that is poorly developed is the source of the C in the marine sediments: it represents differential assimilation as a function of river length, and differential assimilation of C as a function of organic gradients from a riverbank to the watersheds. It is possibly too much to anticipate that this level of interpretation can be assigned to the observed pattern

The role of sedges in the δ13C record interpretation also needs closer consideration. Stock et al. (2004 Austral Ecology) suggest that 14% of sedges are C4 in winter rainfall areas and 67% are C4 in summer rainfall areas. Seasonality of rainfall is clearly a controlling factor in the C3/C4 pathways for sedges, but the interpretation of the sediment core δ13C record seems to hint that they are all C4.

The association between the wet/dry cycles portrayed in the core, and Heinrich Events and the Antarctic Isotope Maxima events is important in resolving the underlying climate forcing. It should be noted that HS4 is the negative excursion in the NGRIP δ18O record around 37 000 years ago (possibly older as it is portrayed in figure 4 – maybe 38 000 -40 000 years ago). It is associated with a dry interval (red shading in figure 4) but the text associates it with a wet period (lines 395-399). Overall the association between wet/dry phases in the core proxies and the AIM and HS data is dependent on the errors in the age model, which was argued to be underestimated, but still comprises several thousand years in the older portion of the core.

It would be useful for those who will undoubtedly make use of this record in their research if the supplementary tables include a model age assignation, and not just the sample depth in the core.

Figures and figure captions

Figure 1: Please depict the SIOCZ and TTT because it is relevant in the discussion. Wonderkrater is depicted in the wrong place (somewhere in Zimbabwe). In reality it is well within the Limpopo catchment. Figure 2: The caption mentions “LR04” twice

in a redundant manner. Figure 3: This caption needs to be rewritten. It is difficult to decipher what is being referred to because of a random sprinkling of right parentheses and colons. Figure 4: This caption attributes blue or green shading as wet, “while wet phases are marked in red or yellow”. Presumably one of these is dry. What is described as blue appears purple – this may be a personal problem, but possibly re-consider the colour that is used. The text “related to low pressure cells” is correct but confusing in its detail and should be revised.

Typos

Line 66: winterly should be winter Line 67, 114-115, 330, 334-336: Define the SIOCZ, is this the same as TTT (in fig 5 it seem synonymous with the southern extent of the ITCZ, but line 330 couples it to TTT, and line 334-336 clearly decouples the SIOCZ and the ITCZ) and also put it on to fig 1 as it comes up repeatedly Line 76: Re introduces the SIOCZ acronym Line 201: permil, but on line 139 per mil. Please be consistent throughout the text Line 244: Fig. 1a should be Fig. 3a

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