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Climate of the Past Discussions

CPD

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Interactive Comment

Interactive comment on "Increased aridity in southwestern Africa during the last-interglacial warmest periods" *by* D. H. Urrego et al.

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Manuscript entitled "Increased aridity in southwestern Africa during the last-interglacial" – CP-2013-99

Dear Proffesor Clausen,

We have addressed bellow individual comments raised by the referees on the manuscript " Increased aridity in southwestern Africa during the last-interglacial". We hope you will find the responses sufficient in detail.

Sincerely yours,

Dunia H. Urrego, Corresponding author on behalf of all co-authors

Response to reviews

Anonymous referee 1. Comment: Add citations of more recent papers to describe oceanic conditions in southern Africa, in particular about the Agulhas leakage.

We have added the reference of Biastoch 2008 to back up the argument about the influence of the Agulhas leakage in the meridional overturning circulation.

Comment: Explain what "high precipitation seasonality" means.

By high-precipitation seasonality we mean a large difference between the dry and the rainy-season. In the revised manuscript we added the following clarification: (i.e. difference between dry-season and rainy-season precipitation).

Comment: Add the tributaries of the Orange river

Figure 1 have been modified to include the Orange river tributaries.

Comment: The reviewer suggests that the results and discussion be separated

Combining the results and discussion into one section is a common practice in the palaeoclimate literature and this format is accepted by Climate of the Past. We feel that separating the results and discussion sections would make the manuscript repetitive and excessive in length.

Comment: The reviewer suggests that we deepen the discussion by contrasting our findings with records from South America and Asia.

We agree that our study should be compared with records of South America because this comparison further strengthens our argument about atmospheric changes around southern Africa. We have added the following sentence line 28 page 4343 referring to the strengthening of Asian monsoon and weakening of South American monsoon during precession minima. "An atmospheric configuration with reduced austral summer precipitation in Southern Africa and the ITCZ shifted northward during the warmest periods of MIS 5 is also consistent with documented strengthening of Asian monsoon and weakening of the South American monsoon during the last-interglacial precession minima (Wang et al., 2004)."

Comment: The reviewer suggests that we concentrate on orbital-scale changes and leave out of the abstract any mention of millennial-scale variability.

We agree that the resolution of our analysis is so far too low, and we have taken out this phrase from the abstract. We still touch on this observation in the discussion but we leave it as an open question to be addressed in the future.

Comment: The reviewer suggested to compare our pollen record with the sea salt Sodium (ssNa) record from Antarctica and to cite the findings by Weldeab about Holocene changes in the position of the austral westerlies.

Wolff et al. (2006) published the chemical measurements from the EPICA Dome C core including ssNa fluxes going back 750 kyr. Wolff et al (2004) mentioned that the sea-ice surface is probably the main source of sea salt in EPICA Dome C, and that it is related to new sea-ice production. We found no mention of ssNa as a marker for atmospheric change. On the other hand, nssCa2+ has been put forward as a reliable proxy for changes in the austral westerlies, however its interpretation as a tracer of source area is currently discussed in http://www.clim-past-discuss.net/9/3321/2013/cpd-9-3321-2013.pdf. We prefer therefore to take a conservative approach and refrain from comparing our pollen record with ssNa or nssCa from Antarctic ice core records.

At the same time, the Holocene southward migration of the westerlies discussed by Weldeab et al (CPD), and correlated with nssCa2+ from Antarctica (Röthlisberger et al., 2008) is equivalent to that we dicuss for the warmest periods of the last interglacial (MIS5e). We have added a sentence about this to the discussion of the revised manuscript.

Comments from Dr. Lydie Dupont – Reviewer 2

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Comment: Dr. Dupont points out that our arguments about fluvial pollen transport from the Orange River are not very strong.

The paper includes a full section about pollen sources in marine core MD96-2098, in which we discuss both sources: aeolian and fluvial. In this section, we point out that this marine site probably receives both aeolian and fluvial terrestrial inputs. We do not argue for a "substantial" fluvial transport. Previous work by Dupont and Wyputta (2003) concludes that south of 25°S wind directions are predominantly west to east and aeolian terrestrial input very low. This limit was established using two marine sites located 4 degrees of latitude apart: one at 23.5° (GeoB1710-3, high aeolian pollen input) and one at 29.5° (GeoB1722-1, low aeolian input). Given the distance between the two sites, establishing a precise limit is challenging. The limit for aeolian input could easily be 27, 26 or 28°. Our marine site MD96-2098 is located at 25.5°, and it is difficult discern whether it is indeed inside or outside the aeolian input area established by Dupont and Wyputta (2003). We feel that we cannot rule out the influence of fluvial pollen input as at least a part of the Orange River plume is directed northwards (Rau et al., 2002), and because XRF and clay analyses from our marine core point to a likely fluvial origin for the sediments of MD96-2098. These arguments are discussed in Section 4.3 of the manuscript.

Comment: Dr. Dupont points out that "the claim that Daniau analysed the clay record of MD96-2098 is an exaggeration".

We don't claim that Daniau et al. (2013) exhaustively analysed the clay record from MD96-2098. We only assert that their analyses on aeolian vs river-transported clays ..."show that both mechanisms were active and that their contribution varies over time independently of glacial and interglacial conditions". We use these results to point out that both aeolian and fluvial inputs are active at the core site. To avoid confusion by the reader, we have slightly modified the previous sentence as follows: "Analyses of aeolian vs river-transported clays from selected intervals of MD96-2098 suggest that both mechanisms were active and that their contribution varies over time independently of glacial and interglacial conditions (Daniau et al 2013)".

Comment: Dr Dupont argues that the discussion of the elemental ratio Ti/Al by Govin et al (2012), indicate that the area under discussion is dominated by aeolian input.

The results and discussion in the paper by Govin actually support our argument about both fluvial and aeolian input at the site. The discussion on Ti/Al ratios in this paper (section 4.2.1) addresses the aeolian vs fluvial input, but there is no mention of the southern African coast. Instead, Govin et al discuss the Fe/K values along the Namibian Coast (between 23 and 33°S) as being relatively high for such a dry region. They point out that such high values reflect the input of suspended material from the Orange River and/or dust from the Namibian desert (section 4.2.2, page 16 bottom left). The results and analysis by Govin et al. (2012) therefore support our argument of both fluvial and aeolian input of terrestrial material at the site, instead of contradicting it. We have added this argument and cited Govin et al. (2012) in the revised manuscript.

Comment: Dr. Dupont raises concerns about the interpretation of Poaceae pollen in our record: "The problem with this interpretation is that the Poaceae pollen percentages of GeoB1711 (2 degrees of latitude further north) are persistently higher than those of MD96-2098. If a Poaceae pollen percentage maximum would indicate the expansion of the Nama Karoo and the fine-leaved savanna northwards (during for instance MIS 5e), then Poaceae pollen percentages further northward should be lower and not higher".

The observation that Poaceae pollen percentages in GeoB1711, north of MD96-2098, are higher during MIS 5e actually supports our interpretation. A northward expansion of fine-leaved savanna and Nama Karoo during MIS 5e will bring the limit of these biomes closer to the location of GeoB1711, then Poaceae pollen percentages should increase in that record. One should therefore expect, in contrast to Dr Dupont's statement, the percentages of Poaceae to be higher in GeoB1711 than in MD96-2098 during MIS 5e.

For the present interglacial when these biomes retreated southwards associated with precession increase, the percentage of Poaceae would be lower in MD96-2098 than in GeoB1711. Pollen input at GeoB1711 is primarily aeolian (Shi et al 2001) and the prevalent direction of winds is southeast to northwest (Dupont & Wyputta 2003), making the current vegetation source for this site the Nama-Karoo, the fine-leaved savanna and the desert. In MD96-2098 the vegetation source additionally includes the Succulent Karoo, hence the slightly reduced Poaceae pollen percentages.

The data from marine surface samples produced by Dupont and Wyputta (2003) and the surface samples from our record show increasing Poaceae percentages southwards. We present this comparison in Figure 4, where Poaceae pollen percentage iso-lines over the Ocean show higher values in MD96-2098 (36%) than in northern sites (30% at 20° South, Dupont & Wyputta 2003). This pollen percentage distribution is one of the arguments we use to support our interpretation of Poaceae as indicator of fine-leaved savanna and Nama-Karoo on the adjacent continent.

Other specific comments

Suggestions have been incorporated when possible. Using "Table in the Supplement" instead of "Supplementary Table" is a change suggested by the typesetter so it was not changed. The reference Correa-Metrio et al. (2010) disappeared during the submission process from the reference list, we added it again. Suggestions on word usage were followed. The lettering in Figures 2 and 3 was increased. The caption of Fig 5 now describes the gray and black curves in panel (c).

Short comment by Dr. L. Scott Comment: The concerns raised by Dr. Scott may be summarized as two main points: 1) the reliability of pollen data from marine cores where the vegetation source is far away; and 2) The modern pollen survey being flawed because Poaceae are not considered as part of the local vegetation around wet areas.

Most of the points raised by Dr. L. Scott are addressed in the paper, but below we present our arguments again and back them up with additional references to the literature.

1) The reliability of pollen data from marine cores where the vegetation source is far away The study of pollen records from marine sediments is a well-established and known technique to reconstruct vegetation changes at orbital and millennial timescales. Experimental studies on present-day pollen assemblages from surface marine sediments from different places around the world indicate that marine pollen assemblages represent an integrated image of the regional vegetation of the close continent (Heusser, 1978; Heusser and Balsam, 1977; Naughton et al., 2007; Turon, 1984)

Vegetation reconstructions from marine records have contributed to our understanding of ocean-land interactions in many regions of the world, including the Iberian Peninsula (Sánchez Goñi et al., 2000), the eastern subtropical Pacific (Lyle et al., 2012), and in the tropical Atlantic (González and Dupont, 2009). In the African continent, marine pollen sequences have been particularly instrumental for our current knowledge of biome and climate dynamics e.g. (Dupont, 2011; Dupont and Behling, 2006; Dupont et al., 2000; Hooghiemstra et al., 1992; Leroy and Dupont, 1994). These examples demonstrate that pollen records from marine sequences are reliable and useful tools to reconstruct changes in the regional vegetation of the adjacent landmasses.

We do agree that possible transport biases and sources of pollen arriving at a marine site need to be carefully considered when working with pollen records from marine sedimentary sequences. This is why we have dedicated a complete section of our paper to this question (section 4.3). We feel that we have carefully discussed the two factors likely to transport terrestrial material to the ocean and possible biases due to transport or preservation. We also present a pollen calibration for terrestrial and marine samples that supports the interpretation of the pollen record, and that highlights the relative contributions of high-pollen producers such as the grasses (Poaceae), compared to other taxa that may be less important in the pollen record even when present in the vegetation source. We emphasize that grasses are the most abundant pollen taxon in semi-arid biomes like the Nama-Karoo and fine-leaved savanna because they are high-pollen producers growing in a low-productivity environment. In biomes like the

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broad-leaved savanna, grasses are abundant but their relative pollen abundance may be masked by the pollen signal of other woody or herbaceous taxa.

2) The modern pollen survey being flawed because Poaceae are not considered part of the local vegetation around wet areas. We decided to include the grasses (Poaceae) in our pollen calibration analysis because they are important components of the southern African vegetation, and not just concentrated or only found around wet spots. Grasses are an incredibly successful group of plants that can be found in many vegetation types around the world, and southern Africa is not an exception. This is supported by numerous works on the composition of semi-desert vegetation. For instance, Born et al. (2007) reports that the Karoo Region can be distinguished from the other regions by the high proportion of grasses (Poaceae). Cowling and Hilton-Taylor (2009) also describe grasses as being one of the 10 top most abundant families in the Namib-Karoo region. Additionally, Jurgens et al. (1997) reports on the abundance of perennial grasses growing on dunes in the Namibian desert, and Desmet (2007) who highlights the dominance of grasses on sandy soils on the Karoo (instead of wet spots as suggested by Dr. Scott).

Our field observations also support this view as we observed large grass-dominated vegetation in the Nama-Karoo areas of southern Africa. We have added a picture from our field expedition to the Supplementary information that we hope will help portray the abundance of grasses in southern African semi-arid vegetation (Supplementary Fig. 5).

The fact that Poaceae pollen is so abundant in the marine record also suggests that grasses are not restricted to wet areas, but instead that they an important component of semi-arid ecosystems in southern Africa. If grasses were restricted to wet areas, their abundance in a marine record adjacent to such arid biomes would be almost null.

Additionally, if grasses were only restricted to wet areas, we would find high percentages of Poaceae only in surface samples from small ponds, and not in moss samples that were collected from rock surfaces. Instead, we found between 20 and 40% Poaceae in moss samples from the succulent karoo and the fynbos vegetation (Supplementary Fig. 2).

Other specific comments P 4326, line 20: Relatively humid Namibian desert grassland is not really shown by Scott et al. (2012) who only report on a 2 ka section of the Holocene which covers a much longer interval.

We have added a precision to the sentence as follows: "... relatively humid Namibian Desert during the late Holocene (i.e. 2000 ka)".

P 4327, line 3: The authors suggest that the marine sequence helps to unravel climatic signals at regional scale, and such signals are obscured by local effects in terrestrial sequences. It is therefore ironical that, in order to help explain the marine pollen sequence, they rely on terrestrial surface pollen samples.

The use of surface samples and pollen rain calibration is well-known and has been used to support numerous palaeoenvironmental reconstructions in the world (e.g. (Björse et al., 1996; Markgraf et al., 2002; Prentice, 1985). It may be important to emphasize the difference between terrestrial sedimentary sequences and surface samples collected over a large region. We use surface samples because we are trying to address the evolution of the vegetation in the past, and using the pollen signal of the modern vegetation is a necessary step to produce a coherent interpretation of the pollen record. Additionally, in the manuscript we don't disregard the terrestrial pollen sequences as being flawed. We only point out that local effects can mask the climatic signal in terrestrial records while marine sequences can compliment the palaeoenvironmental picture at a large scale. We also point out the advantage of time spans reached with marine sequences that are seldom reached with terrestrial sequences.

P 4330, line 4: Mucina et al. is from 2006 not 2007.

The book on biomes of southern Africa is dated 2006. The map of vegetation of southern Africa is indeed from 2007: Mucina, L., Rutherford, M. C., and Powrie, L. W.: Vegetation Map of South Africa, Lesotho and Swaziland, South African National Biodiversity Institute Pretoria, 2007.

Line 28 and 29: Pollen of Stoebe and Tarchonanthus are quite distinct and easy to recognize.

While it is true that these two morphotypes are distinct, we included this caveat because in a few occasions pollen grains were crumpled or in positions where this differentiation was not possible.

P4341, line 28: To say that when the Poaceae pollen increases it indicates Nama Karoo expansion seems wrong considering other modern pollen studies in the region. It is generally thought that prominent Asteraceae pollen a characteristic in spectra from this biome as suggested by previous work (van Zinderen Bakker, 1957; Coetzee 1976; Van Zinderen Bakker and Muller, 1987; Cooremans, 1989; Scott and Cooremans 1992).

We have considered all modern pollen studies compiled by Gajewski et al. (2002) and available in the African pollen database. In this compilation, data from Cooremans, 1989, van Zinderen Bakker, 1957, Scott and Cooremans 1992 are integrated. This means that we have taken into account the pollen studies mentioned by Dr. Scott, and still found that Poaceae pollen percentages are more important in surface samples from the Nama-Karoo and fine-leaved savanna regions (Fig. 4) than Asteraceae (Fig. 3). These previously published data combined with our data show that the pollen of Asteraceae are more abundant in the Succulent Karoo. This is consistent with the abundance of species from the Asteraceae family in the Succulent Karoo, and the relatively low abundance of C4 grasses compared to the Nama-Karoo (Cowling and Hilton-Taylor, 2009).

P 4343, line 16: Why is the distinction between Fn-LSav and Bd-LSav relevant in these pollen assemblages from a marine core, which is very far away from these two types of savanna, and in which there can hardly be any direct evidence of changes in either of them?

We consider crucial to differentiate between the fine-leaved and broad-leaved savannas because despite the similarity in the names, these are two structurally and climatically different vegetation formations. Their difference is related to biomass, soil and precipitation regimes (Scholes 1997). In the fine-leaved savanna fuel load and fire frequency are very low, while the broad-leaved savanna has high fuel load and fire frequency (Archibald et al., 2010; Scholes, 1997). Additionally, the composition of the fine-leaved savanna can be similar to that of the Nama Karoo, with dominance of C4 grasses (Poaceae) and succulent plants, but it differs in having some scattered trees (Cowling et al., 1994).

P 4358, Fig. 3: About Artemisia and Stoebe types, why are there no Artemisia type in the eastern Free State and no Stoebe type in Lesotho when these forms are recorded to be prominent?

We used two kinds of data to build the pollen-percentage isolines. In the southwestern part of the study region, we collected and analysed the pollen content of the surface samples. In other regions like Lesotho or the eastern Free State, we used the pollen data from the African pollen database compiled by Gajewski et al. (2002). We recorded these two types in our samples, but we cannot judge why they are missing from samples we didn't collect or analysed.

Comment: In connection with Restionaceae, there are none of them growing in Namibia according to the herbarium in Windhoek. How is it possible that their pollen grains are so numerous in Southern Namibia?

As we explain in the text, we believe pollen grains from Restionaceae are the result of long-distance transport. This is discussed in the paper: " Restionaceae plants are found mostly in the Fynbos biome (Cowling et al., 1997) and its pollen has been used as a Fynbos indicator (Shi et al., 2001). However, the distribution of its pollen in our surface samples is only partly related to the distribution of the Fynbos biome (less than

5%). Up to 5% of Restionaceae pollen is found in surface samples from the Nama-Karoo, Succulent-Karoo and the Desert (Fig.3), suggesting that these pollen grains are the result of long-distance transport. Restionaceae are wind pollinated (Honig et al., 1992), and its pollen is likely transported by wind far from the vegetation source."

Comment: Fig. 6: This diagram is confusing. It is not indicated what the grey area or the red arrows mean. In (a) there seems to an austral winter position for ITCZ and austral summer position for the westerly system in the same diagram and in (b) there seems to be an austral summer position for ITCZ and an austral winter position for the westerly system in the same diagram.

The Figure caption details that the picture is derived from modern rainfall data. In the caption is also clear that the grey areas illustrate the current configuration of tropical and subtropical convection systems redrawn using average precipitation data between 1979–1995 from the International Research Institute for Climate Prediction (http://iri.ldeo.columbia.edu).

However, we did spot a typo on the Figure caption that could have misled Dr. Scott. The caption for the data on panel (a) corresponds to austral winter, while in (b) it corresponds to austral summer precipitation. This correction has been made. The red arrows show the expansion and contractions of semi-arid biomes, and this is now clarified in the caption.

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