Supplement of Clim. Past, 11, 1417–1431, 2015
http://www.clim-past.net/11/1417/2015/
doi:10.5194/cp-11-1417-2015-supplement


Climate of the Past
Open Access
EGU

*Supplement of*

# Increased aridity in southwestern Africa during the warmest periods of the last interglacial

**D. H. Urrego et al.**

*Correspondence to:* D. H. Urrego (d.urrego@exeter.ac.uk)

***Methods for terrestrial surface-sample collection and analysis***

A total of 31 surface samples were collected along a transect from Cape Town (South Africa) to Lüderitz (Namibia) during two weeks of fieldwork in February 2011. The sampling started after the first rains that followed a seven-year long drought. The area extended from latitudes 26.5° to 34.5°S and from longitudes 15° to 23.8°E (Fig.1) and was designed to cover the four major biomes of southwestern Africa (Table S1): Desert, Fynbos, Nama- and Succulent-Karoo. Although we did not conduct a vegetation survey at each sampling site, the surrounding vegetation was determined based on detailed descriptions and maps of southwestern Africa biomes (Mucina et al., 2007). We were also able to collect one sample in the coastal forest biome. While we did not intend to characterize the pollen spectra from coastal forests, including this sample in the dataset allowed increasing the variability of pollen spectra. Sediment and water samples were collected from ephemeral water puddles that developed after rainy episodes and small permanent waterlogged depressions where pollen deposition and preservation was likely. When we found moss attached to rocks or soil, we collected pitches from several spots within a five-meter radius. As a result, our sample set included 12 sediment, 8 moss, and 11 water samples (Table S1).

Surface samples were concentrated down to pellets using a manual and portable centrifuge in the field. Pellets were treated with standard acetolysis in the laboratory (Faegri and Iversen, 1989) and residues were mounted in glycerol and scanned under the microscope at 400 and 1000x magnification. Pollen sums were greater than 300 grains and spores were quantified but excluded from this total. Four out of 31 surface samples had such low pollen concentration that their spectra were excluded from the analysis (Table S1).

We used previously published pollen spectra from 150 additional surface samples collected between 22° and 35° latitude south (APD, Gajewski et al. 2002) to assess the distribution of pollen percentages and potential as indicators of large biomes of seven abundant pollen taxa. These taxa included *Artemisia*-type, Asteraceae-other, Chenopodiaceae-Amaranthaceae, Poaceae, *Podocarpus*, Restionaceae, and *Stoebe*-type. ArcGIS 10 was used to draw iso-lines of pollen percentages by interpolating values from a total of 178 surface samples through the natural neighbour method. Maps of bioclimatic variables were also drawn for comparison.

**Table S1.** Description of surface samples collected in southwestern Africa and used to characterize the pollen spectra of four southwestern African biomes. Sample number and codes correspond to those of Fig. 1 and 2, and Figures S2 and S3. Samples with low pollen concentration were not assigned a sample code and were not included in the analyses.

| Sample number | Sample code | Latitude | Longitude | Biome | Sample type | Location |
|---|---|---|---|---|---|---|
| 1 | D1 | -26.66 | 15.17 | Desert | Sediment | Luderitz |
| 2 | D2 | -26.61 | 16.08 | Desert | Water | Namibia semi-desert |
| 3 | D3 | -26.66 | 16.28 | Desert | Water | Aus savanna |
| 4 | Nk4 | -26.69 | 17.15 | Nama-Karoo | Water | Buchholzbrunn |
| 5 | Nk5 | -26.75 | 17.22 | Nama-Karoo | Water | Konkiep |
| 6 | Nk6 | -26.76 | 17.71 | Nama-Karoo | Sediment | Bethanie |
| 7 | Nk7 | -26.81 | 17.81 | Nama-Karoo | Water | Seehein |
| 8 | Nk8 | -26.59 | 18.14 | Nama-Karoo | Sediment | Grunau 2 |
| 9 | Nk9 | -26.73 | 18.45 | Nama-Karoo | Water | Grunau 3 |
| 10 | Nk10 | -26.88 | 18.57 | Nama-Karoo | Sediment | Grunau 4 |
| 11 | Nk11 | -27.92 | 17.49 | Nama-Karoo | Sediment | Fish river canyon |
| 12 | Nk12 | -28.48 | 17.90 | Nama-Karoo | Sediment | Noodower |
| 13 | Nk13 | -28.50 | 17.87 | Nama-Karoo | Water | Namibian border |
| 14 | Nk14 | -28.74 | 17.61 | Nama-Karoo | Sediment | Orange |
| 15 | Sk15 | -29.21 | 17.78 | Succulent-Karoo | Water | Namaqualand 23 |
| 16 | - | -29.20 | 17.78 | Succulent-Karoo | Sediment | Swart Doring |
| 0. | Sk17 | -29.66 | 18.00 | Succulent-Karoo | Moss | Goegab |
| 18 | Sk18 | -30.82 | 18.12 | Succulent-Karoo | Sediment | Olifant mouth |
| 19 | Sk19 | -31.25 | 18.54 | Succulent-Karoo | Moss | Namaqualand |
| 20 | - | -31.50 | 18.31 | Succulent-Karoo | Water | Olifant river |
| 21 | Fy21 | -32.19 | 18.96 | Fynbos | Moss | Cederberg |
| 22 | Fy22 | -32.23 | 18.85 | Fynbos | Sediment | Typha swamp |
| 23 | Fy23 | -32.39 | 18.95 | Fynbos | Moss | Citrusdal |
| 24 | Fy24 | -32.91 | 18.75 | Fynbos | Moss | Piketberg 2 |
| 25 | Fy25 | -32.91 | 18.75 | Fynbos | Moss | Piketberg 1 |
| 26 | Fy26 | -34.41 | 20.57 | Fynbos | Sediment | De Hoop East |
| 27 | - | -34.49 | 20.39 | Fynbos | Water | De Hoop reserve |
| 28 | Fy28 | -34.45 | 20.40 | Fynbos | Moss | De Hoop reserve |
| 29 | - | -34.30 | 20.31 | Fynbos | Water | Bree river |
| 30 | Fy30 | -34.45 | 20.73 | Fynbos | Sediment | Klipdrift river |
| 31 | CF31 | -34.02 | 23.90 | Coastal forest | Moss | Tsitsikamma-Stormriver |

**Table S2.** Chronological control for marine core MD96-2098 based on unpublished Accelerator Mass Spectrometer radiocarbon dates (AMS$^{14}$C) and marine isotope events (MIE) identified in the $\delta^{18}$O record from the record of benthic foraminifera *Cibicidoides wuellerstorfi* (Pichevin et al., 2005a; Pichevin et al., 2005b). Calibration details and sources for MIE ages are also shown.

| Uncorrected depth (cm) | Corrected depth[1] (cm) | Sample code | AMS$^{14}$C age/MIE | 95.4% (2s) cal age ranges[2]/calendar age (yr BP) | Calibration data[3]/ Source for MIE age |
|---|---|---|---|---|---|
| 22.5 | 22.5 | SacA 24476 | 2850±30 | 2310-2490 | Hughen et al. (2004) |
| 65 | 65 | SacA 23251 | 6105±30 | 6280-6430 | Hughen et al. (2004) |
| 100 | 100 | SacA 26970 | 8495±40 | 8750-9020 | Hughen et al. (2004) |
| 150 | 150 | SacA 24477 | 10775±40 | 11,730-12,080 | Hughen et al. (2004) |
| 200 | 200 | SacA 26971 | 13970±60 | 16,050-16,860 | Hughen et al. (2004) |
| 241 | 241 | SacA 23252 | 15300±50 | 17,650-18,070 | Hughen et al. (2004) |
| 275 | 275 | SacA 26972 | 15880±50 | 18,230-18,290 | Hughen et al. (2004) |
| 331 | 331 | SacA 23253 | 18010±60 | 20,420-21,220 | Hughen et al. (2004) |
| 430.5 | 430.5 | SacA 26973 | 19150±70 | 21,850-21,930 | Hughen et al. (2004) |
| 481 | 481 | SacA 24478 | 24200±120 | 27,990-28,710 | Hughen et al. (2004) |
| 561 | 561 | SacA 24479 | 28890±180 | 31,910-33,230 | Hughen et al. (2004) |
| 601 | 601 | SacA 26974 | 31870±240 | 35,130-36,450 | Hughen et al. (2004) |
| 647 | 647 | SacA 24480 | 30430±210* | 33,960-34,990 | Hughen et al. (2004) |
| 719 | 704 | SacA 23254 | 40010±520 | 42,740-44,410 | Hughen et al. (2004) |
| 740 | 725 | | 3.3 | 46,000 | Lisiecki and Raymo (2005) |
| 970 | 807 | | 3.31 | 51,000 | Lisiecki and Raymo (2005) |
| 1000 | 837 | | 4 | 57,000 | Lisiecki and Raymo (2005) |
| 1120 | 957 | | 4.23 | 64,000 | Lisiecki and Raymo (2005) |
| 1195 | 1032 | | MIS 5/4 | 73,500 | Sanchez Goñi and Harrison (2010) |
| 1250 | 1087 | | 5.1 | 82,000 | Lisiecki and Raymo (2005) |
| 1280 | 1117 | | 5.2 | 87,000 | Lisiecki and Raymo (2005) |
| 1360 | 1197 | | 5.3 | 103,800 | Drysdale et al. (2007) |
| 1400 | 1237 | | 5.4 | 110,400 | Drysdale et al. (2007) |
| 1460 | 1297 | | Onset of MIS 5 | 129,000 | Masson-Delmotte et al. (2010), Waelbroeck et al. (2008) |
| 1500 | 1337 | | MIS 6/5 | 135,000 | Henderson and Slowey (2000) |
| 1560 | 1397 | | 6.2 | 140,000 | Lisiecki and Raymo (2005) |
| 1600 | 1437 | | 6.3 | 155,000 | Lisiecki and Raymo (2005) |
| 1730 | 1567 | | 6.4 | 160,000 | Lisiecki and Raymo (2005) |
| 1800 | 1637 | | 6.41 | 166,000 | Lisiecki and Raymo (2005) |
| 2020 | 1857 | | 7.1 | 192,000 | Lisiecki and Raymo (2005) |

[1]Corrected depth for gaps reported in stratigraphic log; [2]rounded up to nearest 10 yr; [3]Marine09.14c curve, reservoir age correction = 157 (local delta R) + 400 (Global); *rejected age.

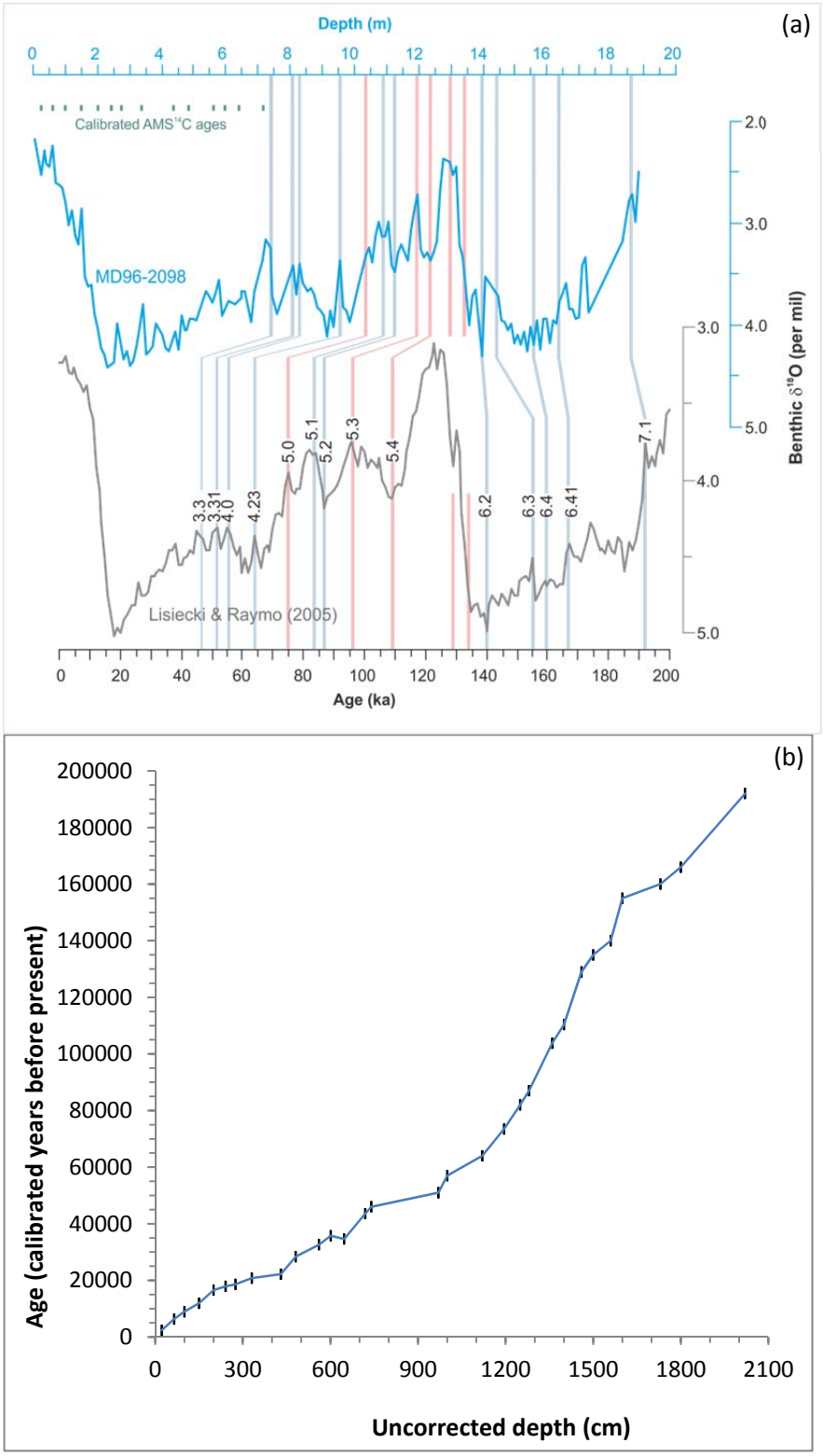



**Figure S1.** (a) Age control of core MD96-2098 based on 14 calibrated Accelerator Mass Spectrometer radiocarbon (AMS $^{14}C$) ages (green dots) and 16 Marine Isotopic Events (MIE, grey and pink bars) from stable Oxygen profile of benthic foraminifera (Bertrand et al., 2002). Radiocarbon ages were calibrated using the Marine09.14c calibration (Hughen et al., 2004; Stuiver and Reimer, 2005), a delta R of 157 years, and global reservoir age of 400 years. Gray bands indicate MIE control points and ages derived from LR04 global stack (Lisiecki and Raymo, 2005). Pink bars indicate MIE ages derived from other chronologies: Sánchez Goñi and Harrison (2010), Drysdale et al. (2007), Masson-Delmotte et al. (2010); Waelbroeck et al. (2008), Henderson and Slowey

(2000). (b) Age-depth curve including error bars with standard deviation around $^{14}C$ calibrated ages.

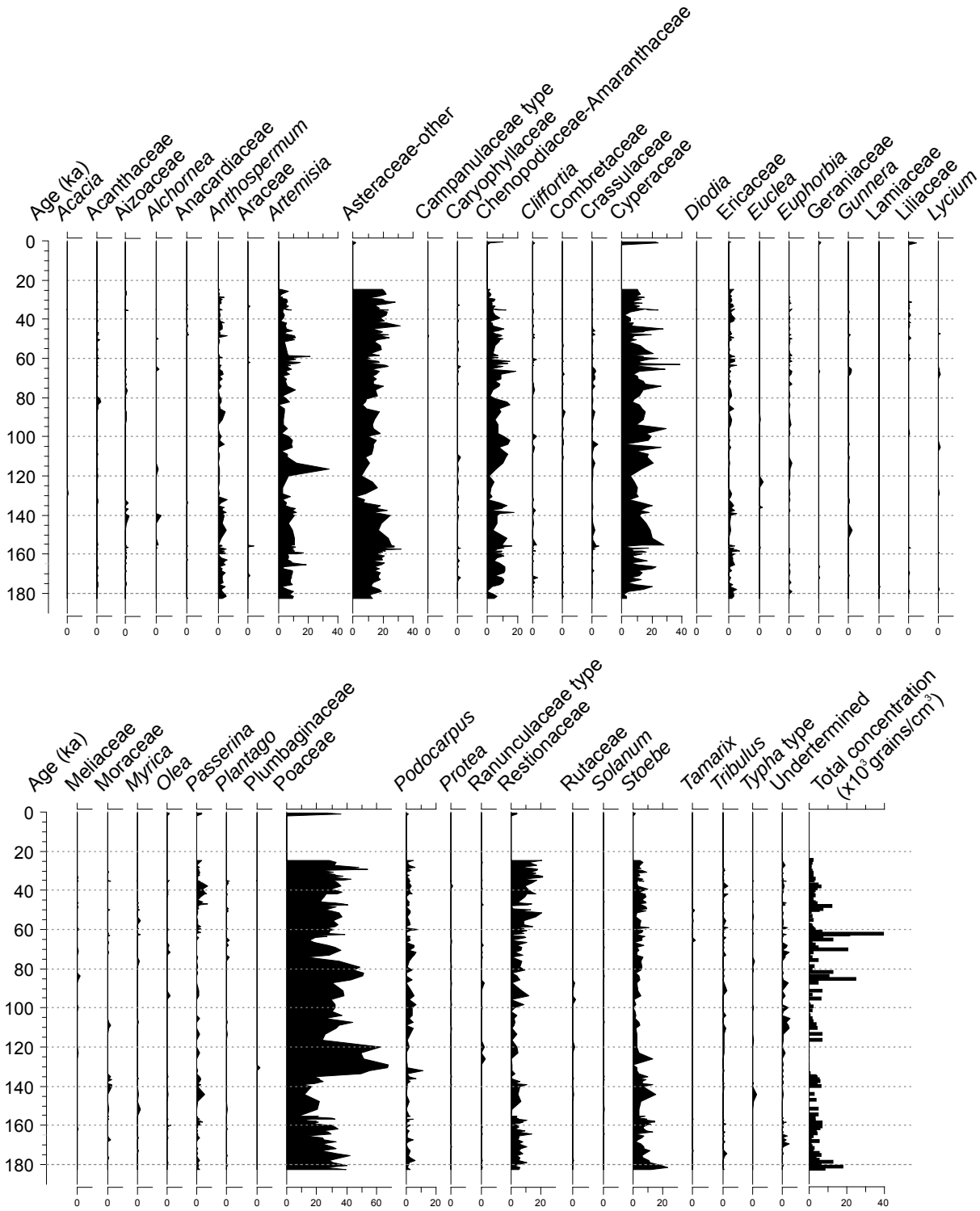


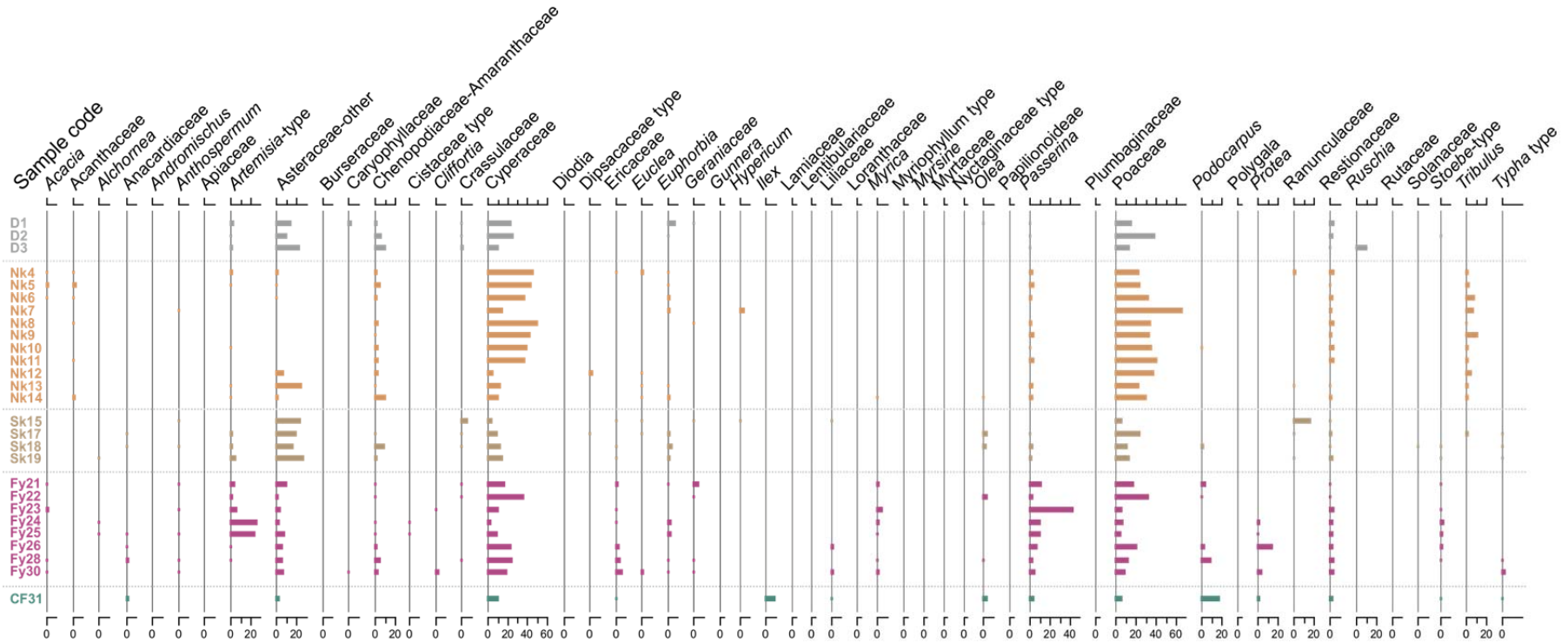

**Figure S2.** Pollen record and total pollen concentrations from MD96-2098. Percentages from the following families group more than one morphotype: Acanthaceae, Aizoaceae, Anacardiaceae, Asteraceae-other, Chenopodiaceae-Amaranthaceae, Crassulaceae, Cyperaceae, Ericaceae, Liliacaee, and Restionaceae.

***Present-day pollen-vegetation-climate relationships in southern Africa***

Asteraceae-other, Chenopodiaceae-Amaranthaceae, Poaceae and Restionaceae add up to 80% of the pollen sums and are found in all surface samples (Fig. S3). Cyperaceae pollen is also found in all but one of our surface samples. High Cyperaceae percentages are observed in samples collected from permanent small, waterlogged depressions or along rivers. As a result, we excluded Cyperaceae pollen percentages from ordination analyses.

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 around wet areas. 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. Numerous works on the composition of semi-desert vegetation support this assertion. 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, Jürgens et al. (1997) reports on the abundance of perennial grasses growing on dunes in the Namibian desert, and Desmet (2007) highlights the dominance of grasses on sandy soils on the Karoo. Our field observations also support this view as we observed large grass-dominated vegetation in the Nama-Karoo areas of southern Africa (Fig.2).

In the surface samples collected in the Desert, Asteraceae-other percentages are up to 20% and Chenopodiaceae-Amaranthaceae percentages are less than 10%. Poaceae and Cyperaceae show up to 45% and between 50 and 60%, respectively. The source of Poaceae, Asteraceae-other and Chenopodiaceae-Amaranthaceae pollen in the Desert can be perennial grasses growing on dunes (Jürgens et al., 1997). Our results show that pollen spectra from the Desert are more similar to spectra from the Succulent-Karoo than to any other biome (Fig. S4), suggesting that Desert surface samples receive pollen from Succulent-Karoo transitional patches.




**Supplementary Figure 3.** Percentage pollen diagram of taxa ordered alphabetically and identified in surface samples from southwestern Africa. Left column indicates the biome where samples were collected based on Mucina et al. (2007) and sample numbers (see Supplementary Table 1 for sample description); D: desert, Nm: Nama-Karoo, Sk: Succulent Karoo, Fy: Fynbos, CF: coastal forest. Percentages from the following families group more than one morphotype: Acanthaceae, Asteraceae-other, Chenopodiaceae-Amaranthaceae, Crassulaceae, Cyperaceae, Ericaceae, Myrtaceae, Ranunculaceae, Restionaceae, and Solanaceae.

In the Nama-Karoo surface samples, Poaceae pollen reaches percentages up to 60% (Fig. S3). Asteraceae-other pollen percentages are null in northern samples but increase to 20% in samples collected near the Succulent-Karoo. Chenopodiaceae-Amaranthaceae pollen percentages are up to 10%. *Tribulus* and Acanthaceae pollen are only found in the Nama-Karoo samples and reach up to 12%, consistent with their abundance in the vegetation source. On the other hand, Crassulaceae and *Euphorbia* pollen occur at low percentages in samples from Nama-Karoo despite having been described as common in the vegetation (Honig et al., 1992). The pollen spectra from samples collected in the Nama-Karoo form a tight cluster in the DCA ordination and are clearly separated from samples from other biomes (Fig. S4).

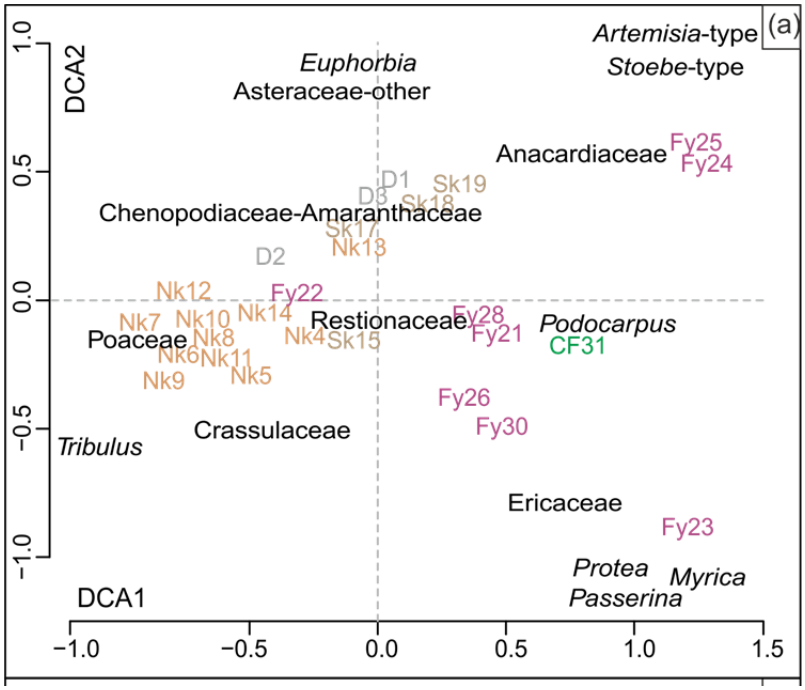



**Figure S4.** Detrended correspondence analysis summarizing changes in pollen spectra from surface samples collected in southwestern Africa. Sample labels indicate sample numbers and letters indicate biomes where samples were collected: D: Desert, Nk: Nama-Karoo, Sk: Succulent-Karoo Fy: Fynbos, CF: coastal forest. Rescaled species scores are shown for the 15 most abundant pollen taxa.

Surface samples collected in the Succulent-Karoo are characterized by pollen percentages of Asteraceae-other up to 20% and Poaceae between 15 and 20% (Fig. S3). This result corresponds with the abundance of species from the Asteraceae family in this biome, and the relatively less abundance of C4 grasses compared to the Nama-Karoo (Cowling and Hilton-Taylor, 2009). Small percentages of *Olea* and *Podocarpus* also found in the pollen spectra of the Succulent-Karoo could be the result of long-distance wind transport. The DCA ordination groups the Succulent-Karoo pollen

spectra near Desert samples, and this clustering is constrained by Asteraceae-other, *Euphorbia* and Chenopodiaceae-Amaranthaceae (Fig. S4).

In surface samples collected within the Fynbos biome, Anacardiaceae, *Anthospermum*, *Artemisia*-type, Ericaceae, *Passerina*, *Protea* and *Stoebe*-type reach highest percentages (Fig. S3). These pollen abundances reflect well the composition of the vegetation source described by (Cowling et al., 1997a), as species of Ericaceae, *Passerina* and *Protea* are particularly characteristic of the Fynbos biome. Up to 10% *Podocarpus* pollen percentages found in the Fynbos likely originate from small forest patches within the area. Poaceae pollen percentages are below 20% in the Fynbos and in the coastal forest sample. *Ilex* pollen is found in the sample from the coastal forest at approximately 5% and *Podocarpus* pollen is up to 18%, consistent with their abundance in the vegetation source. Except for sample Fy22, the composition of pollen spectra from the Fynbos biome in the DCA ordination is clearly distinguished from pollen spectra from other biomes (Fig. S4). The classification of sample Fy22 near samples from the Nama-Karoo likely results from the relatively high abundance of Poaceae pollen in Fy22 compared to other Fynbos samples (Fig. S3).

Some individual taxa are associated with the clustering of pollen spectra from the SWAfr biomes in the DCA ordination (Fig. S4), suggesting their potential as indicators of specific biomes. For instance, Poaceae, Crassulaceae and *Tribulus* obtain the highest loadings to classify the pollen spectra from the Nama-Karoo. Asteraceae-other, Chenopodiaceae-Amaranthaceae and *Euphorbia* are important in the Succulent-Karoo and Desert. Pollen taxa that characterize the Fynbos pollen spectra include Anacardiaceae, *Artemisia*-type, Ericaceae, *Myrica*, *Passerina*, *Protea*, *Stoebe*-type. *Podocarpus* characterizes the pollen spectra from coastal forests and Fynbos biomes.

Pollen percentage iso-lines drawn for six of the most abundant taxa in southern Africa are shown in Fig. S5. These six taxa are also abundant both in terrestrial and marine pollen sequences (Dupont, 2011; Scott et al., 2012) and can therefore be valuable for the interpretation of fossil pollen records. The pollen iso-lines of Asteraceae-other show 25% near the transition of the Nama-Karoo and the Grassland, and 20% in part of the Succulent-Karoo (Fig. S5). Chenopodiaceae-Amaranthaceae pollen percentages are as high as 35% in the Nama-Karoo and are also found up to 50% in a relatively small area of the Desert. This pollen distribution indicates that Chenopodiaceae-Amaranthaceae and Asteraceae-other high pollen percentages can be characteristic of the Succulent-Karoo, Nama-Karoo and Desert biomes of southwestern Africa.

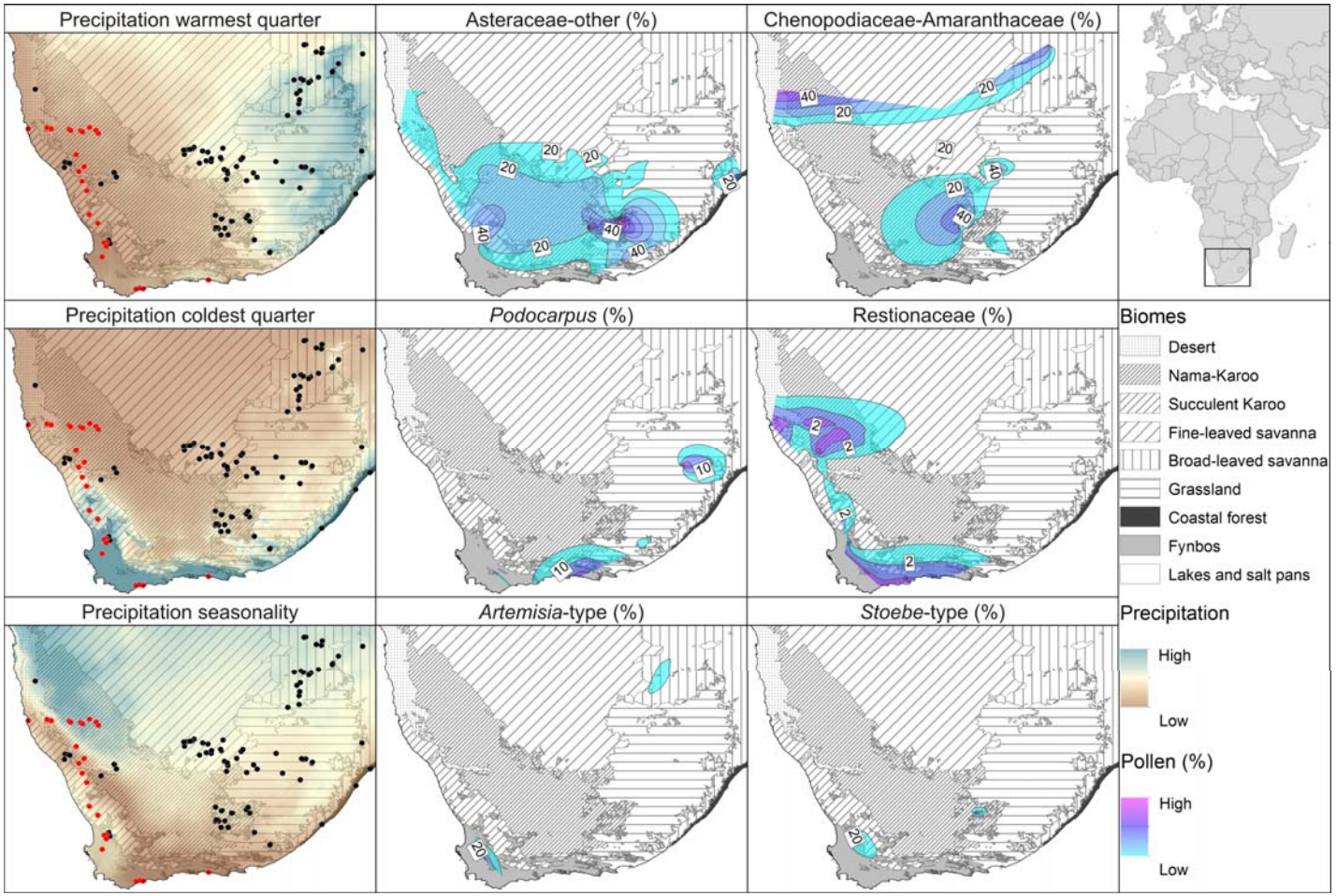



**Figure S5.** Bioclimatic variables and pollen percentage iso-lines drawn over biome units of southern Africa (modified from Scholes (1997); Mucina et al. (2007)). The broad-leaved savanna distribution includes the Mopane and mixed savannas described by Scholes (1997). Iso-lines are plotted based on pollen percentage data from surface samples analysed in this study (red dots) and pollen spectra from other samples previously published and extracted from the African Pollen Database (black dots) (Gajewski et al., 2002). Numbers and lines represent pollen percentages and are shown for taxa discussed in the text: Asteraceae-other, Chenopodiaceae-Amaranthaceae, *Podocarpus*, Restionaceae, *Artemisia*-type, and *Stoebe*-type.

*Podocarpus* pollen percentages in surface samples from southern Africa show a localized pattern in areas with high precipitation, namely coastal forest and in the eastern part of the Fynbos biome (Fig. S5). Consistently, (Gajewski et al., 2002) reports maxima of *Podocarpus* pollen percentages in African regions where precipitation is at least 1000 mm per year.

Restionaceae plants are found mostly in the Fynbos biome (Cowling et al., 1997b) 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%) (Fig. S5). Up to 5% of Restionaceae pollen is found in surface samples from the Nama-Karoo, Succulent-Karoo and the Desert (Fig. S5). Restionaceae are wind pollinated (Honig et al., 1992), suggesting that these pollen grains are the result of long-distance transport (Fig.1). Due to this inconsistency between the vegetation source and the spatial distribution of Restionaceae pollen, it would be difficult to discern whether increases in Restionaceae pollen in palaeoenvironmental reconstructions are the result of wind strengthening or due to Fynbos vegetation expansions without an independent wind tracer.

The distribution of pollen percentages from *Artemisia*-type and *Stoebe*-type are concentrated in the Fynbos biome (Fig. S5), and are positively correlated with PCQ (Fig. S4). Pollen signals from *Artemisia*-type and *Stoebe*-type, along with other taxa characteristic of the Fynbos vegetation (i.e. Ericaceae, *Protea* and *Passerina*, Fig. S3) might therefore be good tracers for past expansions of the biome.

## References


Bertrand, P., Giraudeau, J., Malaize, B., Martinez, P., Gallinari, M., Pedersen, T.F., Pierre, C., Vénec-Peyré, M.T., 2002. Occurrence of an exceptional carbonate dissolution episode during early glacial isotope stage 6 in the Southeastern Atlantic. Marine Geology 180, 235-248.

Born, J., Linder, H.P., Desmet, P., 2007. The Greater Cape Floristic Region. Journal of Biogeography 34, 147-162.

Cowling, R.M., Hilton-Taylor, C., 2009. Phytogeography, flora and endemism, in: Dean, W.R.J., Milton, S. (Eds.), The Karoo. Ecological Patterns and Processes. Cambridge University Press, Cambridge, UK, pp. 42-56.

Cowling, R.M., Richardson, D.M., Mustart, P.J., 1997a. Fynbos, in: Cowling, R.M., Richardson, D.M., Pierce, S.M. (Eds.), Vegetation of Southern Africa. Cambridge University Press, Cambridge, UK, pp. 99-130.

Cowling, R.M., Richardson, D.M., Pierce, S.M., 1997b. Vegetation of Southern Africa. Cambridge University Press, Cambridge, UK.

Desmet, P.G., 2007. Namaqualand—A brief overview of the physical and floristic environment. Journal of Arid Environments 70, 570-587.

Drysdale, R.N., Zanchetta, G., Hellstrom, J.C., Fallick, A.E., McDonald, J., Cartwright, I., 2007. Stalagmite evidence for the precise timing of North Atlantic cold events during the early last glacial. Geology 35, 77-80.

Dupont, L.M., 2011. Orbital scale vegetation change in Africa. Quaternary Science Reviews 30, 3589-3602.

Faegri, K., Iversen, J., 1989. Textbook of Pollen Analysis, 4th ed. Wiley, Chichester.

Gajewski, K., Lézine, A.-M., Vincens, A., Delestan, A., Sawada, M., 2002. Modern climate–vegetation–pollen relations in Africa and adjacent areas. Quaternary Science Reviews 21, 1611-1631.

Henderson, G.M., Slowey, N.C., 2000. Evidence from U-Th dating against Northern Hemisphere forcing of the penultimate deglaciation. Nature 404, 61-66.

Honig, M.A., Linder, H.P., Bond, W.J., 1992. Efficacy of Wind Pollination: Pollen Load Size and Natural Microgametophyte Populations in Wind-Pollinated Staberoha banksii (Restionaceae). American Journal of Botany 79, 443-448.

Hughen, K., Baillie, M., Bard, E., Bayliss, A., Beck, J., Bertrand, C., Blackwell, P., Buck, C., Burr, G., Cutler, K., Damon, P., Edwards, R., Fairbanks, R., Friedrich, M., Guilderson, T., Kromer, B., McCormac, F., Manning, S., Ramsey, C.B., Reimer, P., Reimer, R., Remmele, S., Southon, J., Stuiver, M., Talamo, S., Taylor, F., Plicht, J.v.d., Weyhenmeyer, C., 2004. Marine04 Marine radiocarbon age calibration, 26 - 0 ka BP. Radiocarbon 46, 1059-1086.

Jürgens, N., Burke, A., Seely, M.K., Jacobson, K.M., 1997. Desert, in: Cowling, R.M., Richardson, D.M., Pierce, S.M. (Eds.), Vegetation of Southern Africa. Cambridge Unversity Press, Cambridge, pp. 189-214.

Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic d18O records. Paleoceanography 20, PA1003.

Masson-Delmotte, V., Stenni, B., Pol, K., Braconnot, P., Cattani, O., Falourd, S., Kageyama, M., Jouzel, J., Landais, A., Minster, B., Barnola, J.M., Chappellaz, J., Krinner, G., Johnsen, S., Röthlisberger, R., Hansen, J., Mikolajewicz, U., Otto-Bliesner, B., 2010. EPICA Dome C record of glacial and interglacial intensities. Quaternary Science Reviews 29, 113-128.

Mucina, L., Rutherford, M.C., Powrie, L.W., 2007. Vegetation Map of South Africa, Lesotho and Swaziland, 2nd ed. South African National Biodiversity Institute Pretoria.

Pichevin, L., Cremer, M., Giraudeau, J., Bertrand, P., 2005a. A 190 ky record of lithogenic grain-size on the Namibian slope: Forging a tight link between past wind-strength and coastal upwelling dynamics. Marine Geology 218, 81-96.

Pichevin, L., Martinez, P., Bertrand, P., Schneider, R., Giraudeau, J., Emeis, K., 2005b. Nitrogen cycling on the Namibian shelf and slope over the last two climatic cycles: Local and global forcings. Paleoceanography 20, PA2006.

Sánchez Goñi, M.F., Harrison, S.P., 2010. Millennial-scale climate variability and vegetation changes during the Last Glacial: Concepts and terminology. Quaternary Science Reviews 29, 2823-2827.

Scott, L., Neumann, F.H., Brook, G.A., Bousman, C.B., Norström, E., Metwally, A.A., 2012. Terrestrial fossil-pollen evidence of climate change during the last 26 thousand years in Southern Africa. Quaternary Science Reviews 32, 100-118.

Shi, N., Schneider, R., Beug, H.-J., Dupont, L.M., 2001. Southeast trade wind variations during the last 135 kyr: evidence from pollen spectra in eastern South Atlantic sediments. Earth and Planetary Science Letters 187, 311-321.

Stuiver, M., Reimer, P.J., 2005. CALIB Radiocarbon Calibration, 5.0.1html ed.

Waelbroeck, C., Frank, N., Jouzel, J., Parrenin, F., Masson-Delmotte, V., Genty, D., 2008. Transferring radiometric dating of the last interglacial sea level high stand to marine and ice core records. Earth and Planetary Science Letters 265, 183-194.