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Supplement of

South-western Africa vegetation responses to atmospheric and oceanic changes during the last climatic cycle

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

2 A total of 31 surface samples were collected along a transect from Cape Town (South Africa)
3 to Lüderitz (Namibia) during two weeks of fieldwork in February 2011. The sampling started after the
4 first rains that followed a seven-year long drought. The area extended from latitudes 26.5° to 34.5°S
5 and from longitudes 15° to 23.8°E (Fig.1) and was designed to cover the four major biomes of
6 southwestern Africa (Supplementary-Table1): Desert, Fynbos, Nama- and Succulent-Karoo. Although
7 we did not conduct a vegetation survey at each sampling site, the surrounding vegetation was
8 determined based on detailed descriptions and maps of southwestern Africa biomes (Mucina et al.,
9 2007). We were also able to collect one sample in the coastal forest biome. While we did not intend
10 to characterize the pollen spectra from coastal forests, including this sample in the dataset allowed
11 increasing the variability of pollen spectra. Sediment and water samples were collected from
12 ephemeral water puddles that developed after rainy episodes and small permanent waterlogged
13 depressions where pollen deposition and preservation was likely. When we found moss attached to
14 rocks or soil, we collected pitches from several spots within a five-meter radius. As a result, our
15 sample set included 12 sediment, 8 moss, and 11 water samples (Supplementary-Table1).

16 Surface samples were concentrated down to pellets using a manual and portable centrifuge
17 in the field. Pellets were treated with standard acetolysis in the laboratory (Faegri and Iversen, 1989)
18 and residues were mounted in glycerol and scanned under the microscope at 400 and 1000x
19 magnification. Pollen sums were greater than 300 grains and spores were quantified but excluded
20 from this total. Four out of 31 surface samples had such low pollen concentration that their spectra
21 were excluded from the analysis (Supplementary-Table1).

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

29
30

31 **Supplementary Table 1.** Description of surface samples collected in southwestern Africa and used to
 32 characterize the pollen spectra of four southwestern African biomes. Sample number and codes
 33 correspond to those of Fig. 1 and 2, and Supplementary Figures 2 and 3. Samples with low pollen
 34 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 |

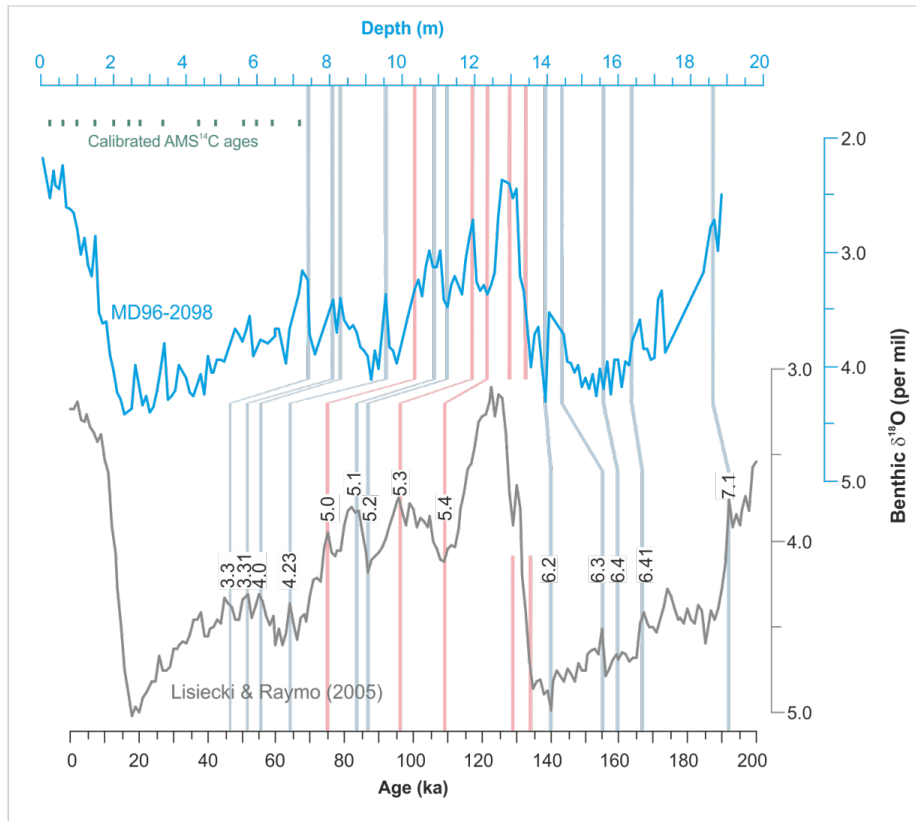
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37 **Supplementary Table 2.** Chronological control for marine core MD96-2098 based on unpublished
 38 Accelerator Mass Spectrometer radiocarbon dates (AMS¹⁴C) and marine isotope events (MIE)
 39 identified in the $\delta^{18}\text{O}$ record from the record of benthic foraminifera *Cibicidoides wuellerstorfi*
 40 (Pichevin et al., 2005a; Pichevin et al., 2005b). Calibration details and sources for MIE ages are
 41 also shown.

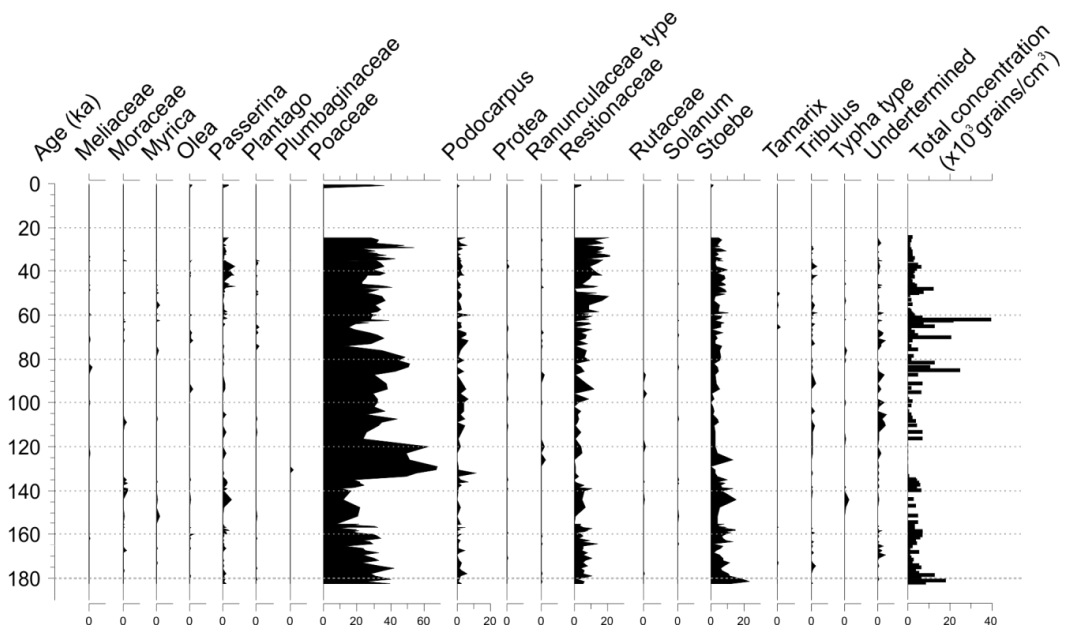
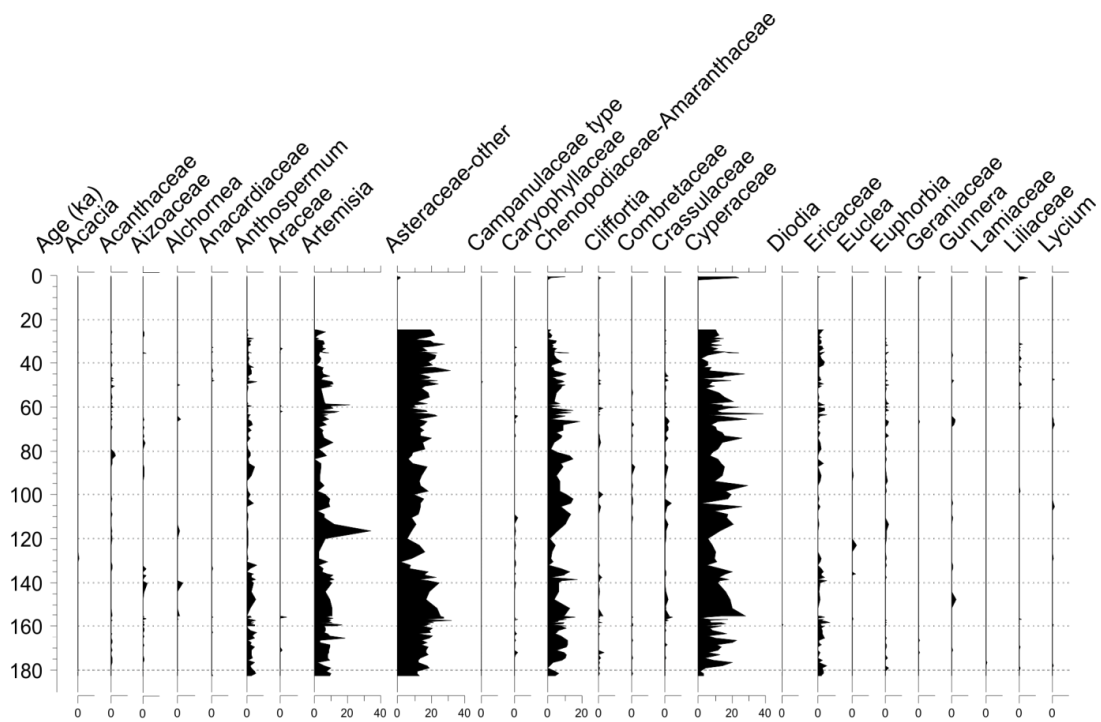
| Uncorrected depth (cm) | Corrected depth ¹ (cm) | Sample code | AMS ¹⁴ C age/MIE | 95.4% (2s) cal age ranges ² /calendar age (yr BP) | Calibration data ³ / Source for MIE age |
|------------------------|-----------------------------------|-------------|-----------------------------|--|---|
| 22.5 | 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) |

42 ¹Corrected depth for gaps reported in stratigraphic log; ²rounded up to nearest 10 yr; ³Marine09.14c curve,
 43 reservoir age correction = 157 (local delta R) + 400 (Global); *rejected age.
 44



45

46 **Supplementary Figure 1.** Age control of core MD96-2098 based on 14 calibrated Accelerator Mass
 47 Spectrometer radiocarbon (AMS ^{14}C) ages (green dots) and 16 Marine Isotopic Events (MIE, grey
 48 and pink bars) from stable Oxygen profile of benthic foraminifera (Bertrand et al., 2002).
 49 Radiocarbon ages were calibrated using the Marine09.14c calibration (Hughen et al., 2004;
 50 Stuiver and Reimer, 2005), a δR of 157 years, and global reservoir age of 400 years. Gray
 51 bands indicate MIE control points and ages derived from LR04 global stack (Lisiecki and Raymo,
 52 2005). Pink bars indicate MIE ages derived from other chronologies: (Sanchez Goñi and Harrison,
 53 2010), (Drysdale et al., 2007), (Masson-Delmotte et al., 2010; Waelbroeck et al., 2008),
 54 (Henderson and Slowey, 2000).
 55



56

57 **Supplementary Figure 2.** Complete pollen record and total pollen concentrations from MD96-2098.

58 Percentages from the following families group more than one morphotype: Acanthaceae,
 59 Aizoaceae, Anacardiaceae, Asteraceae-other, Chenopodiaceae-Amaranthaceae, Crassulaceae,
 60 Cyperaceae, Ericaceae, Liliaceae, and Restionaceae.

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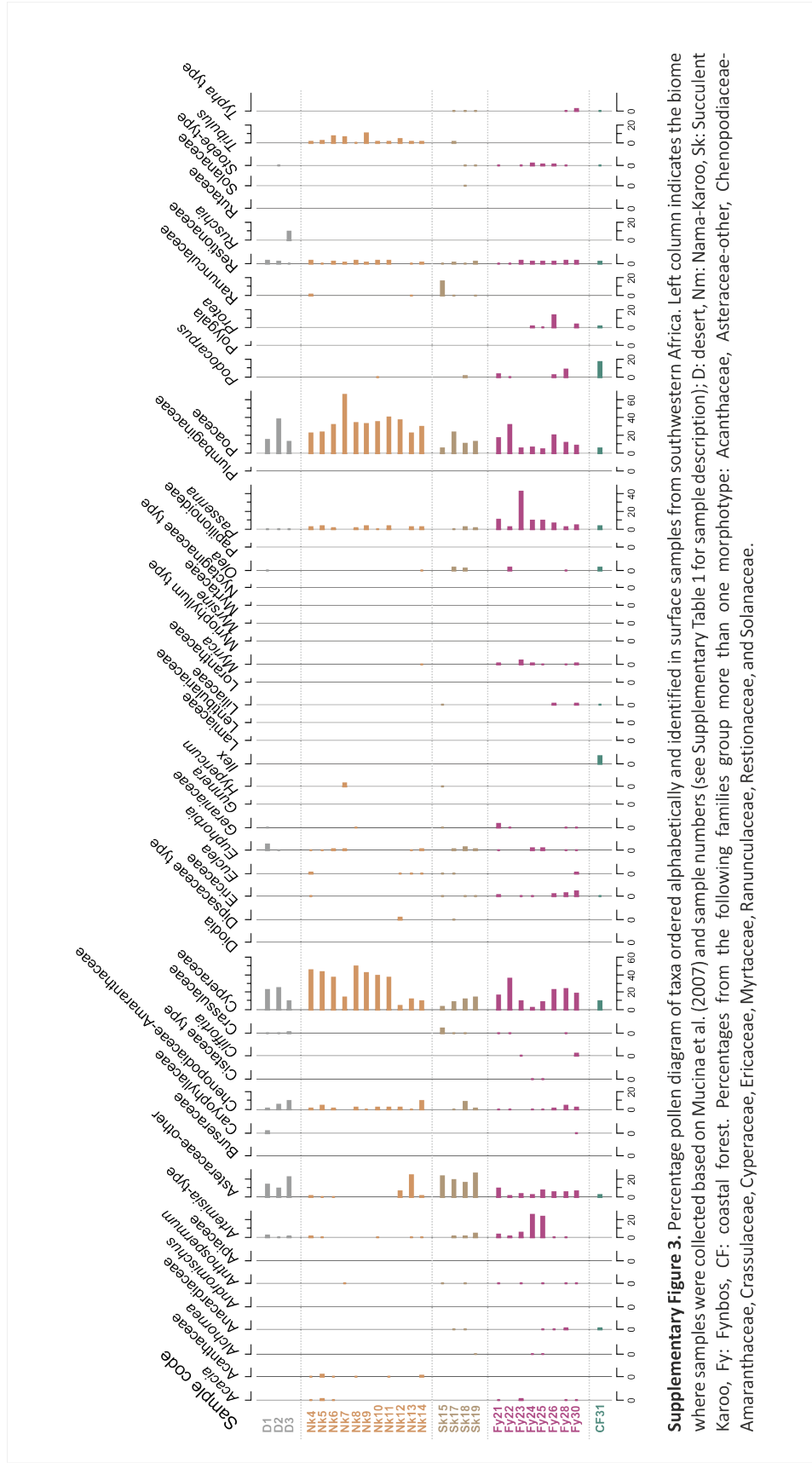
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63 ***Present-day pollen-vegetation-climate relationships in southern Africa***

64 Asteraceae-other, Chenopodiaceae-Amaranthaceae, Poaceae and Restionaceae add up to
65 80% of the pollen sums and are found in all surface samples ([Supplementary-Fig.3](#)). Cyperaceae
66 pollen is also found in all but one of our surface samples. High Cyperaceae percentages are observed
67 in samples collected from permanent small, waterlogged depressions or along rivers. As a result, we
68 excluded Cyperaceae pollen percentages from ordination analyses.

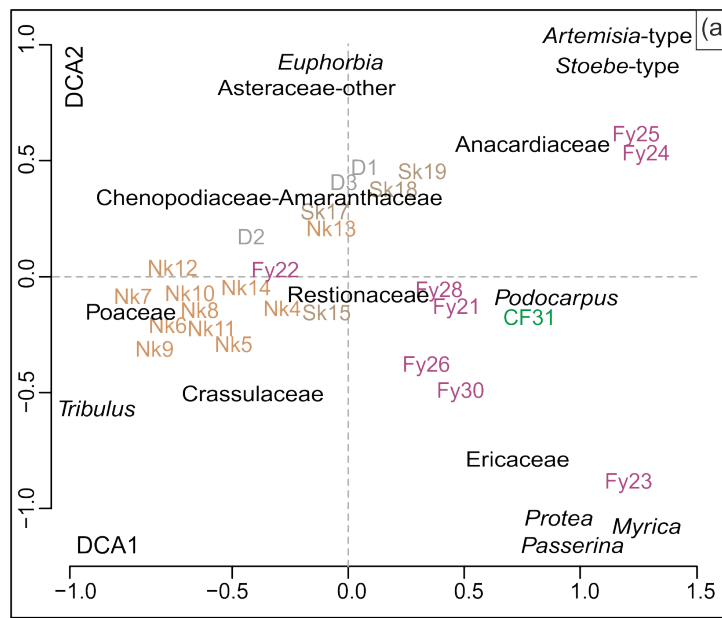
69 We decided to include the grasses (Poaceae) in our pollen calibration analysis because they
70 are important components of the southern African vegetation, and not just concentrated around
71 wet areas. Grasses are an incredibly successful group of plants that can be found in many vegetation
72 types around the world, and southern Africa is not an exception. Numerous works on the
73 composition of semi-desert vegetation support this assertion. For instance, Born et al. (2007) reports
74 that the Karoo Region can be distinguished from the other regions by the high proportion of grasses
75 (Poaceae). Cowling and Hilton-Taylor (2009) also describe grasses as being one of the 10 top most
76 abundant families in the Namib-Karoo region. Additionally, Jurgens et al. (1997) reports on the
77 abundance of perennial grasses growing on dunes in the Namibian desert, and Desmet (2007)
78 highlights the dominance of grasses on sandy soils on the Karoo. Our field observations also support
79 this view as we observed large grass-dominated vegetation in the Nama-Karoo areas of southern
80 Africa (Fig.2).

81 In the surface samples collected in the Desert, Asteraceae-other percentages are up to 20%
82 and Chenopodiaceae-Amaranthaceae percentages are less than 10%. Poaceae and Cyperaceae show
83 up to 45% and between 50 and 60%, respectively. The source of Poaceae, Asteraceae-other and
84 Chenopodiaceae-Amaranthaceae pollen in the Desert can be perennial grasses growing on dunes
85 (Jurgens et al., 1997). Our results show that pollen spectra from the Desert are more similar to
86 spectra from the Succulent-Karoo than to any other biome ([Supplementary-Fig.4](#)), suggesting that
87 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.

89 In the Nama-Karoo surface samples, Poaceae pollen reaches percentages up to 60%
 90 (Supplementary-Fig.3). Asteraceae-other pollen percentages are null in northern samples but
 91 increase to 20% in samples collected near the Succulent-Karoo. Chenopodiaceae-Amaranthaceae
 92 pollen percentages are up to 10%. *Tribulus* and Acanthaceae pollen are only found in the Nama-
 93 Karoo samples and reach up to 12%, consistent with their abundance in the vegetation source. On
 94 the other hand, Crassulaceae and *Euphorbia* pollen occur at low percentages in samples from Nama-
 95 Karoo despite having been described as common in the vegetation (Honig et al., 1992). The pollen
 96 spectra from samples collected in the Nama-Karoo form a tight cluster in the DCA ordination and are
 97 clearly separated from samples from other biomes (Supplementary-Fig.4).
 98



99

100 **Supplementary Figure 4.** Detrended correspondence analysis summarizing changes in pollen spectra
 101 from surface samples collected in southwestern Africa. Sample labels indicate sample
 102 numbers and letters indicate biomes where samples were collected: D: Desert, Nk: Nama-
 103 Karoo, Sk: Succulent-Karoo Fy: Fynbos, CF: coastal forest. Rescaled species scores are
 104 shown for the 15 most abundant pollen taxa.

105

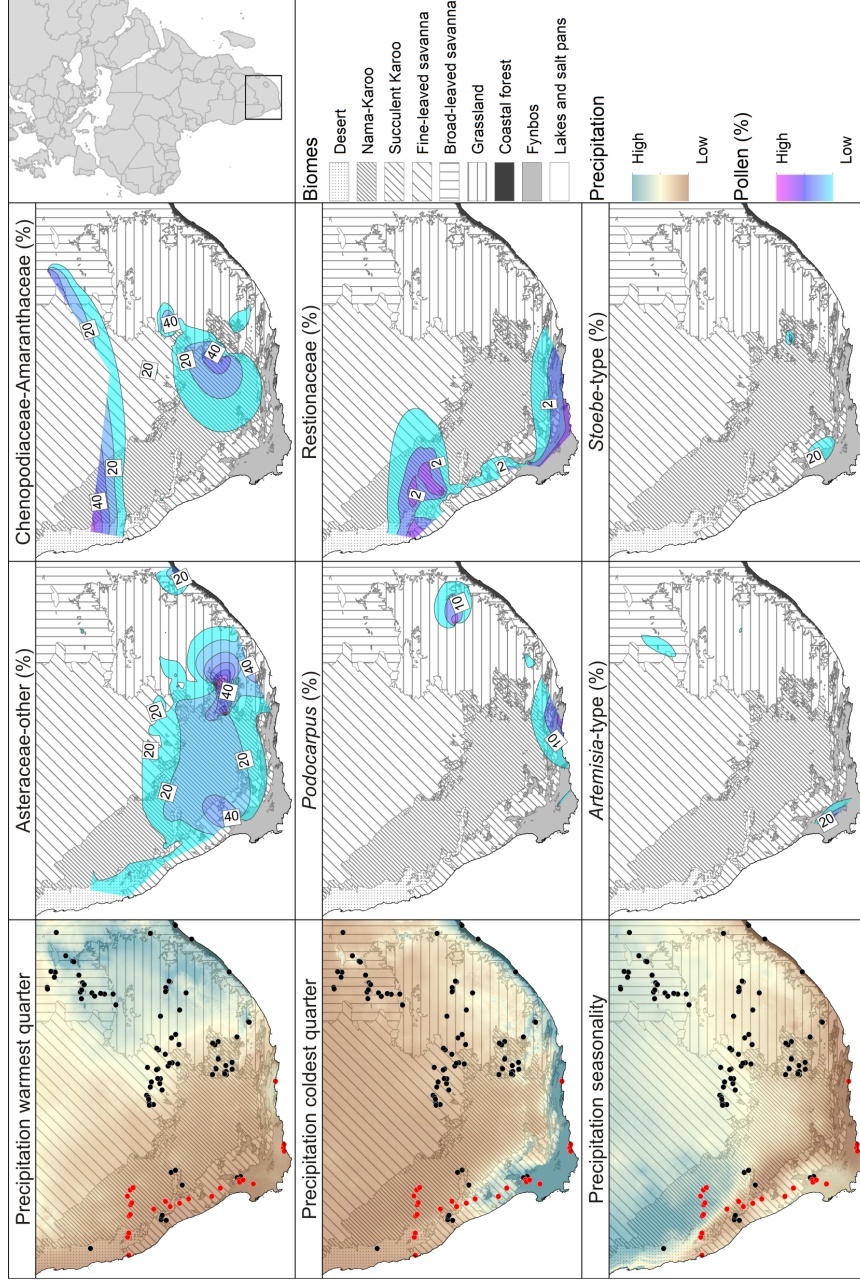
106 Surface samples collected in the Succulent-Karoo are characterized by pollen percentages of
 107 Asteraceae-other up to 20% and Poaceae between 15 and 20% (Supplementary-Fig.3). This result
 108 corresponds with the abundance of species from the Asteraceae family in this biome, and the
 109 relatively less abundance of C4 grasses compared to the Nama-Karoo (Cowling and Hilton-Taylor,
 110 2009). Small percentages of *Olea* and *Podocarpus* also found in the pollen spectra of the Succulent-
 111 Karoo could be the result of long-distance wind transport. The DCA ordination groups the Succulent-

112 Karoo pollen spectra near Desert samples, and this clustering is constrained by Asteraceae-other,
113 *Euphorbia* and Chenopodiaceae-Amaranthaceae (Supplementary-Fig.4).

114 In surface samples collected within the Fynbos biome, Anacardiaceae, *Anthospermum*,
115 *Artemisia*-type, Ericaceae, *Passerina*, *Protea* and *Stoebe*-type reach highest percentages
116 (Supplementary-Fig.3). These pollen abundances reflect well the composition of the vegetation
117 source described by (Cowling et al., 1997a), as species of Ericaceae, *Passerina* and *Protea* are
118 particularly characteristic of the Fynbos biome. Up to 10% *Podocarpus* pollen percentages found in
119 the Fynbos likely originate from small forest patches within the area. Poaceae pollen percentages
120 are below 20% in the Fynbos and in the coastal forest sample. *Ilex* pollen is found in the sample from
121 the coastal forest at approximately 5% and *Podocarpus* pollen is up to 18%, consistent with their
122 abundance in the vegetation source. Except for sample Fy22, the composition of pollen spectra from
123 the Fynbos biome in the DCA ordination is clearly distinguished from pollen spectra from other
124 biomes (Supplementary-Fig.4). The classification of sample Fy22 near samples from the Nama-Karoo
125 likely results from the relatively high abundance of Poaceae pollen in Fy22 compared to other
126 Fynbos samples (Supplementary-Fig.3).

127 Some individual taxa are associated with the clustering of pollen spectra from the SWAfr
128 biomes in the DCA ordination (Supplementary-Fig.4), suggesting their potential as indicators of
129 specific biomes. For instance, Poaceae, Crassulaceae and *Tribulus* obtain the highest loadings to
130 classify the pollen spectra from the Nama-Karoo. Asteraceae-other, Chenopodiaceae-
131 Amaranthaceae and *Euphorbia* are important in the Succulent-Karoo and Desert. Pollen taxa that
132 characterize the Fynbos pollen spectra include Anacardiaceae, *Artemisia*-type, Ericaceae, *Myrica*,
133 *Passerina*, *Protea*, *Stoebe*-type. *Podocarpus* characterizes the pollen spectra from coastal forests and
134 Fynbos biomes.

135 Pollen percentage iso-lines drawn for six of the most abundant taxa in southern Africa are
136 shown in Supplementary-Fig.5. These six taxa are also abundant both in terrestrial and marine pollen
137 sequences (Dupont, 2011; Scott et al., 2012) and can therefore be valuable for the interpretation of
138 fossil pollen records. The pollen iso-lines of Asteraceae-other show 25% near the transition of the
139 Nama-Karoo and the Grassland, and 20% in part of the Succulent-Karoo (Supplementary-Fig.5).
140 Chenopodiaceae-Amaranthaceae pollen percentages are as high as 35% in the Nama-Karoo and are
141 also found up to 50% in a relatively small area of the Desert. This pollen distribution indicates that
142 Chenopodiaceae-Amaranthaceae and Asteraceae-other high pollen percentages can be
143 characteristic of the Succulent-Karoo, Nama-Karoo and Desert biomes of southwestern Africa.



144

145 **Supplementary Figure 5.** Bioclimatic variables and pollen percentage iso-lines drawn over biome units of southern Africa (modified from Scholes (1997);
 146 Mucina et al. (2007)). The broad-leaved savanna distribution includes the Mopane and mixed savannas described by Scholes (1997). Iso-lines are
 147 plotted based on pollen percentage data from surface samples analysed in this study (red dots) and pollen spectra from other samples previously
 148 published and extracted from the African Pollen Database (black dots) (Gajewski et al., 2002). Numbers and lines represent pollen percentages and
 149 are shown for taxa discussed in the text: Asteraceae-other, Chenopodiaceae-Amaranthaceae, *Podocarpus*, *Restionaceae*, *Artemisia*-type, and
 150 *Stoebe*-type.

151

152 *Podocarpus* pollen percentages in surface samples from southern Africa show a localized
153 pattern in areas with high precipitation, namely coastal forest and in the eastern part of the Fynbos
154 biome (Supplementary-Fig.5). Consistently, (Gajewski et al., 2002) reports maxima of *Podocarpus*
155 pollen percentages in African regions where precipitation is at least 1000 mm per year.

156 Restionaceae plants are found mostly in the Fynbos biome (Cowling et al., 1997b) and its
157 pollen has been used as a Fynbos indicator (Shi et al., 2001). However, the distribution of its pollen
158 in our surface samples is only partly related to the distribution of the Fynbos biome (less than 5%)
159 (Supplementary-Fig.5). Up to 5% of Restionaceae pollen is found in surface samples from the Nama-
160 Karoo, Succulent-Karoo and the Desert (Supplementary-Fig.5). Restionaceae are wind pollinated
161 (Honig et al., 1992), suggesting that these pollen grains are the result of long-distance transport.
162 (Fig.1). Due to this inconsistency between the vegetation source and the spatial distribution of
163 Restionaceae pollen, it would be difficult to discern whether increases in Restionaceae pollen in
164 palaeoenvironmental reconstructions are the result of wind strengthening or due to Fynbos
165 vegetation expansions without an independent wind tracer.

166 The distribution of pollen percentages from *Artemisia*-type and *Stoebe*-type are
167 concentrated in the Fynbos biome (Supplementary-Fig.5), and are positively correlated with PCQ
168 (Supplementary-Fig.4). Pollen signals from *Artemisia*-type and *Stoebe*-type, along with other taxa
169 characteristic of the Fynbos vegetation (i.e. Ericaceae, *Protea* and *Passerina* Supplementary-Fig.3)
170 might therefore be good tracers for past expansions of the biome.

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177 **References**

- 178 Bertrand, P., Giraudeau, J., Malaize, B., Martinez, P., Gallinari, M., Pedersen, T.F., Pierre, C., Vénec-
179 Peyré, M.T., 2002. Occurrence of an exceptional carbonate dissolution episode during early glacial
180 isotope stage 6 in the Southeastern Atlantic. *Marine Geology* 180, 235-248.
- 181 Born, J., Linder, H.P., Desmet, P., 2007. The Greater Cape Floristic Region. *Journal of Biogeography*
182 34, 147-162.
- 183 Cowling, R.M., Hilton-Taylor, C., 2009. Phytogeography, flora and endemism, in: Dean, W.R.J.,
184 Milton, S. (Eds.), *The Karoo. Ecological Patterns and Processes*. Cambridge University Press,
185 Cambridge, UK, pp. 42-56.
- 186 Cowling, R.M., Richardson, D.M., Mustart, P.J., 1997a. Fynbos, in: Cowling, R.M., Richardson, D.M.,
187 Pierce, S.M. (Eds.), *Vegetation of Southern Africa*. Cambridge University Press, Cambridge, UK, pp.
188 99-130.
- 189 Cowling, R.M., Richardson, D.M., Pierce, S.M., 1997b. *Vegetation of Southern Africa*. Cambridge
190 University Press, Cambridge, UK, p. 615.
- 191 Desmet, P.G., 2007. Namaqualand—A brief overview of the physical and floristic environment.
192 *Journal of Arid Environments* 70, 570-587.
- 193 Drysdale, R.N., Zanchetta, G., Hellstrom, J.C., Fallick, A.E., McDonald, J., Cartwright, I., 2007.
194 Stalagmite evidence for the precise timing of North Atlantic cold events during the early last glacial.
195 *Geology* 35, 77-80.
- 196 Dupont, L., 2011. Orbital scale vegetation change in Africa. *Quaternary Science Reviews* 30, 3589-
197 3602.
- 198 Faegri, K., Iversen, J., 1989. *Textbook of Pollen Analysis*, 4th ed. Wiley, Chichester.
- 199 Gajewski, K., Lézine, A.-M., Vincens, A., Delestan, A., Sawada, M., 2002. Modern climate–vegetation–
200 pollen relations in Africa and adjacent areas. *Quaternary Science Reviews* 21, 1611-1631.
- 201 Henderson, G.M., Slowey, N.C., 2000. Evidence from U-Th dating against Northern Hemisphere
202 forcing of the penultimate deglaciation. *Nature* 404, 61-66.

203 Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution interpolated
204 climate surfaces for global land areas. *International Journal of Climatology* 25, 1965-1978.

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

208 Hughen, K., Baillie, M., Bard, E., Bayliss, A., Beck, J., Bertrand, C., Blackwell, P., Buck, C., Burr, G.,
209 Cutler, K., Damon, P., Edwards, R., Fairbanks, R., Friedrich, M., Guilderson, T., Kromer, B., McCormac,
210 F., Manning, S., Ramsey, C.B., Reimer, P., Reimer, R., Remmele, S., Southon, J., Stuiver, M., Talamo,
211 S., Taylor, F., Plicht, J.v.d., Weyhenmeyer, C., 2004. Marine04 Marine radiocarbon age calibration, 26
212 - 0 ka BP. *Radiocarbon* 46, 1059-1086.

213 Jurgens, N., Burke, A., Seely, M.K., Jacobson, K.M., 1997. Desert, in: Cowling, R.M., Richardson, D.M.,
214 Pierce, S.M. (Eds.), *Vegetation of Southern Africa*. Cambridge University Press, Cambridge, pp. 189-
215 214.

216 Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$
217 records. *Paleoceanography* 20, PA1003.

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

222 McCune, B., Grace, J.B., 2002. *Analysis of Ecological Communities*. MjM, Glenden Beach, Oregon.

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

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

- 228 Pichevin, L., Martinez, P., Bertrand, P., Schneider, R., Giraudeau, J., Emeis, K., 2005b. Nitrogen cycling
229 on the Namibian shelf and slope over the last two climatic cycles: Local and global forcings.
230 *Paleoceanography* 20, PA2006.
- 231 Sanchez Goñi, M.F., Harrison, S.P., 2010. Millennial-scale climate variability and vegetation changes
232 during the Last Glacial: Concepts and terminology. *Quaternary Science Reviews* 29, 2823-2827.
- 233 Scott, L., Neumann, F.H., Brook, G.A., Bousman, C.B., Norström, E., Metwally, A.A., 2012. Terrestrial
234 fossil-pollen evidence of climate change during the last 26 thousand years in Southern Africa.
235 *Quaternary Science Reviews* 32, 100-118.
- 236 Shi, N., Schneider, R., Beug, H.-J., Dupont, L.M., 2001. Southeast trade wind variations during the last
237 135 kyr: evidence from pollen spectra in eastern South Atlantic sediments. *Earth and Planetary
238 Science Letters* 187, 311-321.
- 239 Stuiver, M., Reimer, P.J., 2005. CALIB Radiocarbon Calibration, 5.0.1html ed.
- 240 Waelbroeck, C., Frank, N., Jouzel, J., Parrenin, F., Masson-Delmotte, V., Genty, D., 2008. Transferring
241 radiometric dating of the last interglacial sea level high stand to marine and ice core records. *Earth
242 and Planetary Science Letters* 265, 183-194.
- 243