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Short communication

Evolving southwest African response to abrupt deglacial North Atlantic climate change events

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ABSTRACT

Climate change during the last deglaciation was strongly influenced by the 'bipolar seesaw', producing antiphase climate responses between the North and South Atlantic. However, mounting evidence demands refinements of this model, with the occurrence of abrupt events in southern low to mid latitudes occurring in-phase with North Atlantic climate. Improved constraints on the north–south phasing and spatial extent of these events are therefore critical to understanding the mechanisms that propagate abrupt events within the climate system. We present a 19,400 year multi-proxy record of climate change obtained from a rock hyrax midden in southernmost Africa. Arid anomalies in phase with the Younger Dryas and 8.2 ka events are apparent, indicating a clear shift in the influence of the bipolar seesaw, which diminished as the Earth warmed, and was succeeded after ~14.6 ka by the emergence of a dominant interhemispheric atmospheric teleconnection.

1. Introduction

While some studies have reported interhemispheric synchrony and symmetry during extreme climate disturbances such as the Younger Dryas cold reversal (YD; 12.9–11.6 ka (Lowe et al., 2008)) (Denton and Hendy, 1994; Goede et al., 1996), abrupt changes in Northern Hemisphere climates (North Greenland Ice Core Project members, 2004) have also been associated with anti-phase responses in the Southern Hemisphere (Kaplan et al., 2010; Putnam et al., 2010). Such antiphase responses are hypothesised to be driven by the oceanic Atlantic Overturning Meridional Circulation (AMOC), which draws heat from the Southern Hemisphere into the North Atlantic, but which is sensitive to disruption by ice and freshwater discharges (Broecker, 1998; McManus et al., 2004). Reduction and intensification of ocean heat transport during northern stadial (cold) and interstadial (warm) intervals leads to the alternating build-up and extraction of Southern Hemisphere heat; the so-called bipolar seesaw (Broecker, 1998; Stocker, 1998; Stocker and Johnsen, 2003).

An increasing number of records suggest that the relative warmth of the Northern Hemisphere's Bølling-Allerød interstadial coincided with the Antarctic Cold Reversal (ACR; 14.7–13.0 ka) (Putnam et al., 2010; Pedro et al., 2011), and that the marked northern cooling of the YD was a period of rising temperatures and glacial retreat in the southern high (Pedro et al., 2011) to mid-latitudes (Kaplan et al., 2010). However, a lack of reliable evidence from the low southern latitudes has still prevented a full assessment of the bipolar seesaw hypothesis, including the location of its 'fulcrum'. Such information is vital to test simulations, which are currently showing no consensus on the spatial extent of past (or future) abrupt climate change events (Kageyama et al., 2010).

To address this problem, we explore the regional impact of key perturbations in the North Atlantic using a multi-proxy record from the arid SW Cape region of South Africa (Fig. 1). The region lies at the juncture between southern Africa's three dominant climate systems: the South Atlantic anticyclone, the tropical easterlies, and

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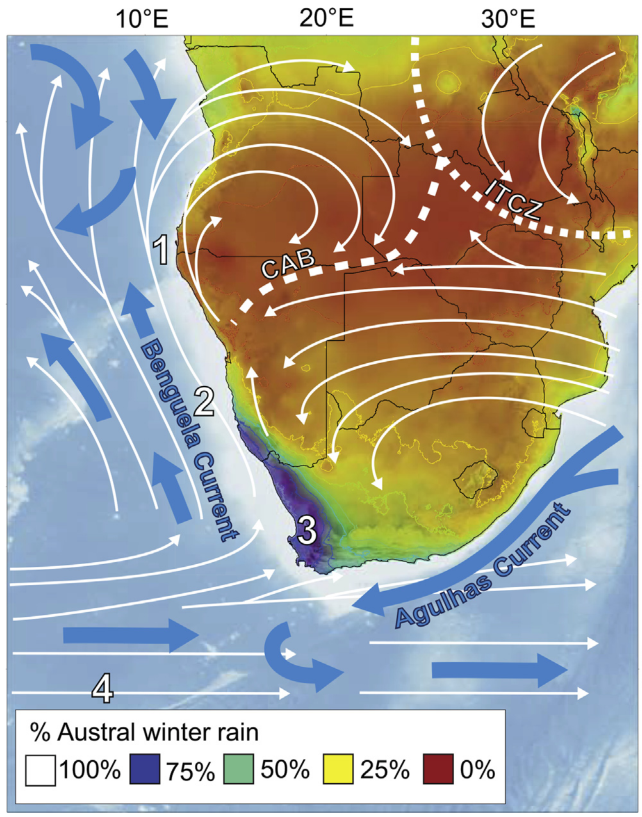

Fig. 1. Map of study region indicating generalised atmospheric (white arrows) and oceanic (blues arrows) circulation systems and the seasonal distribution of rainfall as indicated by the percent of the total mean annual rainfall received during the austral winter months of April–September. The convergence zones of the Congo Air Boundary (CAB) and the Intertropical Convergence Zone (ITCZ) are shown in their generalised austral summer positions. Key sites discussed in the manuscript are indicated by number: 1) GeoB1023-5 (Kim and Schneider, 2003; Kim et al., 2003); 2) ODP1084b (Farmer et al., 2005); 3) the De Rif rock hyrax midden; and 4) TNO57-21 (Barker et al., 2009) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

the austral westerlies (Tyson, 1986). Approximately 75% of the region's precipitation falls during winter, when the westerlies and their related cold fronts migrate northward, advecting moisture from the southern Atlantic to the mountains of the SW Cape (Reason et al., 2006). In the dry summer months, the westerlies and the South Atlantic Anticyclone shift southward, limiting frontal system influence and blocking tropical moisture-bearing systems from the Indian Ocean and tropical Atlantic (Reason et al., 2006).

Little is known about SW Africa's environmental history, mainly due to its aridity and marked rainfall seasonality, which allows for few wetland sediment records. Rock hyrax (*Procavia capensis*) middens have emerged in this setting as valuable archives of palaeoenvironmental information (Carr et al., 2010; Chase et al., 2013, 2015, 2009, 2011, 2012; Meadows et al., 2010; Quick et al., 2011; Scott and Bousman, 1990; Scott et al., 2005; Scott and Vogel, 2000; Scott and Woodborne, 2007). As hyraxes use discrete locations as latrines, deposits of sub-fossilised urine (hyraceum) accumulate in their shelters, much like stalagmites in a cave. These finely laminated amber-like deposits preserve a wide range of proxies, including pollen, charcoal, and stable isotopes, all of which can provide insight into past environmental conditions (Chase et al., 2011; Valsecchi et al., 2013) (see Supplementary Information).

2. Results

The records presented here were obtained from two sections of a 53 cm thick midden collected from De Rif, in the Driehoek Valley of the Cederberg Mountains (32°26′45″S, 19°13′15″E, 1151 m amsl.) (Chase et al., 2011; Valsecchi et al., 2013). Chronologies spanning the past 19,400 years were established using 29 ^{14}C AMS dates (see Supplementary Information). Together, the De Rif midden records reveal coherent patterns of marked environmental variability since the Last Glacial Maximum (LGM; Fig. 2). Highlighted here are aspects of the records that primarily reflect changes in hydroclimate. In a region dominated by C_3 plants, the hyraceum $\delta^{13}C$ record primarily reflects variations in water-use efficiency (Chase et al., 2012; Ehleringer and Cooper, 1988; Farquhar et al., 1989; Farquhar and Richards, 1984; Pate, 2001), although a long-term enrichment in is evident across the mid-to late Holocene. This is consistent with increased water use efficiency of C_3 plants, and an increasing abundance of $\delta^{13}C$ enriched drought-resistant succulent CAM plants under drier conditions (Smith, 1972; Valsecchi et al., 2013). These data are supported by the hyraceum $\delta^{15}N$ record, which also

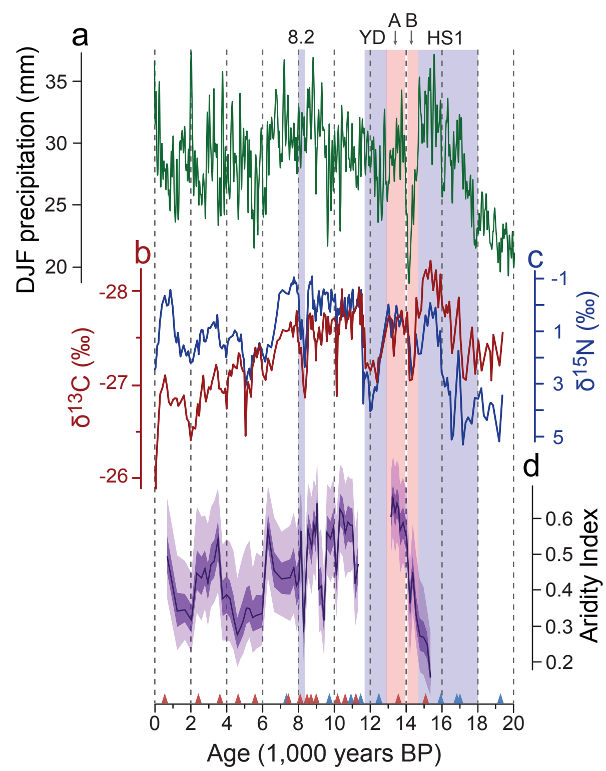

Fig. 2. Comparison of proxy records from the De Rif rock hyrax midden and general circulation model (GCM) simulation data for the region. Radiocarbon ages shown as triangles along x-axis (DR2010 section in red, DR-2 section in blue). Heinrich stadial 1 (HS1), the Younger Dryas cold reversal (YD) and 8.2 ka event are highlighted by blue shading, and the Bølling (B) and Allerød (A) interstadials are shaded in red. Stable nitrogen (b) and carbon (c) records from the middens primarily reflect water-availability in the environment and water-use efficiency of plants respectively. These data are confirmed by pollen analysis of the De Rif midden (Valsecchi et al., 2013) and an aridity index reconstruction using a *pdf*-based modelling technique (Chevalier et al., 2014) applied to the De Rif pollen assemblage (d; shading indicates 20% and 50% errors), which indicate the importance of drought season intensity and length in determining environmental change in the region. First-order similarities between results from the CCSM3 TraCE-21ka transient GCM simulation (He et al., 2013) of austral summer (DJF) (a), and the proxy records support these conclusions, but the lack of a significant Younger Dryas signal in the simulation suggests that the model may not be capturing certain important elements of the global deglacial climate system (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).