

# Last Glacial Maximum simulations over southern Africa using a variable-resolution global model: synoptic-scale verification

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## Abstract

Reconstructing the glacial maximum climates of the Cape south coast region of South Africa is important within the context of understanding the evolution of modern humans in this region. Simulating the Last Glacial Maximum (LGM) climate was also a focal period of the Paleoclimate Intercomparison Project Phase 3 (PMIP3), in order to test the ability of climate models to produce realistic simulations under radiative forcings very different to today's. The purpose of this research is to reconstruct the paleoclimate of the Cape south coast region of South Africa using high resolution regional climate modelling. The model used for this purpose is a variable-resolution global atmospheric model, the conformal-cubic atmospheric model (CCAM), which has been developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. An ensemble of LGM simulations was constructed, through the downscaling of PMIP3 coupled model simulations over southern Africa. A multiple nudging was performed, where CCAM was first integrated globally at a quasi-uniform resolution, with subsequent high-resolution downscaling to southern Africa. This paper describes the global CCAM simulations. The simulations provide new insights into the LGM climate over southern Africa, including evidence that winters during the LGM were significantly wetter than in the present-day climate.

Key words: Last Glacial Maximum, Cape south coast, regional climate model

## INTRODUCTION

This paper focuses on simulations of the Last Glacial Maximum (LGM) climate over southern Africa. The research forms part of a larger project SACP4 (South African Coastal Paleoclimate, Paleoenvironment, Paleoecology, and Paleoanthropology), which explores the paleoscape of the Cape south coast during the latter part of the Quaternary. This region is thought to be of primary importance within the context of the evolution of modern humans. More specifically, the cyclic changes in climate from glacial to interglacial periods is known to have caused dramatic shifts in regional species distributions over the millenia [e.g. Marean et al 2014]. However, there is evidence that early humans thrived along the Cape south coast, under both interglacial and glacial maximums. It is therefore critical to gain insight into the glacial maximum climate of the Cape south coast, to better understand the stresses and opportunities that early humans faced in this region during this critical period in the evolution of our species.

Our focus within the larger SACP4 project is to provide high-resolution simulations of LGM climate over the Cape south coast, which in turn involves the

application of dynamic regional climate model (RCM). The output of the model will be verified against the available paleoarchive evidence, and in a preceding step, the model simulations of the present-day Cape south coast climate are also verified against observations. It may be noted that simulating the LGM is a focal period of the Paleoclimate Intercomparison Project Phase 3 (PMIP3) of the World Climate Research Program (WCRP). PMIP3 provides us with the global simulations of LGM climate, which we need to force the regional simulations. It may be noted that simulating LGM climate is also important from the perspective of testing the ability of climate models to simulate climate under very different radiative forcings. For the LGM, we have relatively good constraints on the main forcing (solar radiative forcing and atmospheric greenhouse gas concentrations). On the other hand, there are limits to which proxy records can reveal information about the state of the climate system during the LGM. In fact, for some of the questions on paleo-climates that cannot be answered using proxy data alone, climate models may be extremely useful to reconstruct the climate of the period in question. The main objective of this paper is to report on simulations of the LGM climate of southern Africa, with the purpose of gaining new insights into the

associated Southern Hemisphere circulation dynamics and surface climate of the Cape south coast.

### EXPERIMENTAL DESIGN

The model used in this paper is the conformal-cubic atmospheric model (CCAM), a variable-resolution global model which has been developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) Marine and Atmospheric Research in Australia [McGregor, 2005]. To obtain high-resolution simulations over the Cape south coast, the model is first applied in quasi-uniform resolution globally and subsequently in stretched-grid mode over southern Africa. The model's ability to realistically simulate present-day southern African climate has been extensively demonstrated (e.g. Engelbrecht et al., 2009; Engelbrecht et al., 2011; Engelbrecht et al., 2013; Malherbe et al., 2013; Winsemius et al., 2014; Engelbrecht et al., 2015).

CCAM is used to perform LGM simulations forced by the sea-surface temperature (SST) and sea-ice concentration (SIC) simulations of six coupled global climate models (CGCMs) of PMIP3. The same sets of models are also used to drive CCAM simulations of present-day climate.

As illustrated in Fig.1, all simulations of present-day climate were obtained for the period 1979-2009. A multiple nudging strategy was followed in order to obtain 8 km resolution simulations of present-day climate over the Cape south coast in South Africa from the initial set of 200 km resolution global simulations. Similarly, 100 years long simulations of LGM climate were obtained, first at 200 km resolution and subsequently at 8 km resolution over southern Africa. In this paper, we present results from the first phase of the downscaling's, namely results from the first ensemble member of the 200 km resolution global simulations.

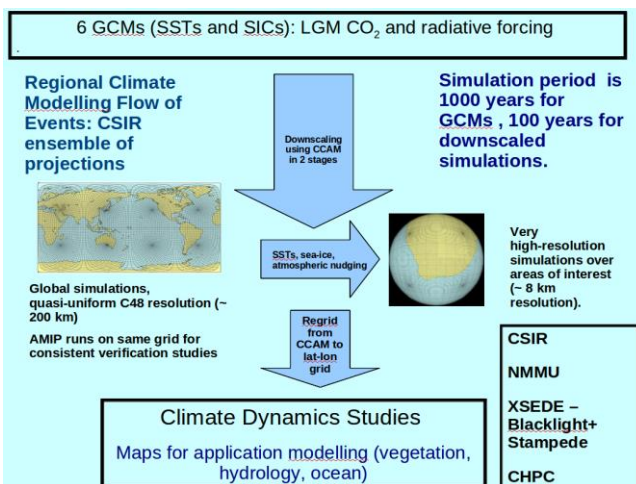


Figure 1: Schematic representation of the experimental design of the paleo-climate simulations over southern Africa.

### Model simulations of present-day climate

A first requirement for confidence in a model projection of climate change is that the model should be able to adequately simulate the present-day climate, since the ability to predict past or future climate depends partly on the model's ability to simulate current climate.

Fig 2 shows the simulated 1000 hPa zonal winds in the southern hemisphere for winter (June - August, JJA) during the period 1979-2009. The values illustrate that the westerlies reach well into southern Africa during the winter of the present-day climate.

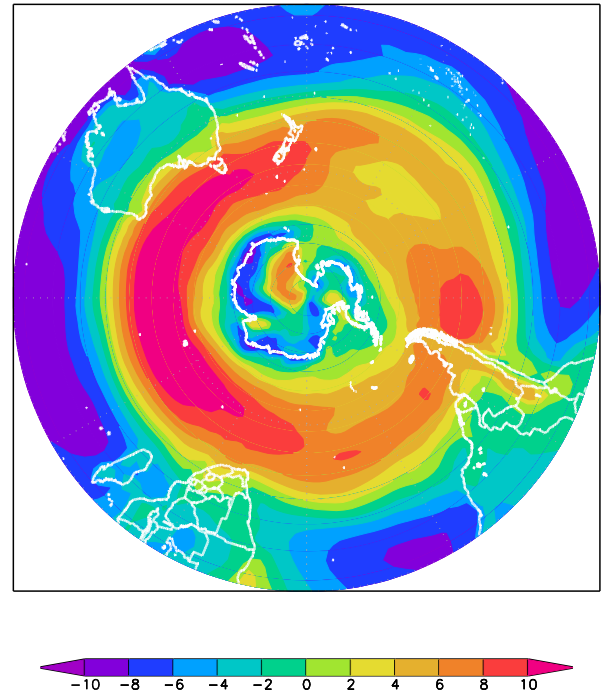
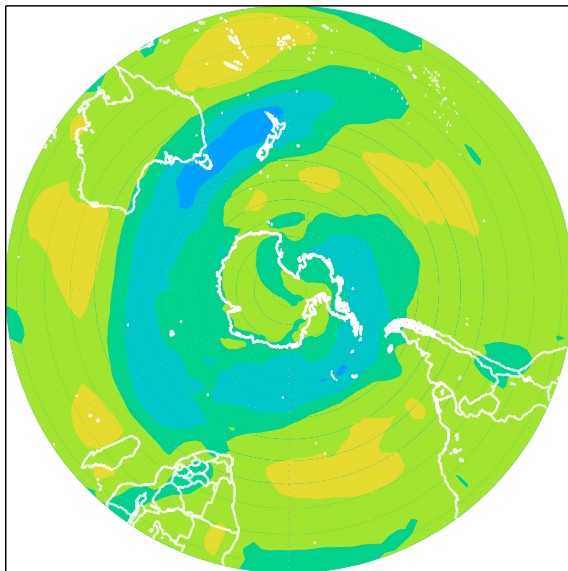


Figure 2: CCAM simulated 1000 hPa zonal winds for the period 1979-2009.

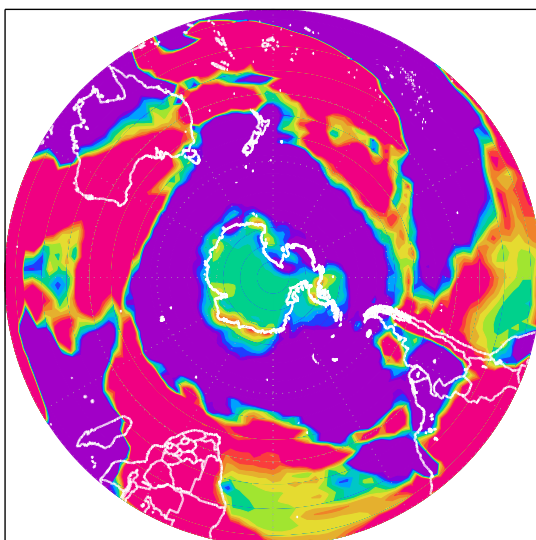
### Model simulations of Last Glacial Maximum climate

Fig. 3 illustrates the changes projected by the model in the westerlies, for the LGM climate as compared to present-day climate. The results are indicative of a clear northwards shift in the westerlies. This would imply more frontal systems reaching the Cape south coast, in association with increased rainfall and a generally cooler climate.



**Figure 3: CCAM simulated 1000 hPa zonal-wind anomalies, for the LGM vs present-day conditions.**

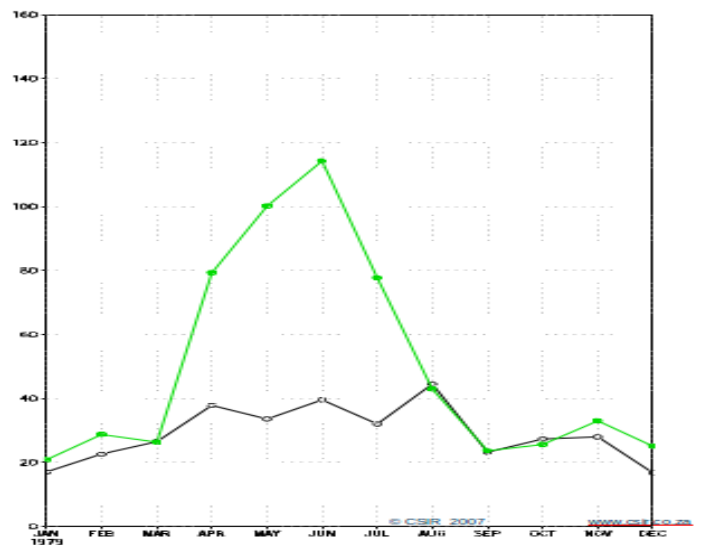
In Fig. 4, we illustrate the model simulated changes in rainfall over the Cape south coast region, for LGM climate compared to present-day climate. The model simulation of present-day rainfall realistically represents the all-year nature of rainfall along the Cape south coast. The results demonstrate that as the westerlies shifted towards the equator, cold front tracks and frontal rain also shifted to the north. Therefore, the model simulates a much wetter winter climate in the southern part of South Africa for LGM than for present-day winters.



**Figure 4: CCAM simulated anomalies winter precipitation, for the LGM vs present-day conditions.**

### Simulated monthly precipitation for Pinnacle Point (Mossel Bay)

Fig. 5 shows the CCAM simulated annual rainfall cycle for the grid box including Pinnacle Point, Mossel Bay (a location of great archeological importance in terms of the evolution of early humans). The x-axis of the graph represents months, whereas the y-axis represents the precipitation. The green line indicates the LGM and the black line indicate the present-day climate (here the model simulations have been bias-corrected using observed data from the Climatic Research Unit). CCAM projects a pronounced increase in winter rainfall over the location, consistent with the projected northward displacement of the westerlies and frontal rain bands. However, the simulations contradict the interpretation of some paleo-proxy data for the Cape south coast. More specifically, the speleothem record for the glacial maximum before the LGM, known as MIS4 (dating to ~74-60 ka), has been interpreted as indicating the occurrence of more summer rain during the LGM [Bar-Matthews (2010)]. Possible explanation for this discrepancy are (1) that the paleoarchive evidence has not interpreted correctly; (2) that conditions differed for the LGM compared to MIS4 and (3) that the LGM simulations performed here are not realistic..



**Figure 5: CCAM simulated annual rainfall cycle at Pinnacle Point, Mossel Bay, for the LGM (green) and present-day climate (black).**

### DISCUSSION AND CONCLUSIONS

The CCAM atmospheric model has been used to obtain global simulations of LGM climate, through the downscaling of PMIP3 CGCM simulations. The single ensemble member analysed here indicates that the LGM precipitation along the Cape south coast may have exhibited a pronounced winter rainfall peak. This result contradicts to some extent the interpretation of the paleoarchive record. The speleothem record of glacial maximum before the LGM has been interpreted as

indicating more summer rain rather than more winter rain [Bar-Matthews (2010)]. The simulations indicate that the paleoarchive evidence may have been interpreted incorrectly since an increase in winter rainfall is highly plausible given the northward displacement of the westerlies during the LGM.

## ACKNOWLEDGEMENTS

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