

# Antarctic stratospheric ozone and seasonal predictability over southern Africa

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## *Abstract*

The impact of time-varying Antarctic stratospheric ozone on southern African summer climate variability is explored through atmospheric global circulation model (AGCM) sensitivity experiments. A control experiment following the design of the Atmospheric Model Intercomparison project (AMIP) was performed first, generating 12 different ensemble members using a lagged-average forecasting approach. These simulations are shown to be skilful in representing southern African summer-season inter-annual variability. This skill can be improved upon, over the entire southern African region, by replacing the climatological ozone distributions in the AMIP experiment by realistic time-varying ozone concentrations.

Key words: seasonal predictability, Antarctic stratospheric ozone, southern Africa, global atmospheric model

## INTRODUCTION

The objective of this paper is to explore the Antarctic stratospheric radiative forcing of climate variability over southern Africa, through a number of novel climate simulation experiments. An atmospheric global circulation model (AGCM), the conformal-cubic atmospheric model (CCAM), is used to perform these experiments. The main hypothesis is that the inclusion of time-dependent radiative forcing in the form of stratospheric ozone in climate models can improve skill in simulating inter-annual variability over southern Africa, in particular for the summer season. Specifically, the notion that summer-season predictability may be improved, stems from recent theoretical and observational studies, which have demonstrated a clear link between Antarctic stratospheric ozone depletion in spring and a lagged response in high- to mid-latitude tropospheric circulation in summer (e.g. Thompson and Solomon, 2002). However, in most state-of-the-art seasonal forecasting or climate simulation systems applied to predict/simulate Southern Hemisphere climate variability, this form of time-varying radiative forcing is not included - the long-term climatological averages are used instead. One possible reason for the current situation is the assumption that seasonal forecast skill largely exists due to tropical sea-surface temperature (SST) forcing of the atmosphere. Due to the large heat capacity of the ocean, this SST forcing can be readily included in seasonal forecasting systems based on AGCMs, using either persisted SST anomalies or predicted SSTs. This paper explores the hypothesis that more-realistic depiction of the atmosphere's ability to absorb and release radiation, through the representation of the time-varying concentrations of stratospheric ozone, can improve the model's skill to simulate/forecast inter-annual summer-circulation variability over southern Africa.

## THE CONFORMAL-CUBIC ATMOSPHERIC MODEL AND EXPERIMENTAL DESIGN

CCAM is a variable-resolution global atmospheric model, developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (McGregor, 2005). It employs a semi-implicit semi-Lagrangian method to solve the hydrostatic primitive equations. The model includes a fairly comprehensive set of physical parameterizations. The GFDL parameterizations for long-wave and short-wave radiation are used, with interactive cloud distributions determined by the liquid and ice-water scheme of Rotstajn (1997). A stability-dependent boundary layer scheme based on Monin Obukhov similarity theory is employed (McGregor et al., 1993), together with the non-local treatment of Holtslag and Boville (1993). In these simulations CCAM was integrated coupled to the dynamic land-surface model CABLE (CSIRO Atmosphere Biosphere Land Exchange Model). The cumulus convection scheme uses a mass-flux closure, as described by McGregor (2003), and includes downdrafts, entrainment and detrainment. CCAM may be applied at quasi-uniform resolution, or alternatively in stretched-grid mode to obtain high resolution over an area of interest. The simulations described here were performed on a C48 quasi-uniform grid (about 200 km resolution in the horizontal), and with 27 levels in the vertical. The CCAM atmosphere is about 50 km deep, and although a higher number of levels in the vertical is certainly preferable to better resolve stratospheric processes, the current spacing does result in realistic simulations of the Southern Hemisphere polar vortex.

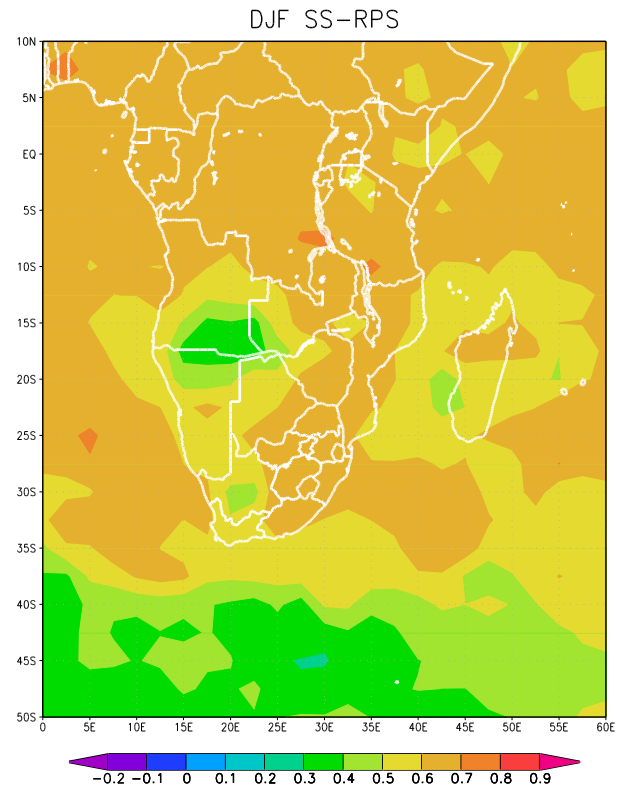
A number of simulations in the style of the Atmospheric Model Intercomparison Project (AMIP) have

been performed to explore the impacts of time-varying ozone forcing on southern African climate. A control experiment was performed first, which followed the specifications of a traditional AMIP simulation: CCAM was forced with observed SSTs and sea-ice at its lower boundary, climatological specifications of CO<sub>2</sub> and stratospheric ozone were applied, and aerosol forcing was set to zero. The simulation was performed for the period February 1978 to December 2005. An ensemble of 12 members was obtained for the control experiment settings, with each member initialized using different initial conditions in February 1978 (using a lagged-average forecasting approach). These simulations were used to establish the baseline skill of the model in simulating inter-annual variability over southern Africa. An additional set of AMIP-style simulations was subsequently performed, also consisting of 12 members, but with the climatological ozone description replaced by the observed time-varying concentrations. The latter were obtained from the Coupled Model Intercomparison Project Phase Five (CMIP5) archive. It may be noted that performing the simulations was computationally- and time-intensive, and relied on the use of a computer cluster of the Centre for High Performance Computing (CHPC) of the CSIR.

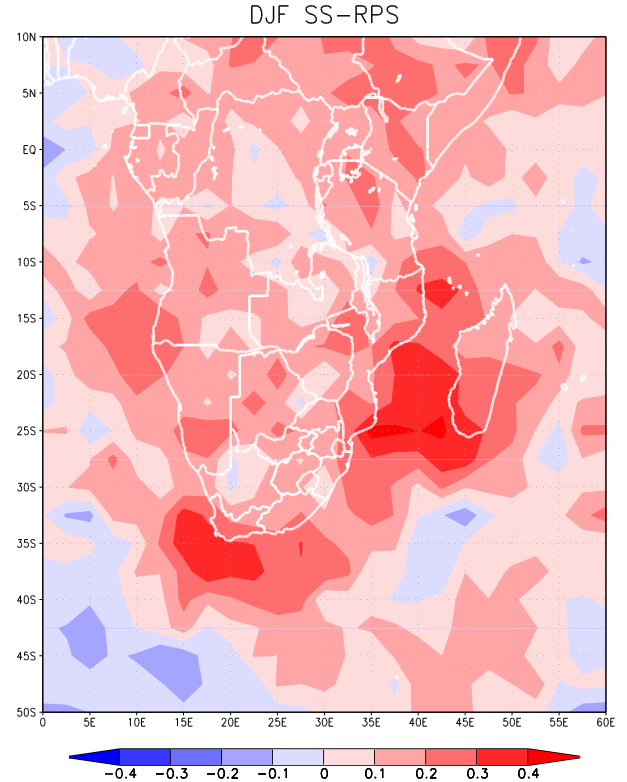
## DISCUSSION

The model skill in simulating year-by-year summer 850 hPa geopotential anomalies over southern Africa (control simulation) is shown in Fig. 1. Skill is measured in terms of the Ranked Probability Skill Score (RPSS), where the climate for 1978-2005 is used as the reference forecast. Prior to this calculation, the geopotential values at each grid point, over the 27 December to February (DJF) seasons between 1978 and 2005, were divided into below-normal, normal and above-normal categories (as defined by terciles). Positive values in Fig. 1 indicate that the model simulations have skill over the reference forecasts based on climatology, whilst negative values indicate areas where the model forecasts are not skilful over climatology. The simulations of summer circulation anomalies are highly skilful, with maximum skill found over the interior regions of tropical Africa and eastern southern Africa. The simulations are less skilful over the western parts of southern Africa, but are still skilful over climatology. The simulations are the least skilful over the Southern Ocean, where the westerly wind regime and fast-propagating frontal systems prevail.

The inclusion of time-varying ozone instead of climatological ozone leads to an improvement in simulation skill over southern and tropical Africa for summer (Fig. 2), compared to the control experiment (Fig. 1). Here the change in skill is depicted in terms of the

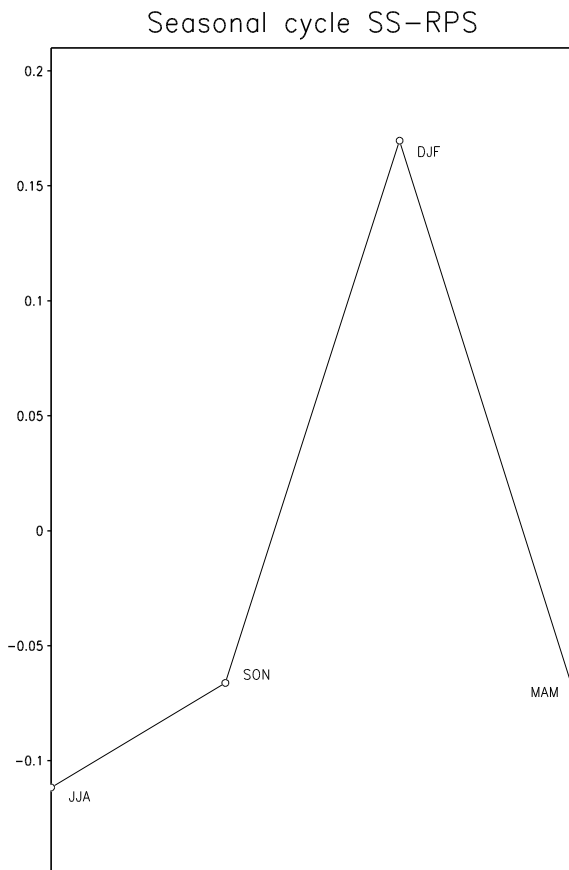


**Fig. 1.** CCAM skill in simulating summer 850 hPa geopotential height anomalies over southern Africa, for the control experiment. The Ranked Probability Skill Score (SS-RPS) is shown, with climatological circulation used as the reference forecast.



**Fig. 2.** Change in CCAM skill in simulating summer 850 hPa geopotential anomalies over southern Africa, for the case of time-varying ozone forcing relative to climatological radiative forcings.

RPSS, but with the CCAM simulations of the control experiment used as the reference forecast. A marked and spatially homogeneous improvement in skill is obtained across the southern African region. This result is consistent with the existing understanding that stratospheric ozone forcing in spring over Antarctica has a chain reaction in the mid-latitudes in the troposphere, lasting into the summer months. However, the propagation of this forcing effect deep into the subtropics and tropics of southern Africa, as suggested by the results obtained, has previously been unknown. It is possible, however, that the improvement in skill obtained is not the result of specifically Antarctic stratospheric ozone forcing, but rather of stratospheric forcing emanating directly from the subtropical and tropical atmosphere. However, similar improvements in skill have not been obtained for the autumn, winter and spring seasons, at least not over the southern African domain. This is demonstrated in Fig. 3, which shows the area-averaged SS-RPS over a southern African domain spanning the region 35 S to 10 S and 10 E to 40 E, for the summer, autumn (March to May, MAM), winter (June to July, JJA), spring (September to October, SON) and summer seasons.



**Fig. 3.** Area-averaged change in CCAM skill in simulating seasonal 850 hPa geopotential anomalies over southern Africa, for the case of time-varying ozone forcing relative to climatological radiative forcings. The southern African domain covers the region 35 °S to 10 °S and 10 °E to 40 °E.

The reductions in skill obtained for the autumn, winter and spring seasons from the inclusion of time-varying stratospheric ozone suggests that the specification of the

time-varying ozone values in the tropics and subtropics is deficient. It also strengthens the deduction that the enhanced skill for summer is obtained due to Antarctic stratospheric ozone forcing in spring. This is an aspect that requires further investigation in future model development research to be performed at the CSIR.

## CONCLUSION

The AGCM CCAM was used to perform AMIP-style simulations designed to investigate the effects of the inclusion of time-varying radiative forcing in the form of stratospheric ozone in improving model skill in representing the inter-annual variability of the seasonal circulation anomalies over southern Africa. The AMIP-style simulations performed span the period 1978-2005. The simulations of the inter-annual variability of seasonal circulation anomalies are skilful for the austral summer in the control experiment. The inclusion of time-varying stratospheric ozone concentrations improves the simulation skill of circulation variability over southern Africa in summer. This result is consistent with dynamic circulation theory, according to which stratospheric forcing over Antarctica in spring has a pronounced mid-latitude response in summer. This study is the first to demonstrate that this response actually reaches the subtropical latitudes of southern Africa. It also implies the potential for an improvement in seasonal forecast skill over southern Africa, in forecasting systems that are initialised in spring using observed stratospheric ozone concentrations.

## ACKNOWLEDGEMENTS

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