THE ROLE OF THE SOUTHERN ANNULAR MODE IN A DYNAMICAL GLOBAL COUPLED MODEL

Asmerom F. Beraki[1,2] and Willem A. Landman[2,3]

[1]South African Weather Service Pretoria, South Africa, asmerom.beraki@weathersa.co.za
[2]Departement of Geography, Geoinformatics and Meteorology, University of Pretoria
[3]Council for Scientific and Industrial Research, Natural Resources and Environment Pretoria, South Africa

The interannual and decadal variability of the Southern Annual Mode (SAM) was examined in the ECHAM 4.5-MOM3-SA ocean-atmosphere coupled general circulation model (OAGCM). The analysis placed emphasis on the behavior of the SAM when its variability and impact becomes noticeable in the extra-tropical subcontinent. Further, the coupling interaction of the SAM with vertically intergraded moisture flux, rainfall and sea surface temperature (SST) was also investigated and compared with observations. The result revealed that the model was successful in capturing observed features of the oscillation. Nevertheless, the model SAM was found to exert more influence on the underlying atmosphere. The analysis unfolded that the low-frequency signal (11years cycle) was more likely explained by natural variability. Further, the model has shown potential in predicting the austral winter slowly evolving climate signal when the temporal vacillation of the SAM is adjusted.

Key works: ECHAM4.5-MOM3-SA, OAGCM, South Africa, Tele-connection, Climate variability.

1. INTRODUCTION

Southern Hemisphere (SH) climate variability was also the focus of several researchers in the early 1980s (e.g., Wallace and Hsu, 1983; Schoeberl and Krueger, 1983). According to these early studies, the SH is characterized by the dominance of quasistationary and zonally propagating waves in the atmospheric circulation. Mo and White (1985) examined the SH teleconnection following the methodology suggested by Wallace and Gutzler (1981) to identify the strongest teleconnection structures. The relationship between the Southern Oscillation and variability in the SH has also been documented in the literature (e.g., Kidson, 1975; van Loon and Madden, 1981; Arkin, 1982; Mo and White, 1984). Trenberth (1981) examined aspects of low-frequency variability of the SH on the interannual timescales with more emphasis on the middle and high latitudes. On the intraseasonal timescale, the SH atmosphere is more dominated by stationary or eastward-propagating wave trains in the meridional belt between 40^{o} and 60^{o}S where the polar jet acts as a waveguide (Berbery et al. 1992).

The Southern Annual Mode (SAM) is characterized by zonally symmetric but out-of-phase pressure anomalies between mid and high latitudes (Limpasuvan and Hartmann, 2000). Previous studies suggested that the SAM is dominant interannual SH mode of variability (e.g., Thompson and Wallace, 2000; Yuan and Li, 2008) and the positive feedback between mid to high latitude eddy activity and zonal flow is responsible for its maintenance (Lorenz and Hartmann, 2001). The influence of SAM on South African (rainfall) climate variability is regulated by the shift of mid-latitude jet stream (Reason and Rouault, 2005). The main objective of the study is therefore to explore the behavior of the SAM and its coupling role in the South African Weather Service (SAWS) ocean-atmosphere general circulation model (OAGCM called the ECHAM 4.5-MOM3-SA; Beraki et al., 2013).

2. DATA AND METHOD

In this experiment, OAGCM's 700 hPa geopotential height (GH) and mean sea level pressure (SLP) are analyzed. The hindcast integrations from which the model data were obtained cover the period from 1982 to 2009 (28 years). The National Centers for Environmental Prediction Reanalysis II (NCEP-R2) Department of Energy (DOE) upper air data (Kanamitsu *et al.*, 2002) are used as a proxy for observations. In addition, optimum interpolation SST (OISST) version 2 (Reynolds *et al*. 2002) and rainfall station data for the same period obtained from the SAWS database.

The OAGCM and observed data were standardized by the square root of the cosine of latitude to balance for latitudinal difference in magnitude of variation. To recover the interannual and longer timescales signals, we also filter the seasonal time series of climate indices with a Gaussian filter (Trenberth, 1984; Yaun and Li, 2008). The coupled model and NCEP SAM indices are computed by projecting the 700mb GH to the leading empirical orthogonal function (EOF; Mo, 2000).

3. RESULTS AND DISCUSSIONS

To examine the ability of the OAGCM to reproduce the observed behavior of the SAM, the loading pattern of the SAM were obtained from the year-round detrended monthly mean anomaly. Since we obtained virtually similar spatial loadings using the SLP and 700mb GH, we adopted the latter to represent the spatial and temporal behaviour of the SAM. Fig. 1 shows the SAM spatial loading of the OAGCM and of the NCEP/DOE. The model is reasonably successful to reproduce the polar and mid-latitude out-of-phase pressure anomalies as shown by the NCEP/DOE. It appears that the signature of the largest variability of the cold season is eminent (Mo, 2000) in the spatial loadings. Notwithstanding, the percentage of variance explained by the leading mode is overestimated in the model (40.85%) compared to NCEP/DOE data (27.53%) suggesting that the SAM may exert more influence on the underlying climate system in the model relative to the observed.

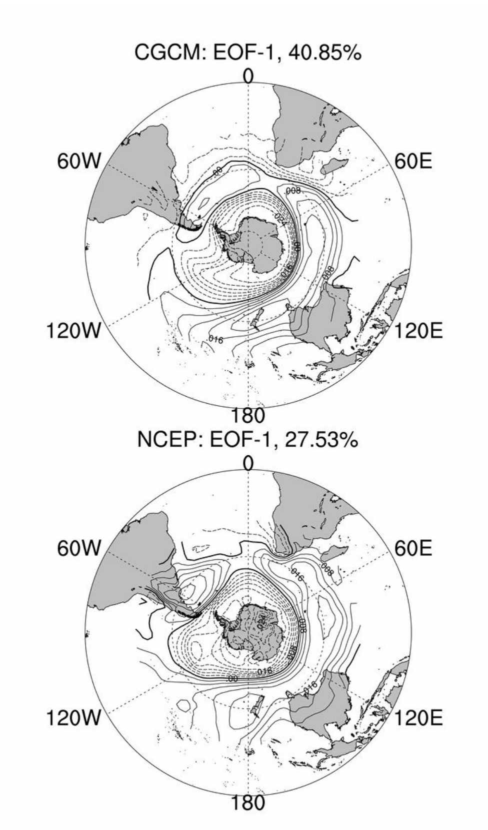

Figure 1, The spatial loading of the leading EOF mode that represents the SAM as found in the 700mb GH and represented by the OAGCM (a) and NCEP/DOE (b). The variance explained by the two systems is also shown.

The temporal variability of the SAM represented by the leading principal component (PC) is depicted in Fig. 2. The interannual and decadal variability of the SAM appear to be predictable according to this result despite the fact the amplitude of the former is overestimated in the models in most cases. The OAGCM is able to capture the low-frequency signal of the 11-years cycle of the SAM during the austral winter from April to September. The model SAM is found mostly to be out-of-phase with NCEP/DOE though it is more imminent during May-to-July (MJJ; inverted for comparison; Fig. 2(b)). The result reveals that the decadal variability of the SAM and its positive phase over the resent decade may largely be attributed to natural variability since the model is forced with the annual cycle of ozone while the anthropogenic forcing is neglected. Notwithstanding, the source of this trend is a matter of scientific debate with stratospheric ozone losses, greenhouse gas increases, and natural variability all being possible contributors (see, Arblaster et al., 2006). Many resent studies, however, attributed the trend to human influences (i.e., either changes in stratospheric ozone or greenhouse warming; e.g., Carril et al., 2005; Cai et al., 2003).

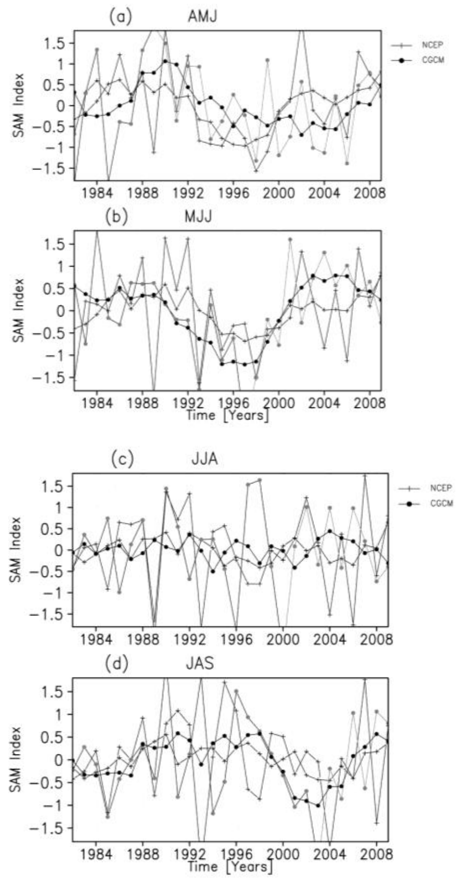

Figure 2, The OAGCM and NCEP/DOE SAM temporal characteristics during the austral winter around July. Grey lines imply seasonal variations while the thicker dark lines are 5 year running mean. The model SAM during MJJ (b) is out-of-phase and inverted for the sake of comparison. The slowly enveloping component (11-year cycle) is correlated statistically significant at the 95% level during AMJ (48%) and MJJ (-61%).

Fig. 3 shows the interannual (decadal) coupling of SAM and rainfall during the austral Winter (MJJ). As suggested earlier, the NCEP and OAGCM are out-of-phase. The result suggests that there is a negative (positive) association between SAM and South African rainfall in the NCEP over the western (eastern) part of South Africa. This result is consistent with other reports (e.g., Reason and Rouault 2005; Gillett et al. 2006). However, the interannual seasonal variation of rainfall is not strongly associated with the SAM (map not shown). The SAM has been dominated by its positive phase over the last decade (Fig. 2) that might be responsible for the recurrent drought of the Western Cape of South Africa (Reason and Rouault 2005).

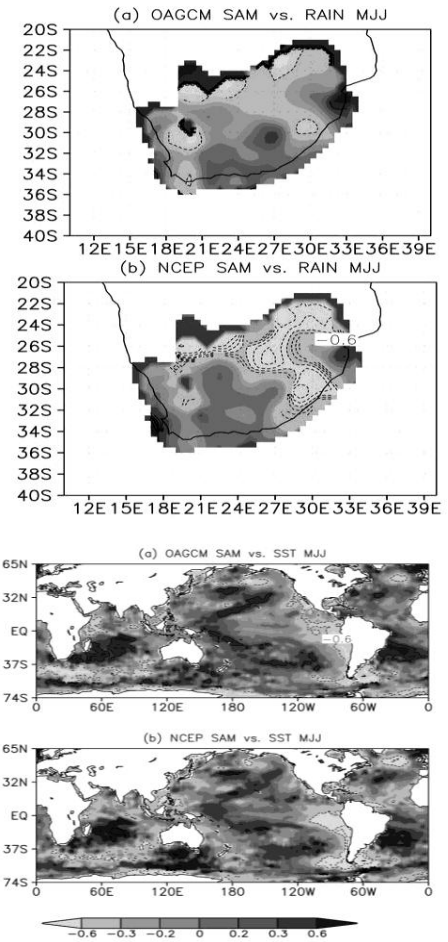

Figure 3, The correlation of the OAGCM's and NCEP/DOE's SAM indices with the observed rainfall (a,b) (SST; c,d) during the austral winter (MJJ). The rainfall and SST was detrended and filtered to recover the slowly enveloping interannual to decadal coupling of the SAM and South African rainfall (global SST). Contours show tele-connection centres that are statistically significant at the 95% level. The OAGCM tele-connections are inverted to facilitate the comparison.

The analysis also reveals that the SAM is positively and negatively associated with the SST on certain locations such as the Indian Ocean adjacent to Madagascar and eastern equatorial Pacific respectively as shown in Figs. 3(c) and (d). Modelling studies indicated that the positive (negative) phase of the SAM apparently strengthens (weakens) the circumpolar westerlies and vortex (e.g., Kushner et al., 2004) which in turns maintains the ability of frontal activities and associated air masses to reach the sub-continent. This may have a tendency of suppressing (conducing) conditions which may promote the transport of colder air and moisture from the adjacent southern Atlantic Ocean. The coupling of the SAM with vertically integrated tropospheric moisture flux may support this notion (map not shown).

What appears to be apparent in the study is that the model SAM is characterized by out-of-phase problem in most cases. This drawback may be attributed to the fact that the model is lacking the sea-ice model. Recent studies have demonstrated the importance of the sea-ice and SAM coupling (e.g., Yuan and Li, 2008). Despite that the cause of the problem need to be identified and rectified, the model may provide useful information on the likelihood of rainfall conditions during the austral winter season (often unpredictable) by correcting the phase of the SAM in the model.

4. CONCLUSIONS

The role of the SAM and its coupling interactions are assessed in a modelling context. The interannual and decadal variability of the SAM appear to be predictable in the ECHAM 4.5-MOM3-SA OAGCM. The result further revealed that the model was successful in capturing observed features of the oscillation. Nevertheless, the model SAM was found to exert more influence on the underlying atmosphere than the NCEP/DOE did. The analysis further unfolded that the long-term low-frequency signal was sufficiently explained by natural variability. However, research on the interaction of OAGCM's SAM with other climate drivers such as the Indian Ocean Dipole (IOD), Pacific South America (PSA) Oscillation should be expanded and further investigated in order to continue to improve on the physics of the OAGCM.

5. ACKNOWLEDGEMENT

The authors gratefully acknowledge WRC and ACCESS for financial assistance and CHPC for providing computational facility.

6. REFERENCES

Arblaster, Julie M., Gerald A. Meehl, (2006) Contributions of External Forcings to Southern Annular Mode Trends. *J. Climate*, **19**: 2896–2905. doi: http://dx.doi.org/10.1175/JCLI3774.1

Arkin, P. A. (1982) The relationship between interannual variability in the 200 mb tropical wind field and the Southern Oscillation. *Mon. Wea. Rev*.,**110**: 1393–1404.

Beraki, A.F., D. G. DeWitt, W.A. Landman, and C. Olivier (2013) Dynamical seasonal climate prediction using an ocean-atmosphere coupled climate model developed in partnership between South Africa and the IRI, submitted to *J. Climate*.

Berbery EH, Nogues-Paegle J, Horel JD. (1992) Wave-like extratropical Southern Hemisphere teleconnections. *Journal of Atmospheric Science*, 49: 155–177.

Cai, W., P.H. Whetton, and D.J. Karoly (2003) The response of the Antarctic Oscillation to increasing and stabilized atmospheric CO2. *J. Climate*, **16**, 1525-1538.

Carril A. F., C. G. Menéndez, and A. Navarra, (2005) Climate response associated with the Southern Annular Mode in the surroundings of Antarctic Peninsula: A multimodel ensemble analysis, *Geophys. Res. Lett*., **32**, L16713,

doi:10.1029/2005GL023581.

Gillett NP, Kell TD and Jones PD (2006) Regional climate impacts of the Southern Annular Mode. Geophys Res Lett 33:L23704.

Kanamitsu, M., A. Kumar, J. K. Schemm, H. M. H. Juang, W. Wang, F. Yang, S. Y. Hong, P. Peng, W. Chen, and M. Ji, (2002) NCEP dynamical seasonal forecast system 2000. *Bull. Amer. Meteor. Soc*., **83**: 1019-1337.

Kidson, J. W., (1986) Index cycles in the Southern Hemisphere during the Global Weather Experiment. *Mon. Wea. Rev*., **114**: 1654–1663.

Kushner, P. J., and L. M. Polvani, 2004: Stratosphere–troposphere coupling in a relatively simple AGCM: The role of eddies. *J. Climate*, **17**: 629–639.

Limpasuvan V and Hartmann DL (2000) Wave-maintained annular modes of climate 16 variability. J Climate 13(24):4414-4429.

Lorenz, D. J., and D. L. Hartmann (2001) Eddy-zonal flow feedback in the Southern Hemisphere. J. Atmos. Sci., **58**: 3312-3327.

Mo, K. C., (2000) Relationships between Low-Frequency Variability in the Southern Hemisphere and Sea Surface Temperature Anomalies. *J. Climate*, **13**: 3599-3610.

Mo, K.C. and C. H. White (1985) Teleconnections in the Southern Hemisphere. *Mon. Wea. Rev*., **113**: 22–37.

Reason, C. J. C. and M. Rouault (2005), Links between the Antarctic Oscillation and winter rainfall over western South Africa, Geophys. Res. Lett., 32, L07705, doi:10.1029/2005GL022419.

Reynolds, R. W., N. A. Rayner, T. M. Smith, and D. C. Stokes (2002) An improved in situ and satellite SST analysis for climate. *J. Climate*, **15**: 1609-1625.

Schoeberl, M. R., and A. J. Krueger (1983): Medium-scale disturbances in total ozone during Southern Hemisphere summer. *Bull. Amer. Meteor. Soc*.,**64**: 1358–1365.

Thompson, D. W. J., and J. M. Wallace (2000) Annular modes in the extratropical circulation, Part I: Month-to-month variability. *J. Climate*, **13**: 1000–1016.

Trenberth, K. E. (1981) Observed Southern Hemisphere eddy statistics at 500 mb: Frequency and spatial dependence. *J. Atmos.* Sci.,**38** : 2585–2605.

Trenberth (1984), Signal versus Noise in the Southern Oscillation. *Monthly Weather Review* **112**: 326-332

Van Den Dool, Huug M., Zoltan Toth (1991) Why Do Forecasts for “Near Normal” Often Fail?. *Wea. Forecasting*, **6**: 76–85.

Yuan, X., and C. Li (2008) Climate modes in southern high latitudes and their impacts on Antarctic sea ice, *J. Geophys. Res.*, 113, C06S91, doi:10.1029/2006JC004067.

Wallace, J. M., and D. S. Gutzler (1981) Teleconnections in the geopotential height field during the Northern Hemisphere winter. *Mon. Wea. Rev*., **109**: 784–812.

Wallace, J. M. and Hsu, H.-H. (1983) Ultra-long waves and two-dimensional Rossby waves. *J. Airnos. Sci*. **40** :2211-2219.