

# INTERACTIONS BETWEEN THE SOUTHERN ANNULAR MODE, ENSO AND SOUTHERN OCEAN SURFACE TEMPERATURES

Ian G. Watterson \*  
CAWCR, Aspendale, Australia

## 1. INTRODUCTION

A recent study (Watterson, 2009) of climate simulations by the CSIRO Mk3.0 coupled atmosphere-ocean model shows that both the model's southern annular mode (SAM) and ENSO drive interannual variations in the temperatures and rainfall of both the continents and oceans of the Southern Hemisphere (SH). While the simulated sea surface temperature (SST) anomalies are small, there is the potential for a feedback on SAM on longer timescales, which may enhance the link between the two modes of variability. Such interactions may generate interdecadal variability of Australian climate, in particular, raising the prospects for long-term predictability. To explore these issues, this study examines both a 1080-y unforced run of the Mk3.5 version of the model and simulations of the atmospheric model (AGCM) in which SAM-related SST anomalies are imposed.

## 2. RELATIONSHIPS IN THE COUPLED MODEL

### 2.1 Indices

Based on Gong and Wang (1999), a simple index  $S$  for SAM in Mk3 is defined from monthly sea-level pressure (PSL):

$$S = (\text{Mean } 65\text{-}60^{\circ}\text{S})/4 - (\text{Mean } 46\text{-}40^{\circ}\text{S})/1.5,$$

where Mean represents the PSL anomaly relative to average annual cycle, averaged over the zonal band given, in hPa. (The exact weightings are not important.) The anomalies of the equatorial Pacific SSTs in the Nino3.4 region are used for the ENSO index,  $E$ .

Seasonal and annual averages were taken for years 81-1160 of the Mk3.5 run, and the indices were detrended before further analysis. The standard deviations (SDs) are larger for winter (JJA) and spring (SON), as seen in Table 1. The SD of decadal means of  $S$  is 0.18 (Table 1), compared with 1.63 for the full monthly series.

	ANN	DJF	MAM	JJA	SON
SD 1-y	0.64	0.68	0.72	1.60	1.31
SD 10-y	0.18	0.20	0.21	0.48	0.38

Table 1. The SD of the SAM index  $S$ , for the annual case, and each season, for both single years (1-y) and decades (10-y).

\* *Corresponding author address:* Ian G. Watterson, CSIRO, PB1 Aspendale, Vic. 3195, Australia; e-mail: ian.watterson@csiro.au

### 2.2 Correlations with grid point variables

The correlation field for pressure with  $S$  is very similar for 1 and 10-yr means, as seen from Fig. 1a, b. A small tropical ENSO component is also seen, and likewise  $E$  relates to the two SAM zonal bands. As a result  $S$  correlates with  $E$  with coefficient  $r$  of  $-0.12$  for monthly values, rising to  $-0.30$  for decadal means.

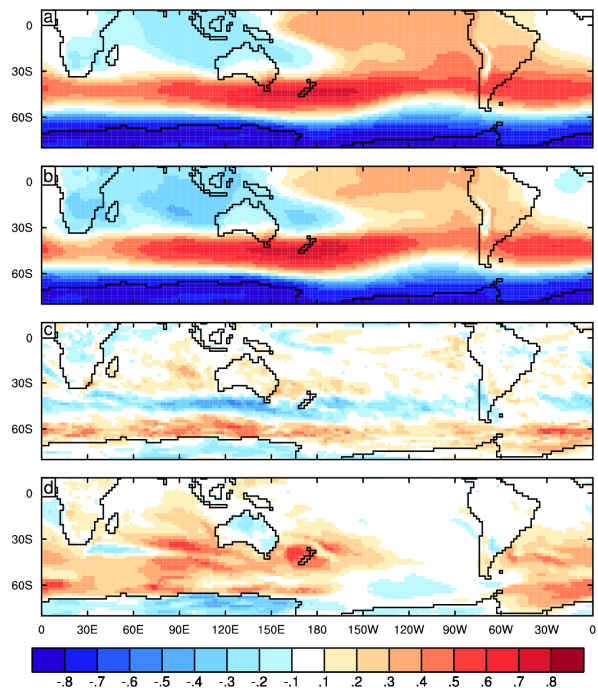


Fig. 1. Correlation ( $r$ ) between the means of the SAM index and grid point values: (a) annual PSL, (b) decadal PSL, (c) decadal rainfall, (d) decadal surface T. For (c) and (d) the index has its ENSO component removed.

Even after removing this decadal ENSO component from the index, SAM relates with much of the interdecadal variability in parts of the SH for rainfall and surface T (Fig. 1c, d), although less for Australia. The dimensional anomaly of surface temperature for a 3 SD index anomaly of the full  $S$  index, shown in Fig. 2c, is modest over Australia, but it is stronger for single years, as seen in Fig. 2a.

### 2.2 SSTs

The SST anomalies associated with annual  $S$  in Fig. 2a show a combination of the model ENSO in the tropics and the familiar SAM pattern (Sen Gupta and

England 2008, Watterson, 2009) of warming in the midlatitudes and cooling further south, except around the Antarctic Peninsula. The SAM anomalies remain as the period is lengthened (2b-d), but unlike those in Mk3.0 and Mk2 (Watterson, 2001), the sign is reversed around East Antarctica. The extratropical anomalies are very nearly as large if the ENSO component of the index is removed, for both annual and decadal cases.

Surface heat fluxes are found to drive much of the broad-scale initial SST response. An analysis of heat convergence associated with currents in Mk3.5 indicates that this contributes to the enhanced warming in the Tasman Sea and off Argentina. Upwelling around the Antarctic coasts can also modify the surface T at longer timescales, and the differences in the stratification around the coast between Mk3.0 and Mk3.5 may cause the different decadal patterns (S. O'Farrell, personal comm.). Note that Böning et al. (2008) have suggested that non-eddy resolving ocean models, like these, do not simulate a realistic sub-Antarctic response to SAM wind stresses, in any case.

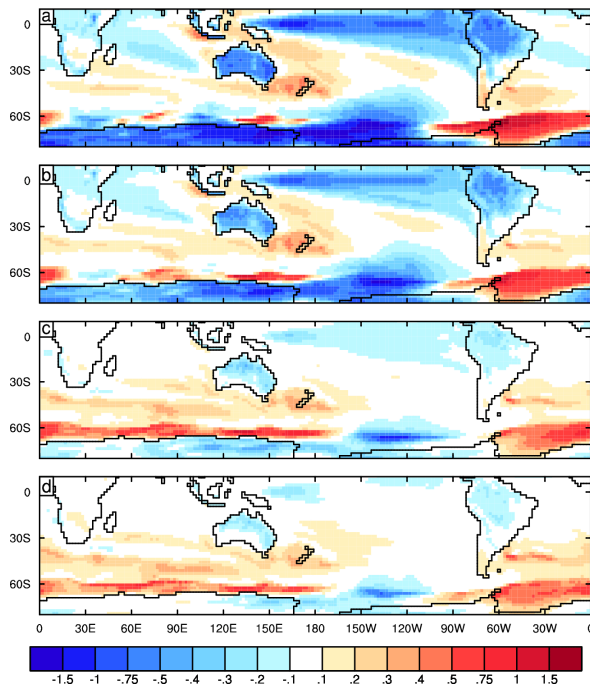


Fig. 2. Dimensional anomalies of surface T (in °C) for a 3 SD anomaly of S for periods of (a) 1, (b) 3, (c) 10, and (d) 27 years.

### 3. FORCED RESPONSE IN THE AGCM

To test the potential response of the atmosphere to these SSTs, the decadal pattern (Fig. 2c) south of 20°S, enhanced to represent 5 SD, was added to the specified annual cycle of SSTs of the Mk3.5 atmospheric model. Means over 30 years (after discarding year 1) of this run (label A) were compared with those from a control run. Assuming linearity, results

were scaled back (by factor 0.57) to 3 SD of the decadal S index (with ENSO removed).

The maps (not shown) of surface air T over the ocean have much in common with Fig. 2c, as expected. Air temperatures aloft are weakly warmed, however there is considerable seasonal variation in this response. The winter case has midlatitude midtropospheric zonal mean warming resembling SAM itself. This is consistent with the PSL anomalies, shown for two seasons and the annual case in Fig. 3, together with the SAM pattern. Calculating the S index from these changes gives the values in Table 2. The winter and annual changes are statistically significant (at 90%), although uncertain, being similar to the decadal SD from the coupled model run (Table 1).

Given the magnitude, and the model dependence, of the sub-Antarctic SST anomalies in Fig. 2c, a further AGCM run, label B, was performed with the 80-54°S anomalies omitted. The results (Fig. 3, Table 2) are similar (not statistically different) to those of run A. The 54-20° S SST anomaly that drives the change has a mean of 0.086°C. The results suggest a positive feedback to SAM. Averaging the SD of annual means of S from these three runs of the AGCM and six others gives 0.53. This compares with 0.61 for S with the ENSO component removed in the coupled model.

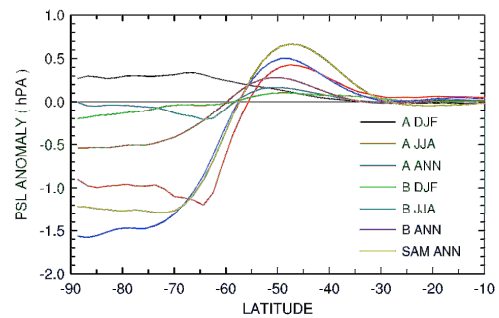


Fig. 3. Zonal mean pressure anomalies forced by SAM-related SSTs for a 3 SD decadal anomaly of S, for summer (DJF), winter (JJA) and annual cases in the A and B runs. The 3 SD decadal SAM pattern (annual case) in the coupled model is shown as SAM ANN.

	ANN	DJF	MAM	JJA	SON
AGCM run A	0.11	-0.03	0.22	0.47	-0.22
AGCM run B	0.14	0.07	0.15	0.40	-0.05

Table 2. Changes in the S index in the AGCM for run A (SSTAs 80-20°S) and run B (SSTAs 54-20°S), scaled as in Fig. 3.

Given recent trends in Australian rainfall, the regional response to these SSTs is of interest. The mean annual and seasonal changes from both runs are shown in Fig. 4 (below). Small changes are seen over the sub-Antarctic SST anomalies in run A. Increases occur over the warmer Tasman Sea in both. There is a weak SAM pattern (Fig. 1c) in the winter and annual cases. However, over land grid squares, including Australia, there are few statistically significant changes.

#### 4. CONCLUSIONS

Based on relationships in the 1080-y run of the coupled Mk3.5 model, positive SAM drives positive midlatitude SST anomalies on interannual time scales. Further experiments with the Mk3.5 AGCM show that these result in a small positive feedback on the atmospheric SAM. In the decadal mean the response is about 20% of the original SAM anomaly. This appears to result in the interannual SD of the SAM index being some 17% larger in the coupled model than in the AGCM. A further enhancement of the index SD, by 4%, occurs because of the model ENSO.

The interannual variability of the SAM index is largest for the winter (JJA) season. Much of the SAM response in the AGCM experiment also occurs in winter. It is conceivable that the variability of multi-year winter averages can be preferentially enhanced, but this is barely evident from the ratio of decadal to annual index SDs (of Table 2).

An interesting difference between SAM-related SSTs in Mk3.5 and Mk3.0 is revealed as the averaging period is increased beyond one-year, with those around the East Antarctic coast changing in sign in Mk3.5 to match anomalies in the midlatitudes farther north. The additional AGCM experiment suggests that these sub-Antarctic anomalies have little influence elsewhere, however.

The results suggest that if a SAM anomaly is forced, e.g. by ozone or global warming, the positive feedback can augment this, particularly in JJA.

Observed midlatitude SST changes over 1950-2006 are at least as large as those imposed in the experiments here, so they may drive some of the observed trend in SAM over those years. The seasonal response may be sensitive to the SST patterns. Further analysis of the trends is warranted.

#### 6. References

Böning, C. W., A. Dispert, M. Visbeck, S. R. Rintoul and F. U. Schwarzkopf 2008: The response of the Antarctic Circumpolar Current to recent climate change. *Nature Geoscience*, 1, 864-869.

Gong D and S. Wang, 1999: Definition of Antarctic Oscillation Index. *Geophys. Res. Lett.*, 26, 459-462.

Sen Gupta A., M. H. England, 2006. Coupled ocean-atmosphere-ice response to variations in the southern annular mode. *Journal of Climate* 19: 4457-4486.

Watterson, I. G., 2001: Zonal wind vacillation and its interaction with the ocean: Implications for interannual variability and predictability. *J. Geophys. Res.*, 106, 23965-23975.

Watterson, I. G., 2009: Components of rainfall and temperature anomalies and change associated with modes of the Southern Hemisphere, *Int. J. Climatol.*, in press (and on-line DOI: 10.1002/joc.1772).

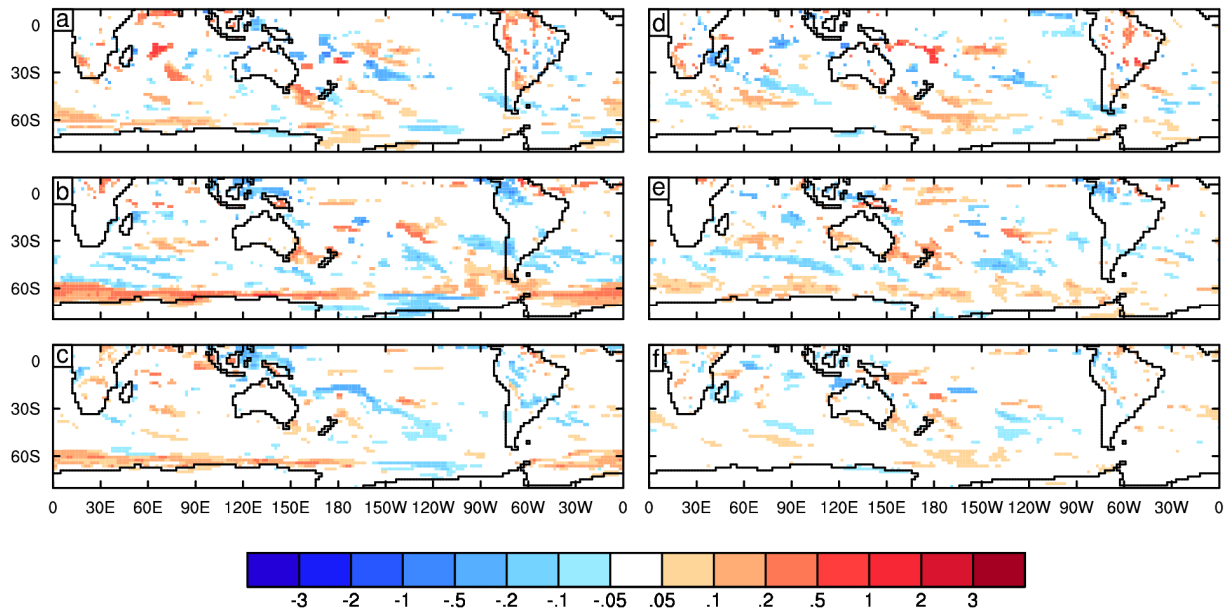


Fig. 4. Rainfall anomalies (in  $\text{mm d}^{-1}$ ) forced by SAM-related SSTs for a 3 SD decadal anomaly of S in the runs A (left) and B (right), for DJF (a, d), JJA (b, e) and annual (c, f) cases. Values at less than 80% significance are omitted.