UNDERSTANDING THE VARIABILITY OF AUSTRALIAN RAINFALL: THE ROLE OF SST ANOMALIES

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1. INTRODUCTION

Australian rainfall has exhibited substantial variability over the past century, including declines in the south in recent decades. These have some consistency in sign with changes expected from the trends in greenhouse gases, ozone and aerosols, but the rainfall trends are not fully understood (e.g., Murphy and Timbal, 2008). Often, there are significant correlations between annual rainfall and sea surface temperatures (SSTs) in the Pacific Ocean and Indian Ocean (IO), which may relate to the trends. In some cases it is unclear whether the SST anomalies drive those in rainfall, or are merely coincidental. A shortage of observational data limits the assessment of decadal variability. To explore these issues, this study examines both a 1080-y unforced run of the CSIRO Mk3.5 coupled atmosphere-ocean model (Gordon and coauthors, 2007) and simulations of the atmospheric model (AGCM) in which SST anomalies were imposed.

2. RELATIONSHIPS IN THE COUPLED MODEL

2.1 Regional Rainfall

Annual averages of simulated grid point data were taken for years 81-1160 of the Mk3.5 PIcntrl run from CMIP3 (see www-pcmdi.llnl.gov), from which 108 decadal averages were formed. These were detrended before further analysis (necessary because of a slow warming over the period). Rainfall was averaged over four regions of particular interest, defined in Fig. 1.

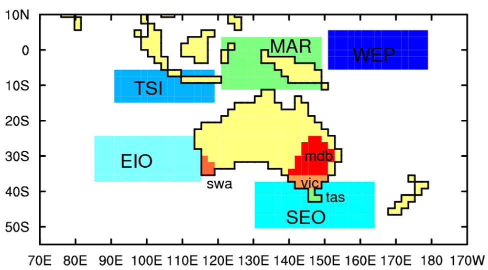

Fig. 1. Regions considered in the study, as represented in Mk3.5. The four land regions are the Murray-Darling Basin (mdb), Southwest Western Australia (swa), Victoria (vic) and Tasmania (tas). Ocean regions are Western Equatorial Pacific (WEP), ‘Maritime’ (MAR), Tropical Southeastern IO (TSI), Eastern IO (EIO) and ocean to the southeast (SEO).

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The mean and standard deviation (SD) for each annual and decadal series are given in Table 1. Aside from mdb the model has a dry bias but it produces plausible relative variability. The decadal series have considerable independence, as seen from the cross-correlations given. Correlations for annual series are similar, both here and for most other results, so the presentation focuses on the decadal results.

Reg.	Mean	SD-1	SD-10	r-swa	r-vic	r-tas
mdb	1.36	0.37	0.11	25	76	30
swa	0.59	0.20	0.06		30	7
vic	1.19	0.29	0.09			61
tas	1.46	0.24	0.07			

Table 1. Statistics of annual rainfall averaged over four land regions. The mean and standard deviations (SD) for both single years (SD-1) and decades (SD-10) are in mm d^{-1}. Cross-correlations (r × 100) between pairs of decadal series are then given.

2.2 Correlations with grid point variables

Correlating the rainfall series with grid point rainfall produces values of typically 0.9 for local points, as expected, but also remote patterns (not shown). The correlations with decadal surface temperature (T) are also often statistically significant (larger than 0.19 for the 95% level), as seen in Fig. 2.

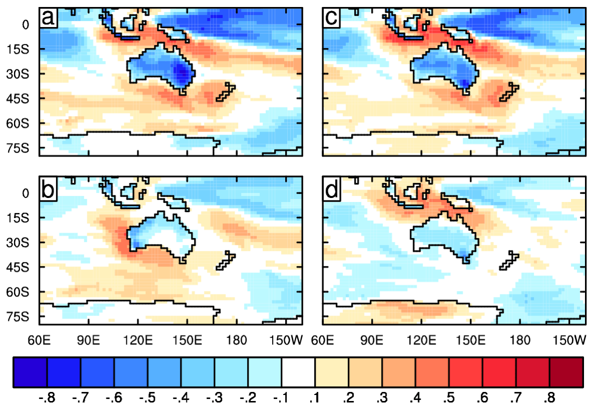

Fig. 2. Correlation (r) between the decadal mean grid point T and regional rainfall for: (a) mdb, (b) swa, (c) vic and (d) tas.

While the anti-correlation for mdb and vic with central equatorial Pacific SSTs is reduced from the annual case, there remains a substantial ENSO-like pattern, particularly in the WEP region, as defined in

Fig. 1. Correlations are moderate, and positive, for the ocean to the southeast (SEO). For swa, the largest correlations are with waters to the west, within the broad EIO region. There is perhaps surprisingly little correlation of tas rainfall with SEO SSTs, but still some with those well to the north, including the MAR and TSI regions. All these five ocean regions have (at least in part) been identified in various previous studies as relating to Australian rainfall variability.

2.3 SST indices

To examine the potential role of the ocean regions further, we consider indices formed by averaging grid point SSTs as for the rainfall series. Correlations between the decadal-mean SST series and grid point values of both T and rainfall are shown in Fig. 3. Local values for T are high, although in the MAR case SSTs to the north east of New Guinea are not coherent with those in the centre of the region, which diminishes the r values.

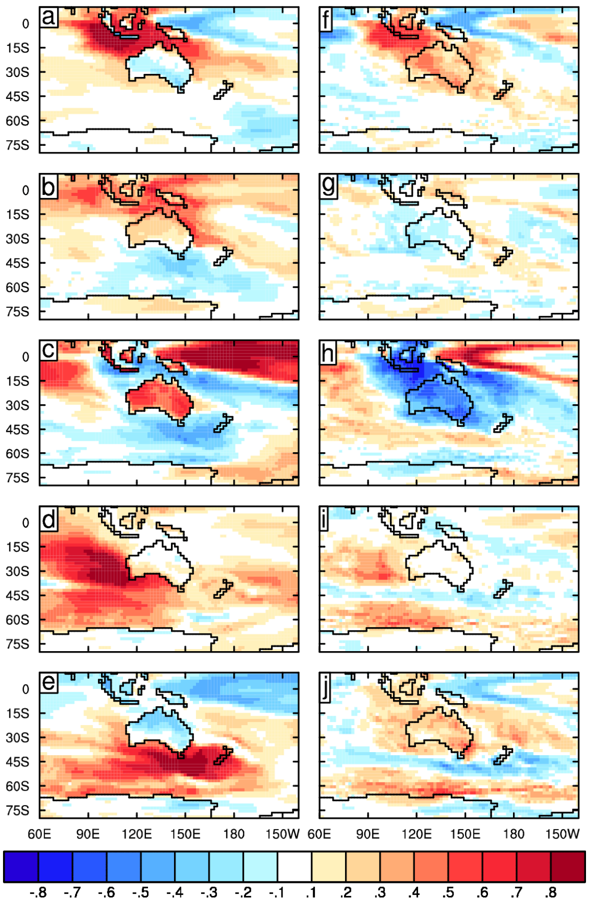

Fig. 3. Correlation (r) between the decadal mean SST indices and grid point T (left) and rainfall (right) for: TSI (a, f), MAR (b, g), WEP (c, h), EIO (d, i) and SEO (e, j).

Rainfall is mostly enhanced over the regions with raised T, although negative r holds for most of SEO (Fig. 3j). The remote rainfall correlations are the main interest. Rainfall over all Australia is positively correlated with the TSI index (Fig. 3f), and negatively correlated with WEP (Fig. 3h). Correlations with the mdb rainfall series are notable: -0.70 for WEP and +0.33 for TSI. Significant correlations with grid point rainfall occur for the other cases in Fig. 3. Results are generally similar for annual values, although the EIO relates more strongly to drier years over eastern Australia. Naturally, there are further variations for individual seasons (not shown).

3. FORCED RESPONSE IN THE AGCM

Of course, such correlations between SST indices and remote rainfall do not prove that the local SST anomalies force those in rainfall. In any case, the SST results in Fig. 3 show that other warmer or cooler regions may be involved (in particular the negative ENSO-like component in Fig 3e). One approach to examine causality is to demonstrate predictability of seasonal rainfall, using time-lagging. In the decadal case, though, we might assume that the rainfall is in near-equilibrium with long-term patterns of SST anomalies. It is of interest to test the potential response of the Mk3.5 atmosphere to localized and steady SST anomalies. For each of the five ocean regions, a simulation of the AGCM was performed in which an idealized anomaly of +1°C over the individual region was added to the specified annual cycle of SSTs in the model. Means over 30 years (after discarding year 1) were compared with those from a control run.

For each case the perturbed ocean region is clearly seen in the anomaly of annual mean surface air temperature plotted in Fig. 4 (a-e). Nearby land is warmed in some cases, in particular the tas region is on average 0.6°C warmer in the SEO case.

The dominant rainfall changes in the maps shown in Fig. 4 (f-j) are increased rainfall over the warmer tropical SSTs. Local rainfall is increased only slightly in the EIO and SEO cases. Indeed, from the averages in Table 4 (row ‘local’), it is seen that the tropical changes are over 10 times those in the midlatitudes.

Rainfall is significantly perturbed away from the ocean region in some cases. The TSI region, which is also associated with the equatorial Indian Ocean Dipole, drives increased rainfall over most of Australia. The WEP drives a rainfall pattern with much in common with the ENSO-like correlations of Fig. 3h, including lower rainfall over Australia, particularly mdb (Table 2). The intervening MAR region drives a relatively small change over Australia with increases in the centre, and also tas. The EIO and SEO regions produce little change, and even the tas rainfall is not enhanced like the surrounding SEO. For most Australian grid points, T change is of opposite sign to that of rainfall change, consistent with the expected surface heat flux perturbations.

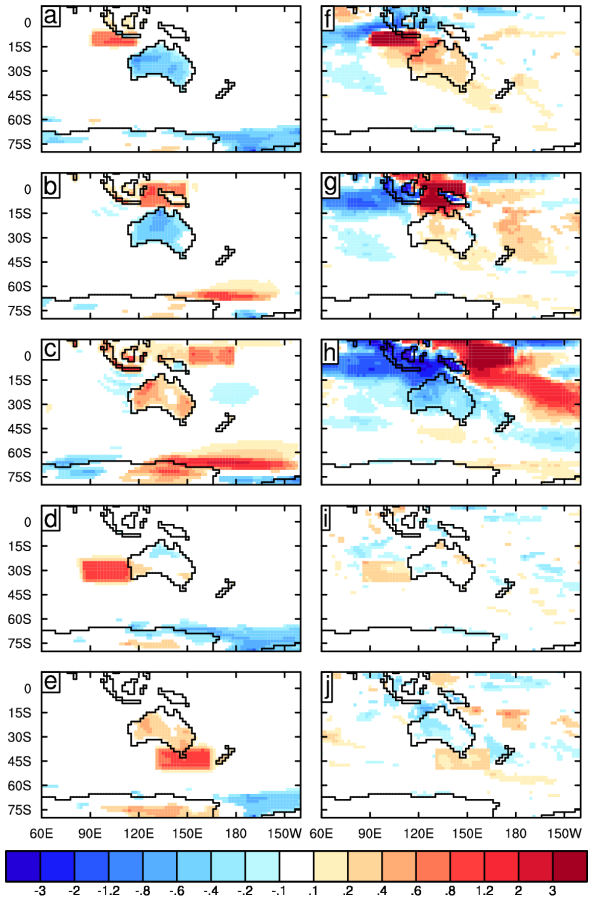

Fig. 4. Mean surface air T (left, in °C) and rainfall (right, in mm d[-1]) anomalies forced by SST anomalies in the five ocean regions, as in Fig. 3. Values at less than 80% significance (based on yearly means) are omitted.

Reg.	TSI	MAR	WEP	EIO	SEO
local	3.25	4.34	6.22	0.22	0.23
mdb	0.23	0.00	-0.34	0.00	-0.11
swa	0.04	0.00	-0.24	0.01	-0.01
vic	0.18	0.06	-0.21	0.06	-0.11
tas	0.13	0.12	-0.04	0.08	-0.03

Table 2. Changes in mean rainfall, in mm d^{-1}, forced by idealized SST anomalies, as simulated by the Mk3.5 AGCM. Each column corresponds to the run with the perturbed ocean region named at the top (in the order of Fig. 3 a-e). The rainfall average is over the region given at the start of each row, with 'local' meaning the ocean region itself

4. DISCUSSION

The classical mechanism for the influence of equatorial SST anomalies is through latent heating associated with perturbed rainfall. This drives circulation changes and teleconnections to the midlatitudes through stationary Rossby waves. The large rainfall (and heating) changes simulated by the AGCM (Table 2), as well as upper-tropospheric wind and surface pressure anomalies (not shown), are broadly consistent with this. Seasonal differences in the propagation occurs, as anticipated by the simple theory of Watterson and Schneider (1987), but even for idealized SSTs, the rainfall changes can be complex (e.g., Fig. 4h), hampering understanding through such theory.

The AGCM anomalies are larger than those in the coupled model, except for annual variations in WEP (with SD 0.8°C). The SD of decadal means of WEP is 0.19°C compared to, at most, 0.13°C for the other four indices. The mdb anomaly from the AGCM for a 1 SD WEP index is -0.064 mm d^{-1}, quite close to that from the coupled model regression fit, -0.078 mm d^{-1}. The AGCM is similarly consistent for pairs involving TSI and vic. However, the correlations with SEO and EIO are either of the wrong sign or too large (especially in the annual case) to be consistent with the AGCM. With the SEO series cross-correlated with the WEP series (r = -0.45), it is likely that WEP is the actual driver.

5. CONCLUSIONS

The 1080-y simulation of Mk3.5 exhibits substantial decadal variability in southern Australian rainfall. Averages over the Murray-Darling Basin, Victoria and SW Australia correlate significantly with variations in SSTs of surrounding oceans. Experiments with the AGCM show that a warmer west Pacific drives lower rainfall over Australia, in contrast to SSTs further west. However midlatitude SST anomalies have much less impact, both locally and over Australia, suggesting that relationships involving them are coincidental. The results may contribute to an understanding of recent observed decreases in rainfall, and are of interest to seasonal predictability also.

This work contributes to the SEACI research program.

6. References

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Watterson, I. G. and E. K. Schneider (1987) The Effect of the Hadley Circulation on the Meridional Propagation of stationary waves. *Q. J. Roy. Met. Soc.*, 113, 779-813,