SEACI Project 2.1.5a: Analysis of outputs from climate change experiments

Draft Report

Topic: Simulation of climate and climate change by global models

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Specific Project:The Application of an Automatic Synoptic System Identification Algorithm to CSIRO Mark 3 Climate Model Output

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Overall Project Objective: Relate rainfall changes over South-Eastern Australia and Murray-Darling Basin from the CSIRO Mark 3 Model to synoptic events

This Project Sub-Component Objective: To carry out a climatological synoptic analysis of the CSIRO Mk3 Model daily fields to determine the frequency of occurrence and the distribution of cutoff lows over southeastern Australia in the model, and relate these to rainfall.

Methodology: Using an automated objective technique, identify cutoff lows in the Mk3 model daily fields over southeastern Australia and compare the statistics obtained for the historical period with an approximately 30 year manual analysis of NCEP data for northwestern Victoria. The related rainfall can be assessed using techniques recently published by Watterson (2006?).

1. Introduction

Numerical weather prediction (NWP) models have achieved a high level of accuracy in simulating the behaviour of synoptic weather systems for periods up to a week or so. However, although numerical climate models are known to give a realistic representation of the mean state of the atmosphere, the extent to which these models simulate faithfully the mix of synoptic systems in the real atmosphere has been less well demonstrated.

Investigations of individual rainfall events over southern Australia in winter and more broadly, in the cropping season (April to October), have identified the cutoff low as one of the most significant synoptic rain-producing weather systems (Pook et al., 2006; Qi et al., 1999; Griffiths et al., 1998; Mills and Wu, 1995; Wright, 1989; Hill, 1969). Cutoff lows have been shown to contribute at least 50% of rainfall in northwestern Victoria during the growing season and 80% of daily rainfall events exceeding 25 mm per station (Pook et al, 2006). These major rain events are not only critical to agricultural production but they also represent an important source of run-off into Australia's inland river systems. Since seasonal and long-term rainfall represents the integrated contribution of a finite number of synoptic weather systems it is highly desirable that a climate model is capable of a realistic treatment of cutoff lows if it is to provide reliable rainfall trends.

In order to more readily investigate the occurrence of cutoff lows in various regions of Australia and their identification within numerical models an automated objective technique has been devised. The automated system is designed to apply the objective rules developed and applied by a trained synoptic analyst to identify cutoff lows in a manual analysis program.

2. Data

The data for the original synoptic analyses were obtained from the National Centres for Environmental Prediction (NCEP) - National Centre for Atmospheric Research (NCAR) climate reanalysis data set (Reanalysis 1) [Kalnay et al. 1996; Kistler et al. 2001]. NCEP produces 4 analyses per day (at six-hourly intervals from 0000 UTC) at a resolution of 2.5˚ latitude by 2.5˚ longitude for the standard atmospheric levels from the surface to the lower stratosphere. The analysed fields employed in this analysis were mean sea level pressure (MSLP), the geopotential height of the 500 hPa pressure surface, the (computed) 1000-500 hPa atmospheric thickness and the 1000-500 hPa thickness anomaly relative to the long-term climatology.

Additionally, daily weather maps at 2300 UTC published in the Australian Bureau of Meteorology's 'Monthly Weather Review' series (Simmonds and Richter, 2000) were used in parallel with NCEP/NCAR for the manual analysis. As discussed in Pook et al. (2006), the starting point for the manual analysis was set at 1970. For the purposes of this comparison, the analysis concludes in October 2000.

The CSIRO Mark 3 Climate Model (Gordon et al., 2002) was chosen as a 'state of the art' climate model which has been subjected to rigorous testing in the Australian region. Output from the ‘N20’ run of the model was selected as suitable for application of the automated cutoff low identification system. An equivalent period to the period 1970 to 2000 in the model history has been selected for analysis from the Mark 3 model run. As for the NCEP/NCAR the analysed fields employed in this analysis were MSLP, 500 hPa geopotential, 1000-500 hPa thickness and the 1000-500 hPa thickness anomaly relative to the long-term climatology (1941 to 2000).

3. Method

An automated identification system was developed which applied the criteria adopted within the manual analysis system to identify cutoff low pressure systems in a given analysis set. The analysis region was defined by a fixed box with limits, 30˚S, 127.5˚E; 30˚S, 147.5˚E; 42.5˚S, 147.5˚E and 42.5˚S, 125˚E as shown in Figure 1.

Following previous experience in the manual analysis program the criteria for cutoff low identification which were adopted for the automated system are:

a). A closed low is present at 500 hPa with an associated cold trough evident in the 1000-500 hPa thickness field as evidenced by a negative thickness anomaly from the long-term mean of at least 20 geopotential metres.

Or

b). A closed low is present in the surface MSLP field (<1007 hPa) and an associated cold trough is located aloft with a negative thickness anomaly from the long-term mean of at least 20 geopotential metres.

All days during which a cut-off low could be identified in the analysis region from any of the analysis times, whether or not rain was reported over the designated rainfall station network, were counted as ‘cutoff days’. In the manual system, these conditions were assessed by the analyst but in the automated system curvature and u component constraints were applied to determine that a closed circulation was present.

4. Results and Statistics

Figure 2 demonstrates that the mean number of cutoff days per growing season which were identified within the Mark 3 Model data (21.2) is less than half (46%) the number obtained in the original manual analysis (45.9) and only about 10% of growing season days. By way of contrast, application of the automated system within the NCEP/NCAR Reanalysis data returns a mean seasonal value for the number of cutoff days of 48.2 days (105% of the manual result) which amounts to 23% of growing season days.

In Figure 3 the monthly distribution of cutoff days for the Mark 3 Model is contrasted with the results for NCEP/NCAR and the manual system. The Mark 3 monthly distribution has a minimum in July (2), a maximum in October (4.9) and a secondary maximum in April (3.7). The most striking aspect of the monthly distribution is the low frequency of occurrence in the winter months. In the NCEP experiment, there is a minimum in April (5.5), and a maximum in October (8.7) with approximately constant values in winter (6.6 -7). The manual analysis has a similar profile to that obtained from NCEP in autumn and winter but there is a marked divergence between the NCEP and manual results in October which has not yet been explained.

5. Discussion and Conclusions

An automated analysis system applied to output from the CSIRO Mark 3 model has identified less than half the number of cutoff low days per growing season found in a similar experiment using NCEP/NCAR reanalysis data. The results of the NCEP/NCAR experiment agree closely with those obtained for the growing season in the manual analysis system employed by Pook et al. (2006). In turn, the numbers of cutoff low days found by Qi et al. (1999) when adjusted to apply to a similar region of southern Australia are in broad agreement with the manual analysis results.

The treatment of the seasonal cycle of cutoff low days by the Mark 3 model is an important outcome of this experiment. Although the model accurately captures the winter precipitation rate for northwestern Victoria of approximately 1.2 mm per day (see Fig. 4 of Preliminary Report by I. Watterson, 23 November, 2006) it achieves this rate with only 30% of the observed cutoff low days. This raises the issue for synoptic climatologists of whether the model is getting the precipitation correct via incorrect synoptic meteorological mechanisms (see for example, Risbey and Stone, 1995). This appears to be the case in winter, at least, where the MSLP mean in Mark 3 greatly overestimates the meridional pressure gradient between 30˚S and 45˚S and fails to capture the marked high pressure ridge in the South Tasman Sea (see Fig. 3 of Preliminary Report by I. Watterson, 23 November, 2006). The latter is a surface reflection of the 'split' that develops in the westerly flow in the region as blocking frequency reaches its annual peak. Its virtual absence in the model suggests that a 'cutting-off' mechanism over southeastern Australia is poorly developed.

6. Suggestions for Future Work

The discrepancy in numbers of cutoff low days in October between the NCEP and manual analyses indicates that the automated identification system requires further refinement.

It would be a valuable exercise to run the automated system with output from the CSIRO Mark 3.5 climate model in order to determine if it better captures the cutoff low statistics than the Mark 3 model.

As the identification system has only been run for an analysis box located over southern Australia and the Great Australian Bight it would be desirable to select an analysis region which is more representative of the Murray –Darling Basin.

References

Gordon, H. B. et al. (2002): The CSIRO Mk3 Climate System Model. *CSIRO Atmospheric Research Technical Paper* **60**. 130 pp.

Griffiths, M,, M. J. Reeder, D. J. Low and R. A. Vincent, 1998: Observations of a cut-off low over southern Australia. *Q.J.R. Meteorol. Soc.*, **124,** 1109-1132.

Hill, H. W., 1969: A cyclonic disturbance in the upper troposphere associated with widespread rain over southeastern Australia. Tech. Note No. 92, WMO No. 228, TP 122, *Symp. Hydrological Forecasting*, Surfer's Paradise, Australia, 37-50.

Hines, K. M., D. H. Bromwich and G. J. Marshall, 2000: Artificial surface pressure trends in the NCEP-NCAR reanalysis over the southern ocean and Antarctica. *J. Climate*, **13,** 3940-3952.

Kalnay, E. and Coauthors, 1996: The NCEP/NCAR 40-year reanalysis project, *Bull. Amer. Meteor. Soc.*, **77**, 437-471.

Kistler, R. and Coauthors, 2001: The NCEP/NCAR 50-year reanalysis project, *Bull. Amer. Meteor. Soc.*, **82**, 247-267.

Mills, G.A. and B-J. Wu, 1995: The 'Cudlee Creek' flash flood – an example of synoptic-scale forcing of a mesoscale event. Aust. Met. Mag., **44**, 201-218.

Pook, M. J., P. C. McIntosh and G. A. Meyers, 2006: The Synoptic Decomposition of Cool-Season Rainfall in the Southeastern Australian Cropping Region. *Journal of Applied Meteorology and Climatology*, **45**, 1156–1170.

Qi, L., L. M. Leslie and S. X. Zhao, 1999: Cut-off low pressure systems over southern Australia: climatology and case study. *Int. J. Climatol*., **19**, 1633-1649.

Risbey, J. S., and P. H. Stone, 1996: A Case Study of the Adequacy of GCM Simulations for Input to Regional Climate Change Assessments. *J. Climate,* **9,** 1441-1467.

Simmonds, I. and T. Richter, 2000: Synoptic comparison of cold events in summer and winter in Melbourne and Perth. *Theor. Appl. Climatol.*, **67,** 19-32.

Wright, W. J., 1989: A synoptic climatological classification of winter precipitation in Victoria. *Aust. Met. Mag.*, **37**, 217-229.

Figures

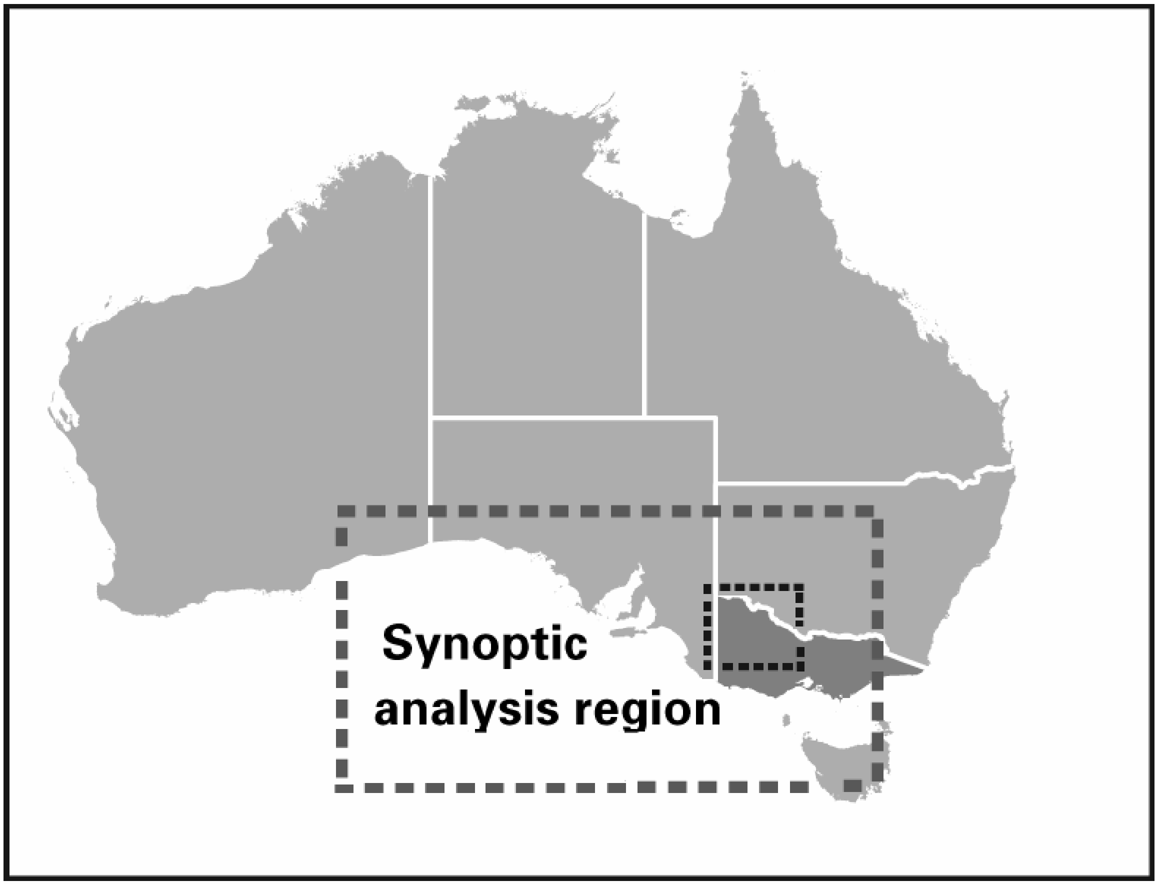

Figure 1. Map of Australia showing the region within which the analysis of synoptic systems, including cutoff lows, was confined. The smaller box delineates the region of Victoria containing the eight high quality rainfall stations used in the original daily rainfall analysis as described in Pook et al. (2006).

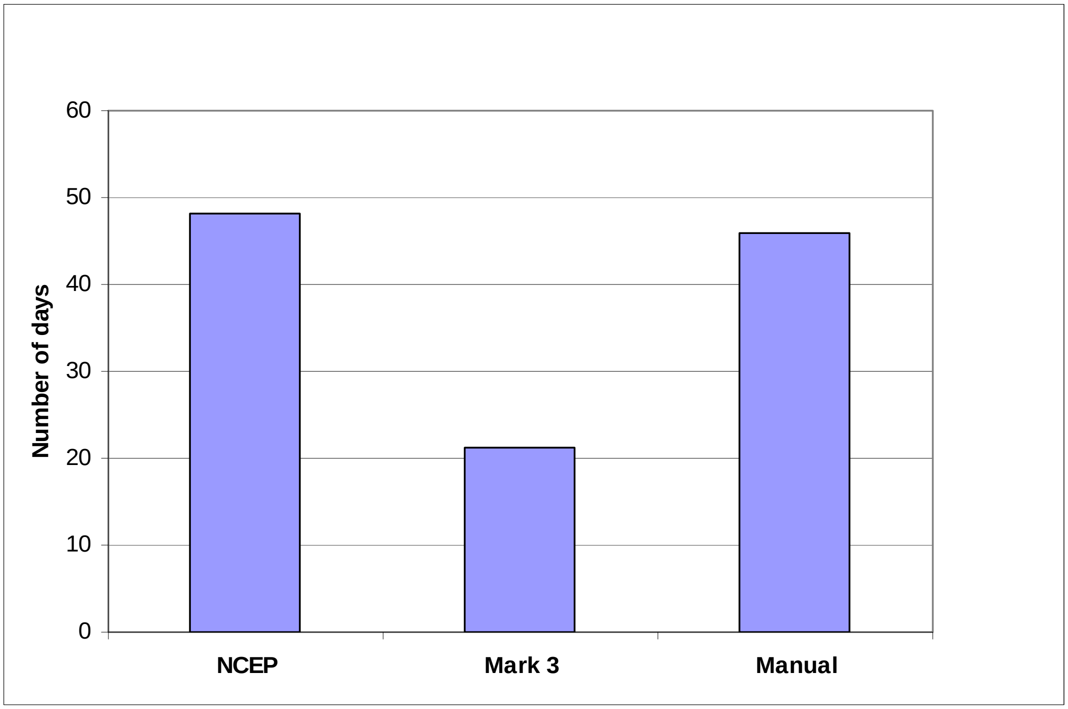

Figure 2. The mean number of days per annual growing season (April to October) on which cutoff lows were identified by the automated system within the designated region for the NCEP/NCAR Reanalysis and the CSIRO Mark 3 Model fields. The results from the manual analysis for the same period (1970 to 2000) are included for comparison.

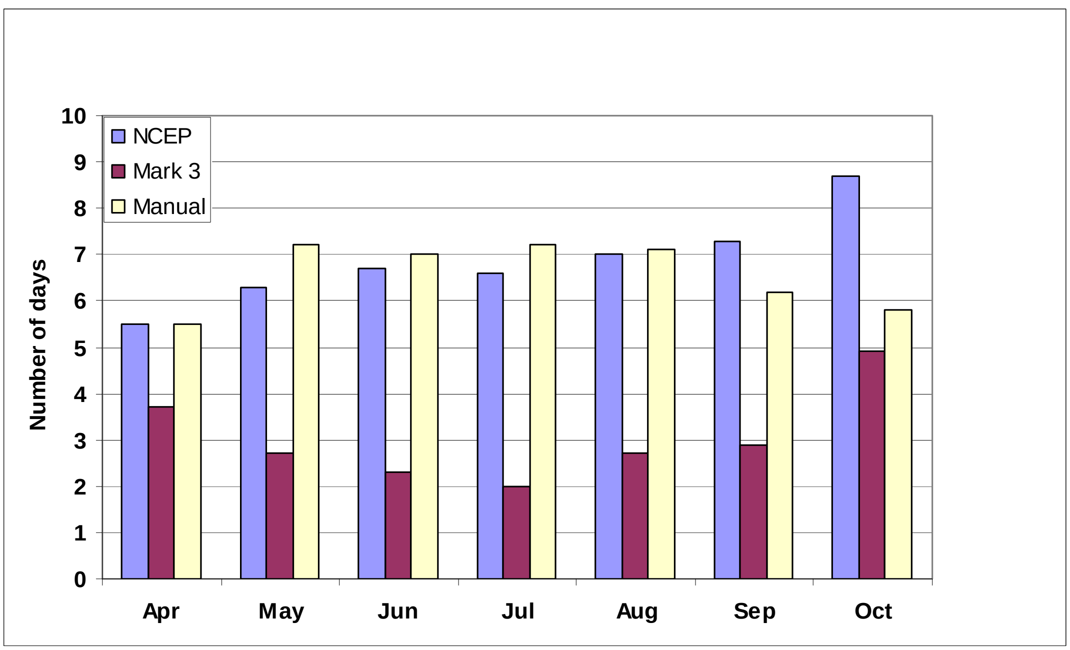

Figure 3. The mean number of days per month on which cutoff lows were identified by the automated system within the designated region for the NCEP/NCAR Reanalysis and the CSIRO Mark 3 Model fields. The results from the manual analysis for the same period (1970 to 2000) are included for comparison.