PROJECT 1.1: DETECTION AND ATTRIBUTION OF CHANGES TO WEATHER SYSTEMS AND LARGE SCALE CIRCULATION DRIVERS

Principal Investigators

Carsten Segerlund Frederiksen, Bureau of Meteorology, Centre for Australian Weather and Climate Research, PO Box 1289, Melbourne, Victoria, 3001

Phone: 03 9669 4566; Email: c.frederiksen@bom.gov.au

Jorgen Segerlund Frederiksen, CSIRO Marine and Atmospheric Research, Centre for Australian Weather and Climate Research, Private Bag 1, Aspendale, Victoria, 3195, Phone: 03 92394683; Email: jorgen.frederiksen@bom.gov.au

Milestone 1.1.1 *Report on observed changes in mean SH climate and high frequency systems affecting WA* (Completed 31/12/2009)

This milestone has been completed and was reported on extensively in the IOCI3 Report 1.

Milestone 1.1.2 *Report on simulated changes in mean SH climate and transients under observed anthropogenic forcing* (Completed 31/12/2009)

This milestone has been completed and was reported on extensively in the IOCI3 Report 1.

Milestone 1.1.3 *Report on observed changes in low frequency weather systems affecting WA in both observations and models* (Progress Report – due to be completed 31/12/2010)

Key Research Findings

Twentieth century changes in Southern Hemisphere low frequency weather systems that affect WA during July have been studied using a global two-level primitive equation instability model. Focus has been on changes between the time intervals (1949-68), (1975-94) and (1997-2006), with emphasis on mid-latitude blocking, Northwest Cloudband (NWCB) disturbances and Intra-seasonal Oscillation (ISO) modes.

While there have been large reductions in July rainfall over SWWA since (1949-68), there have been slight increases over central WA. Our work has sought to understand likely causes of these rainfall differences, by examining the changes in the properties of the NWCB and ISO modes, in particular, which are known to affect rainfall over the sub-tropical regions of WA.

Our results show that the leading NWCB modes crossing WA have increased their growth rates by ~25% in the time interval (1975-94) compared with (1949-68), and by ~45% in the time interval (1997-2006) compared with (1949-68). The leading NWCB modes have periods of about 8 days throughout. These modes consist of wave trains of high and low pressure anomalies that originate in the Indian Ocean and propagate eastward over Australia and into the South Pacific, and affect rainfall over central WA.

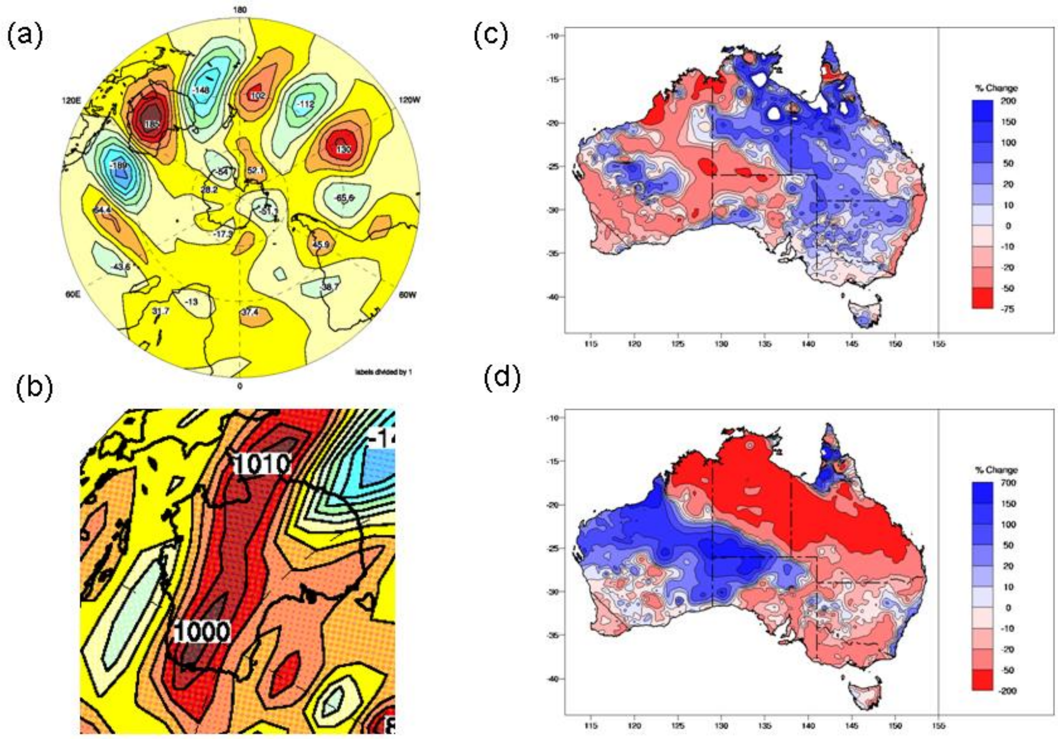

Figure 1.1.1 (a) The 300 hPa streamfunction of the leading NWCB disturbance mode at a particular phase emanating from the central Indian Ocean and propagating eastward over Australia; (b) the upper level divergence (proportion to rainfall) associated with the leading NWCB mode; (c) % change in rainfall (1975-94)-(1949-68); (d) % change in rainfall (1997-2006)-(1949-68).

The impact of the NWCB modes on WA July rainfall is illustrated in Fig.1.1.1 for the leading NWCB mode. Fig.1.1.1 (a) shows the structure of 300hPa streamfunction of the leading NWCB mode. It consists of a wave train emanating from the central Indian Ocean with maximum impact over central WA and propagating eastward across Australia and into the South Pacific Ocean. Fig1.1.1 (b) shows the corresponding 300hPa divergence of this mode, which is proportional to precipitation, and has maximum impact over central WA. Figs 1.1.1 (c) and (d) show the percentage change in rainfall between the periods (1975-94) and (1949-68), and the periods (1997-2006) and (1949-68), respectively. Consistent with the increasing growth rate, and hence greater potential for development of the NWCB weather systems, there are continuing increases in the percentage change in rainfall over central WA.

The leading intra-seasonal oscillation modes also consist of propagating wave trains of pressure anomalies extending again from central Indian Ocean across central and northern WA. Their growth rates have also increased by about 30% in the time intervals (1975-94) and (1997-2006) compared with (1949-68). As well, the periods of these modes have reduced from ~60 days to ~40 days to ~25 days in the later times. Both increases in the growth rate of the NWCB and ISO activity at later times would be consistent with increases in rainfall over central WA.

We have also studied the changes in blocking modes between the different time intervals in the 20th century. Leading blocking modes primarily have effects on eastern Australia. Leading mid-latitude blocking modes have dipoles over and to the east of the Tasman Sea. During the time intervals (1975-94) and (1997-

2006) there is a reduction in growth rates of the leading mid-latitude blocking modes of ~11% and ~19%, respectively compared with (1949-68). For higher latitude blocking modes, the changes between the three time intervals are not significant.

An examination of the high latitude, or Antarctic, modes, such as for example the southern annular mode (SAM) during the three time intervals, show little systematic change in their structure or growth rate, suggesting that there is little relevance to the changing climate of WA during the 20th century.

Milestone 1.1.4 *Report on possible projected changes in SH circulation and WA weather systems under future IPCC scenarios* (Progress Report – due to be completed 31/12/2010)

Key Research Findings

The ability of models from the Coupled Model Inter-comparison Project Three (CMIP3) to reproduce changes in the large scale southern hemisphere circulation that relate to the observed changes in storm development over SWWA between the periods (1949-1968) and (1975-1994) has been further investigated. In particular, we have evaluated the models' ability to capture the observed changes in the Phillips instability criterion, which is a useful diagnostic for identifying changes in the growth rate and preferred location of storm development. About a third of the twenty-two models we looked at are able to reproduce to some extend the sign of the changes, but tend to underestimate the magnitude. In the observations reductions of about 4-5 ms^{-1} upstream and over SWWA are associated with a 33% reduction in growth rate and hence less storm development; the best model has reductions of about 3-4 ms^{-1} , while most "good" models have reductions about half the observed.

Interestingly, when sea surface temperatures (SST), natural and anthropogenic forcings are used in the atmosphere-only general circulation experiments of the Climate of the Twentieth Century (C20C) project, all the models that we had access to showed changes in the Phillips criterion between the periods (1949-1968) and (1975-1994) with similar magnitudes to the NCEP changes. The fact that the atmospheric component of many of these CMIP3 models can reproduce the large circulation changes associated with the Phillips criterion when forced by observed SST anomalies and prescribed forcings suggests that many of the coupled models are not able to correctly reproduce these SST anomalies. This may point to problems with the ocean component or the coupling between the ocean and atmosphere in these models.

We have also looked more closely at the relationship between changes in the Phillips criterion and changes in winter rainfall during the twentieth century and the extent to which climate models capture them. In particular, we have investigated possible linear trends in the Phillips criterion and rainfall, and the decadal variations about these trends, to try to elucidate the roles of anthropogenic forcing and internal variability. Observed trends in the Phillips instability criterion are about -0.12 ms^{-1} per year upstream and over SWWA and highly statistically significant, while "good" model trends are at best half this value and not as significant. Corresponding rainfall trends over SWWA are about -0.4mm/month per year, while "good" model trends are again about half. Both the observed and model results suggest that a 1 ms^{-1} reduction in Phillips criterion is associated approximately with a 6mm/month reduction in rainfall over SWWA.

Based on our evaluation of the CMIP3 models, we have focussed on the *miroc3_2_hires* and *miroc3_2_medres* models to investigate possible future trends and changes in the Phillips criterion (and hence storm development) and in Australian rainfall over the period (2001-2100), using some of the Special Report on Emission Scenarios (SRES) scenarios. For the *miroc3_2_hires* model, we had simulations available for SRES B1, and A1B scenarios, involving CO_2 concentrations of 550ppm and 700ppm by 2100, respectively. For the *miroc3_2_hires* model, we also had simulations for SRESA2 (820ppm by 2100) and a "commit" run, with CO_2 concentrations fixed at about 365ppm for the period (2001-2100).

Model projections for (2001-2100) for these two models under the SRES scenarios with increasing anthropogenic CO_2 gas forcing show trends in the Phillips criterion upstream and over southern Australia between -0.04 ms^{-1} per year and -0.05 ms^{-1} per year, suggesting continued reductions in storm development (see Figure 1.1.2). There are associated negative trends in rainfall over SWWA of about -0.2 mm/month per year. These trends become more significant with increasing anthropogenic CO_2 concentration (Fig.1.1.2)

These model trends are similar to those simulated by the models during the 20th century. Keeping in mind that they are about half the observed trends, this suggests that we are likely to see similar or larger reductions in SWWA rainfall over the next fifty years as occurred over the previous fifty years, with further similar reductions over the subsequent fifty years. For example, over SWWA, where the 1940s July rainfall averaged about 120mm, there has been a reduction of between 25-30mm over the second half of the 20th century; we might expect further similar reductions by 2050.

An analysis of trends in model "commit" runs (with constant anthropogenic CO_2 gas forcing of about 365 ppm) over the 2001-2100 period shows no significant trends in the Phillips criterion, indicating that the trends are the result of the prescribed anthropogenic CO_2 gas forcing. This, together with the similarity of the patterns of change during the 20th and 21st centuries, also suggests that the observed trend during the 20th century may be largely related to anthropogenic forcing.

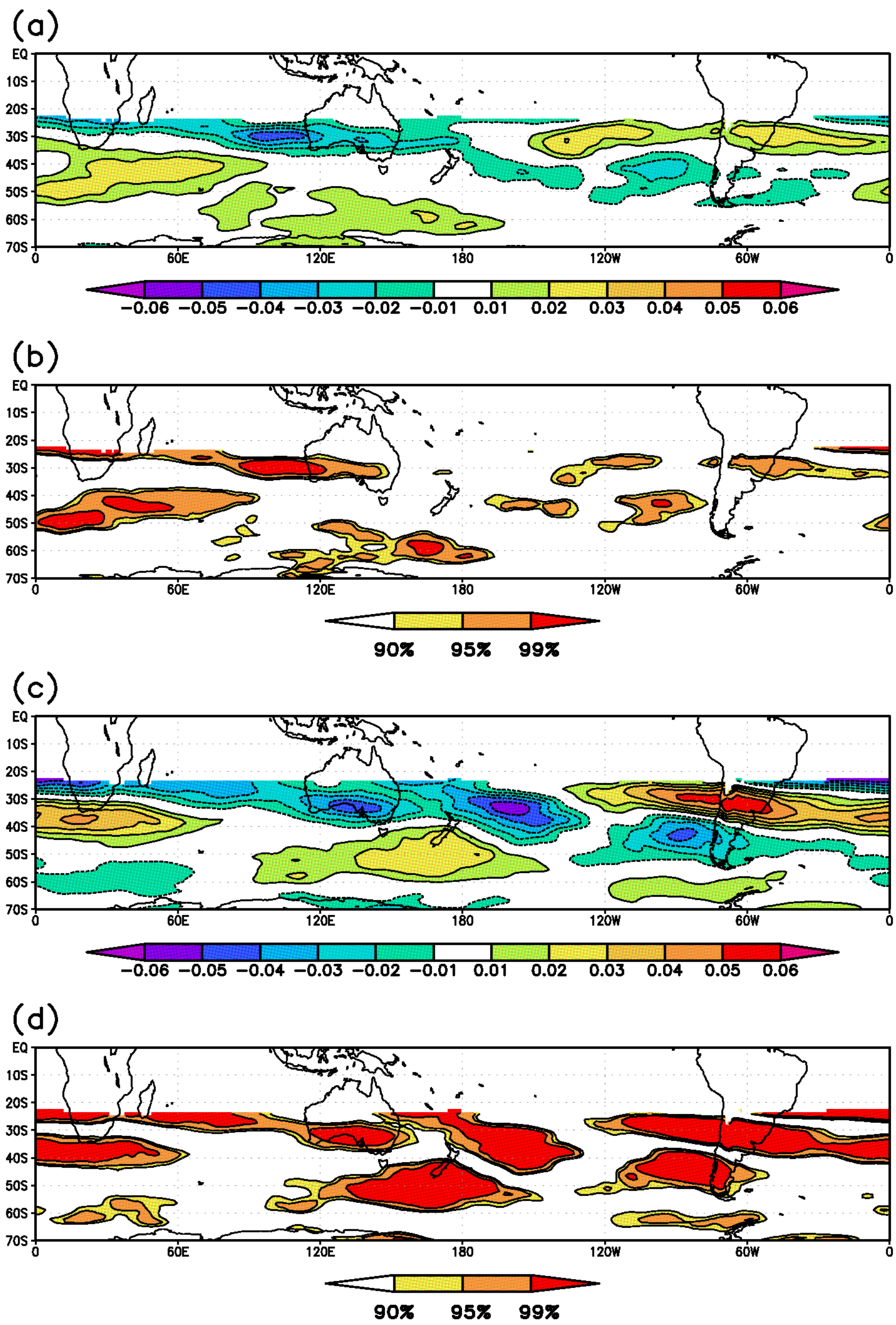

Figure 2.1.2 Trends for (2001-2100) in Phillips criterion (ms^{-1} per year) for *miroc3_2_hires* under (a) SRESB1 and (c) SRESA1B (corresponding significance in (b) and (d)).

Interestingly, many of the models that did not simulate the twentieth century changes, show similar patterns of trend in the Phillips criterion when forced with increasingly larger CO_2 gas concentrations. This suggests that these changes are "robust" given sufficient CO_2 gas forcing.

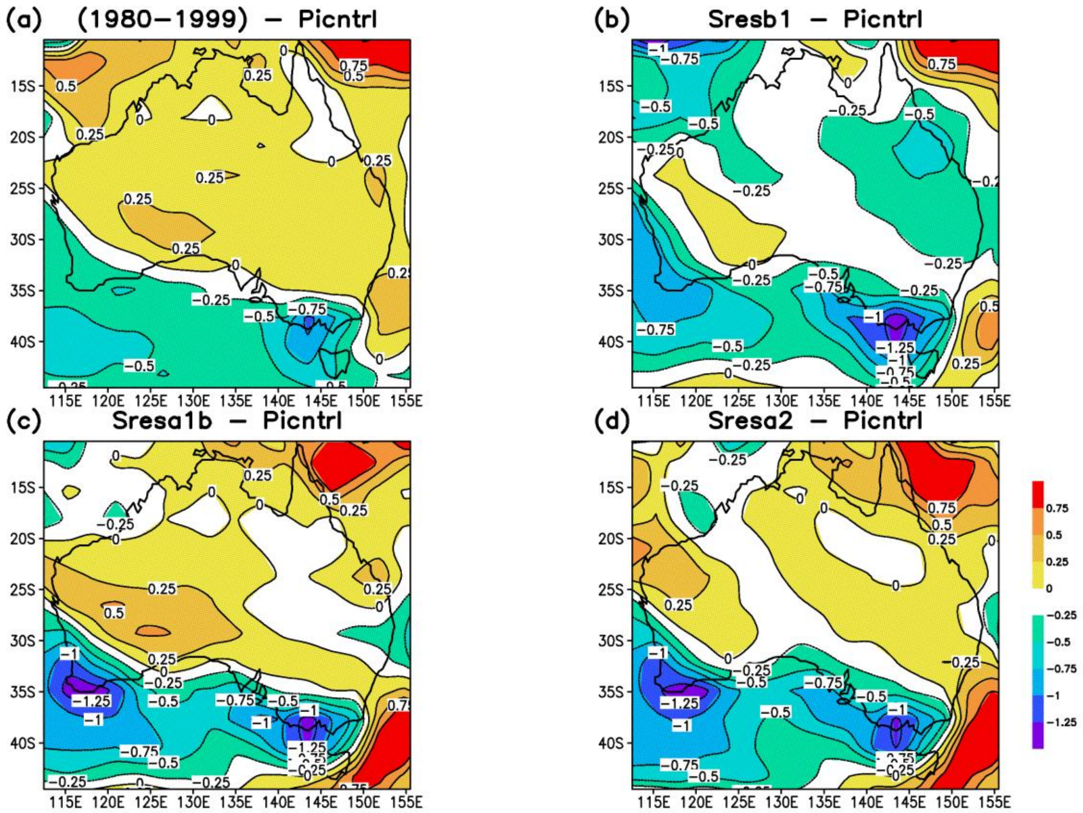

Figure 1.1.3 Differences in Australian rainfall (mm/day) for (a) (1980-1999) – PICNTRL and projected changes for (b) SRESB1 (2080-2099) – PICNTRL, (c) SRESA1B (2080-2099) – PICNTRL and (d) SRESA2 (2080-2099) – PICNTRL, for *miroc3_2_medres* model.

When compared to pre-industrial conditions, the models show quite dramatic changes in the rainfall climatology under the SRES scenarios. This is illustrated in Fig.1.1.3 for the *miroc3_2_medres* model, which shows differences between twenty average rainfall climates for the periods (1980-1999), and (2080-2099) for SRESB1, SRESA1B and SRESA2 simulations compared with the last twenty years of a pre-industrial (PICNTRL) run. Model rainfall reductions over SWWA range from 0.5mm/day at the end of the 20th century to over 1.25mm/day at the end of the 21st century under SRESA1B and SRESA2.

List of Publications Accepted and Submitted

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2010: *Australian Winter Circulation and Rainfall Changes and Projections.* Journal of Climate Change Strategies and Management. (accepted).

Frederiksen, J.S., C.S. Frederiksen, S.L. Osbrough and J.M. Sisson, 2010: *Causes of changing Southern Hemispheric weather systems.* GH2009 book, CSIRO publication. "Managing Climate Change", Chapter 8, 85-98, Eds. Imogen Jubb, Paul Holper and Wenju Cai, CSIRO Publishing.

Frederiksen, J.S., C.S. Frederiksen and S.L. Osbrough, 2009: *Modelling of changes in Southern Hemisphere weather systems during the 20th century.* 18th World IMACS/MODSIM Congress, Cairns, Australia, 13-17 July, 2009. *Modsim09*, 2562-2568. (http://www.mssanz.org.au/modsim09/G1/frederiksen_j.pdf)

Frederiksen, C.S., J.S. Frederiksen and J.M. Sisson, 2009: *Simulations of twentieth century atmospheric circulation changes over Australia.* 18th World IMACS/MODSIM Congress, Cairns, Australia, 13-17 July, 2009. *Modsim09*, 2555-2561. (http://www.mssanz.org.au/modsim09/G1/frederiksen_c.pdf)

Frederiksen, J.S., C.S. Frederiksen and S.L. Osbrough, 2009: *Changes in Southern Hemisphere storm tracks during the twentieth century.* A Changing Climate: Western Australia in focus, presenters' abstract papers. The University of Western Australia publication, 46pps. 10-1

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2010: *Changes and Projections in Australian Winter Rainfall and Circulation: Anthropogenic forcing and internal variability.* International Journal of Climate Change: Impacts and Responses. (submitted).

List of IOCI-Related Presentations at National and International Conferences, Symposia and Workshops

Conferences attended to present IOCI3 findings up until the end 2009 were reported on in IOCI3 Report 1.

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2010: *Changes and Projections in Australian Winter Rainfall and Circulation: Anthropogenic forcing and internal variability.* 2nd International Climate Change Conference, Qld. Univ., Queensland, 8-11 July, 2010.