EXECUTIVE SUMMARY

This report marks the conclusion of the first phase of Stage 3 of the Indian Ocean Climate Initiative (IOCI 3). It is comprised of ten parts, with each part corresponding to a research project within the Initiative. The research outcomes support a number of broad conclusions that may be summarised as follows:

Project 1.1: Detection and Attribution of Changes to Weather Systems and Large Scale Circulation Drivers

- The changes in Southern Hemisphere autumn and winter storms have been studied using a global two-level primitive equation instability model with reanalysed observed May and July basic states during the 20th century.
- For July, storm track modes growing on the subtropical jet show a dramatic reduction in growth rate post-1975. This reduction in the intensity of storm development has continued to the present time for storm track modes that cross Australia and is associated with the observed decrease in rainfall in southwest Australia (SWWA).
- For May, the strength of the subtropical storm track crossing Australia has decreased while the polar storm track has increased. This again is associated with a decrease in the strength of the divergence field and rainfall over SWWA and generally across southern Australia. These effects have become more pronounced with time.
- For both autumn and winter, the rainfall reduction is also associated with a decrease in the vertical mean latitudinal temperature gradient and in the peak upper tropospheric jet-stream zonal winds near 30^{o} south throughout most of the Southern Hemisphere.
- The performance of coupled models to simulate twentieth century winter circulation changes throughout the southern hemisphere, and particularly over Australia has been examined. Changes include a decrease in the vertical mean meridional temperature gradient and in the peak upper tropospheric jet-stream zonal winds throughout most of the southern hemisphere, but especially upstream and over Australia. These and other circulation changes, including

changes in the Hadley circulation, and trends in the Southern Annular Mode, affect winter rainfall over SWWA and southern Australia.

- The response of the Coupled Model Intercomparison Project 3 (CMIP3) climate models to observed anthropogenic forcing, including increasing greenhouse gases, from pre-industrial to the end of the twentieth century has been examined and compared with reanalysed observations. Focus has been on the ability to simulate (a) the reduction in the strength of the wintertime subtropical 300hPa zonal wind upstream and over southern Australia, and a strengthening in the zonal wind further south, and (b) a reduction in the baroclinic instability, related to the vertical wind shear, of the subtropical SH circulation.
- The CMIP3 models display quite disparate abilities to simulate these two diagnostics. Our analysis also suggests that there is a component of decadal variability in the model results that is dependent on the base period chosen in the pre-industrial runs.
- The better CMIP3 models suggest that further large reductions in the growth rate of storm track modes affecting SWWA, as well as rainfall, are possible under SRESB1, SRESA1B and SRESA2 scenarios, especially over the Australian region.
- The ability of a number of climate models with anthropogenic forcing, including increasing greenhouse gas concentrations, to replicate the changes in transient weather systems during the 20th century has also been examined. In particular, the CSIRO Mark 3.0 and 3.5, UKMO HAdGem1 coupled models, and the ACCESS atmospheric model, have been examined. The first 3 models have some difficulty reproducing the observed changes, but the ACCESS model reproduced the observed storm track quite well.

Project 1.2: South-west Western Australia's Regional Surface Climate and Weather Systems

- The data quality from rainfall recording stations formerly noted for their high-quality and long-term records have been re-assessed. Some stations with long-term, high-quality data have had reductions in quality in recent years for a range of reasons, including the consolidation of farms. This information has fed into Project 1.4.

- Annual average rainfall declined in south-west Western Australia in the late 1960s and has not recovered since. A further shift to lower rainfall was identified at approximately the year 2000. The early decline was associated with a decrease in the number of days on which a winter deep low pressure system influenced the region. The recent decline was not associated with a continuing decrease in the number of deep low pressure systems, but rather had a strong contribution from an increase in the number of days when a high pressure system influences the region.
- Recent years have also seen extremely high values of winter mean sea-level pressure over SWWA. Both the increased pressures and increased daily occurrence of high pressure systems are as projected for the end of this century by climate models forced with increasing levels of atmospheric greenhouse gases. The magnitudes of the changes expressed by most models suggest that the recent high values might be expected to continue and possibly amplify.
- The large decline in rainfall in the late 1960s in May to July has persisted and expanded spatially. Both trends and percentage change were analysed to explore this signal. Trends reveal that regions where rainfall did not decline in the late 1960s are now seeing a decline in early winter, whilst the percentage change also suggested a strengthening signal in regions already drying (the far south-west and wheatbelt), a signal that is not so clear using trend analysis.
- The interannual variability in the far south-west continues to decline. Trends in the 95th percentile rainfall were generally weak, except along the south coast since 1970 and at Manjimup since 1950. The signal at Manjimup which shows a weakening of the decreasing trend in the extreme rainfall between the 1950-2007 period and the 1970-2007 period supports the findings in Milestone 1.2.1 that recent declines are not associated with a further decrease in the daily occurrence of deep low pressure systems.
- In the summer half year there were minimal trends from both 1950 and 1970 except inland and along the south coast where increases were seen in both totals and, as summer rainfall is dominated by extreme events, extremes.

- Analysis of ‘standard’ seasons’ was found to potentially ‘hide’ important information, as found by the analysis of the spring compared to ‘late winter’ (August to October) trends. The map of spring trends showed decreases everywhere. In late winter there were only weak trends from 1950, but some stronger trends from 1970: increases at Manjimup and Nyerilup and decreases at Peppermint Grove. The reason for these mixed signals in the trends is that rainfall in August and September had been increasing, but decreasing in October and November.

Project 1.3: Quantification of the Limits of Seasonal Predictability of WA Rainfall and Surface Temperature

- Two new techniques have been developed for estimating the predictive characteristics of WA surface temperature and rainfall in all three month seasons. The methods have been developed as major extensions of previous techniques developed by the principal investigator and other authors.
- The underlying principle of the methodologies is the separation of the total interannual variance of the seasonal mean of the climate variable into two components. One of these components is related to variability within the season and is generally considered to be unpredictable at the "long-range", that is, a season or more before the forecast period. The other component is associated with slowly varying external forcings on the atmosphere (e.g. sea surface temperature (SST), greenhouse gas forcing) and slowly varying (interannual or longer time scale) internal atmospheric variability.
- The methods have been applied to observed WA surface temperature and rainfall to estimate their potential predictability. The results suggest that WA maximum and minimum surface temperature have fairly high potential predictability in all seasons over wide spread areas of the state. The spatial patterns of potential predictability are generally quite different for maximum and minimum temperature, suggesting there are different processes involved. There are also quite large spatial variations in the patterns between different seasons.
- The results suggest that slow processes related to external forcing such as, for example, sea surface temperature variability, and slow internal dynamics

dominate the interannual variance of surface temperature. Consequently, surface temperature is highly potentially predictable and it would be worthwhile to further investigate the slow processes, or drivers, responsible for this. It is also expected that dynamical and statistical (once the slow processes and drivers have been identified) forecast schemes would have fairly high predictive skill.

- Rainfall variability has been found to be dominated by intraseasonal processes, which at the long range are essentially unpredictable. Consequently, the potential predictability of WA rainfall is lower than for surface temperature. However, there are seasons when the potential predictability is relatively high over some regions of the state. Over the SWWA, the potential predictability ranges between 20-30% during the winter seasons MJJ and JJA; there is much less potential for seasonal prediction in the other seasons. The highest potential predictability over northwest WA occurs during the summer seasons DJF and JFM.

Project 1.4: Regionally Specific Climate Data and Monitoring for the North-West and South-West to Support the Understanding of Past, Present and Future Climate

- The high quality daily rainfall network has been expanded from 40 stations to a potential 228 daily reporting stations. There has been a particular increase in the north-west of the state, where previously there were very few high-quality stations.
- This improvement in the network is essential for properly characterising climate change at fine spatial and temporal scales. Such observations are also an important input of downscaling techniques aimed at predicting future rainfall changes. This information will be essential for the planning and management of existing and future agricultural areas, mining industry activities and ecological and environmental studies.
- The previously existing Australian high-quality daily station temperature dataset of 103 stations over Australia, including 19 in Western Australia, has been extended to 112 stations, with six new stations in Western Australia, making a total of 25. This will improve the spatial resolution of long-term

temperature analyses, particularly in the south-west. Four new stations have been added in this area (Morawa, Merredin, Bridgetown and Katanning).

- In addition, records from Albany were severely affected by a 1965 move, with no overlap period, from the town centre to the airport 10 km inland, but the re-opening in 2002 of a site near the pre-1965 location has greatly improved the confidence with which adjustments for that area can be made. A specific goal which the updated dataset will fulfil is to allow the apparent summer cooling since 1950 to be resolved more precisely; in the previous, relatively coarse, network, analyses “projected” anomalies at Albany a substantial distance inland, an effect which will be reduced by the new network.
- The new dataset extends the record back to 1910 and up to 2009. It includes a large quantity of recently digitised data which were not available for use in previous studies, as well as fully incorporating more recent data.
- The new dataset allow century-scale analyses of changes in temperature extremes, both in Western Australia and elsewhere, and will also allow monthly data from the 1910-1949 period to be included in the Bureau’s real-time monitoring products.
- A purpose built web area attached to the Bureau of Meteorology’s website is being built to make available the new rainfall and temperature high-quality datasets to State stakeholders. This web area will use the OpenLayers platform, which allows innovative site navigation and provides users with other relevant information, such as roads, rivers, elevation and place names.
- Dr Marco Marinelli has been recruited to provide an enhanced local capacity in climate analysis and monitoring and to liaise with State stakeholders.

Project 2.1: Observed and Modelled Climate of the North-West:

- A new version of CSIRO's high resolution global climate model (Mk3.6 GCM) has been constructed. Mk3.6 includes a comprehensive, interactive aerosols scheme. This model will be used to further investigate the extent to which the observed rainfall increase in the North-West is being driven by the Asian aerosol haze.
- Comparison of the mean summer and winter climate simulations in Mk3.6 with those of its predecessors show several encouraging improvements in the

new version, especially with regard winter rainfall and mean sea level pressure (MSLP). The improved simulation of winter rainfall over south-western WA makes the Mk3.6 model potentially attractive for use in downscaling studies over that region.

- The predecessors of Mk3.6 (Mk3.5 and Mk3.0) have been previously ranked as 12th and equal 13th out of the 23 GCMs used in the IPCC AR4. Using the same assessment criterion, the improved performance of Mk3.6 would rank it fifth out of 24 GCMs.
- In comparison with its predecessors, the most dramatic improvement in Mk3.6 was in the model's simulation of the leading modes of annual rainfall variability. Mk3.6 was best able to capture the spatial pattern of the leading El Niño Southern Oscillation (ENSO) related rainfall mode, which is centred over eastern Australia, whereas earlier versions incorrectly located the centre of this mode over WA. This improvement is important, because if the ENSO-related mode in the model is located over northern WA, the simulated rainfall response there may be unrealistically dominated by the response of ENSO to the applied forcing.
- In comparison with seven other GCMs, Mk3.6 has the best simulation of the spatial pattern of the two leading modes of Australian rainfall variability. The second rainfall mode, centred over north-western WA, was also captured best by Mk3.6, although the correlation of this mode with ENSO was too strong.
- An accurate simulation of the first rainfall mode is important for studies of Australian climate change, because this mode correlates strongly with ENSO, which dominates rainfall variability over most of eastern and central Australia. The second rainfall mode is also potentially important, because its observed time series shows a significant upward trend in recent decades, corresponding to increased rainfall over northern WA, and decreased rainfall over eastern Australia.

Project 2.2: Tropical Cyclones in the North-West

- The IOCI research activities marked the first time the researchers had focussed their attention on Tropical Cyclones in the Southern Indian Ocean. Research during this first year has concentrated on gaining familiarity with the tropical cyclone data set in the region and on investigating whether there are trends. It is well documented that the sea surface temperatures during the cyclone season have increased over the past 25 years by approximately half a degree C. It is important to determine whether there has been an increase in tropical cyclone activity in response to this climate signal.

- A collaborative study with the Bureau of Meteorology National Climate Centre was conducted looking at trends in the official tropical cyclone data set since the beginning of the satellite era. For the Southern Indian Ocean it was found that the trends in the frequency of cyclones are small and not significant. Looking at the trends in the more intense cyclones, for most cyclone categories there is no significant trend. However, for the proportion of cyclones exceeding 940 hPa there has been an increase of the order of 20% over a 25 year period. This trend is significant.
- The relationship between tropical cyclone and sea surface temperature has been studied for both the Southern Indian Ocean and for the entire Southern Hemisphere. The major finding is that in-situ statistical relationships (such as linear correlations) between indices of cyclone activity and sea surface temperature are dominated by large scale patterns, reflecting the large scale structure of the El Nino-Southern Oscillation (ENSO) phenomenon.
- The implications of this for the tropical cyclone response to global warming are that the relationship between cyclone activity and sea surface temperature is not simply a local one. The sea surface temperature responds to the circulation on a planetary scale. Possibly the cyclones respond to local sea surface temperatures; but they also respond to the same planetary scale influences that govern ENSO behaviour. This makes the scientific issue of determining the response of tropical cyclones to changing sea surface temperatures more complicated. To determine such a response the sea surface temperature changes must be interpreted in terms of their effect on the larger scale dynamical circulations systems which give rise to cyclones.
- The IOCI project contributes to Dr John McBride's participation (as co-chair) of a WMO (World Meteorological Organizations) Expert Team on Climate Change Impacts on Tropical Cyclones. During year-one of IOCI-3, this group

has prepared an expert assessment statement on tropical cyclones and climate change, submitted to Nature Geosciences.

- A statistical forecast model of tropical cyclones for the 1 week to 3 week time frame has been developed for the western Australian region. The model is based on an earlier model developed by Leroy and Wheeler (Monthly Weather Review 2008). To carry out the development of the new model the first author of the earlier model (Anne Leroy) was employed on IOCI funds on a 2-week consultancy in late 2009.
- Work has started on developing a theoretical framework for understanding the inter-annual variability of tropical cyclone behaviour in the southern Indian Ocean.

Project 2.3: Statistical Downscaling for the North-West:

- A preliminary network consisting of 57 daily rainfall gauges has been selected. These gauges have substantive records for the period from 1958 to 2008. Of these 57 gauges, 19 are in the Kimberley and 38 in the Pilbara/Gascoyne regions. Records for 10 gauges appear to contain untagged accumulations, particularly over the last 10 years. The percentage of missing data in-filled by interpolation varies considerably between stations and periods. This network will be refined through further consultation with the Bureau of Meteorology.
- Initial fitting of a statistical downscaling model for the summer half-year (November to April) has been undertaken to determine the dominant spatial patterns of rainfall occurrence (states), their seasonality, and trends. The trends found are consistent with the observed rainfall increase in the North-West.
- Work has commenced on the selection of atmospheric predictors for the downscaling scheme.

Project 2.4: Physical-Statistical Modelling of Extreme Weather Events:

- Recording rain gauge ('pluviometer') data has been obtained from both the Bureau of Meteorology and the Department of Water for sites in the North-West and South-West, and the time periods covered by these records assessed.

- Data from the NCEP/NCAR Reanalysis project have been downloaded for a number of atmospheric variables that are pertinent to the study of weather extremes.
- Initial results obtained from the use of a sparse regression method known as RaVE (**R**apid **Va**riable **E**limination) indicate that it can generate parsimonious atmospheric predictor sets for downscaling models that are both sensible and interpretable. Unlike conventional approaches to predictor selection, RaVE simultaneously indicates the locations of important grid points in Reanalysis datasets as well as key atmospheric predictors.
- The results of a parallel preliminary study indicate that RaVE is also a useful methodology for linking the parameters of the probability distributions of weather extremes to atmospheric variables.
- A hierarchical Bayesian spatial model for extreme rainfall (over varying intensities) has been developed. The model will be used to update rainfall intensity-frequency-duration and depth-area characteristics, to assess their historical variability over time and to identify key climate drivers.
- Two approaches for modelling runs of rainfall and temperature extremes (*extreme value and near-extreme theory and aggregated continuous-time Markov chains)* have been identified and formulated. They are judged as worthy of further development.
- A new monsoon index for the North-West describing the regional atmospheric circulation and its linkage to regional rainfall has been developed. Results show that the index has a significant positive correlation with summer (December-March) rainfall ($r = 0.81$).

Project 3.1: Statistically-Downscaled Projections for the South-West:

- Preliminary results from an intercomparison of GCMs show that those models that perform well on an annual, or even a seasonal, basis do not necessarily reproduce the month to month patterns seen in the observed record.
- Through collaboration with the International Research Institute for Climate and Society (Earth Institute, Columbia University), a new version of the computer code for the statistical downscaling model used by CSIRO Land and Water has been ported and is undergoing testing. Preliminary results are

encouraging. The new code provides much faster model calibration and the previous restriction on the number of rainfall sites that could be considered in a model run (31 sites) has been lifted. This means that additional sites of interest to State government agencies can be incorporated into the downscaling scheme.

- Through collaboration with the Department of Statistical Science, University College London, a statistical modelling approach that combines information from multiple GCMs to emulate the range of underlying uncertainty they represent has been developed. An exploratory application has been undertaken using six AR4 GCMs for the example of statistically downscaled projections of winter (May-July) rainfall for 30 sites in the South-West. Initial results indicate that the technique can account for GCM biases in atmospheric predictors and that the pooling of GCM results leads to an underestimate of the uncertainty in statistically-downscaled rainfall projections.

Project 3.2: Climate Extremes: Potential Forecast Skill and Climate Change Scenarios

- A literature review documenting current work on atmospheric predictors of extreme rainfall that is relevant to the South-West has been carried out.
- A climate index based on the dynamics of a normalized seasonality index called the Southwest Western Australian Circulation (SWAC) has been developed. The index describes regional circulation and its linkage to winter rainfall. Results show that the winter SWAC has a significant positive correlation with winter rainfall. The variation of the SWAC is not only responsible for the interannual variability of winter rainfall, but also for the long term trend in rainfall: the decreasing trend in early winter (MJJ) rainfall is due to the weakening of SWAC; and there is a weak upward trend in late winter (ASO) rainfall resulting from the weakly increasing strength of the SWAC in late winter. The relationship between the SWAC and SWWA rainfall is robust, and largely independent of the influence of other large-scale circulations such as the Southern Annular Mode and ENSO.

The first 12 months of IOCI 3 have been productive. The research output produced so far inspires optimism that the Initiative will lead to new knowledge and skills that will in turn provide valuable economic and social benefits for the North-West and South-West regions of Western Australia.

List of Publications

Bates, B., P. Hope, B. Ryan, I. Smith and S. Charles, 2008: Key findings from the Indian Ocean Climate Initiative and their impact on policy development in Australia. Climatic Change, DOI 10.1007/s10584-007-9390-9

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. (http://www.mssanz.org.au)

Frederiksen, C.S., J.S. Frederiksen, J.M. Sisson, and S.L. Osbrough, 2009: *Australian Winter Circulation and Rainfall Changes and Projections.* Journal of Climate Change Strategies and Management. (submitted).

Frederiksen, C.S., S. Grainger and X. Zheng, 2008: *A Method for Estimating the Potential Long-range Predictability of Precipitation over Western Australia.* ANZIAM J., 50, C569-C583. http://anziamj.austms.org.au/ojs/index.php/ANZIAMJ/article/view/1411

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, 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. (http://www.mssanz.org.au)

Frederiksen, J.S., C.S. Frederiksen, S.L. Osbrough and J.M. Sisson, 2009: *Causes of changing Southern Hemispheric weather systems.* GH2009 book, CSIRO publication. (in press)

Hope, P. and B. Timbal and R. Fawcett, 2009: Associations between rainfall variability in the southwest and southeast of Australia and their evolution through time. International Journal of Climatology

Hope, P. and C.J. Ganter, 2010: Recent and projected rainfall trends in south-west Australia and the associated shifts in weather systems. In: Book of Proceedings from Greenhouse 2009 Conference. CSIRO publishing. in press.

Hope, P. Report for: McIntosh, P, 2008, Australia's Regional Climate Drivers, report to Managing Climate Variability; My contribution: Comparison of manual analysis with statistical techniques

Phatak, A (2009). Using GeneRaVE for Extremes: An Initial Attempt. CSIRO Mathematical and Information Sciences Technical Report, CMIS 09/96, June 2009.

Phatak, A, Bates, BC and Charles, SP (2009). Statistical downscaling using sparse variable selection methods. Submitted to *Environmental Modelling and Software*, July 2009.

Rojas, M., P. Moreno, M. Kageyama, M. Crucifix, C. Hewitt, A. Abe-Ouchi, R. Ohgaito, E.C. Brady, P. Hope, 2008: The southern westerlies during the Last Glacial Maximum in PMIP2 simulations. Climate Dynamics

S. Grainger, C.S. Frederiksen and X. Zheng, 2008: *Estimating the Potential Predictability of Western Australian Surface Temperature using Monthly Data.* ANZIAM J., 50, C598-C609. http://anziamj.austms.org.au/ojs/index.php/ANZIAMJ/article/view/1414

S. Grainger, C.S. Frederiksen and X. Zheng, 2009: *Estimating the Potential Predictability of Australian Surface Maximum and Minimum Temperature.* Clim. Dyn., 32:443-455, doi 10.1007/s00382-008-0506-3.

Thomas Knutson, John McBride, Johnny Chan, Kerry Emanuel, Greg Holland, Chris Landsea, Isaac Held, James Kossin, A. K. Srivastava, and Masato Sugi, Tropical Cyclones and Climate Change: An Assessment. Submitted to Nature Geosciences

Timbal, B. and P. Hope, 2008: Observed Early Winter Mean Sea level Pressure Changes over Southern Australia: a comparison of existing datasets. CAWCR Research Letters Issue, 1, 1-7

List of IOCI-related Presentations

Bates, B.C., *Climate Activities in Australia*, (keynote), Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia.

Bates, B.C., R. Chandler and S.P. Charles, *Trends in Hydroclimatic Series in Southwest WA*, IOCI Session Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia.

Bates, B.C., *Climate Change Overview*. Joint AMOS-WAMSI Symposium, 27 March 2009, Perth, Western Australia

Bates, B.C., *Climate Change: A Predetermined Future?*, WA Wetlands Conference, 1 February 2008, Perth, Western Australia.

Bates, B.C., *Climate Change and Implications for Surface Water Management*, Invited Seminar, Australian Rivers Institute, Griffith University, 8 May 2008, Brisbane, Queensland.

Bates, B.C., *Global Warming – Natural Phenomena versus Human Activity*, Australian Veterinary Association, Annual Conference, 26 May 2008, Perth, Western Australia.

Bates, B.C., *Water Resources: Hydroclimatic Forensics through Reanalysis*, Atmospheric Circulation Reconstruction over the Earth (ACRE) workshop, 24 June 2008 Zurich, Switzerland.

Bates, B.C., *CSIRO's Work Plans for Northern Australia*, Northern Australia Workshop, 30 June 2008, Perth, Western Australia.

Bates, B.C., *Global Warming and Natural Resources Management – An Update*, briefing, Natural Resources Management Council, Western Australia, 5 September 2008, Perth, Western Australia.

Bates, B.C., *Global Warming and its Likely Impact on the Southwest*, Carbon Futures – The Impact of Climate Change and the Carbon Pollution Reduction Scheme on Australia's South West, Critical Horizons seminar series, 4 December 2008. Bunbury, Western Australia.

Bates, B.C., *Water in a Changing Climate*, Intelligent Use of Water Summit, 19 March 2009, Sydney, New South Wales

Bates, B.C., *Climate Change and Weather Extremes: The State of Knowledge*, FESA Emergency Management Conference, 17 April 2009Perth, Western Australia.

Bates, B.C., *An Update on Climate Change Science*, (invited seminar), Department of Fisheries, WA, 8 May 2009, Perth, Western Australia

Bates, B.C., *Climate Change and the Adaptation Challenge*, Community Climate Change Dialogue, Conservation Council of WA, 28 June 2009, Perth, Western Australia.

Braganza, K., D. Collins, D. Jones, M. Marinelli, C.J. Ganter, P. Hope and G. Cook, *Improved Climate Data and Monitoring for Western Australia to Support the Understanding of Past, Present and Future Climate*, IOCI Session, Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia.

Braganza, K., D. Collins, D. Jones, M. Marinelli, C.J. Ganter, P. Hope and G. Cook, *Improved Climate Data and Monitoring for Western Australia to Support the Understanding of Past, Present and Future Climate*. Joint AMOS-WAMSI Symposium, 27 March 2009, Perth, Western Australia

Frederiksen, C.S. and J.S. Frederiksen, 2009: *Atmospheric Winter Circulation Changes affecting Western Australia in Climate Models and Reanalyses.* Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia.

Frederiksen, C.S., S. Grainger and X. Zheng, 2008: *A Method for Estimating the Potential Long-range Predictability of Precipitation over Western Australia.* 14th Biennial Computational Techniques and Applications Conference, 13-16 July, 2008, ANU, Canberra, Australia.

Frederiksen, C.S., S. Grainger and X. Zheng, 2009: *Australian rainfall variability and predictability : the relative importance of slow and intraseasonal processes.* GWEX 2009: 6th International Scientific Conference on the Global Energy and Water Cycle, 24-28 August 2009, Melbourne, Australia

Frederiksen, J.S. and C.S. Frederiksen, 2009: *Seasonal and Decadal Shifts in Weather Systems affecting Western Australia.* Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia.

Frederiksen, J.S. and C.S. Frederiksen, 2009: *Twentieth Century Changes in*

Southern Hemisphere Storm Tracks in Climate Models and Reanalyses. Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia.

Frederiksen, J.S. and C.S. Frederiksen, 2009: *Changes in Southern Hemisphere Storms and Rainfall*. 9th International Conference on Southern Hemisphere Meteorology and Oceanography, 9-13 February, 2009, Melbourne, Victoria, Australia.

Frederiksen, J.S. and C.S. Frederiksen, 2009: *Changes in Southern Hemisphere cyclogenesis and rainfall since the mid-1970s*. Western Pacific Geophysics Meeting, American Geophysical Union, 29 July – 1 August, 2008, Cairns, Queensland, Australia.

Frederiksen, J.S. and C.S. Frederiksen, 2009: *Interdecal Changes in Southern Hemisphere, Storms and Rainfall.* MOCA-09: Joint Assembly of IAMAS, IAPSO and IACS, 19-29 July 2009, Montreal, Canada.

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, University of Western Australia, 27 March, 2009, Perth, Western Australia, Australia.

Frederiksen, J.S.,C.S. Frederiksen and S.L. Osbrough, 2009: *Decadal Shifts in Weather Systems Affecting Southern Australia.* GWEX 2009: 6th International Scientific Conference on the Global Energy and Water Cycle, 24-28 August 2009, Melbourne, Australia.

Fu, G., and Charles, S.P. ,2009: *Assessing IPCC fourth assessment report GCMs for statistical downscaling in south-west Western Australia*. Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia

Ganter, C. and P. Hope: *Changes in intensity of south west Western Australian rainfall* (poster). 9th International Conference on Southern Hemisphere Meteorology and Oceanography, 9 to 13 February 2009, Melbourne, Australia

Grainger, S., C.S. Frederiksen and X. Zheng, 2008: *Estimating the Potential Predictability of Western Australian Surface Temperature using Monthly Data.* 14th Biennial Computational Techniques and Applications

Conference, 13-16 July, 2008, ANU, Canberra, Australia.

Hope, P. and C.J. Ganter, 2009: *Historical, recent and projected rainfall trends in Western Australia* (invited), Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia.

Hope, P., B. Timbal, M. Wheeler and R. Fawcett, 2009: *A strengthening link between rainfall variability in the east and west of southern Australia*. 9th International Conference on Southern Hemisphere Meteorology and Oceanography, 9 to 13 February 2009, Melbourne, Australia

Hope, P., I. Simmonds, M. Pook, K. Keay, J. Risbey and P. McIntosh, 2009: *A comparison of frontal number using a range of identification methods - A case study in south Western Australia* (poster). 9th International Conference on Southern Hemisphere Meteorology and Oceanography, 9 to 13 February 2009, Melbourne, Australia

Hope, P., *Understanding the Drivers of Australia's Rainfall Shifts and Variability and what this means for the Future,* 5th Australian Water Summit, April 2009, Sydney, New South Wales.

Hope, P., Panel discussion of: *Facing a Hot, Dry Future. How your Research-Driven Career in Environmental, Sustainability or Water Management will help us Adapt to Climate Change,* The University of Melbourne, April 2009, Melbourne, Victoria.

McBride J.L. and H. Ramsay, 2009: *Relationships between tropical cyclone activity and sea surface temperature in the Southern Hemisphere*. Second International Summit on Hurricanes and Climate Change, Aegean Conference, Corfu Greece, 31 May – 4 June 2009.

McBride J.L. and H. Ramsay, 2009: *Southern Hemisphere Sea Surface Temperatures and Tropical Cyclone Activity.* Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia

Phatak, A., Charles S.P. and M.J. Palmer, 2009: *Selection of atmospheric predictors in statistical downscaling of rainfall occurrence, amounts, and extremes in South Australia.*(Poster) Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia.

Rotstayn, L. *Why Aerosols Matter for Australian Climate Change*, IOCI Session, Greenhouse 2009 Conference on Climate Change and Resources, 23-26 March, Perth, Western Australia.

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Carsten Frederiksen
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