Indian Ocean Climate Initiative

Second Research Report - Towards Understanding Climate Variability in south western Australia

Research reports on the Second Research Phase of the Indian Ocean Climate Initiative

IOCI October, 2001 **Second Research Report**

Second Research Report - *Towards an Understanding of Climate Variability in south western Australia*

Research reports on the Second Research Phase
of the Indian Ocean Climate Initiative

Bureau of Meteorology Research Centre

CSIRO Atmospheric Research

CSIRO Land and Water

CSIRO Mathematical and Information Sciences

Indian Ocean Climate Initiative a Contributing Partnership

Department of Premier and Cabinet
Dept of Industry and Technology
Agriculture WA
Dept of Environment Water & Catchment Protection
Water Corporation
Dept of Conservation and Land Management
WA Region of the Bureau of Meteorology
Fire & Emergency Services

IOCI - A WA initiated partnership to foster -

- *research in climate variability; and*
- *developments in seasonal forecasting;*

for regions of western and southern Australia affected by the Indian and Southern Oceans; and particularly for south western Australia

Core Research Team -

Bureau of Meteorology Research Centre
CSIRO Atmospheric Research
CSIRO Land and Water
CSIRO Mathematical and Information Sciences

CONTENTS

ISBN: 0 7307 6679 9

Published by: Indian Ocean Climate Initiative Panel
Address:
Executive Officer IOCIP,
C/- Dept of Environment, Water and Catchment Protection
Hyatt Centre, 3 Plain St.
East Perth, WA 6004, Australia
October, 2001

Abstract:

This report describes the research findings of Phase 3 of the Indian Ocean Climate Initiative (IOCI). IOCI is a five-year program of research into the effects of the Indian and Southern Oceans on interseasonal to interdecadal climate variability in the South West region of Western Australia, and the development of operational seasonal outlooks that have sufficient skill for effective decision making. IOCI was established through a partnership of federal and state government agencies. Key findings include: (1) the underlying causes of the observed winter rainfall decline is not simply due to changes in Indian Ocean sea surface temperatures; (2) there has been an abrupt shift and a clearly defined trend in the frequency characteristics of the synoptic patterns that influence rainfall occurrence; (3) the timing of the shift appears to coincide with the well-documented change in the behaviour of the El-Niño that occurred in the mid 1970s. The trend appears to be due to a different mechanism, and its interaction with El-Niño; (4) a new approach to modelling shifts in, and interactions between, climate processes has been developed to investigate this phenomenon further; (5) long climate model simulations indicate that the recent low precipitation sequence is uncommon but not extreme; (6) natural climate variability is the most likely major cause of the observed reduction in winter rainfall; (7) the enhanced greenhouse effect may have contributed to the winter rainfall decline; and (8) there is some skill in predicting total rainfall and mean temperatures for spring and summer, and extreme temperatures in summer.

Indian Ocean Climate Initiative Panel

West Australian contributing agencies and members:	
Department of Industry and Technology	Ms. Linda Penny
Office of Premier and Cabinet	Dr. Paul Vogel
Agriculture WA	Dr. Ian Foster
Dept. Environment Water & Catchment Protection (Water)	Mr. Ed Hauck (Exec. Officer, IOCIP)
Water Corporation	Mr. Keith Barrett
CALM	Dr. Drew Haswell
Dept. Environment Water & Catchment Protection (Environment)	Mr Rod. Banyard
Fire and Emergency Services	Mr. Jeff Mustard
Commonwealth contributing agency:	
Bureau of Meteorology WA Regional Director	Messrs. Len Broadbridge, John Cramb
National Research bodies:	
Bureau of Meteorology Research Centre	Drs. Michael Manton, Neville Nicholls
CSIRO Climate and Atmosphere Sector Coordinator	Drs. Graeme Pearman, Ian Smith
CSIRO Land & Water	Dr. Bryson Bates (Res. Manager)
CSIRO Mathematical and Information Sciences	Dr. Eddy Campbell
Independent Chair:	
Brian Sadler PSM FTSE	

reword

The Indian Ocean Climate Initiative (IOCI) was established in Western Australia on January 1, 1998. Its role is to pursue the overlapping interests of several economic sectors in respect to research, development and applications relating to climate variability. The program was stimulated by desire to gain regional economic and environmental benefit from contemporary national and international climate research. The Initiative was given added impetus by concerns as to the implications of the 25-30 year long sequence of low winter rainfalls which was being experienced in south-west Western Australia.

The low rainfall sequence continues, and the winter of 2001 has been the driest on record for a large area of the South West. This situation is of major concern to climate-affected industries and to natural resources management in the region. Regional averages and understandings of climate variability and risk are being altered forever by this experience. The changes are large and have major implications economically, environmentally and socially. There is a need to assist decision-making with a greater understanding of the climatic phenomena of southern and western Australia, including the influences of the Indian and Southern Oceans.

Initially, IOCI was formed as a program of strategic research into the effects of the Indian and Southern Oceans on climate variability in south-western Australia. It is a contributing partnership of central government and government agencies in Western Australia with involvement in climate issues. A number of agencies that had worked, semi-independently, on climate research saw the need for a program that could develop regional applications from broader scale national research activities. The initial research contracts provide $300,000 per year for a core program from Jan 1998 to Dec 2002. The core research is conducted by the Bureau of Meteorology Research Centre, and by the CSIRO divisions of Atmospheric Research, Land and Water, and Mathematical and Information Sciences. The research institutions match the partnership inputs through in-kind contributions.

The objectives of IOCI are to gainfully improve management decisions of climate-affected industries, and environmental management, through:

- i*mproved understanding and definition of inter-annual and inter-decadal climate variability; and*
- *enabling seasonal outlooks with sufficient skill for operational decision making.*

The potential beneficiaries include: agriculture; water supply; forest fire control; wetlands management; water resources management; public health; tourism; conservation of bio-diversity and nature reserves; urban and industrial infrastructure; finance and insurance.

The initial 5 year program has three research phases as follows:

First Research Phase:	*Jan 1998 to June 1999 (report published)*
Second Research Phase:	*June 1999 to Dec 2000 (this report)*
Third Research Phase:	*December 2000 to December 2002 (work in progress)*

Since embarking on its strategic program IOCI has become increasingly aware of the significance of longer-term change and variability to its research goals and to the issues confronting decision-makers. IOCI research has reached a view that the observed climate behaviour of the last 25 - 30 years in south-western Australia is best interpreted as a change of climate state. This altered state is associated with changes in atmospheric circulation and is evident as changes in some previously recognised climatic relationships and norms.

As a consequence of these changes IOCI has needed to look at human influences on climate behaviour as well as natural change and long term natural variation. Although there is a strong probability that Greenhouse gas accumulations in the atmosphere will lead to a rainfall decline in south-western Australia, the evidence suggests that the observed rainfall decline began too soon to be solely attributable to enhanced Greenhouse effects and that there are other, possibly natural, causes involved. Modelling also suggests such dry situations may have occurred before under natural conditions. The explanation for the decline is important to adaptive decision-making and is being pursued further in current research.

The climate application issues of south-western Australia, for which IOCI is providing support, might be seen in two distinct priority levels. Support to inter-seasonal forecasting represents opportunity. Support for adaptation to climate change represents necessity. Large changes in south-western climate have made the adaptation issue one of immediate concern. Decision-makers need support in making appropriate judgements about future climate baselines as a basis for sound adaptation strategies and these issues are occupying increasing attention in IOCI's program .

IOCI is already progressing on the third research phase of its core program. A key part of this current phase will be the publication of a report, especially for decision-makers, consolidating the state of knowledge on South West climate variability up to June 2002. This proposed publication will be accompanied by educative seminars or workshops.

The IOCI Panel is now pleased to be distributing the underlying report of its second phase of core research activity. The Panel believes the report represents another important step in consolidating and developing an understanding of the variability of the climate in southern and western Australia.

The report is commended for study by those who have need to make plans or decisions which must consider the effects of climate variability.

Brian Sadler
Chair IOCIP
October 2001

Summary

This report marks the conclusion of IOCI Phase 3. It follows a two-day national seminar and workshop (IOCI2000) held in Perth in November 2000 at which progress reports were presented by the research groups in draft form. Leaders in the science and application of interseasonal climate forecasts were invited to IOCI2000, and a high level of national and international expertise was assembled. The seminar program provided an overview of the growing state of knowledge about climate variability in southwest Western Australia (SWA) while the workshop provided a peer review of the research findings and the direction of the proposed research program for 2001 to 2002. The workshop was productive and led to general agreement about future research directions.

The following report is comprised of four parts. The research outcomes support a number of broad conclusions that may be summarised as follows:

The Drying Trend

- Further investigation supports the viewpoint that the underlying causes of the observed reduction in SWA winter rainfall is not simply due to changes in Indian Ocean sea surface temperatures (SSTs).
- Analysis of the results obtained from a stochastic downscaling model revealed an abrupt shift and a clearly defined trend in the frequency characteristics of the synoptic patterns that influence precipitation occurrence over SWA. The timing and nature of these changes are consistent with the characteristics of the observed low precipitation sequence.
- The changes in the frequency characteristics of the synoptic patterns and the resultant low precipitation sequence since the mid 1970s are due to changes in a combination of atmospheric variables reflecting the location and intensity of low and high pressure systems, and the moisture content of the lower troposphere. The low precipitation sequence cannot be ascribed to change(s) in a single variable such as mean sea level pressure.
- The timing of the shift appears to coincide with the well-documented change in the behaviour of the El-Niño – Southern Oscillation that occurred in the mid 1970s. The trend appears to be due to a different mechanism, and its interaction with El-Niño.

Seasonal Predictions

Linear Statistical Methods

The potential for using near-global patterns of sea surface temperature variation in seasonal climate prediction for SWA was examined. The climate variables examined were proposed by Panel members as being important for agriculture or environmental and water resource management in the southwest. Some skill was possible in predicting total rainfall and mean temperatures for spring and summer, as well as predicting extreme temperatures in summer. These predictions would be available a month or two in advance of the season predicted.

The potential use of some newly proposed modes of climate variation, known as the Antarctic Circumpolar Wave (ACW) and the Indian Ocean Dipole (IOD), was also examined. Some evidence was found that these modes might be related to SWA climate. Subsequent work, since the end of the second IOCI research phase, has found, however, that these modes

do not improve on the predictions available using the near-global patterns of sea surface temperature variability referred to above. This is because both the ACW and the IOD are closely related to the El Niño - Southern Oscillation, which is also represented in the near-global sea surface temperature patterns.

At the request of Panel members, some preliminary work was done to investigate whether observed climate variations could be used to predict crop yields. It was found that early seasonal rainfall and temperature were good predictors of wheat yield. This provided more accurate predictions than did the near-global sea surface temperature patterns. The relationship between early winter climate and yield probably occurs partly because of farmer reactions to the early winter climate – if the climate early in the season is good, then farmers will plant early and this will tend to lead to good yields.

Nonlinear Statistical Methods

An alternative perspective on seasonal prediction could be provided by so-called nonlinear statistical methods. These methods allow for behaviour such as the sudden break that has been observed in the southwest's rainfall, which is not a feature of straightforward linear behaviour. Nonlinear methods therefore provide a broader framework within which to search for climate predictors.

- A physically motivated statistical model for modelling nonlinear climate processes has been developed. The approach can now be applied to practical problems.
- The nonlinear method can identify good predictors and the lags at which they influence climate variables, such as rainfall. Within this modelling framework, changes between climate regimes are triggered by a switching variable, and comparisons between alternative switching variables can be made.
- We would expect broad scale climate features to be good candidates to cause switching behaviour. Examples include, amongst others, large-scale circulation patterns, the El Niño-Southern Oscillation (as measured by SOI), and Indian Ocean SSTs. These may operate individually or in combination.
- There is some evidence that SOI and mid-Indian Ocean SST gradients play a role in switching between rainfall regimes. At this stage, this is cited as evidence that the new nonlinear method is producing sensible results, rather than new insights *per se*.
- Interactions between climate processes are likely to influence rainfall in SWA. Some reasonably straightforward extensions to the nonlinear method will facilitate the search for subtler climate teleconnections arising from such interactions.

Numerical Climate Models and Stochastic Downscaling

The Phase 1 report documented results from the CSIRO climate model referred to as Mark2. Further analysis of these results has continued but, at the same time, a new climate model (Mark3) has been developed and used to address several key questions. When forced by observed sea surface temperatures (SSTs), the Mark3 model provides better simulations of rainfall over SWA. This improvement is seen in both the representation of the seasonal cycle, the amplitude of the seasonal cycle and the amplitude of interannual variations.

The downscaling model described in the Phase 1 report has also been further tested in order to improve the representation of rainfall at both the local and monthly time scale.

Interdecadal Variability

- Stochastic downscaling of the 1000-year long simulation with the Mark2 model indicates that the recent low precipitation sequence over SWA is uncommon but not extreme.
- Results from a much longer 10,000-year simulation with the Mark2 model confirm the earlier analyses, which indicate that annual rainfall totals over SWA can exhibit variability on decadal, multi-decadal, and even millennial time scales due to internal processes. The results did not reveal any links between changes in rainfall at these time scales and changes in other variables such as SSTs.
- The Mark3 model has been forced by observed SSTs for the period 1949 to 1990. The results from an ensemble of three such experiments do not show any evidence of a protracted reduction in rainfall over the period when the observed reduction took place. This type of result has also been noted in other climate model experiments. This tends to suggest that:
    1. Owing to sparse observations in some regions, the SST data used in the model experiments may not accurately reflect changes that may have taken place and which may be responsible for the decline, or
    2. There are other factors involved which are not represented in these “forced” SST experiments, or
    3. Rainfall is not sufficiently well simulated by large scale climate models to capture trends at the relatively small scales.

Interannual variability

- After revision of the set of atmospheric predictor variables used in the stochastic downscaling model, it was found that parameter estimates derived from atmospheric and precipitation data for the period 1978 to 1992, inclusive, could be used to simulate monthly precipitation over SWA for the period 1958-1998. This suggests that the model is robust against secular breaks in atmospheric circulation and precipitation, and that it may be a useful tool for downscaling an interseasonal climate forecast produced by a numerical climate model.
- Results from the Mark2 1000-year simulation indicate that links between Indian Ocean SSTs and rainfall over SWA can be simulated as a consequence of changes in the atmospheric circulation driving pressure, winds, rainfall and SST changes rather than as a consequence of the SSTs driving the other variables. This tends to confirm previous results suggesting that the Indian Ocean offers little in the way of predictability of SWA winter rainfall.
- Similarly, an analysis of the relationship between an Antarctic Circumpolar Wave -type phenomenon in the Mark2 model did not indicate that this provides a source of predictability for SWA winter rainfall. Nor was it possible to identify any link between high latitude Indian Ocean SSTs and SWA winter rainfall.
- The Mark3 model results reveal weak evidence of links between SWA rainfall anomalies and SST anomalies in the Pacific Ocean, but no evidence of any significant links to the Indian Ocean. This is consistent with what is known about the limited predictability for this region during winter.

- A seasonal prediction model based on the Mark2 model has been developed and exhibits skill at predicting an index of El Nino/La Nina events. This suggests that, to the extent that these events have any effect on SWA winter rainfall, there may be some limited value in these predicted indices - particularly as they are predicted with lead times up to 12 months.

Greenhouse Simulations

CSIRO climate model

- The latest CSIRO climate change simulations using the Mark2 model comprise ensembles and also take into account a range of CO_2 loadings and the effects of increased atmospheric sulphate content. The different experiments all yield decreases in annual rainfall of about -10% by the end of the 21st century. Combined with increased temperatures of up to +3.0 °C, they also indicate a decrease in soil moisture of about -15%.
- In addition, an equilibrium climate change simulation ($2\times CO_2$ only) has been performed with the Mark3 model. This is a simplified, but relatively inexpensive, greenhouse simulation. The simulated global changes are somewhat less than the Mark2 results. Despite these differences, the results for SWA are similar.
- None of the greenhouse simulations from either of the models show evidence of any significant decrease in rainfall for the SWA region over the period 1970-2000 (as has been observed). The internal (or "natural") variability in the various time series for rainfall tends to dominate any long-term trends over the latter part of the 20th century.
- One interpretation of the CSIRO results is that the enhanced greenhouse effect may have made only a minor contribution to the observed reduction in SWA winter rainfall.

Other climate models

- The results of climate change experiments from several different models have been stratified according the ability of each model to reproduce the seasonal cycle of rainfall for SWA. As a result, only three models (the Hadley Centre model, the Geophysical Fluid Dynamics Laboratory (GFDL) model and the CSIRO Mark2 model) were selected.
- Of these three, the Hadley Centre model yields the largest percentage decrease in SWA winter rainfall by the end of the 21st century while the GFDL model yields the least. As is the case with the Mark2 model, these two models do not simulate a significant reduction for the end of the 20th century.
- However, the Hadley Centre model does simulate a similar magnitude reduction in winter rainfall over the period 2000-2025. If it is assumed that the Hadley Centre model is correct, except for an error in timing of about 25 years, then it is possible that the observed reduction may represent a substantial contribution from the enhanced greenhouse effect.
- Reducing the uncertainties in the interpretation of the observed reduction and estimates for the future climate can be achieved by:

  (i) careful scrutiny of climate change simulations as they become available

  (ii) performing a range of analyses to detect significant signals in the results

  (iii) applying downscaling techniques in order to achieve more realistic estimates of expected changes in rainfall

The first three years of the IOCI has been productive, and has heightened international scientific attention on southwestern Australia. The numerous and substantial findings of the third phase of research inspire confidence that further knowledge gains are possible, and that these gains will provide valuable social and economic benefits for the region.

Bryson Bates
CSIRO Land and Water