

**On Long-Term Climate Studies Using a
Coupled General Circulation Model**

by

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B.A. (Hons.), M.A.

Submitted in fulfilment of the
requirements for the Degree of
Doctor of Philosophy

University of Tasmania

November 2006

Declarations

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Abstract

Coupled atmosphere-ocean general circulation models are the simplest models which are capable of simulating both the variability which occurs within each component of the climate system, and the variability which arises from the interactions between them. Only recently has it become computationally feasible to use coupled general circulation models to study climate variability and change on timescales of $O(10^4)$ years and longer. Flux adjustments are often employed to maintain a control climate that is both stable and realistic; however, the magnitude of the adjustments represents a source of concern.

This study employs the CSIRO Mk3L climate system model, a low-resolution coupled atmosphere-sea ice-ocean general circulation model. The atmospheric and oceanic components are spun up independently; the resulting atmospheric simulation is realistic, while the deep ocean is too cold, too fresh and too buoyant. The spin-up runs provide the initial conditions for the coupled model, which is used to conduct a 1400-year control simulation for pre-industrial conditions. After some initial adjustment, the simulated climate experiences minimal drift. The dominant mode of internal variability is found to exhibit the same spatial structure and correlations as the observed El Niño-Southern Oscillation phenomenon.

The ability of Mk3L to simulate the climate of the mid-Holocene is evaluated. It correctly simulates increased summer temperatures at northern mid-latitudes, and cooling in the tropics. However, it is unable to capture some of the regional-scale features of the mid-Holocene climate, with the precipitation over northern Africa being deficient. The model simulates a $\sim 13\%$ reduction in the strength of El Niño, a much smaller decrease than that implied by the palaeoclimate record.

A 1400-year transient simulation is then conducted, in which the atmospheric CO_2 concentration is stabilised at three times the pre-industrial value. The transient simulation exhibits a reduction in the rate of North Atlantic Deep Water formation, followed by its gradual recovery, and a cessation of Antarctic Bottom Water formation. The global-mean surface air temperature warms 2.7°C upon a trebling of CO_2 , and 5.3°C by the end of the simulation.

A number of modifications to the spin-up procedure for the ocean model are evaluated. A phase shift in the prescribed sea surface temperatures and salinities is found to reduce the phase lag between the model and observations, and to lead to a reduction in the magnitude of the diagnosed flux adjustments. When this spin-up run is used to initialise the coupled model, the reduced flux adjustments are found to have negligible impact upon the nature of the internal variability. While the flux adjustments are not found to have any *direct* influence upon the response of the model to external forcing, they are found to have an *indirect* influence via their effect upon the rate of drift within the control simulation.

An iterative spin-up technique is also developed, whereby the response of the ocean model is used to derive a set of *effective* surface tracers. These result in a much more realistic vertical density profile within the ocean. The coupled model exhibits slightly increased internal variability, with reduced convection within the ocean. There is a slightly greater surface warming in response to an increase in the atmospheric CO_2 concentration, with the reduced convection resulting in slower penetration of the surface warming to depth.

Acknowledgements

I would like to thank Bill Budd, Nathan Bindoff, Jason Roberts, Scott Power, Xingren Wu and Tas van Ommen for their supervision and guidance throughout my PhD candidature. Jason deserves special mention for many fruitful discussions, without which many of the ideas presented herein would never have evolved. His tireless support as I was writing this document was also very much appreciated.

Thanks should go to CSIRO Marine and Atmospheric Research for allowing me to use their climate system model, and for their assistance throughout this project.

The simulations presented herein were conducted on facilities at the Australian Partnership for Advanced Computing in Canberra, and at the Interactive Virtual Environments Centre in Perth, Western Australia. This project would not have been possible without access to these facilities, and I would like to thank the staff at both centres for their support.

Two productive visits were made to the Climate Modelling Group at the University of Victoria in British Columbia, Canada, during the course of this project. My time there was of enormous benefit, and I would like to thank Andrew Weaver and the remainder of the group for their hospitality.

This project was supported through grants of computer time from the APAC Merit Allocation Committee (project e56), the Tasmanian Partnership for Advanced Computing (project e00) and the Interactive Virtual Environments Centre (project ivec0042). Financial support was also received from the Australian Government (an International Postgraduate Research Scholarship), the University of Tasmania (a Tasmania Research Scholarship), the Antarctic CRC (an Antarctic CRC Top-Up Scholarship) and the Trans-Antarctic Association (grant TAA/99/12).

I would like to acknowledge use of the Ferret program (www.ferret.noaa.gov) in the production of the figures presented herein, and the NOAA-CIRES Climate Diagnostics Center (www.cdc.noaa.gov) for making a range of datasets freely available.

I would also like to thank Jason Roberts and Vicki Randell for their diligence in proof-reading this document.

List of Acronyms

AABW	Antarctic Bottom Water
ACC	Antarctic Circumpolar Current
AGCM	Atmospheric General Circulation Model
AMIP	Atmospheric Model Intercomparison Project
APAC	Australian Partnership for Advanced Computing
BP	Before Present
CFL	Courant-Friedrichs-Lewy
CIRES	Cooperative Institute for Research in Environmental Sciences
CMIP	Coupled Model Intercomparison Project
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DJF	December-January-February
DOE	Department of Energy
EMIC	Earth System Model of Intermediate Complexity
ENSO	El Niño-Southern Oscillation
GCM	General Circulation Model
IPCC	Intergovernmental Panel on Climate Change
iVEC	Interactive Virtual Environments Centre
JJA	June-July-August
MSLP	Mean Sea Level Pressure
NADW	North Atlantic Deep Water
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NH	Northern Hemisphere
NOAA	National Oceanic & Atmospheric Administration
OGCM	Ocean(ic) General Circulation Model
OI	Optimum Interpolation
PMIP	Paleoclimate Modelling Intercomparison Project
RMS	Root-Mean-Square
SAT	Surface Air Temperature
SH	Southern Hemisphere
SOI	Southern Oscillation Index
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
WOCE	World Ocean Circulation Experiment

Run nomenclature

Each of the simulations presented herein is given a two-part name, which is constructed as follows:

type-experiment

type indicates the type of simulation being performed, and can have the following values:

A	Atmosphere model spin-up run
CON	Coupled model control run
O	Ocean model spin-up run
3CO2	Coupled model simulation for a $3\times\text{CO}_2$ stabilisation scenario
6ka	Coupled model simulation for the mid-Holocene [6ka BP]

experiment indicates the experiment, and can have the following values:

DEF	Default configuration of the model
EFF	Effective surface tracers used to spin up the ocean model
SHF	Phase-shifted surface tracers used to spin up the ocean model
<i>nd</i>	Relaxation timescale of <i>n</i> days used to spin up the ocean model
<i>Spsu</i>	Sub-ice surface tracers used to spin up the ocean model ($dS = S$ psu)

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