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

by

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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.

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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 $3\times CO_2$ 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
nd	Relaxation timescale of n days used to spin up the ocean model
Spsu	Sub-ice surface tracers used to spin up the ocean model (dS = S psu)

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