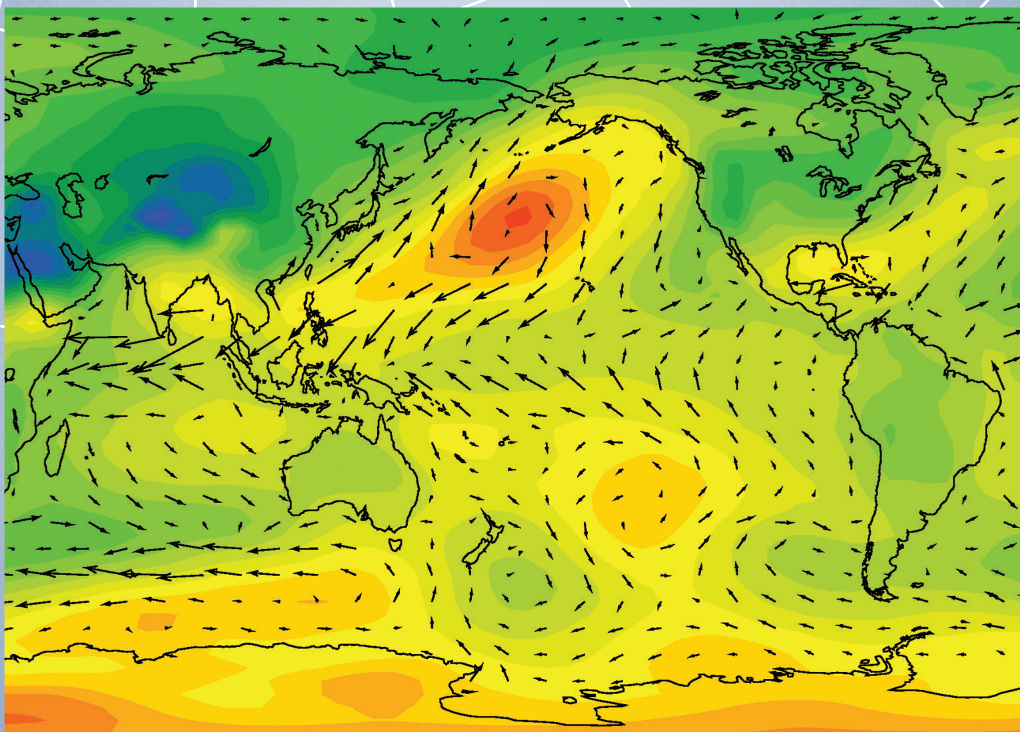
WWW.ACECRC.ORG.AU

ANTARCTIC CLIMATE & ECOSYSTEMS
COOPERATIVE RESEARCH CENTRE

TECHNICAL REPORT:

The CSIRO Mk3L climate system model v1.2



Technical Report: The CSIRO Mk3L climate system model v1.2

Prepared by: Dr Steven Phipps, ACE CRC, University of NSW, June 2010.

TR01-100603

ISBN 978-1-921197-04-8

The Manager
Communications
Antarctic Climate & Ecosystems
Cooperative Research Centre

Private Bag 80
Hobart Tasmania 7001
Tel: +61 3 6226 7888
Fax: +61 3 6226 2440
Email: enquiries@acecrc.org.au
www.acecrc.org.au

Established and supported under the Australian Government's Cooperative Research Centre Program.

Australian Government
Department of the Environment, Water, Heritage and the Arts
Australian Antarctic Division

CSIRO

UTAS

Australian Government
Department of Climate Change and Energy Efficiency

AWI
Alfred Wegener Institute for Polar and Marine Research in the Helmholtz Association

NIWA
Taihoro Nukurangi

The ACE CRC's core partners are: the Australian Antarctic Division; CSIRO; University of Tasmania; the Australian Government's Department of Climate Change and Energy Efficiency; the Alfred Wegener Institute for Polar and Marine Research (Germany); and the National Institute of Water and Atmospheric Research Ltd (New Zealand).

ACE also has formal partnerships with the Department of the Environment, Water, Heritage and the Arts (DEWHA); Tasmanian Government; Centre for Polar Observation and Modelling (CPOM – UK); Chinese Academy of Meteorological Sciences (CAMS); Institute of Low Temperature Science (ILTS – Japan); First Institute of Oceanography (FIO – China); Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS – France); Memorial University of Newfoundland (MUN); National Institute of Polar Research (NIPR - Japan); University of Texas at Austin; University of Texas at San Antonio; Vrije Universiteit Brussel (VUB); GHD Pty Ltd; Myriax Software Pty Ltd; Pitt & Sherry; RPS MetOcean Pty Ltd; and SGS Economics and Planning Pty Ltd.

The CSIRO Mk3L climate system model v1.2

Contents

Acknowledgements

This work was supported by awards under the Merit Allocation Scheme on the NCI National Facility at the Australian National University.

The World Ocean Atlas 1998, NCEP-DOE Reanalysis 2 and NOAA Optimum Interpolation Sea Surface Temperature Analysis v2 datasets were provided by the NOAA-ESRL Physical Sciences Division, Boulder, Colorado, USA from their website at http://www.esrl.noaa.gov/psd/.

The author wishes to acknowledge use of the Ferret program for analysis and graphics in this report (http://ferret.pmel.noaa.gov/Ferret/).

Chapter 1

Introduction

1.1 The CSIRO Mk3L climate system model

The CSIRO Mk3L climate system model is a computationally-efficient coupled atmosphere-sea ice-ocean general circulation model, suitable for studying climate variability and change on millennial timescales.

The atmospheric component of Mk3L comprises a spectral general circulation model, a sea ice model and a land surface model. A coarse horizontal resolution of R21 is employed, giving zonal and meridional resolutions of 5.625° and ∼3.18° respectively. A hybrid vertical coordinate is used, with 18 vertical levels. The model incorporates both a cumulus convection scheme and a prognostic stratiform cloud scheme. The radiation scheme treats longwave and shortwave radiation independently, and is able to calculate the cloud radiative forcings. Code has been incorporated to calculate the values of the Earth's orbital parameters, enabling them to be varied dynamically at runtime.

The sea ice model includes both ice dynamics and ice thermodynamics. The land surface model allows for 13 land surface and/or vegetation types and nine soil types, and incorporates prognostic soil and snow models. The vegetation types and land surface properties are pre-determined, however, and are therefore static.

The oceanic component of Mk3L is a z-coordinate general circulation model. The horizontal resolution is double that of the atmospheric component, with four oceanic gridboxes exactly matching each atmospheric gridbox. The zonal and meridional resolutions are therefore 2.8125° and ∼1.59° respectively, and there are 21 vertical levels. The prognostic variables are potential temperature, salinity, and the zonal and meridional components of the horizontal velocity. The vertical velocity is diagnosed through the application of the continuity equation. *In situ* density is calculated using the equation of state of McDougall et al. (2003). The scheme of Gent and McWilliams (1990) is employed, in order to parameterise the adiabatic transport of tracers by mesoscale eddies.

The coupling between the atmosphere and ocean models within Mk3L rigorously conserves both heat and freshwater. Flux adjustments can be applied within the coupled model, although the control climate of the model is stable on millennial timescales even when flux adjustments are not employed.

The source code has been designed to ensure that Mk3L is portable across a wide range of computer architectures, whilst also being computationally efficient. Dependence on external libraries is restricted to the netCDF and FFTW libraries, both of which are freely available and open source, while a high degree of shared-memory parallelism is achieved through the use of OpenMP directives. On an eight-core Intel Nehalem processor, Mk3L can complete a 1000-year simulation in around three weeks.

1.2 History

Version 1.0 of Mk3L was first distributed in 2006, and is described by Phipps (2006).

Subsequent development work has sought to upgrade the model physics, to improve the realism of the simulated climatology, and to make the model faster, easier to use and more portable. The most significant physical enhancement over this period has been to double the default horizontal resolution of the ocean model. This has improved the simulated oceanic simulation, and enables the model to be run without flux adjustments.

Version 1.1 of Mk3L was released on 10 March 2008, and version 1.2 was released on 7 August 2009. The release notes for these versions are provided in Appendices A and B respectively. This document describes version 1.2, and represents an updated version of Phipps (2006).

1.3 Overview

This report constitutes both technical documentation and a user's guide, and has been written with both beginners and experienced users in mind.

Chapter 2 describes the model physics; beginners can happily skip this chapter. Chapter 3 explains how to compile and run Mk3L, while Chapter 4 explains how to configure the model via the control file. Chapter 5 describes the restart and auxiliary files that are required, while Chapter 6 describes the output files, including the processing of model output.

A number of appendices are also included, which provide further information regarding the development and use of Mk3L. Appendices A and B provide the release notes that were distributed with versions 1.1 and 1.2 of the model respectively. Appendix C describes the procedures used to generate auxiliary files, while Appendix D provides sample control files and run scripts.

Chapter 2

Model description

2.1 Introduction

The CSIRO Mk3L climate system model comprises two components: an atmospheric general circulation model, which incorporates both a sea ice model and a land surface model, and an oceanic general circulation model. The atmospheric general circulation model represents a low-resolution version of the atmospheric component of the CSIRO Mk3 coupled model (Gordon et al., 2002), while the oceanic general circulation model represents an upgraded version of the oceanic component of the CSIRO Mk2 coupled model (Gordon and O'Farrell, 1997).

This combination of low spatial resolution and up-to-date model physics results in a model which is computationally efficient, and yet which has a control climatology that is realistic and stable on multi-millennial timescales. Relative to the CSIRO Mk2 coupled model, enhancements to the physics within Mk3L include:

- Atmosphere model:
  - an increase in the vertical resolution from 9 to 18 levels
  - the implementation of a prognostic scheme for stratiform cloud
  - the implementation of a new cumulus convection scheme
  - the ability to calculate the Earth's orbital parameters at runtime
  - an enhanced land surface model
- Ocean model:
  - a doubling of the horizontal resolution
  - the implementation of the McDougall et al. (2003) equation of state
  - the implementation of a Robert time filter
  - improved treatment of mixing across unresolved straits
- Coupled model:
  - the implementation of fully conservative coupling
  - the implementation of a freshwater hosing scheme

The development of version 1.0 of Mk3L is described in detail by Phipps (2006), while the additional features implemented in versions 1.1 and 1.2 are described in Appendices A and B respectively.

The Mk3L atmosphere, ocean and coupled models are described in Sections 2.2, 2.3 and 2.4 respectively. The derivation of flux adjustments, which can be applied within the coupled model, is described in Section 2.5.

2.2 Atmosphere model

The Mk3L atmosphere model represents a low-resolution version of the Mk3 atmosphere model (Gordon et al., 2002). The standard configuration of the Mk3 atmosphere model employs a spectral resolution of T63; however, a spectral resolution of R21 is also supported for research purposes, and it is this resolution which is used within Mk3L. The zonal and meridional resolutions are therefore 5.625° and $\sim$3.18° respectively.

The atmosphere model consists of three components: an atmospheric general circulation model, a multi-layer dynamic-thermodynamic sea ice model and a land surface model. As each of these components is documented in detail by Gordon et al. (2002), only a brief summary is provided here. This summary concentrates on those features which are unique to Mk3L.

2.2.1 Atmospheric general circulation model

The dynamical core of the atmosphere model is based upon the spectral method, and uses the flux form of the dynamical equations (Gordon, 1981). Physical parameterisations and non-linear dynamical flux terms are calculated on a latitude-longitude grid, with Fast Fourier Transforms used to transform fields between their spectral and gridded forms. Semi-Lagrangian transport is used to advect moisture (McGregor, 1993), and gravity wave drag is parameterised using the formulation of Chouinard et al. (1986).

A hybrid vertical coordinate is used, which is denoted as the η-coordinate. The Earth's surface forms the first coordinate surface, as in the σ-system, while the remaining coordinate surfaces gradually revert to isobaric levels with increasing altitude. The 18 vertical levels used in the Mk3L atmosphere model are listed in Table 2.1 (Gordon et al., 2002, Table 1). Some model variables are interpolated onto pressure levels before being saved; these levels are also shown in Table 2.1.

The topography is derived by interpolating the $1^\circ\times1^\circ$ dataset of Gates and Nelson (1975) onto the model grid. Some modifications are then made, in order to avoid areas of significant negative elevation upon fitting to the (truncated) resolution of the spectral model (Gordon et al., 2002). The resulting topography is shown in Figure 2.1.

Time integration is via a semi-implicit leapfrog scheme, with a Robert-Asselin time filter (Robert, 1966) used to prevent decoupling of the time-integrated solutions at odd and even timsteps. The Mk3L atmosphere model uses a timestep of 20 minutes.

The radiation scheme treats solar (shortwave) and terrestrial (longwave) radiation independently. Full radiation calculations are conducted every two hours, allowing for both the annual and diurnal cycles. Clear-sky radiation calculations are also performed at each radiation timestep. This enables the cloud radiative forcings to be determined using Method II of Cess and Potter (1987), with the forcings being given by the differences between the radiative fluxes calculated with and without the effects of clouds.

Level (k)	η	Approximate height (m)	Pressure (hPa)
18	0.0045	36355	5
17	0.0216	27360	10
16	0.0542	20600	20
15	0.1001	16550	30
14	0.1574	13650	50
13	0.2239	11360	70
12	0.2977	9440	100
11	0.3765	7780	150
10	0.4585	6335	200
9	0.5415	5070	250
8	0.6235	3970	300
7	0.7023	3025	400
6	0.7761	2215	500
5	0.8426	1535	600
4	0.8999	990	700
3	0.9458	575	850
2	0.9784	300	925
1	0.9955	165	1000

Table 2.1: The hybrid vertical levels used within the Mk3L atmosphere model: the value of the η-coordinate, and the approximate height. Also shown are the pressure levels on which some model variables are saved.

The shortwave radiation scheme is based on the approach of Lacis and Hansen (1974), which divides the shortwave spectrum into 12 bands. Within each of these bands, the radiative properties are taken as being uniform. Ozone concentrations are taken from the AMIP II recommended dataset (Wang et al., 1995). Additional code has been inserted into Mk3L, enabling both the solar constant and the epoch to be specified within the model control file, with the Earth's orbital parameters being calculated at runtime (Phipps, 2006).

The longwave radiation scheme uses the parameterisation developed by Fels and Schwarzkopf (Fels and Schwarzkopf, 1975, 1981; Schwarzkopf and Fels, 1985, 1991), which divides the longwave spectrum (wavelengths longer than 5 μm) into seven bands. Values for the CO_2 transmission coefficients must be provided via an auxiliary file (Section 5.2).

The cumulus convection scheme is based on the U.K. Meteorological Office scheme (Gregory and Rowntree, 1990), and generates both the amount and the liquid water content of convective clouds. This scheme is coupled to the prognostic cloud scheme of Rotstayn (1997, 1998, 2000), which calculates the amount of stratiform cloud, using the three prognostic variables of water vapour mixing ratio, cloud liquid water mixing ratio and cloud ice mixing ratio.

In the stand-alone atmosphere model, four types of surface gridpoint are employed: land, sea, mixed-layer ocean and sea ice. The temperatures of the sea gridpoints are determined by monthly-mean observed sea surface temperatures, which are provided via an auxiliary file (Section 5.2). Linear interpolaton in time is used to estimate values at each timestep, with no allowance for any diurnal variation. At high latitudes, sea gridpoints may be converted to mixed-layer ocean gridpoints, with self-computed temperatures; these

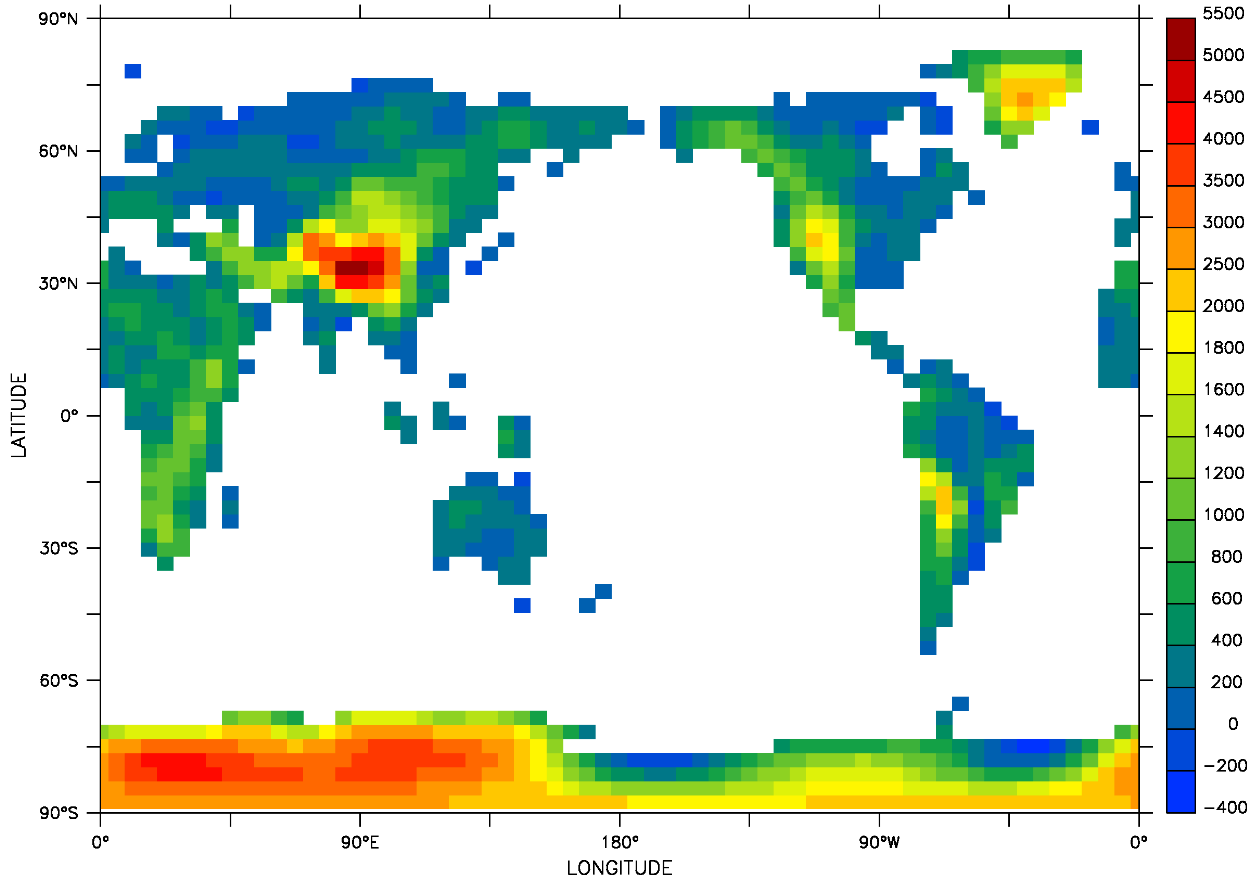


Figure 2.1: The topography of the Mk3L atmosphere model: the elevation of land gridpoints (m).

can then evolve into sea ice gridpoints. This is discussed further in the following description of the sea ice model.

2.2.2 Sea ice model

The sea ice model includes both ice dynamics and ice thermodynamics, and is described by O'Farrell (1998). Internal resistance to deformation is parameterised using the cavitating fluid rheology of Flato and Hibler (1990, 1992). The thermodynamic component is based on the model of Semtner (1976), which splits the ice into three layers, one for snow and two for ice. Sea ice gridpoints are allowed to have fractional ice cover, representing the presence of leads and polynyas.

Ice advection arises from the forcing from above by atmospheric wind stresses, and from below by oceanic currents. The currents are obtained from the ocean model when running as part of the coupled model; in the stand-alone atmosphere model, climatological ocean currents are provided via an auxiliary file (Section 5.2).

The advance and retreat of the ice edge in the stand-alone atmosphere model is controlled by using a mixed-layer ocean to compute water temperatures for those sea gridpoints which lie adjacent to sea ice. The mixed-layer ocean has a fixed depth of 100 m, and the evolution of the water temperature T_s is calculated using the surface heat flux terms and a weak relaxation towards the prescribed sea surface temperature T_{SST}, as follows (Gordon et al., 2002, Equation 19.6):

$$\gamma_0 \frac{dT_s}{dt} = (1 - \alpha_s) S_s^{\downarrow} + R_s^{\downarrow} - \epsilon_s \sigma T_s^4 - (H_s + E_s) + \lambda_c (T_{SST} - T_s) \tag{2.1}$$

Here, γ_0 represents the areal heat capacity of a 100 m-thick layer of water, t represents time, α_s represents the surface albedo, $S_s^{\downarrow}$ and $R_s^{\downarrow}$ represent the net downward surface fluxes of shortwave and longwave radiation respectively, ϵ_s represents the surface emissivity, σ represents the Stefan-Boltzmann constant, H_s and E_s represent the net upward surface fluxes of sensible and latent heat respectively, and λ_c represents a relaxation constant. Mk3L uses a relaxation timescale of 23 days.

A mixed-layer ocean gridpoint can become a sea ice gridpoint either when its temperature falls below the freezing point of seawater, which is taken as being -1.85°C, or when ice is advected from an adjacent sea ice gridpoint. When a mixed-layer ocean gridpoint is converted to a sea ice gridpoint, the initial ice concentration is set at 4%. The neighbouring equatorward gridpoint, if it is a sea gridpoint, is then converted to a mixed-layer ocean gridpoint.

Within a gridpoint that has fractional sea ice cover, both in the stand-alone atmosphere model and the coupled model, the water temperature is calculated using a mixed-layer ocean with a fixed depth of 100 m. The surface heat flux is given by Equation 2.1, except that the final relaxation term is replaced with a basal heat flux F_i, which is calculated as follows (Gordon et al., 2002, Equation 19.8):

$$F_i = \frac{k_{frz} \rho_w c_w dz (T_{SST} - T_f)}{(dz/2)^2} + F_{geog} \tag{2.2}$$

Here, k_{frz} = 0.15×10^{-4} s^{-1} is the heat transfer coefficient, ρ_w and c_w are the density and specific heat capacity of seawater respectively, dz = 25 m is the thickness of the upper layer of the ocean model, and T_f = -1.85°C represents the freezing point of seawater. T_{SST} represents the prescribed sea surface temperature in the case of the stand-alone atmosphere model, and the temperature of the upper level of the ocean in the case of the coupled model. The additional fixed component F_{geog} allows for the effects of sub-gridscale mixing. Its value is resolution-dependent and, at the horizontal resolution of R21 used in Mk3L, is equal to 2 Wm^{-2} in the Northern Hemisphere, and 15 Wm^{-2} in the Southern Hemisphere.

If, within the coupled model, the temperature of the upper level of the ocean T_{OC} falls below -2°C, an additional term is added to the ice-ocean heat flux, as follows (Gordon et al., 2002, Equation 19.9):

$$F_{frz} = \frac{k_{frz} \rho_w c_w dz (T_{OC} - T_f)}{(dz/2)^2} \tag{2.3}$$

In this case, k_{frz} is increased to 6×10^{-4} s^{-1} in order to stimulate the formation of sea ice in sub-freezing waters.

Surface processes can lead to either a decrease in ice volume, as a result of either melting or sublimation, or an increase in ice volume; this can occur either when the depth of snow exceeds 2 m, in which case the excess is converted into an equivalent amount of ice, or when the weight of snow becomes so great that the floe becomes completely submerged. When the latter occurs, any submerged snow is converted into “white” ice.

Lateral and basal ice growth and melt are determined by the temperature of the mixed-layer ocean. Additional ice can grow when the water temperature falls below the freezing point of seawater, -1.85°C, subject to a maximum allowable thickness of 6 m. Once the water temperature rises above -1.5°C, half of any additional heating is used to melt ice; once it rises above -1.0°C, all of the additional heating is used to melt ice. In the case of the stand-alone atmosphere model, a sea ice gridpoint is converted back to a mixed-layer ocean gridpoint once the sea ice has disappeared. The neighbouring equatorward gridpoint, if it is a mixed-layer ocean gridpoint, is then converted back to a sea gridpoint.

2.2.3 Land surface model

The land surface model is an enhanced version of the soil-canopy scheme of Kowalczyk et al. (1991, 1994). A new parameterisation of soil moisture and temperature has been implemented, a greater number of soil and vegetation types are available, and a multi-layer snow cover scheme has been incorporated.

The soil-canopy scheme allows for 13 land surface and/or vegetation types and nine soil types. The land surface properties are pre-determined, and are provided via auxiliary files (Section 5.2). Seasonally-varying values are provided for the albedo and roughness length, and annual-mean values for the vegetation fraction. The stomatal resistance is calculated by the model, as are seasonally-varying vegetation fractions for some vegetation types. The soil model has six layers, each of which has a pre-set thickness. Soil temperature and the liquid water and ice contents are calculated as prognostic variables. Run-off occurs once the surface layer becomes saturated, and is assumed to travel instantaneously to the ocean via the path of steepest descent.

The snow model computes the temperature, snow density and thickness of three snowpack layers, and calculates the snow albedo. The maximum snow depth is set at 4 m (equivalent to 0.4 m of water).

2.3 Ocean model

The Mk3L ocean model is a coarse-resolution, z-coordinate general circulation model, based on the implementation by Cox (1984) of the primitive equation numerical model of Bryan (1969). It is based upon the Mk2 ocean model (Gordon and O'Farrell, 1997; Hirst et al., 2000; Bi, 2002), but with a doubling of the horizontal resolution and a number of enhancements to the model physics.

The prognostic variables used by the model are potential temperature, salinity, and the zonal and meridional components of the horizontal velocity. The Arakawa B-grid (Arakawa and Lamb, 1977) is used, in which the tracer gridpoints are located at the centres of the gridboxes, and the horizontal velocity gridpoints are located at the corners. The vertical velocity is diagnosed through application of the continuity equation. *In situ* density is calculated using the equation of state of McDougall et al. (2003).

The horizontal grid matches the Gaussian grid of the atmosphere model, such that four tracer gridboxes on the ocean model grid coincide exactly with each atmosphere model gridbox. The zonal and meridional resolutions are therefore 2.8125° and $\sim$1.59° respectively. There are 21 vertical levels, which are listed in Table 2.2.

The bottom topography is derived by area-averaging the ETOPO2v2c bathymetry (National Geophysical Data Center, 2006) onto the model grid. A number of modifications are then made, in order to ensure numerical stability and increase the realism of the simulated climate: (a) two passes of a smoothing filter are made, (b) the depths of various key straits are manually adjusted so as to be consistent with the true values, and (c) the depth at each gridpoint is set to a minimum value of 3 model levels [80m] in the tropics and 5 model levels [160m] at higher latitudes. The resulting bathymetry is shown in Figure 2.2.

Level	**Thickness**	**Depth (m)**		κ_e
(k)	**(m)**	**Centre**	**Base**	**(m^2s^{-1})**
1	25	12.5	25	0^*
2	25	37.5	50	70^*
3	30	65	80	180^*
4	37	98.5	117	290^*
5	43	138.5	160	420^*
6	50	185	210	$580^\dagger$
7	60	240	270	$600^{\dagger\ddagger}$
8	80	310	350	$600^\ddagger$
9	120	410	470	$600^\ddagger$
10	150	545	620	$600^\ddagger$
11	180	710	800	$600^\ddagger$
12	210	905	1010	$600^\ddagger$
13	240	1130	1250	$600^\ddagger$
14	290	1395	1540	$600^\ddagger$
15	360	1720	1900	$600^\ddagger$
16	450	2125	2350	$600^\ddagger$
17	450	2575	2800	$600^\ddagger$
18	450	3025	3250	$600^\ddagger$
19	450	3475	3700	$600^\ddagger$
20	450	3925	4150	$600^\ddagger$
21	450	4375	4600	$600^\ddagger$

Table 2.2: The vertical levels used within the Mk3L ocean model: the thickness, the depth of the centre and base of each gridbox, and the value of the isopycnal thickness diffusivity. *These values are hard-coded into the model. †The maximum allowable values for levels 6 and 7 are 580 and 770 m^2s^{-1} respectively; lower values may be specified via the model control file. ‡These values are specified via the model control file, and represent the default values used in Mk3L.

The bathymetry of the Mk3L ocean model defines four basins which have no resolved connection with the world ocean: the Baltic, Black and Caspian Seas, and the Persian Gulf. It does not therefore adequately represent the physical connections which exist within the ocean; with the exception of the Caspian Sea, each of these basins exchanges water with the world ocean via straits which are not resolved on the model grid. The effects of these exchanges are parameterised within the model through an imposed mixing between the gridpoints which lie to either side of each unresolved strait (Phipps, 2006). An additional, but non-physical, mixing of 0.01 Sv is imposed between the Caspian and Black Seas, in order to connect the Caspian Sea to the world ocean and therefore prevent any long-term drift in its mean temperature or salinity.

Time integration is via a leapfrog scheme, with a Robert time filter (Robert, 1966) used to prevent decoupling of the time-integrated solutions at odd and even timesteps. Fourier filtering is used to reduce the timestep limitation arising from the CFL criterion (e.g. Washington and Parkinson, 1986) associated with the convergence of meridians at high latitudes, particularly in the Arctic Ocean (Cox, 1984). In the Mk3L ocean model, Fourier filtering is only applied northward of 79.6°N in the case of tracers, and northward of 80.4°N in the case of horizontal velocities. The *rigid-lid* boundary condition (Cox, 1984) is employed to remove the timestep limitation associated with high-speed external gravity waves. The ocean bottom is assumed to be

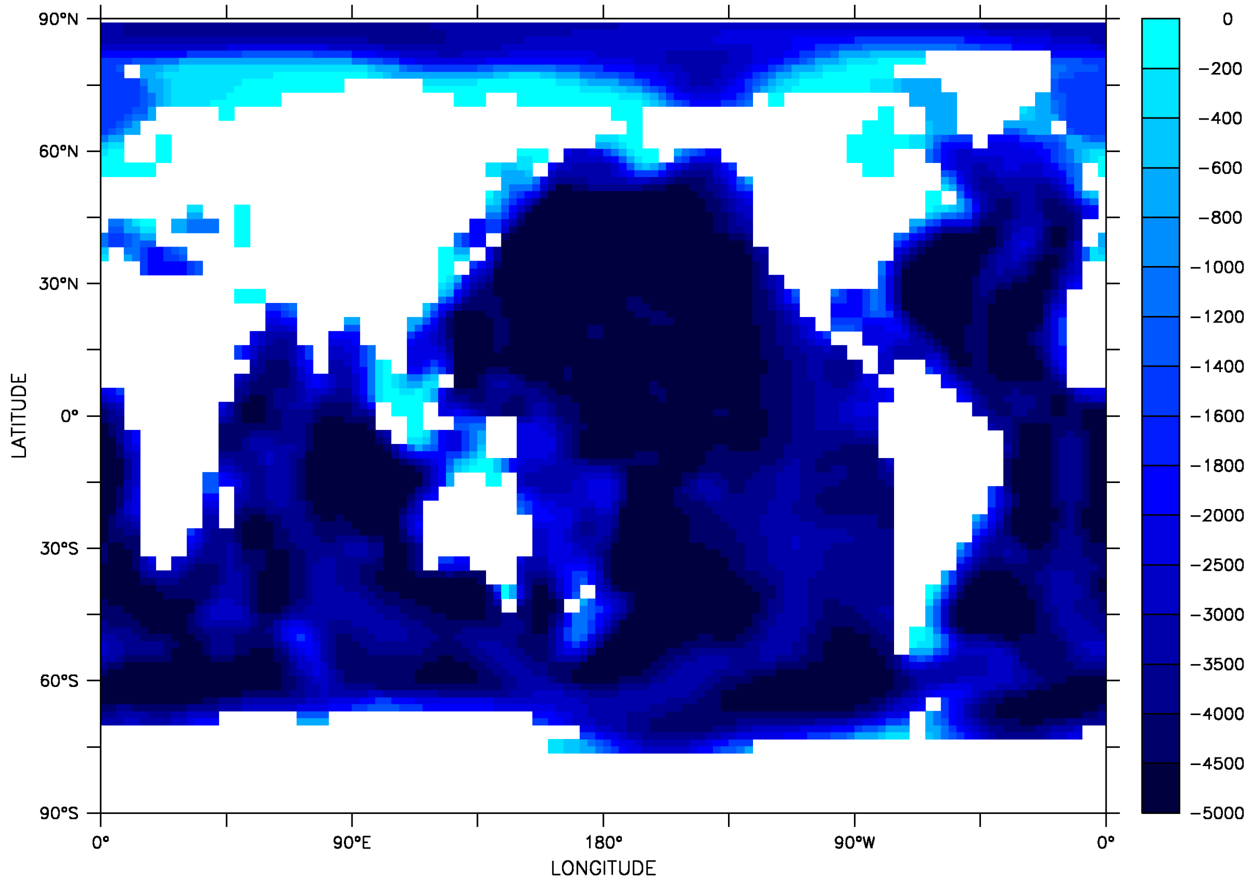


Figure 2.2: The bathymetry of the Mk3L ocean model: the depth of ocean gridpoints (m).

insulating, while no-slip and insulating boundary conditions are applied at lateral boundaries.

The stand-alone ocean model employs an asynchronous timestepping scheme, with a timestep of 1 day used to integrate the tracer equations and a timestep of 20 minutes used to integrate the momentum equations. Within the coupled model — and during the final stage of spin-up runs, prior to coupling to the atmosphere model — a synchronous timestepping scheme is employed, with a timestep of 1 hour used to integrate both the tracer and momentum equations.

The vertical diffusivity κ_v varies as the inverse of the Brunt-Väisälä frequency, following the scheme of Gargett (1984). The minimum diffusivity is set at 3×10^{-5} m^2s^{-1}, except in the upper levels of the ocean, where it is increased in order to simulate the effects of mixing induced by surface winds. The minimum diffusivity between the upper two levels of the model is set at 2×10^{-3} m^2s^{-1}, while that between the second and third levels is set at 1.5×10^{-4} m^2s^{-1}. Whenever static instability arises, the vertical diffusivity is increased to 100 m^2s^{-1}, simulating convective mixing.

Two parameterisations are incorporated in order to represent mixing along isopycnal surfaces (i.e. surfaces of constant density). The first of these parameterisations is the isopycnal diffusion scheme of Cox (1987), which allows for a more realistic representation of the tendency for tracers to be mixed along surfaces of constant density. In the default configuration of Mk3L, the isopycnal diffusivity is set to the depth-independent value of 600 m^2s^{-1}.

The second parameterisation is the scheme of Gent and McWilliams (1990) and Gent et al. (1995), which parameterises the adiabatic transport of tracers by mesoscale eddies. An eddy-induced horizontal transport velocity is diagnosed, which is added to the resolved large-scale horizontal velocity to give an effective horizontal transport velocity. The continuity equation can be used to derive the vertical component of either the eddy-induced transport velocity or the effective transport velocity. For reasons of numerical stability, there is a transition to horizontal diffusion within the Arctic Ocean; in the default configuration of Mk3L, the horizontal diffusivity is set to the depth-independent value of 600 m^{2}s^{-1}.

The default values for the isopycnal thickness diffusivity are shown in Table 2.2. Note that the values for levels 1 to 5 are fixed, and are hard-coded into the model. The diffusivities for levels 6 and 7 may not exceed 580 and 770 m^{2}s^{-1} respectively, with these upper limits also being hard-coded. The values for the remaining levels are specified via the model control file. The decrease in the isopycnal thickness diffusivity in the upper layers, with a value of zero at the surface, is required by the continuity constraint imposed on the eddy-induced transport (Bi, 2002).

In the stand-alone ocean model, monthly values for the sea surface temperature (SST), sea surface salinity (SSS), and the zonal and meridional components of the surface wind stress are read from auxiliary files (Section 5.2). Linear interpolation in time is used to estimate values at each timestep. The temperature and salinity of the upper layer of the model are relaxed towards the prescribed SST and SSS, using a default relaxation timescale of 20 days. In Mk3L, it is possible for a different relaxation timescale to be specified via the model control file (Section 4.3).

2.4 Coupled model

The coupling between the AGCM and OGCM is described in detail by Phipps (2006), and rigorously conserves heat and freshwater. Within the coupled model, four fields are passed from the atmosphere model (AGCM) to the ocean model (OGCM): the surface heat flux, surface salinity tendency, and the zonal and meridional components of the surface momentum flux. Four fields are also passed from the OGCM to the AGCM: the sea surface temperature (SST), sea surface salinity (SSS), and the zonal and meridional components of the surface velocity.

The Mk3L coupled model runs in a synchronous mode, with one OGCM timestep (1 hour) being followed by three AGCM timesteps (3×20 minutes). The surface fluxes calculated by the AGCM are averaged over the three consecutive AGCM timesteps, before being passed to the ocean model. Bilinear interpolation is used to interpolate the AGCM fields to the spatial resolution of the OGCM.

In the case of the surface fields passed from the OGCM to the AGCM, instantaneous values for the zonal and meridional components of the surface velocity are passed to the AGCM. These velocities act as the bottom boundary condition on the sea ice model for the following three AGCM timesteps. In the case of the SST and SSS, however, the OGCM passes two copies of each field: one containing the values at the current OGCM timestep, and one containing the values which have been predicted for the next OGCM timestep. The AGCM then uses linear interpolation in time to estimate the SST and SSS at each AGCM timestep. Area averaging is used to interpolate the OGCM fields to the spatial resolution of the AGCM.

Flux adjustments can be applied to each of the fluxes passed from the AGCM to the OGCM, and also to the SST and SSS. Any need to apply adjustments to the surface velocities is avoided by using climatological values, diagnosed from an OGCM spin-up run, to spin up the AGCM.

2.5 Flux adjustments

Four fields are passed from the atmosphere model (AGCM) to the ocean model (OGCM): the surface heat flux, the surface salinity tendency, and the zonal and meridional components of the surface momentum flux. Any differences between the surface fluxes calculated by the stand-alone AGCM, and those which are required to maintain the stand-alone OGCM in its equilibrium state, will represent a potential source of drift within the coupled model. Flux adjustments can therefore be applied to each of these four fields.

The derivation of the flux adjustments is straightforward. If F_A is the surface flux diagnosed from an AGCM spin-up run, and F_O the surface flux diagnosed from an OGCM spin-up run (or, in the case of the components of the surface momentum flux, the flux applied to the stand-alone OGCM), then the flux adjustment ΔF is given by

$$\Delta F(\lambda, \phi, t) = F_A(\lambda, \phi, t) - F_O(\lambda, \phi, t) \tag{2.4}$$

where λ, ϕ, t represent longitude, latitude and the time of year respectively. The flux adjustments therefore vary temporally, as well as spatially. Within the coupled model, if F represents the surface flux calculated by the AGCM, then the adjusted flux F' which is passed to the OGCM is given by

$$F'(\lambda, \phi, t) = F(\lambda, \phi, t) - \Delta F(\lambda, \phi, t) \tag{2.5}$$

[Note that within Mk3L, the flux adjustments are *subtracted* from the AGCM surface fluxes.]

Four fields are also passed from the OGCM to the AGCM: the sea surface temperature (SST), the sea surface salinity (SSS), and the zonal and meridional components of the surface velocity. Any differences between the values of these fields, and the values which were imposed as the bottom boundary condition on the stand-alone AGCM, will also represent a potential source of drift within the coupled model. Any need to apply adjustments to the components of the surface velocity is avoided through the use of climatological surface currents, diagnosed from an OGCM spin-up run, to spin up the AGCM. However, adjustments can be applied to the SST and SSS.

The derivation of the adjustments to the SSS is straightforward. If S_{obs} is the SSS which was imposed as the surface boundary condition on the stand-alone OGCM, and S_O is the SSS which was simulated by the model, then the SSS adjustment ΔS is given by

$$\Delta S(\lambda, \phi, t) = S_{obs}(\lambda, \phi, t) - S_O(\lambda, \phi, t) \tag{2.6}$$

Within the coupled model, if S represents the SSS calculated by the OGCM, then the adjusted sea surface salinity S' which is passed to the AGCM is given by

$$S'(\lambda, \phi, t) = S(\lambda, \phi, t) + \Delta S(\lambda, \phi, t) \tag{2.7}$$

The derivation of the adjustments to the SST is more complex. If T_A is the SST which was imposed as the surface boundary condition on the stand-alone AGCM, and T_O is the SST simulated by the stand-alone OGCM, then the SST adjustment ΔT is given by

$$\Delta T(\lambda, \phi, t) = T_A(\lambda, \phi, t) - T_O(\lambda, \phi, t) \tag{2.8}$$

However, the stand-alone OGCM uses a mixed-layer ocean to calculate the SST at high latitudes. If T_{obs} is the SST which was imposed as the surface boundary condition on the stand-alone AGCM, and ΔT_{mlo} is the temperature of the mixed-layer ocean (expressed as an anomaly, relative to the value of T_{obs}), then T_A is given by

$$T_A(\lambda, \phi, t) = T_{obs}(\lambda, \phi, t) + \Delta T_{mlo}(\lambda, \phi, t) \tag{2.9}$$

Substituting this value for T_A into Equation 2.8, the SST adjustment is given by

$$\Delta T(\lambda, \phi, t) = T_{obs}(\lambda, \phi, t) + \Delta T_{mlo}(\lambda, \phi, t) - T_O(\lambda, \phi, t) \tag{2.10}$$

Flux adjustments are applied at the spatial resolution of the model to which each field is passed. The adjustments to the surface heat flux, surface salinity tendency, and the zonal and meridional components of the surface momentum flux, are therefore applied at the spatial resolution of the ocean model, while the adjustments to the SST and SSS are applied at the spatial resolution of the atmosphere model.

Chapter 3

Compiling and running Mk3L

3.1 Introduction

This chapter describes how to compile and run the CSIRO Mk3L climate system model. Although there is an emphasis on the NCI National Facility (National Computational Infrastructure, 2010), instructions are given which should enable the user to compile and run the model on any suitable machine.

Section 3.2 outlines the software which is required to compile Mk3L, while Sections 3.3 and 3.4 describe how to install and compile the model respectively. Section 3.5 describes how to test the model installation, while Section 3.6 outlines the procedure for running the model.

3.2 System requirements

The CSIRO Mk3L climate system model is designed to compile on any UNIX/Linux machine, without any modifications to the source code being required. However, the following software is required in order to compile the model:

- a Fortran/Fortran 90 compiler
- the netCDF library (Unidata, 2010)
- version 2.x of the FFTW library (FFTW, 2010)

The netCDF and FFTW libraries are both freely available and open source. Note that Mk3L is not currentlty compatible with version 3.x of the FFTW library; this will be addressed in future versions.

Although not essential in order to compile the model, an auto-parallelising Fortran compiler may lead to enhanced performance on multiple processors (Phipps, 2006).

3.3 Installation

The source code for Mk3L is managed using the *subversion* version control system (CollabNet, 2009).

Version 1.2 can be obtained by entering the following subversion command, remembering to replace `<username>` and `<password>` with your username and password for the Mk3L subversion repository:

```
svn checkout --username <username> --password <password> \
  http://svn.tpac.org.au/repos/CSIRO_Mk3L/tags/version-1.2/
```

If you do not have a username and password, it will be necessary to apply for an account first at

```
http://www.tpac.org.au/main/csiromk3l
```

Note also that, on the NCI National Facility, it may be necessary to enter the command

```
module load subversion
```

before you can use subversion.

The above subversion command creates a top-level directory `version-1.2/`, containing the following subdirectories:

`core/`	contains the source code for Mk3L, and all the restart files, auxiliary files, control files and scripts which are needed to run the model
`data/`	contains some useful datasets
`doc/`	contains documentation
`post/`	contains utilities for the processing of model output
`pre/`	contains utilities for the generation of restart and auxiliary files

3.4 Compilation

3.4.1 On the NCI National Facility

The model is configured by default for compilation on `xe.nci.org.au`, an SGI XE Cluster located at the NCI National Facility in Canberra (National Computational Infrastructure, 2010).

To compile the model on this facility, change to the directory `core/scripts/` and enter the command

```
./compile
```

This compiles not only Mk3L, but also the following utilities, which are used for runtime processing of ocean model output (Section 6.3):

```
annual_averages
convert_averages
convert_averages_ogcm
```

Upon compilation, the executables are installed in the directory `core/bin/`.

3.4.2 On other facilities

On other computing facilities, it will be necessary to provide information regarding the compilers and the locations of the netCDF and FFTW libraries. This information is contained within a *macro definition file*.

Macro definition files can be found in the directory

```
core/bld/
```

and are provided for the following machines:

`ac.apac.edu.au`	The SGI Altix AC at the NCI National Facility
`linux`	Linux (generic)
`shine-cl.nexus.csiro.au`	An Intel Xeon machine at CSIRO Marine and Atmospheric Research
`xe.nci.org.au`	The SGI XE Cluster at the NCI National Facility

To compile the model on a machine for which a macro definition file already exists, make the following changes:

1. Remove the symbolic link `macros`
2. Create a new symbolic link `macros`, pointing to the appropriate macro definition file

To compile the model on a machine for which a macro definition file does *not* already exist, the following changes are required instead:

1. Copy one of the existing macro definition files
2. Update the parameter definitions within the new file, as necessary
3. Remove the symbolic link `macros`
4. Create a new symbolic link `macros`, pointing to the new file

An example macro definition file is as follows:

```
# Purpose
# -------
# Makefile macros for xe.nci.org.au.
#
# Usage
# -----
# The values of the following variables must be set:
#
# CPP            Preprocessor
# CPPFLAGS       Options to pass to the preprocessor
#
# FC             Fortran compiler
```

```
# F90            Fortran 90 compiler
# FFLAGS         Options to pass to the Fortran compiler
# F90FLAGS       Options to pass to the Fortran 90 compiler
# FIXEDFLAGS     Options to pass to the Fortran 90 compiler for fixed-format
#                source files
#
# AUTO           Auto-parallelising compiler (if available)
# AUTOFLAGS      Options to pass to the auto-parallelising compiler
#
# INC            The directory containing the netCDF header file
# LIB            The directories containing the netCDF and FFTW libraries
#                (note that Mk3L is only compatible with FFTW 2.x)
#
# History
# -------
# 2008 Dec 11   Steven Phipps   Original version

CPP = fpp
CPPFLAGS =

FC = ifort
F90 = $(FC)
FFLAGS = -fpe0 -openmp -align dcommons -r8 -warn nouncalled
F90FLAGS = $(FFLAGS)
FIXEDFLAGS = $(FFLAGS) -fixed

AUTO = $(FC)
AUTOFLAGS = $(FFLAGS)

INC = -I/apps/netcdf/3.6.3/include
LIB = -L/apps/netcdf/3.6.3/lib/Intel -L/apps/fftw2/2.1.5/Intel/lib
```

Within each file, values for the following parameters must be supplied:

`CPP`	The command which invokes the preprocessor
`CPPFLAGS`	The options to pass to the preprocessor
`FC`	The command which invokes the Fortran compiler
`F90`	The command which invokes the Fortran 90 compiler
`FFLAGS`	The options to pass to the Fortran compiler
`F90FLAGS`	The options to pass to the Fortran 90 compiler
`FIXEDFLAGS`	The options to pass to the Fortran 90 compiler for fixed-format source files
`AUTO`	The command which invokes the auto-parallelising compiler
`AUTOFLAGS`	The options to pass to the auto-parallelising compiler
`INC`	The directory containing the netCDF header file `netcdf.inc`
`LIB`	The directories containing the netCDF and FFTW libraries

3.5 Testing the installation

Mk3L includes three scripts, located in the directory `core/scripts/`, which enable the user to test that the model has been compiled successfully. From within this directory, enter any of the following three commands:

`./test_atm`	Runs the atmosphere model for one day
`./test_cpl`	Runs the coupled model for one day
`./test_oce`	Runs the ocean model for one month

Each of these tests will typically take ∼1 minute. If the model runs correctly, it will write a succession of diagnostic information to standard output. In the case of `test_atm` and `test_cpl`, the test is successful if the last line of this output is:

```
Stopped after  1 days.
```

In the case of `test_oce`, the test is successful if the last line is:

```
 Timestep was    3600.00000000000
```

3.6 Running the model

3.6.1 The basics

The command which runs Mk3L is simply

```
./model < input
```

`model` is the executable, and `input` is the model control file (Chapter 4). The model writes various diagnostic information to standard output; this is usually redirected to an output file by running the model using a command such as

```
./model < input > output
```

In order to run successfully, the model requires that various restart and auxiliary files also be provided; these are described in Chapter 5.

3.6.2 Queueing systems

For short jobs, such as the test scripts above, the model can be run interactively. However, for production purposes, the model is typically run for several hours at a time. For longer jobs such as this, it will be necessary to use a queueing system when running on facilities such as the NCI National Facility.

Within the directory `core/scripts/` are three scripts which demonstrate how to run the model using PBS, which is the queueing system employed at NCI. From within this directory, enter any of the following three commands:

`qsub qsub_test_atm`	Runs the atmosphere model for one day
`qsub qsub_test_cpl`	Runs the coupled model for one day
`qsub qsub_test_oce`	Runs the ocean model for one month

The `qsub` command is part of PBS, and submits a job for execution under the control the queueing system. The command

```
qsub qsub_test_cpl
```

therefore requests that PBS run the script `qsub_test_cpl`.

The three scripts `qsub_test_atm`, `qsub_test_cpl` and `qsub_test_oce` are equivalent to `test_atm`, `test_cpl` and `test_oce` respectively, except that they use the queueing system on `xe.nci.org.au`. On other facilities, these scripts may require modification before they can be submitted to the queue, and may require the use of a command other than `qsub`.

The script `qsub_test_cpl` is as follows, and contains directives (the lines beginning with `#PBS`) which pass information to the queueing system:

```
#!/bin/tcsh
#PBS -q express
#PBS -l walltime=0:05:00
#PBS -l vmem=200MB
#PBS -l ncpus=1
#PBS -l jobfs=1GB
#PBS -wd
#
# Purpose
# -------
# Runs the CSIRO Mk3L climate system model for one day, in coupled mode, using
# PBS.
#
# Usage
# -----
# qsub qsub_test_cpl
#
# History
# -------
# 2006 May 21   Steven Phipps   Original version
# 2007 Oct 24   Steven Phipps   Updated for change to directory structure
# 2008 Feb 5    Steven Phipps   Modified for the conversion of the coupled
#                               model auxiliary files to netCDF
# 2008 Feb 6    Steven Phipps   Modified for the conversion of the atmosphere
#                               model auxiliary files to netCDF
# 2008 Mar 8    Steven Phipps   Modified for the conversion of the ocean model
```

```
#                               and coupled model restart files to netCDF
# 2008 Nov 21   Steven Phipps   Added the line "limit stacksize unlimited"
# 2008 Nov 22   Steven Phipps   Added the line "setenv KMP_STACKSIZE 16M"

# Set the stack sizes
limit stacksize unlimited
setenv KMP_STACKSIZE 16M

# Create a temporary directory, if it doesn't already exist, into which to copy
# the model output at the end. Delete the contents if it does already exist.
set TMP_DIR = ~/mk3l_tmp/
if (-e $TMP_DIR) /bin/rm $TMP_DIR/*
if (! -e $TMP_DIR) mkdir $TMP_DIR

# Copy the model executable to the run directory
cp ../bin/model $PBS_JOBFS

# Copy the control file to the run directory
cp ../control/input_cpl_1day $PBS_JOBFS/input

# Copy the restart files to the run directory
cp ../data/atmosphere/restart/rest.start_default $PBS_JOBFS/rest.start
cp ../data/coupled/restart/oflux.nc_default $PBS_JOBFS/oflux.nc
cp ../data/ocean/restart/orest.nc_sync $PBS_JOBFS/orest.nc

# Copy the basic data files to the run directory
cp ../data/atmosphere/basic/* $PBS_JOBFS
cp ../data/ocean/basic/* $PBS_JOBFS

# Copy the runoff relocation data to the run directory
cp ../data/atmosphere/runoff/landrun21 $PBS_JOBFS

# Copy the CO2 radiative data file for 280ppm to the run directory
cp ../data/atmosphere/co2/co2_data.280ppm.18l $PBS_JOBFS/co2_data.18l

# Copy the sea surface temperatures to the run directory (these are only used
# for diagnostic purposes)
cp ../data/atmosphere/sst/ssta.nc_default $PBS_JOBFS/ssta.nc

# Copy the flux adjustments to the run directory
cp ../data/coupled/flux_adjustments/hfcor.nc_default $PBS_JOBFS/hfcor.nc
cp ../data/coupled/flux_adjustments/sfcor.nc_default $PBS_JOBFS/sfcor.nc
cp ../data/coupled/flux_adjustments/txcor.nc_default $PBS_JOBFS/txcor.nc
cp ../data/coupled/flux_adjustments/tycor.nc_default $PBS_JOBFS/tycor.nc
cp ../data/coupled/flux_adjustments/sstcor.nc_default $PBS_JOBFS/sstcor.nc
cp ../data/coupled/flux_adjustments/ssscor.nc_default $PBS_JOBFS/ssscor.nc
cp ../data/coupled/flux_adjustments/dtm.nc_default $PBS_JOBFS/dtm.nc

# Change to the run directory
```

```
cd $PBS_JOBFS

# Run the model
./model < input > output

# Copy everything back to the temporary directory
/bin/cp * $TMP_DIR
```

The directives have the following meanings:

`#PBS -q express`

Instructs the queueing system to place the job in the `express` queue. This is more expensive than the `normal` queue, but is useful for ensuring that short jobs run promptly.

`#PBS -l walltime=0:05:00`

Sets a walltime limit of 5 minutes for the job.

`#PBS -l vmem=200MB`

Sets a memory limit of 200 MB for the job.

`#PBS -l ncpus=1`

Specifies that only one processor is required.

`#PBS -l jobfs=1GB`

Requests that temporary disk space of 1 GB be created. This is created in a directory with the name `$PBS_JOBFS`.

`#PBS -wd`

Starts the job in the directory from which it was submitted.

Although these scripts only run the model for a very short time, they demonstrate the essential steps that must always be taken in order to run the model:

1. Create a run directory.
2. Copy the executable, control file, restart file and auxiliary files to this directory.
3. Run the model.
4. Move the output to a more permanent directory.

3.6.3 Advanced

Scripts which have been used to run the model for production purposes are provided in Section D.3. They perform the same steps as the simple scripts above, but also perform processing and archiving of model output. The processing of model output is described in Chapter 6.

Chapter 4

The control file

4.1 Introduction

The control file configures the model for a particular simulation, determining the mode in which the model is to run, the duration of the simulation, the physical configuration of the atmosphere and ocean models, and which model variables are to be saved to file. For most purposes, the user will be able to configure the model via the control file, rather than having to make any changes to the source code.

Section 4.2 describes the parameters which are read from the control file by the atmosphere model, while Section 4.3 describes the parameters which are read by the ocean model. Sample control files, which have been used to run the model for production purposes, are provided in Section D.2.

4.2 Atmosphere model

The atmosphere model reads six `namelist` groups from the control file:

`control`	controls the basic features of each simulation
`diagnostics`	controls the diagnostic output
`statvars`	specifies which monthly-mean statistics are to be saved to file
`histvars`	specifies which daily statistics are to be saved to file
`params`	configures the Kuo convection scheme
`coupling`	controls the coupling between the atmosphere and ocean (coupled model only)

Each of these `namelist` groups is now described in detail. Note that `coupling` is only read when the model is running in coupled mode, or when the atmosphere model is being spun up for the purposes of deriving flux adjustments, and need not be provided otherwise.

It should be emphasised that default values for most of the `namelist` parameters are specified within the model. It will only be necessary for the user to specify values if they wish to change the default settings.

4.2.1 `control`

Overview

The parameters contained within `control` determine the basic features of each model simulation. Detailed descriptions of each of these parameters are provided below; however, there are only a few parameters that the user is likely to want to change:

`locean, lcouple`

These parameters determine the mode in which the model is to run:

`locean=.true.`	Stand-alone ocean mode (this overrides `lcouple`)
`locean=.false./lcouple=.false.`	Stand-alone atmosphere mode
`locean=.false./lcouple=.true.`	Coupled mode

`nsstop, ndstop, lastmonth, months`

For the coupled model and stand-alone atmosphere model, these parameters determine the duration of the simulation:

`nsstop`	Stop after `nsstop` timesteps
`ndstop`	Stop after `ndstop` days
`lastmonth`	Stop at the end of calendar month `lastmonth` (1=January, 2=February, ..., 12=December)
`months`	Stop after `months` months

The model examines each of these parameters in turn, in the above order (i.e. `nsstop` first, and `months` last). The first parameter to have a non-zero value is the one that takes effect. The following points should be noted, however:

- The coupled model and stand-alone atmosphere model cannot be run for more than 12 months at a time.
- For runs longer than 31 days, `lastmonth` or `months` must be used to specify the duration of the run, and *not* `nsstop` or `ndstop`.

For the stand-alone ocean model, the duration of the simulation is specified by the values of `iocmn` and `iocyr` (Section 4.3).

`bpyear, csolar`

These parameters control the insolation. The value of `bpyear` specifies the epoch, in years before present (where the “present” is the year AD 1950); the value of `csolar` specifies the solar constant in Wm^{-2}.

`runtype`

This parameter, which consists of a string of five alphanumeric characters, specifies the name of the experiment. `runtype` is appended to the names of the output files generated by the model.

To avoid duplication of experiment names between different users, it is recommended that the first two characters of `runtype` should be taken from the initials of the user or their group. For example:

- if the user's name is Jane Smith, experiments should be called `js001`, `jsa01` or similar
- if the user's group is the CCRC, experiments should be called `cc001`, `cca01` or similar

Detailed description

The parameters contained within `control` consist of a number of different data types. The `logical` parameters are listed in Table 4.1, while the `integer` and `real` parameters are listed in Table 4.2, and the `character` parameters in Table 4.3. As a result of modifications made to the model over time, some of the parameters are obsolete, and no longer have any effect. These parameters do not need to be present within the control file.

`logical` **parameters**

The `logical` parameters (Table 4.1) specify the configuration in which the model is to run, and which physical schemes are to be used within the atmosphere model. The recommended configuration is as follows:

- use of the prognostic cloud scheme [`dcflag` and `qcloud` set to `.true.`]
- use of the Semtner sea ice model, incorporating leads and sea ice dynamics [`semice`, `leads` and `idyn` set to `.true.`]
- use of the "New SIB" land surface scheme [`nsib` set to `.true.`]
- use of the UK Meteorological Office convection scheme [`ukmo` set to `.true.`]
- use of the NCAR boundary layer scheme [`ncarpbl` set to `.true.`]
- implicit treatment of the vorticity equation [`impvor` set to `.true.`]
- use of the hybrid vertical coordinate [`hybrid` set to `.true.`]
- use of AMIP II ozone data [`amipo3` set to `.true.`]

`integer` **and** `real` **parameters**

In addition to the `logical` parameters, the `integer` and `real` parameters (Table 4.2) further specify the configuration of the atmosphere model. The following configuration is recommended:

- a timestep of 20 minutes [`mstep` set to 20]

Variable name	Description	Value	
		Default	Rec'd
amipo3	If true, use AMIP II ozone data	.true.	.true.
autoname	If true, compute name of output restart file automatically	.false.	.false.
coupled_aero	If true, use coupled aerosol model	.false.	.false.
dcflag	If true, compute cloud amounts (otherwise use observational dataset)	.true.	.true.
filewrflag	If true, write restart file at end of run	.false.	.true.
hybrid	If true, use hybrid vertical coordinate	.true.	.true.
idyn	If true, and semice and leads also true, use dynamical sea ice model	.true.	.true.
impvor	If true, use implicit treatment of vorticity equation	.true.	.true.
jsfdiff	If true, use Frederiksen spectral diffusion (only available at a horizontal resolution of T63)	.false.	.false.
lcouple[1]	If true, run in coupled mode, otherwise run in stand-alone AGCM mode (if locean true, lcouple has no effect)	.false.	.true./ .false.
leads	If true, and semice also true, allow leads in sea ice model	.true.	.true.
locean[1]	If true, run in stand-alone OGCM mode	.false.	.true./ .false.
ncarpbl	If true, use NCAR boundary layer scheme	.false.	.true.
ncepagcm	If true, use NCEP data to initialise model	.false.	.false.
nestflag	If true, save boundary conditions for limited area model	.false.	.false.
newriver	If true, use new river routing scheme (only available at a horizontal resolution of T63)	.false.	.false.
nsib	If true, use "New SIB" land surface scheme	.true.	.true.
pi_emissions	If true, and coupled_aero also true, use pre-industrial emissions	.false.	.false.
qcloud	If true, and dcflag also true, use prognostic cloud scheme	.true.	.true.
qflux	If true, use a slab ocean, otherwise use observed SSTs (stand-alone AGCM only)	.false.	.false.
semice	If true, use Semtner sea ice model	.true.	.true.
ukconv	If true, use UKMO convection scheme	.true.	.true.

Table 4.1: The logical parameters contained within the namelist group control: variable names, brief descriptions, the default values and the recommended values. [1]The values of lcouple and locean determine the mode in which the model runs. The physical schemes are described by Gordon et al. (2002).

- the radiation scheme is called once every six timesteps [`nrad` set to 6]
- the model runs for one calendar year at a time [`lastmonth` set to 12]
- the solar constant is set equal to 1365 Wm^{-2} [`csolar` set to 1365.0]
- within the prognostic cloud scheme, the critical relative humidities for cloud formation are set equal to 75% over land, and 85% over the ocean [`rcritl` and `rcrits` set to 0.75 and 0.85 respectively]
- within the prognostic cloud scheme, the albedo reduction factors are set equal to 0.595 for convective cloud, and 0.865 for non-convective cloud [`refac1` and `refac2` set to 0.595 and 0.865 respectively]

Note that the default behaviour of the model is to call the radiation scheme once every two hours. If `nrad` is positive and the value is not equal to 120/`mstep`, then `nrad` will be reset to 120/`mstep` by the model. The interval between calls to the radiation scheme can be varied by setting `nrad` to a negative value; this specifies that the radiation scheme should be called once every `-nrad` timesteps.

`character` **parameters**

The `character` parameters (Table 4.3) are largely used to specify the names of input and output files. The exception is `chtst`, which indicates whether the run should begin with a leapfrog timestep (which would be the case if using a restart file generated by a previous run) or a forward timestep (which would be the case if using a new restart file).

Note that Mk3L does not include any code to calculate the CO_2 transmission coefficients; instead, these are read from an auxiliary file. Such a file can be generated using the utility `radint`, which is supplied with the model (Section 5.5.1).

4.2.2 `diagnostics`

Overview

The parameters contained within `diagnostics` control the diagnostic output of the model. This includes control over which statistics are to be written to standard output, and which model variables are to be saved to file. Detailed descriptions of each of these parameters are provided below; however, the most important parameters are the following:

`statsflag`

`statsflag` must be set to true if the user wishes to save monthly-mean atmosphere model variables to file. The model then reads the parameters from the `namelist` group `statvars` (Section 4.2.3), which specifies which variables should be saved.

One netCDF output file is generated for each variable; the filenames are of the form `svvv_xxxxx.nc`, where `vvv` is the variable name, and `xxxxx` is the experiment name, as specified by the value of `runtype` (Section 4.2.1).

Variable name	Description	Value	
		Default	Rec'd
`bpyear`	Epoch [years before present]	0	0
`csolar`	Solar constant [Wm^{-2}]	1366.77333333333	1365.0
`incd`	Obsolete	-	-
`lastmonth`	If $>$ 0, and `nsstop`=0 and `ndstop`=0, stop at end of calendar month `lastmonth`	0	12
`months`	If $>$ 0, and `nsstop`=0, `ndstop`=0 and `lastmonth`=0, stop after `months` months	1	0
`mstep`	Timestep [minutes]	30	20
`naerosol_d`	Specifies type of direct sulphate aerosol forcing (0-3, 0 = no forcing)	2	0
`naerosol_i`	Specifies types of indirect sulphate aerosol forcing (0-3, 0 = no forcing)	0, 0	0, 0
`ndstop`	If $>$ 0 and $\leq$ 31, and `nsstop`=0, stop after `ndstop` days	0	0
`nest_interval`	If `nestflag` true, interval between saving boundary conditions [minutes]	480	480
`nest_start`	If `nestflag` true, interval before first saving boundary conditions [minutes]	240	240
`ngwd`	If $\neq$ 1, use new gravity wave drag scheme	1	1
`nrad`	Number of timesteps between calls to radiation scheme; if 0, use no radiation; if $<$ 0, force a radiation timestep other than two hours	4	6
`nsemilag`	Obsolete	-	-
`nsstop`	If $>$ 0, stop after `nsstop` timesteps; if $<$ 0, stop after zero timesteps and dump restart file; if -2, also reset day counter to zero	0	0
`nthreads`	Obsolete	-	-
`rcritl`	In prognostic cloud scheme, critical RH for cloud formation over land	0.75	0.75
`rcrits`	In prognostic cloud scheme, critical RH for cloud formation over the ocean	0.85	0.85
`refac1`	In prognostic cloud scheme, albedo reduction factor (convective cloud)	0.85	0.595
`refac2`	In prognostic cloud scheme, albedo reduction factor (other cloud)	0.95	0.865

Table 4.2: The `integer` and `real` parameters contained within the `namelist` group `control`: variable names, brief descriptions, the default values and the recommended values.

Variable name	Description	Value	
		Default	Rec'd
chtst	If OLD, begin with leapfrog timestep; if NEW begin with forward timestep	OLD	OLD
co2_datafile	Name of CO_2 data file	co2_data.hbg18	co2_data.18l
irfilename	Name of input restart file	(none)	rest.start
isfilename	Obsolete	-	-
o3_datafile	Name of O_3 data file (only used if amipo3 false)	o3_data.hbg18	(none)
orfilename	Name of output restart file (only used if filewrflag true and autoname false)	(none)	rest.end
osfilename	Obsolete	-	-
runtype[1]	Experiment name	earth	*Variable*
so4_direct_file	If naerosol_d equal to 1 or 2, name of aerosol data file (direct forcing)	(none)	(none)
so4_ind_rad_file	If naerosol_i(1) equal to 1 or 2, name of data file (indirect forcing - radiation)	(none)	(none)
so4_ind_rain_file	If naerosol_i(2) equal to 1 or 2, name of data file (indirect forcing - rainfall)	(none)	(none)

Table 4.3: The character parameters contained within the namelist group control: variable names, brief descriptions, the default values and the recommended values. [1]runtype specifies the experiment name, and should be different for each simulation.

savehist, hist_interval

When savehist is set to true, model variables are saved to a netCDF file at a frequency determined by the value of hist_interval. The model reads the parameters from the namelist group histvars (Section 4.2.4), which specifies which variables should be saved to file.

The model has the capability of generating either one or two history files. For example, to save model variables once every six hours, the user would specify:

```
savehist=.true.
hist_interval=360
```

However, to save model variables once every six hours to one history file, and once every 24 hours to another, the user would specify:

```
savehist(1)=.true., savehist(2)=.true.
hist_interval(1)=360, hist_interval(2)=1440
```

Either one or two history files are generated each month. If only one history file is generated, then this has the filename `histyyyyymm.xxxxx.nc`, where `yyyyy` and `mm` are the year and month respectively, and `xxxxx` is the experiment name, as specified by the value of `runtype` (Section 4.2.1). If two history files are generated, then these have the filenames `histayyyyymm.xxxxx.nc` and `histbyyyyymm.xxxxx.nc`.

`savefcor`

`savefcor` should be set to true for atmosphere model spin-up runs, and false otherwise. This parameter specifies whether or not the atmosphere model surface fluxes are saved to file, enabling flux adjustments to be diagnosed for use within the coupled model.

`glmean_interval`

Every `glmean_interval` minutes, a single line of global statistics is written to standard output; this information can be useful for monitoring the progress of a simulation. The variables displayed on this line are listed in Table 4.4.

Detailed description

As with `control`, the parameters contained within `diagnostics` also consist of different data types. The `logical` parameters are listed in Table 4.6, while the `integer` parameters are listed in Table 4.5.

`logical` **parameters**

The `logical` parameters (Table 4.6) largely control which statistics are written to standard output, and which model variables are saved to file. They should generally be set to false, in order to prevent large amounts of unnecessary diagnostic information from being generated.

Note that the parameters `gmap1`, `gmap2` and `zavgp` are "multi-control" flags. When set to false, they override the values of each of the parameters which follow them in Table 4.6, effectively setting them all to false as well. When `gmap1`, `gmap2` and `zavgp` are set to true, however, the values of each of these parameters are examined in turn.

`integer` **parameters**

The `integer` parameters (Table 4.5) largely control the frequency at which statistics are generated.

4.2.3 `statvars`

`statvars` contains logical flags which determine which monthly-mean model variables are to be saved to file; they only have effect if `statsflag` in `diagnostics` is set to true. Table 4.7 lists the flags which are contained within `statvars`, and the monthly-mean variables which will be saved to file if each flag is set to true.

Variable	Description	Units
DAY	Day number	days since 1 January 00000
HR	Time of day	hours since 00 UT
PMSL	Global-mean sea level pressure (not displayed on every line)	hPa
SBAL	Global-mean surface energy balance	Wm^{-2}
T(9)	Global-mean temperature at top of atmosphere	K
T*	Global-mean surface temperature	K
Tmn	Minimum surface temperature	K
Tmx	Maximum surface temperature	K
Kzn	Zonal kinetic energy per unit mass	Jkg^{-1}
Ked	Eddy kinetic energy per unit mass	Jkg^{-1}
LWG	Global-mean LW radiation at the surface	Wm^{-2}
LWt	Global-mean LW radiation at top of atmosphere	Wm^{-2}
SWg	Global-mean SW radiation at the surface	Wm^{-2}
SIt	Global-mean incoming SW radiation at top of atmosphere	Wm^{-2}
SOt	Global-mean outgoing SW radiation at top of atmosphere	Wm^{-2}
CLFR	Global-mean cloud radiative forcing	Wm^{-2}
AL	Planetary albedo	%
HC	Global-mean high cloud	%
MC	Global-mean medium cloud	%
LC	Global-mean low cloud	%
TC	Global-mean total cloud	%
EVP	Global-mean evaporation	mm/day
RAI	Global-mean precipitation	mm/day
HFLX	Global-mean surface sensible heat flux	Wm^{-2}
WATR	Global-mean precipitable water	mm
SNOD	Global-mean snow depth	cm
SICD	Global-mean sea ice thickness	m
TEMP	Mean atmospheric temperature	K
K/yr	Heating rate from the diffusion correction	K/year
Umx	Maximum wind speed	ms^{-1}

Table 4.4: The statistics written to standard output every glmean_interval minutes by the atmosphere model.

Variable name	Description	Value	
		Default	Rec'd
glmean_interval	Interval between prints of global means to standard output [minutes]	480	240
hist_interval	If savehist true, interval between the saving of model variables to file [minutes]	2*1440	*Variable*
idayp	Interval between calls to printing routines; if zero, print at end of run only [days]	0	0
insdebug	See debug (Table 4.6)	1	(none)
insdiag	See sdiagflag (Table 4.6)	15*integer	(none)
lgdebug	See debug (Table 4.6)	1	(none)
lgdiag	See sdiagflag (Table 4.6)	15*integer	(none)
mgdebug	See debug (Table 4.6)	1	(none)
mgdiag	See sdiagflag (Table 4.6)	15*integer	(none)
minw	If dynfp true, interval between dynamical field prints [minutes]	480	(none)
nsdiag	See sdiagflag (Table 4.6)	11	(none)

Table 4.5: The integer parameters contained within the namelist group diagnostics: variable names, brief descriptions, the default values and the recommended values.

Variable name	Description	Value	
		Default	Rec'd
cdmap	If true, print map of surface drag coefficient	.false.	.false.
clforflag	If true, calculate cloud radiative forcing	.false.	.true.
debug	If true, save timeseries of data at the gridpoint specified by the values of insdebug, lgdebug and mgdebug (see Table 4.5) to the file debug.out	.false.	.false.
dynfp	If true, do dynamical field print	.false.	.false.
iener	If true, generate detailed energy diagnostics	.false.	.false.
ispec	If true, generate spectral amplitudes of fields	.false.	.false.
laust	Obsolete	-	-
lbrmap	Obsolete	-	-
ltrace	If true, employ Lagrangian advection of tracers	.false.	.false.
mlomap	If true, print map of temperature of sea ice and mixed-layer ocean gridpoints	.false.	.false.
rainflag	If true, save daily rainfall to the file rainyyyyymm.xxxxx	.false.	.false.
savefcor[1]	If true, save surface fluxes to the file fcoryyyyymm.xxxxx	.false.	.true./ .false.
savegbrf	If true, save global means to the file gbrfyyyyymm.xxxxx	.false.	.false.
saveglmean	If true, save global means to the file glmnyyyyymm.xxxxx	.false.	.false.
savehist	If true, save model variables to file every hist_interval minutes	2* .false.	2* .false.
saveicuv	Obsolete	-	-

Variable name	Description	Value	
		Default	Rec'd
saveqflux	If true, save the "qflux" fields to the file qflxyyyyymm.xxxxx	.false.	.false.
savezflux	If true, save zonal means of meridional fluxes to the file zflxyyyyymm.xxxxx	.false.	.false.
sdiagflag	If true, save timeseries of data at the nsdiag gridpoints specified by the values of insdiag, lgdiag and mgdiag (see Table 4.5) to the file sptsyyyyymm.xxxxx	.false.	.false.
sltrace	If true, employ semi-Lagrangrian advection of tracers	.false.	.false.
statsflag	If true, save monthly-mean model variables to file	.false.	.true.
tempflag	If true save daily maximum and minimum surface and screen temperatures to the files tgmx-, tgmn-, tsmx- and tsmnyyyyymm.xxxxx	.false.	.false.
uvtflag	If true, save daily zonal wind, meridional wind and temperature to the files uday-, vday- and tdayyyyyymm.xxxxx	.false.	.false.
gmap1	If false, set the following four flags to false	.false.	.false.
cldm	If true, print maps of cloud	.false.	
cvrnm	If true, print maps of convection and rainfall	.false.	
gwicm	If true, print maps of snow depth and ice depth	.false.	
rhnmm	If true, print maps of relative humidity and mixing ratio	.false.	
gmap2	If false, set the following four flags to false	.false.	.false.
evapm	If true, print map of average evaporation	.false.	
pmslm	If true, save sea level pressure to the file pmslyyyyymm.xxxxx	.false.	
rainm	If true, print map of average rainfall	.false.	
surfm	If true, print maps of average surface heat fluxes	.false.	
zavgp	If false, set the following sixteen flags to false	.true.	.true.
conzp	If true, print map of zonal-mean cloud fraction	.true.	.true.
dynzp	If true, print zonal-mean dynamical fields and heating rates	.true.	.true.
phz1p	If true, print zonal-mean moisture and heat flux statistics	.true.	.true.
phz2p	If true, print zonal-mean cloud, heat flux, temperature and moisture statistics	.true.	.true.
plotclds	If true, plot zonal-, monthly-mean cloud amounts	.false.	.true.
plotevrn	If true, plot zonal-, monthly-mean evaporation and rain	.false.	.true.
plotheat	If true, plot zonal-, monthly-mean energy balances	.false.	.true.
plotnetr	If true, plot zonal-, monthly-mean top of atmosphere radiation balance	.false.	.true.
savezcfr	If true, save zonal-mean cloud fraction to the file zcfryyyyymm.xxxxx	.false.	.false.
savezonr	If true, save zonal-mean relative humidity to the file zonryyyyymm.xxxxx	.false.	.false.

Variable name	Description	Value	
		Default	Rec'd
savezont	If true, save zonal-mean temperature to the file zontyyyyymm.xxxxx	.false.	.false.
savezonu	If true, save zonal-mean zonal wind to the file zonuyyyyymm.xxxxx	.false.	.false.
savezonv	If true, save zonal-mean meridional wind to the file zonvyyyyymm.xxxxx	.false.	.false.
savezonw	If true, save zonal-mean "sigma dot" to the file zonwyyyyymm.xxxxx	.false.	.false.
savezqcl	If true, and qcloud also true, save zonal-mean prognostic cloud statistics to the files zqcl-, zqcf-, zqev-, zqsb-, zaut-, zcol- and zacryyyyymm.xxxxx	.false.	.false.
savezqlp	Obsolete	-	-

Table 4.6: The logical parameters contained within the namelist group diagnostics: variable names, brief descriptions, the default values and the recommended values. In the names of the output files, yyyyy and mm represent the year and month respectively, and xxxxx represents the experiment name, as specified by the value of runtype (Section 4.2.1). [1]savefcor should be set to true for atmosphere model spin-up runs, and false otherwise.

Flag	Model variable	Description	Units
		Surface statistics	
dtm_sflg	dtm	Mixed-layer ocean temperature anomaly	K
evp_sflg	evp	Evaporation	mm/day
hfl_sflg	hfl	Surface sensible heat flux	Wm^{-2}
int_sflg[1]	int	Interception of rainfall by foliage	mm/day
per_sflg[1]	per	Soil percolation	mm/day
pev_sflg[1]	pev	Potential evaporation	mm/day
psl_sflg	psl	Sea-level pressure	hPa
rnc_sflg	rnc	Convective precipitation	mm/day
rnd_sflg	rnd	Precipitation	mm/day
run_sflg[1]	run	Runoff	mm/day
sev_sflg[1]	sev	Scaling evaporation	mm/day
tax_sflg	tax	Zonal surface wind stress	Nm^{-2}
tay_sflg	tay	Meridional surface wind stress	Nm^{-2}
tb2_sflg	tb2	Soil temperature at level 2	K
tb3_sflg	tb3	Soil temperature at lowest level	K
tgf_sflg[1]	tgf	Vegetated ground temperature	K
tgg_sflg[1]	tgg	Bare ground temperature	K
thd_sflg	thd	Daily maximum screen temperature	K
thf_sflg[1]	thf	Daily maximum vegetated ground temperature	K
thg_sflg[1]	thg	Daily maximum bare ground temperature	K

Flag	Model variable	Description	Units
thm_sflg	thm	Extreme maximum screen temperature	K
tld_sflg	tld	Daily minimum screen temperature	K
tlf_sflg[1]	tlf	Daily minimum vegetated ground temperature	K
tlg_sflg[1]	tlg	Daily minimum bare ground temperature	K
tlm_sflg	tlm	Extreme minimum screen temperature	K
tsc_sflg	tsc	Screen temperature	K
tsu_sflg	tsu	Surface temperature	K
vmo_sflg	vmo	Surface wind speed	ms^{-1}
wfb_sflg	wfb	Upper level soil moisture	fraction
wfg_sflg	pmc wfg	Moisture puddles Lower level soil moisture	mm fraction
Cloud statistics			
clc_sflg[2]	clc	Convective cloud	fraction
cld_sflg	cld	Total cloud	fraction
clh_sflg	clh	High cloud	fraction
cll_sflg	cll	Low cloud	fraction
clm_sflg	clm	Medium cloud	fraction
lwp_sflg[2]	iwp lwp	Ice water path Liquid water path	kgm^{-2} kgm^{-2}
pwc_sflg[2]	pwc	Precipitable water content	mm
ref_sflg[2]	cli ref	Liquid cloud fraction Effective radius for liquid clouds	fraction μm
rev_sflg[2]	rev	Re-evaporation of rain	mm/day
sno_sflg[2]	sno	Snowfall	mm/day
ssb_sflg[2]	ssb	Sublimation of snow	mm/day
Radiation statistics			
als_sflg[1]	als	Surface albedo	fraction
rgc_sflg	rgc	Net LW radiation at ground (clear sky)	Wm^{-2}
rgd_sflg	rgd	Downward LW radiation at ground	Wm^{-2}
rgn_sflg	rgn	Net LW radiation at ground	Wm^{-2}
rtc_sflg	rtc	LW radiation out at top of atmosphere (clear sky)	Wm^{-2}
rtu_sflg	rtu	LW radiation out at top of atmosphere	Wm^{-2}
sgc_sflg	sgc	Net SW radiation at ground (clear sky)	Wm^{-2}
sgd_sflg	sgd	Downward SW radiation at ground	Wm^{-2}
sgn_sflg	sgn	Net SW radiation at ground	Wm^{-2}
soc_sflg	soc	SW radiation out at top of atmosphere (clear sky)	Wm^{-2}
sot_sflg	sot	SW radiation out at top of atmosphere	Wm^{-2}
Snow and ice statistics			
div_sflg[4]	wdf wls	Sea ice divergence removed by rheology Sea ice residual divergence	s^{-1} s^{-1}
gro_sflg[4]	gro	Monthly sea ice growth	m
ich_sflg[3]	ich	Sea ice advection	m

Flag	Model variable	Description	Units
ico_sflg[3]	icd	Sea ice thickness times concentration	m
	ico	Sea ice concentration	fraction
icu_sflg[4]	icu	Sea ice zonal velocity	ms^{-1}
icv_sflg[4]	icv	Sea ice meridional velocity	ms^{-1}
ire_sflg[4]	ire	Sea ice redistribution	m
isf_sflg[3]	isf	Sea ice-ocean salt flux	mm/day
itf_sflg[3]	itf	Sea ice-ocean heat flux	Wm^{-2}
sid_sflg	sid	Sea ice thickness	m
snd_sflg	snd	Snow depth	cm
Freshwater flux into ocean statistics			
fwf_sflg	fw1	Precipitation minus evaporation	mm/day
	fw2	Ice water A	mm/day
	fw3	Ice water B	mm/day
	fw4	River outflow	mm/day
Statistics on vertical levels			
c_sflg	c01–c18	Cloud amount on hybrid vertical levels	fraction
g_sflg	g01–g18	Geopotential height on pressure levels	m
l_sflg	l01–l18	Latent heating on hybrid vertical levels	K/day
q_sflg	q01–q18	Specific humidity on pressure levels	kg/kg
rh_sflg	r01–r18	Relative humidity on pressure levels	fraction
t_sflg	t01–t18	Temperature on pressure levels	K
u_sflg	u01–u18	Zonal wind on pressure levels	ms^{-1}
v_sflg	v01–v18	Meridional wind on pressure levels	ms^{-1}

Table 4.7: The flags contained within the `namelist` group `statvars`: the name of the flag, and the names, descriptions and units of the variable(s) which will be saved to file if each flag is set to true. [1]Only saved if `nsib` is true. [2]Only saved if `qcloud` is true. [3]Only saved if `semice` is true. [4] Only saved if `semice`, `leads` and `idyn` are all true.

Generally, each flag controls one variable. However, there are some exceptions, particularly the variables which are saved on vertical levels. If `c_sflg` is set to true, for example, then 18 output files will be created, containing the variables `c01`, `c02`, ..., `c18`. These variables contain the cloud amounts on each model level.

Note that some variables can only be saved when the corresponding physical schemes are being used: the “New SIB” land surface scheme (`nsib`), the prognostic cloud scheme (`qcloud`), and the Semtner sea ice model, incorporating leads and sea ice dynamics (`semice`, `leads` and `idyn`).

Note also that Table 4.7 excludes the flags which relate to the new river routing scheme (`newriver`) and the coupled aerosol model (`coupled_aero`), as neither of these are supported in Mk3L.

4.2.4 histvars

histvars contains logical flags which determine which model variables are to be saved to the history file(s); they only have effect if savehist in diagnostics is set to true. Table 4.9 lists the flags which are contained within histvars, and the variables which will be saved if each flag is set to true. Note that for some of the variables, instantaneous values are saved, whereas for the others, the values are accumulated over the history period (with the value saved being either the total, average, maximum or minimum value, as appropriate).

As with statvars, each flag generally controls one variable. However, the variables which are saved on vertical levels are again an exception, with each of these flags controlling 18 variables.

There are some important differences between statvars and histvars. Some variables are avilable within statvars, but not within histvars, and vice versa. histvars also contains the flag all_hflg, which simply specifies that all the available variables be saved; an equivalent flag is not available within statvars. Another significant difference is that, in the case of histvars, the vertical fields are all saved on the hybrid vertical levels whereas, in the case of statvars, many of the vertical fields are saved on pressure levels.

Note also that, in the case of histvars, variables will be saved even if the corresponding physical scheme is not being used. When this occurs, the values which are saved will not be meaningful.

4.2.5 params

params contains parameters which configure the Kuo convection scheme. This scheme is now obsolete and should not be used. Although params must be present within the control file, this group should be left empty.

4.2.6 coupling

coupling contains parameters which control the coupling between the atmosphere and ocean. This namelist group is *only* read when the model is running in coupled mode, or when the atmosphere model is being spun up for the purposes of deriving flux adjustments (i.e. when savefcor is set to true); it need not be provided otherwise.

Table 4.8 lists the parameters contained within coupling. Descriptions of each of these parameters are as follows:

crelax_flag, crelax_tau

When crelax_flag is set to true, the sea surface temperatures and sea surface salinities within the coupled model are relaxed towards observed values, with the timescale for the relaxation being specified by crelax_tau. The surface fluxes arising from the relaxation are saved to the file fort.41[1].

[1]Mk3L relies upon Fortran's implicit file naming whereby, if data is written to unit nn and this unit has not been connected to an external file using the open statement, data is written to the file fort.nn. It is dangerous to rely upon this behaviour, however, as it does not form part of the Fortran standard. This will be rectified in future versions of the model.

Variable name	Description	Value	
		Default	Rec'd
`crelax_flag`	If true, relax SSTs and SSSs towards observed values	`.false.`	`.false.`
`crelax_tau`	Relaxation timescale [days]	3650.0	365.0
`fluxadj`	If true, apply flux adjustments	`.true.`	`.true.`
`hosing_flag`	If true, apply freshwater hosing	`.false.`	*Variable*
`hosing_rate`	Freshwater hosing rate [Sv]	1.0	*Variable*
`isync`	If 0, use concurrent [asynchronous] coupling; if 1, use sequential [synchronous] coupling	1	1
`ovolume`	Volume of ocean [m^3]	1.27e18	*Variable*
`subice`	If true, apply fixed component to sea-ice ocean heat flux	`.true.`	`.true.`

Table 4.8: The parameters contained within the `namelist` group `coupling`: variable names, brief descriptions, the default values and the recommended values.

Flag	Model variable	Description	Units	Inst. /Acc.
`all_hflg`	Save all the available variables			
Two-dimensional fields				
`als_hflg`	`als`	Surface albedo	fraction	I
`cld_hflg`	`cld`	Total cloud	fraction	I
`clda_hflg`	`clda`	Average total cloud	fraction	A
`clh_hflg`	`clh`	High cloud	fraction	I
`cll_hflg`	`cll`	Low cloud	fraction	I
`clm_hflg`	`clm`	Medium cloud	fraction	I
`evp_hflg`	`evp`	Evaporation	mm/day	A
`hfl_hflg`	`hfl`	Surface sensible heat flux	Wm^{-2}	A
`icb_hflg`	`icb`	Bottom of low cloud	1–18	I
`ich_hflg`	`ich`	Level of high cloud	1–18	I
`icm_hflg`	`icm`	Level of medium cloud	1–18	I
`ico_hflg`	`ico`	Sea ice concentration	fraction	I
`ict_hflg`	`ict`	Top of low cloud	1–18	I
`imsl_hflg`	`imsl`	Surface type	1–4	I
`int_hflg`	`int`	Interception of rainfall by foliage	mm/day	A
`pev_hflg`	`pev`	Potential evaporation	mm/day	A
`psf_hflg`	`psf`	Surface pressure	mb	I
`psl_hflg`	`psl`	Sea-level pressure	mb	I
`rgc_hflg`	`rgc`	Net LW radiation at ground (clear sky)	Wm^{-2}	A
`rgd_hflg`	`rgd`	Downward LW radiation at ground	Wm^{-2}	A
`rgn_hflg`	`rgn`	Net LW radiation at ground	Wm^{-2}	A
`rhsa_hflg`	`rhsa`	Screen-level relative humidity	percent	A
`rnc_hflg`	`rnc`	Convective precipitation	mm/day	A
`rnd_hflg`	`rnd`	Precipitation	mm/day	A

Flag	Model variable	Description	Units	Inst. /Acc.
rtc_hflg	rtc	LW radiation out at top of atmosphere (clear sky)	Wm^{-2}	A
rtu_hflg	rtu	LW radiation out at top of atmosphere	Wm^{-2}	A
run_hflg	run	Runoff	mm/day	A
sev_hflg	sev	Scaling evaporation	mm/day	A
sgc_hflg	sgc	Net SW radiation at ground (clear sky)	Wm^{-2}	A
sgd_hflg	sgd	Downward SW radiation at ground	Wm^{-2}	A
sgn_hflg	sgn	Net SW radiation at ground	Wm^{-2}	A
sid_hflg	sid	Sea ice thickness	m	I
sit_hflg	sit	Downward SW radiation at top of atmosphere	Wm^{-2}	A
snd_hflg	snd	Snow depth	cm	I
soc_hflg	soc	SW radiation out at top of atmosphere (clear sky)	Wm^{-2}	A
sot_hflg	sot	SW radiation out at top of atmosphere	Wm^{-2}	A
tax_hflg	tax	Zonal surface wind stress	Nm^{-2}	A
tay_hflg	tay	Meridional surface wind stress	Nm^{-2}	A
tb2_hflg	tb2	Soil temperature at level 2	K	I
tb3_hflg	tb3	Soil temperature at lowest level	K	I
tgf_hflg	tgf	Vegetated ground temperature	K	I
tgg_hflg	tgg	Bare ground temperature	K	I
tgh_hflg	tgh	Maximum surface temperature	K	A
tgl_hflg	tgl	Minimum surface temperature	K	A
tsc_hflg	tsc	Screen temperature	K	I
tsca_hflg	tsca	Average screen temperature	K	A
tsh_hflg	tsh	Maximum screen temperature	K	A
tsl_hflg	tsl	Minimum screen temperature	K	A
tsu_hflg	tsu	Surface temperature	K	I
tsua_hflg	tsua	Average surface temperature	K	A
v10ma_hflg	v10ma	Average 10m wind speed	ms^{-1}	A
wfb_hflg	wfb	Upper level soil moisture	fraction	I
wfg_hflg	wfg	Lower level soil moisture	fraction	I
zht_hflg	zht	Surface height	m	Once[1]
Three-dimensional fields				
q_hflg	q01–q18	Specific humidity on hybrid vertical levels	kg/kg	I
t_hflg	t01–t18	Temperature on hybrid vertical levels	K	I
u_hflg	u01–u18	Zonal wind on hybrid vertical levels	ms^{-1}	I
v_hflg	v01–v18	Meridional wind on hybrid vertical levels	ms^{-1}	I

Table 4.9: The flags contained within the `namelist` group `histvars`: the name of the flag, and the names, descriptions and units of the variable(s) which will be saved to file if each flag is set to true. The final column indicates whether the values saved are instantaneous (I) or accumulated (A). [1]The surface height is only saved once to each history file.

This option provides an alternative method of deriving flux adjustments for use within the coupled model. It should *not* be used otherwise.

`fluxadj`

When `fluxadj` is set to true, flux adjustments are applied within the coupled model.

Mk3L can be run with or without flux adjustments, and has a stable control climatology in both cases. The appropriate configuration will depend upon the nature of the experiment being performed by the user. However, the control climate is more realistic when flux adjustments are used and, in most cases, the appropriate value of `fluxadj` is true.

`hosing_flag, hosing_rate`

When `hosing_flag` is set to true, freshwater hosing is applied, with the hosing rate being specified by `hosing_rate`.

The region over which the hosing is applied is controlled via tha auxiliary file `hosemask` (Section 5.2.3).

`isync`

When `isync` is set to 0, concurrent (or asynchronous) coupling is employed. In this case, the sea surface temperatures passed to the atmosphere are those calculated by the ocean model for the previous timestep.

When `isync` is set to 1, sequential (or synchronous) coupling is employed. In this case, the sea surface temperatures passed to the atmosphere are linearly interpolated in time between those calculated by the ocean model for the previous timestep and those predicted for the next timestep.

The default value of `isync` is 1, and this value should be left unchanged by the user. However, the default value may be changed to 0 in a future release of the model.

`ovolume`

The value of `ovolume` only has meaning when the atmosphere model is being spun up for the purposes of deriving flux adjustments (i.e. when `savefcor` is set to true). In this case, it should be set equal to the volume of the ocean within the model to which the atmosphere will be coupled. However, for most purposes, the default value of 1.27×10^{18} m^3 will be sufficiently accurate.

When running in coupled mode, the value of `ovolume` is replaced with the actual volume of the ocean. In this case, it is not therefore necessary for the user to provide a value.

`subice`

When `subice` is set to true, an additional component is added to the sea ice-ocean heat flux in order to allow for the effect of sub-gridscale mixing (Section 2.2.2).

The default value of `subice` is true, and it is recommended that this value be left unchanged.

4.3 Ocean model

The ocean model reads eleven `namelist` groups from the control file:

`contrl`	controls the basic features of the run
`eddy`	specifies various physical parameters
`eddy2`	configures horizontal diffusion
`etrans`	configures Gent-McWilliams eddy diffusion
`tsteps`	specifies the timesteps
`parms`	specifies various numerical and physical parameters
`icple`	specifies the duration of stand-alone ocean model runs
`pltg`	controls diagnostic output
`coefs`	specifies various miscellaneous parameters
`accel`	specifies acceleration factors
`osave`	specifies which monthly-mean statistics are to be saved to file

Each of these `namelist` groups is discussed below.

It should be noted that the ocean model source code has been heavily modified relative to the original code of Cox (1984). Many additional parameters are now read from `namelist` input, while many of the original parameters have been removed.

As with the atmosphere model, default values for most of the `namelist` parameters are specified within the model. It is only necessary for the user to specify values if they wish to change the default settings.

4.3.1 Overview

The parameters contained within the ocean model `namelist` groups are largely used to determine the physical configuration of the model. Detailed descriptions of each of the parameters are provided below; however, there are only a few parameters that the user is likely to want to change:

`iocmn, iocyr`

When running in stand-alone ocean mode, the duration of the simulation is determined by the values of `iocmn` and `iocyr`. If `iocmn` is less than 12, the simulation stops after `iocmn` months; if `iocmn` is equal to 12, it stops after `iocyr` years.

`dttsf, dtuvf, dtsff`

`dttsf`, `dtuvf` and `dtsff` specify the tracer, velocity and streamfunction timesteps respectively. It is recommended that they all be set to 3600 seconds (1 hour); for the asynchronous stage of ocean model spin-up runs, however, it is recommended that `dttsf` be set to 86400 seconds (1 day), and that `dtuvf` and `dtsff` be set to 1200 seconds (20 minutes).

Variable	Description	Units
`TIMESTEP`	Timestep counter	-
`YEAR`	Model date	years
`DAY`	Model date	days
`ENERGY`	Total kinetic energy per unit volume	Jm^{-3}
`DT`	Change in mean temperature of ocean	K
`DS`	Change in mean salinity of ocean	kg/kg
`SCANS`	Relaxation scan counter	-

Table 4.10: The statistics written to standard output every `ntsi` tracer timesteps by the ocean model.

`ntsi, nnergy`

Every `ntsi` tracer timesteps, a single line of statistics is written to standard output; the variables displayed on this line are listed in Table 4.10.

Every `nnergy` tracer timesteps, a variety of energy, salinity and transport statistics is also written to standard output.

4.3.2 Detailed description

The parameters contained within each of the `namelist` groups are listed in Table 4.11.

`contrl`

The default configuration of the ocean model employs the McDougall et al. (2003) equation of state (`m2003_eos` set to true) and the Robert time filter (`robert_time_filter` set to true, with `pnu` set to 0.005). It is recommended that these values be left unchanged.

If not using the Robert time filter, `nmix` specifies the number of tracer timesteps to be conducted between each mixing timestep (Cox, 1984); the default value in Mk3L is 19.

`ntsi` and `nnergy` specify the frequency at which diagnostic output should be written to standard output, while the parameter na specifies whether or not a restart file should be written at the end of each run.

`nfirst` specifies whether or not the ocean model should be initialised from scratch (i.e. without a restart file). This option is unncessary, as restart files are supplied with the model. The default value of 0 should therefore be left unchanged.

When `check_conservation` is set to true, additional calculations are performed to check that the model conserves heat and salt. However, these calculations are expensive and cause the model to generate a large volume of additional output. This option should therefore only be used during model development.

`eddy`

The parameters `amf` and `fkpmf` set the horizontal and vertical viscosities respectively. When `cos_amf` is set to true, the horizontal viscosity is varied in proportion to the cosine of the latitude. This option has been

Variable name	Description	Value	
		Default	Rec'd
contrl			
`check_conservation`	If true, check conservation of heat and salt	`.false.`	`.false.`
`m2003_eos`	If true, use McDougall et al (2003) equation of state	`.true.`	`.true.`
`na`	If equal to 1, write restart file at end of run	1	1
`nfirst`	If equal to 1, initialise model from scratch	0	0
`nmix`	Number of tracer timesteps between mixing timesteps	19	19
`nnergy`	Number of tracer timesteps between writes of energy diagnostics to standard output	87600	3650^{A}/ $87600^{S,C}$
`ntsi`	Number of tracer timesteps between writes of run statistics to standard output	720	30^{A}/ $720^{S,C}$
`pnu`	Smoothing coefficient for Robert time filter	0.005	0.005
`robert_time_filter`	If true, use Robert time filter	`.true.`	`.true.`
eddy			
`ahi1f`	Isopycnal tracer diffusivity at surface [cm^{2}s^{-1}]	0.6e7	0.6e7
`ahi2f`	Isopycnal tracer diffusivity at infinite depth [cm^{2}s^{-1}]	0.6e7	0.6e7
`ahi3f`	Scaling distance for varying diffusivity [cm]	5.0e4	5.0e4
`amf`	Horizontal viscosity at equator [cm^{2}s^{-1}]	3.2e9	3.2e9
`cos_amf`	If true, vary horizontal viscosity as cosine of latitude	`.true.`	`.true.`
`fkpmf`	Vertical viscosity [cm^{2}s^{-1}]	20.0	20.0
`slmxrf`	Inverse maximum slope	100.0	100.0
eddy2			
`ahh1f`	Horizontal diffusivity at surface [cm^{2}s^{-1}]	0.6e7	0.6e7
`ahh2f`	Horizontal diffusivity at infinite depth [cm^{2}s^{-1}]	0.6e7	0.6e7
`ahh3f`	Scaling distance for varying diffusivity [cm]	5.0e4	5.0e4
etrans			
`ahe1f`	Isopycnal thickness diffusivity at surface [cm^{2}s^{-1}]	0.6e7	0.6e7
`ahe2f`	Isopycnal thickness diffusivity at infinite depth [cm^{2}s^{-1}]	0.6e7	0.6e7
`ahe3f`	Scaling distance for varying diffusivity [cm]	5.0e4	5.0e4
`no_gm_arctic`	If true, replace Gent-McWilliams eddy diffusion with horizontal diffusion in Arctic Ocean	`.true.`	`.true.`
tsteps			
`dtsff`	Streamfunction timestep [seconds]	3600.0	1200.0^{A}/ $3600.0^{S,C}$
`dttsf`	Tracer timestep [seconds]	3600.0	86400.0^{A}/ $3600.0^{S,C}$
`dtuvf`	Velocity timestep [seconds]	3600.0	1200.0^{A}/

			3600.0^{S,C}
parms			
`acorf`	If $>$ 0.0, treat Coriolis term implicitly, with forward component weighted by `acorf`	0.5	0.5
`critf`	Relaxation convergence criterion [cm^{3}s^{-1}]	1.0e8	1.0e8
`mxscan`	Maximum number of relaxation scans permitted	1000	1000
`sorf`	Over-relaxation coefficient	1.4	1.4
`trelax`	Relaxation timescale [days] (stand-alone ocean model only)	20.0	20.0
icple			
`iocmn`	If $<$ 12, stop after `iocmn` months (stand-alone ocean model only)	12	12
`iocyr`	If `iocmn` equal to 12, stop after `iocyr` years (stand-alone ocean model only)	50	50
pltg			
`jplot`	Latitude row for which to display diagnostics	25	25
coefs			
`cdrag`	Coefficient of bottom drag [dimensionless]	2.6e-3	2.6e-3
`itset`	If equal to 1, reset time counters to zero at start (stand-alone ocean model only)	1	1
accel			
`dtxf`	Acceleration factors	21*1.0	21*1.0
osave			
`save_cdepthm`	If true, save the maximum depth of convection	`.true.`	`.true.`
`save_over`	If true, save the meridional overturning streamfunctions	`.true.`	`.true.`
`save_res`	If true, save the barotropic streamfunction	`.true.`	`.true.`
`save_rho`	If true, save the density	`.false.`	`.true.`
`save_sal`	If true, save the salinity	`.true.`	`.true.`
`save_smfmer`	If true, save the meridional wind stress	`.true.`	`.true.`
`save_smfzon`	If true, save the zonal wind stress	`.true.`	`.true.`
`save_stfht`	If true, save the surface heat flux	`.true.`	`.true.`
`save_stfsal`	If true, save the surface salinity tendency	`.true.`	`.true.`
`save_temp`	If true, save the potential temperature	`.true.`	`.true.`
`save_u`	If true, save the zonal velocity	`.true.`	`.true.`
`save_uedd`	If true, save the eddy-induced zonal velocity	`.true.`	`.false.`
`save_v`	If true, save the meridional velocity	`.true.`	`.true.`
`save_vedd`	If true, save the eddy-induced meridional velocity	`.true.`	`.false.`
`save_w`	If true, save the vertical velocity	`.true.`	`.true.`
`save_wedd`	If true, save the eddy-induced vertical velocity	`.true.`	`.false.`

Table 4.11: The parameters contained within the eleven `namelist` groups read by the ocean model: variable names, brief descriptions, the default values and the recommended values. ^{A} Asynchronous ocean model. ^{S} Synchronous ocean model. ^{C} Coupled model.

found to improve the climatology of the model, and it is therefore recommended that the default value be left unchanged.

The parameters `ahi1f`, `ahi2f` and `ahi3f` are used to specify a depth-dependent isopycnal tracer diffusivity, with the diffusivity `ahi` being calculated within the model as follows (`zdzz` specifies the depth of the centre of each gridbox, in centimetres):

$$\mathtt{AHI(K) = AHI2F + (AHI1F - AHI2F) * EXP(-ZDZZ(K)/AHI3F)} \tag{4.1}$$

The recommended values of `ahi1f` and `ahi2f`, which are both equal to 0.6×10^7, specify a depth-independent isopycnal tracer diffusivity of 0.6×10^7 cm^{2}s^{-1}.

`slmxrf` sets the inverse maximum slope. This parameter specifies the upper limit on the isopycnal slope to be used when calculating the mixing tensor, with values being capped at 1/`slmxrf`.

`eddy2`

The parameters `ahh1f`, `ahh2f` and `ahh3f` specify a depth-dependent horizontal diffusivity, in an analagous manner to `ahi1f`, `ahi2f` and `ahi3f`. The recommended values of `ahh1f` and `ahh2f`, which are both equal to 0.6×10^7, specify a depth-independent horizontal diffusivity of 0.6×10^7 cm^{2}s^{-1}.

Note that horizontal diffusion is only applied within the Arctic Ocean, and only when the parameter `no_gm_arctic` (which is contained within the `namelist` group `etrans`) is set to true.

`etrans`

This group contains parameters which control Gent-McWilliams eddy diffusion (Gent and McWilliams, 1990). The parameters `ahe1f`, `ahe2f` and `ahe3f` specify a depth-dependent isopycnal thickness diffusivity, in an analagous manner to `ahi1f`, `ahi2f` and `ahi3f` (`zdz` specifying the depth of the base of each gridbox, in centimetres):

$$\mathtt{ahe(k) = ahe2f + (ahe1f - ahe2f) * exp(-zdz(k-1)/ahe3f)} \tag{4.2}$$

The recommended values of `ahe1f` and `ahe2f` specify a depth-independent isopycnal thickness diffusivity of 0.6×10^7 cm^{2}s^{-1}. However, it should be noted that, for the upper seven levels of the ocean, upper limits for the diffusivity are hard-coded into the model. These values specify an isopycnal thickness diffusivity which decreases from 0.77×10^7 cm^{2}s^{-1}, at a depth of 270 m, to zero at the surface (Section 2.3).

When `no_gm_arctic` is set to true, Gent-McWilliams eddy diffusion is replaced with eddy diffusion within the Arctic Ocean. This option has been found to improve the climatology of the model, and it is therefore recommended that the default value be left unchanged.

`tsteps`

The parameters `dttsf`, `dtuvf` and `dtsff` specify the tracer, velocity and streamfunction timesteps respectively. It is recommended that all these timesteps be set to 3600 seconds (1 hour). For the asynchronous stage of ocean model spin-up runs, it is recommended that `dttsf` be set to 86400 seconds (1 day), and that `dtuvf` and `dtsff` be set to 1200 seconds (20 minutes).

`parms`

This group contains four numerical parameters: `acorf`, `critf`, `mxscan` and `sorf`. These parameters are documented by Cox (1984), and the default values can be left unchanged.

It also contains one physical parameter, `trelax`. This only has an effect within the stand-alone ocean model, and specifies the timescale for the relaxation of the simulated sea surface temperature and salinity towards the prescribed values.

`icple`

The parameters `iocmn` and `iocyr` specify the duration of stand-alone ocean model runs; the recommended values are 12 and 50 respectively. These parameters have no effect in the coupled model; in this case, the duration of the run is specified by the values of `nsstop`, `ndstop`, `lastmonth` and `months` (Section 4.2).

`pltg`

The only parameter contained within this group is `jplot`, which specifies the latitude row for which diagnostic information is displayed every `nnergy` timesteps.

`coefs`

The only physical parameter specified within this group is `cdrag`, which sets the coefficient of bottom drag.

When `itset` is set to `1`, the time counters are reset to zero at the start of each run. However, this parameter only has an effect within the stand-alone ocean model, and it is recommended that the default value be left unchanged.

`accel`

The `namelist` group `accel` specifies time acceleration factors for each level of the model. These factors can be set to values larger than 1, if the user wishes to use the method of Bryan (1984) to accelerate the convergence of the ocean towards equilibrium. However, it is recommended that they be set to 1.0.

`osave`

The parameters contained within this group specify which monthly-mean statistics are saved to file. The ocean model generates a very large volume of output, and the user should carefully consider which statistics are required. It is nonetheless recommended that all statistics except for the eddy-induced velocities (`uedd`, `vedd` and `wedd`) be saved.

Chapter 5

Input files

5.1 Introduction

This chapter describes the restart and auxiliary files which are required in order to run Mk3L. It also outlines how to generate new restart and auxiliary files, in order to configure the model for alternative scenarios.

Section 5.2 describes the restart and auxiliary files which are required by the model, while Section 5.3 documents the origin of the default restart and auxiliary files that are supplied with the model source code. Sections 5.4 and 5.5 describe the utilities that are also supplied with the model, for the generation of restart and auxiliary files respectively.

5.2 Overview

The restart and auxiliary files required by Mk3L depend not only upon the mode in which it is being run (i.e. stand-alone atmosphere model, stand-alone ocean model or coupled model), but also upon its physical configuration. Certain physical schemes require that the model read in datasets at runtime; for example, the "New SIB" land surface scheme (Gordon et al., 2002) reads data from a number of files.

It is beyond the scope of this document to describe all the restart and auxiliary files which might be required by the model, in all the possible configurations. This section, however, lists the files required by the model in its default configuration.

Sections 5.2.1 and 5.2.2 describe the restart and auxiliary files required by the atmosphere and ocean models respectively, both in stand-alone mode and when running as part of the coupled model. Section 5.2.3 describes the additional files which are required by the coupled model.

5.2.1 Atmosphere model

The names of the restart file, and of the file containing the CO_2 transmission coefficients, are specified by the parameters `irfilename` and `co2_datafile` respectively, which are contained within the `namelist` group `control` (Section 4.2). The names of the other auxiliary files are hard-coded into the model, and are shown in Table 5.1.

Filename	Format	Description	Required?	
			Atm	**Cpl**
(User-specified)	Binary	Restart file	Yes	Yes
(User-specified)	Text	CO_2 transmission coefficients	Yes	Yes
`albedo.nc`	netCDF	Land surface albedos	Yes	Yes
`amip2o3.dat`	Text	AMIP 2 ozone volume mixing ratios	Yes	Yes
`icedivl.nc`	netCDF	Sea ice divergence limiter mask	Yes	Yes
`landrun21`	Text	Run-off relocation data	Yes†	Yes
`ocuv.nc`	netCDF	Ocean currents	Yes	No
`psrk.nc`	netCDF	Surface pressure data (∼topography)	Yes	Yes
`sibrs.nc`	netCDF	Stomatal resistance (“New SIB” scheme)	Yes	Yes
`sibsig.nc`	netCDF	Vegetation fraction (“New SIB” scheme)	Yes	Yes
`sibsoil.nc`	netCDF	Soil type (“New SIB” scheme)	Yes	Yes
`sibvegt.nc`	netCDF	Vegetation/land type (“New SIB” scheme)	Yes	Yes
`sibz0.nc`	netCDF	Roughness length (“New SIB” scheme)	Yes	Yes
`sssa.nc`	netCDF	Sea surface salinities	Yes†	No
`ssta.nc`	netCDF	Sea surface temperatures	Yes	Yes‡

Table 5.1: The restart and auxiliary files required by the Mk3L atmosphere model: the filename, the format, a brief description, and whether it is required in stand-alone mode (Atm) and in coupled mode (Cpl). †Only required by the stand-alone atmosphere model if calculating surface fluxes for the purpose of diagnosing flux adjustments for the coupled model. ‡Only required for diagnostic purposes.

The topographic information is contained within the file `psrk.nc`, while the vegetation and soil information for the “New SIB” land surface scheme is contained within the files `sibrs.nc`, `sibsig.nc`, `sibsoil.nc`, `sibvegt.nc` and `sibz0.nc`. The albedos are provided by the file `albedo.nc`, and the file `icedivl.nc` is required by the sea ice model.

Other auxiliary files may be required, depending upon the mode in which the model is being run. The boundary conditions on the stand-alone atmosphere model are provided by the files `ssta.nc`, which contains the sea surface temperatures, and `ocuv.nc`, which contains the ocean currents required the sea ice model. `ssta.nc` is also required by the model when running in coupled mode but, in this case, the information is only used for diagnostic purposes.

An additional file, `sssa.nc`, which contains sea surface salinities, must be supplied when the atmosphere model is being spun up for the purpose of diagnosing flux adjustments for the coupled model (i.e. when the `namelist` variable `savefcor` is set to true). This file contains sea surface salinities, which are required to convert surface freshwater fluxes to equivalent surface salinity tendencies (Phipps, 2006).

The file `landrun21` contains the river routing data, which is used to transfer surface run-off to the ocean. This file is required by the model when running in coupled mode, and must also be supplied when the atmosphere model is being spun up for the purpose of diagnosing flux adjustments.

All the auxiliary files read by the atmosphere model are either in netCDF or plain text format, and therefore are fully portable. The restart file is in binary format, and is therefore machine-dependent. If a restart file generated on one machine is to be used to initialise the model on another, this may require that the file be converted from one binary format to another (Section 5.4).

Filename	Format	Description	Required?	
			Oce	Cpl
bsnmask.nc	netCDF	Ocean basin masks	Yes†	Yes†
orest.nc	netCDF	Restart file	Yes	Yes
sss.nc	netCDF	Sea surface salinities	Yes	No‡
sst.nc	netCDF	Sea surface temperatures	Yes	No‡
stress.nc	netCDF	Surface wind stresses	Yes	No

Table 5.2: The restart and auxiliary files required by the Mk3L ocean model: the filename, the format, a brief description, and whether it is required in stand-alone mode (Oce) and in coupled mode (Cpl). †Only required if the meridional overturning streamfunctions are being calculated at runtime. ‡These files are required by the coupled model if relaxing the SSTs and SSSs towards observed values for the purposes of deriving flux adjustments.

5.2.2 Ocean model

The name of the restart file, `orest.nc`, is hard-coded into the model. This file is in netCDF and is therefore fully portable.

As with the atmosphere model, the auxiliary files required by the ocean model depend upon the mode in which it is being run. The only file required in both stand-alone and coupled modes is `bsnmask.nc`. This file contains a mask which defines the Atlantic, Pacific and Indian Oceans, and is required when the meridional overturning streamfunctions are being calculated at runtime (i.e. when the `namelist` variable `save_over` is set to true).

In stand-alone mode, the boundary conditions are provided by the files `sss.nc`, `sst.nc` and `stress.nc`, which contain the sea surface salinities, sea surface temperatures, and surface wind stresses respectively.

The files `sss.nc` and `sst.nc` are also required in coupled mode when relaxing the sea surface temperatures and salinities towards observed values for the purposes of deriving flux adjustments (i.e. when the `namelist` variable `crelax_flag` is set to true).

All the auxiliary files are in netCDF and are therefore fully portable.

5.2.3 Coupled model

The coupled model also requires a restart file, containing the surface fluxes to be passed to the ocean at the first timestep. At the start of each run, the ocean model is executed before the atmosphere model; no surface fluxes will have been calculated by this point, and so they must be read from file instead. The name of the restart file, `oflux.nc`, is hard-coded into the model. This file is in netCDF and is therefore fully portable.

There are no auxiliary files that are *always* required by the coupled model. When flux adjustments are being applied — i.e. when the `namelist` variable `fluxadj` is set to true — seven auxiliary files must be provided: `dtm.nc`, `hfcor.nc`, `sfcor.nc`, `sscor.nc`, `sstcor.nc`, `txcor.nc` and `tycor.nc`.

Of these seven files, `hfcor.nc`, `sfcor.nc`, `txcor.nc` and `tycor.nc` contain the flux adjustments to be applied to the surface heat flux, the surface salinity tendency, and the zonal and meridional components of the surface momentum flux, respectively. These adjustments are applied to the surface fluxes passed from

Filename	Format	Description
`dtm.nc`†	netCDF	Climatological mixed-layer ocean temperature anomalies
`hfcor.nc`†	netCDF	Surface heat flux adjustments
`hosemask`‡	Text	Freshwater hosing mask
`oflux.nc`	netCDF	Restart file
`sfcor.nc`†	netCDF	Surface salinity tendency adjustments
`ssscor.nc`†	netCDF	Sea surface salinity adjustments
`sstcor.nc`†	netCDF	Sea surface temperature adjustments
`txcor.nc`†	netCDF	Zonal wind stress adjustments
`tycor.nc`†	netCDF	Meridional wind stress adjustments

Table 5.3: The restart and auxiliary files required by the Mk3L coupled model, in addition to those required by the atmosphere and ocean models: the filename, the format, and a brief description. †Only required if flux adjustments are being applied. ‡Only required when freshwater hosing is being applied.

the atmosphere model to the ocean model.

The files `ssscor.nc` and `sstcor.nc` contain the adjustments to be applied to the sea surface salinity and sea surface temperature respectively, and are applied to the surface fields passed from the ocean model to the atmosphere model.

The file `dtm.nc` contains climatological mixed-layer ocean temperature anomalies, diagnosed from an atmosphere model spin-up run. These are only used for diagnostic purposes, and are used to adjust the observed sea surface temperatures read from the file `ssta.nc`, to allow for the fact that the stand-alone atmosphere model uses a mixed-layer ocean at high latitudes (Section 2.2).

When freshwater hosing is being applied — i.e. when the `namelist` variable `hosing_flag` is set to true — the auxiliary file `hosemask` must be provided. This file contains a mask which defines the region over which the freshwater hosing is to be applied.

All the auxiliary files required by the coupled model are either in netCDF or plain text, and they are therefore fully portable.

5.3 Default input files

Default versions of all the restart and auxiliary files are supplied with Mk3L. These files can be found in the following directories:

`core/data/atmosphere/`	The files required by the atmosphere model
`core/data/coupled/`	The files required by the coupled model
`core/data/ocean/`	The files required by the ocean model

The contents and origins of each of the files are outlined in the following sections.

5.3.1 Atmosphere model

`core/data/atmosphere/basic/albedo.nc`

This file contains land surface albedos for the present day. The data was supplied by CSIRO Marine and Atmospheric Research and subsequently converted to netCDF.

`core/data/atmosphere/basic/amip2o3.dat`

This file contains AMIP II ozone concentrations (Wang et al., 1995), and was supplied by CSIRO Marine and Atmospheric Research.

`core/data/atmosphere/basic/icedivl.nc`

This file contains a sea ice divergence limiter mask, which specifies gridpoints where the sea ice divergence should be set equal to zero. The data was supplied by CSIRO Marine and Atmospheric Research and subsequently converted to netCDF.

`core/data/atmosphere/basic/psrk.nc`

This file contains surface pressure data for the present-day topography. The data was supplied by CSIRO Marine and Atmospheric Research and subsequently converted to netCDF.

```
core/data/atmosphere/basic/sibrs.nc
core/data/atmosphere/basic/sibsig.nc
core/data/atmosphere/basic/sibsoil.nc
core/data/atmosphere/basic/sibvegt.nc
core/data/atmosphere/basic/sibz0.nc
```

These files contain the data required by the "New SIB" land surface scheme, for the present-day distributions of vegetation and soil. The data was supplied by CSIRO Marine and Atmospheric Research and subsequently converted to netCDF.

`core/data/atmosphere/co2/co2_data.280ppm.18l`

This file contains the CO_2 transmission coefficients for an atmospheric carbon dioxide concentration of 280 ppm, and was generated using the utility `radint` (Section 5.5.1).

`core/data/atmosphere/currents/ocuv.nc_default`

This file contains climatological ocean currents for the start of each month, diagnosed from the final 100 years of Mk3L ocean model spin-up run k28. It was generated using the procedure outlined in Section C.4.

`core/data/atmosphere/hosing/hosemask`

This file contains a sample mask for the freshwater hosing scheme. It was supplied by Jessica Trevena, and specifies that freshwater hosing be applied over the Southern Ocean south of 60°S.

`core/data/atmosphere/restart/rest.start_default`

This is a Mk3L atmosphere model restart file, and contains the state of the model at the end of spin-up run spc38.

`core/data/atmosphere/runoff/landrun21`

This file contains run-off relocation data for the present-day topography; this data is used to determine the path that run-off follows to the ocean. The file was generated during the development of Mk3L.

`core/data/atmosphere/sss/sssa.nc_default`

This file contains climatological sea surface salinities for the start of each month, diagnosed from the final 100 years of Mk3L ocean model spin-up run k28. It was generated using the procedure outlined in Section C.4.

`core/data/atmosphere/sst/ssta.nc_default`

This file contains climatological NOAA OI v2 sea surface temperatures for the start of each month, and was generated using the procedure outlined in Section C.4.

5.3.2 Ocean model

`core/data/ocean/data/basic/bsnmask.nc`

This file defines the ocean basins which are used to calculate the meridional overturning streamfunctions, and was generated during the development of Mk3L.

`core/data/ocean/data/ocean/restart/orest.nc_async`

This restart file was generated by integrating the Mk3L ocean model to equilibrium under asynchronous timestepping, using the default sea surface salinities, sea surface temperatures and surface wind stresses as the surface boundary conditions. It contains the state of the ocean model at the end of the asynchronous stage of spin-up run k28.

`core/data/ocean/data/ocean/restart/orest.nc_sync`

This restart file was generated by integrating the Mk3L ocean model to equilibrium under synchronous timestepping, using the default sea surface salinities, sea surface temperatures and surface wind stresses as the surface boundary conditions. It contains the state of the ocean model at the end of spin-up run k28.

`core/data/ocean/data/ocean/restart/orest.nc_woa1998`

This restart file represents a state in which the ocean is at rest, and the temperatures and salinities are set equal to the annual-mean World Ocean Atlas 1998 values. It was generated during the development of Mk3L.

`core/data/ocean/data/ocean/sss/sss.nc_monthly`

This file contains climatological World Ocean Atlas 1998 sea surface salinities for the midpoint of each month, and was generated using the procedure outlined in Section C.3.

`core/data/ocean/data/ocean/sst/sst.nc_monthly`

This file contains climatological World Ocean Atlas 1998 sea surface temperatures for the midpoint of each month, and was generated using the procedure outlined in Section C.3.

`core/data/ocean/data/ocean/stress/stress.nc_monthly`

This file contains climatological NCEP-DOE Reanalysis 2 wind stresses for the midpoint of each month, and was generated using the procedure outlined in Section C.3.

5.3.3 Coupled model

```
core/data/coupled/flux_adjustments/dtm.nc_default
core/data/coupled/flux_adjustments/hfcor.nc_default
core/data/coupled/flux_adjustments/sfcor.nc_default
core/data/coupled/flux_adjustments/ssscor.nc_default
core/data/coupled/flux_adjustments/sstcor.nc_default
core/data/coupled/flux_adjustments/txcor.nc_default
core/data/coupled/flux_adjustments/tycor.nc_default
```

These files contain flux adjustments diagnosed from Mk3L spin-up runs, and were generated using the procedures outlined in Sections 5.5 and C.5. The atmosphere model surface fluxes were diagnosed from the final 90 years of spin-up run spc38, and the ocean model surface fluxes from the final 100 years of spin-up run k28.

`core/data/coupled/restart/oflux.nc_default`

This is a coupled model restart file, in which all the surface fluxes are set equal to zero.

5.4 Generating restart files

A variety of utilities are supplied to assist the user in the generation of new restart files; these are located in the directory `pre/restart/`.

5.4.1 Atmosphere model

Given the short timescale on which the atmosphere responds to changes in the external boundary conditions, the initial state of the atmosphere model is essentially irrelevant. The atmosphere model restart file does, however, also set the model's internal calendar. At the start of a simulation, the model reads the date from the restart file; if this file was written by a previous simulation at the end of (say) year 00100, then the first day of the new simulation will be regarded as being 1 January 00101.

When beginning a fresh simulation, the user will generally wish to reset the date; the Fortran 90 program `redate_restart_mk3.f90` enables the user to do this. This program reads an existing Mk3/Mk3L restart file, and prompts the user to enter a date. A new restart file is then generated, in which the date has been reset to the specified value, but which is otherwise identical. Note that the date must be specified in days since 1 January 00000; it is recommended that the value 365, which corresponds to 1 January 00001, be entered. The default restart value `rest.start_default` has the date set to this value.

The atmosphere model restart file is written in a machine-dependent binary format. The program `redate_restart_mk3.f90` could readily be adapted to convert atmosphere model restart files between two alternative binary formats, enabling Mk3L to be ported to a new architecture.

5.5 Generating auxiliary files

A variety of utilities are supplied to assist the user in the generation of new auxiliary files; these are located in the directories `pre/auxiliary/` and `pre/co2/`.

5.5.1 Atmosphere model

CO_2 transmission coefficients

Files containing the CO_2 transmission coefficients should be generated using the utility `radint`; this is provided in the directory `pre/co2/`. To compile `radint`, change to this directory and enter the commands

```
make
make clean
```

[Note that the makefile may require modification before radint can be compiled on facilities other than the NCI National Facility.]

Two executables will be produced: pset and radint. pset generates data files which are required by radint, and must therefore be executed before radint can be used. To generate the necessary data files, enter the command

```
./pset -n 18
```

Note that these data files only need to be generated once, and that pset therefore does not have to be executed again.

radint can now be used to generate auxiliary files containing the CO_2 transmission coefficients. To generate the auxiliary file for an atmospheric CO_2 concentration of <concentration> ppm, enter the command

```
./radint -c <concentration>
```

This will generate a file, co2_data, containing the transmission coefficients. Note that it is only possible to generate these coefficients for atmospheric CO_2 concentrations between 165 and 1320 ppm.

5.5.2 Coupled model

Flux adjustments

It is beyond the scope of this document to describe, in full, the procedure that must be followed in order to derive flux adjustments. However, the necessary utilities are distributed with Mk3L, and these utilities are described in this section.

hfcor.nc, sfcor.nc

Two Fortran 90 programs are supplied which, between them, can be used to generate the auxiliary files hfcor.nc and sfcor.nc:

```
downscale_athf.f90
generate_hfcor.f90
```

downscale_athf uses bilinear interpolation to interpolate climatological surface fluxes from the Mk3L atmosphere model onto the ocean model grid. This program is executed using the following command:

```
./downsale_athf <imsl_file> <in_file> <var_name> <out_file>
```

The four arguments to this command are as follows:

`imsl_file`	name of netCDF file containing array IMSL
`in_file`	name of netCDF file containing climatological surface fluxes from AGCM
`var_name`	name of variable containing climatological surface fluxes from AGCM
`out_file`	name of netCDF output file

`generate_hfcor` then calculates the flux adjustments and generates an auxiliary file. This program is executed using the following command:

```
./generate_hfcor <agcm_file> <agcm_var> <ogcm_file> <ogcm_var> <lon_var> \
                 <lat_var> <aux_file>
```

The seven arguments to this command are as follows:

`agcm_file`	name of netCDF file containing climatological surface fluxes from AGCM
`agcm_var`	name of variable containing climatological surface fluxes from AGCM
`ogcm_file`	name of netCDF file containing climatological surface fluxes from OGCM
`ogcm_var`	name of variable containing climatological surface fluxes from OGCM
`lon_var`	name of variable containing longitude data for OGCM
`lat_var`	name of variable containing latitude data for OGCM
`aux_file`	name of auxiliary file to generate [`hfcor.nc` or `sfcor.nc`]

`txcor.nc, tycor.nc`

Two Fortran 90 programs are supplied which, between them, can be used to generate the auxiliary files `txcor.nc` and `tycor.nc`:

`downscale_tau.f90`
`generate_txcor.f90`

`downscale_tau` uses bilinear interpolation to interpolate climatological surface fluxes from the Mk3L atmosphere model onto the ocean model grid. This program is executed using the following command:

```
./downsale_tau <in_file> <out_file>
```

The two arguments to this command are as follows:

`in_file`	name of netCDF file containing climatological surface stresses from AGCM
`out_file`	name of netCDF output file

`generate_txcor` then calculates the flux adjustments and generates an auxiliary file. This program is executed using the following command:

```
./generate_txcor <agcm_file> <agcm_var> <ogcm_file> <ogcm_var> <lon_var> \
                 <lat_var> <aux_file>
```

The seven arguments to this command are as follows:

`agcm_file`	name of netCDF file containing climatological surface stresses from AGCM
`agcm_var`	name of variable containing climatological surface stresses from AGCM
`ogcm_file`	name of netCDF file containing climatological surface stresses used to spin up OGCM
`ogcm_var`	name of variable containing climatological surface stresses used to spin up OGCM
`lon_var`	name of variable containing longitude data for OGCM
`lat_var`	name of variable containing latitude data for OGCM
`aux_file`	name of auxiliary file to generate [`txcor.nc` or `tycor.nc`]

`dtm.nc, sstcor.nc`

Two Fortran 90 programs are supplied which, between them, can be used to generate the auxiliary files `dtm.nc` and `sstcor.nc`:

```
sst_start_128_112.f90
generate_sstcor.f90
```

`sst_start_128_112` uses area averaging to interpolate climatological sea surface temperatures from the Mk3L ocean model onto the atmosphere model grid. This program is executed using the following command:

```
./sst_start_128_112 <infile> <outfile>
```

The two arguments to this command are as follows:

`infile`	name of netCDF file containing climatological SSTs from OGCM
`outfile`	name of netCDF output file

`generate_sstcor` then calculates the flux adjustments and generates the auxiliary files `dtm.nc` and `sstcor.nc`. This program is executed using the following command:

```
./generate_sstcor <agcm_file> <agcm_var> <lon_var> <lat_var> <dtm_file> \
                  <dtm_var> <ogcm_file> <ogcm_var>
```

The eight arguments to this command are as follows:

`agcm_file`	name of netCDF file containing climatological SSTs used to spin up AGCM
`agcm_var`	name of variable containing climatological SSTs used to spin up AGCM
`lon_var`	name of variable containing longitude data for AGCM
`lat_var`	name of variable containing latitude data for AGCM
`dtm_file`	name of netCDF file containing climatological mixed-layer ocean ΔT values from AGCM
`dtm_var`	name of variable containing climatological mixed-layer ocean ΔT values from AGCM
`ogcm_file`	name of netCDF file containing climatological SSTs from OGCM
`ogcm_var`	name of variable containing climatological SSTs from OGCM

`ssscor.nc`

The Mk3L coupled model can apply adjustments to the sea surface salinities passed from the ocean model to the atmosphere model. However, the need to apply such adjustments can be eliminated by using climatological sea surface salinities from the ocean model as the bottom boundary condition when spinning up the atmosphere model.

This procedure was followed when carrying out the default spin-up runs for the Mk3L atmosphere and ocean models (runs spc38 and k28 respectively). There is therefore no need to apply sea surface salinity adjustments within the coupled model. Although the auxiliary file `ssscor.nc` still needs to be provided, the adjustments contained within this file should be set to zero.

A Fortran 90 program is supplied, which can be used to generate a version of the auxiliary file `ssscor.nc` in which the adjustments are set to zero:

`zero_ssscor.f90`

This program was used to generate the default auxiliary file `ssscor.nc_default`.

Chapter 6

Output files

6.1 Introduction

This chapter covers the output which is generated by Mk3L. The types of output produced by the model are summarised in Section 6.2. Section 6.3 describes the utilities which are supplied with Mk3L, and which are intended for the runtime processing of ocean model output. Section 6.4 lists the utilities which are also distributed with the model, and which are intended to assist with the analysis of model output.

6.2 Overview

The model generates four types of output:

- Diagnostic information
- Atmosphere model output
- Ocean model output
- Restart files

Each of these types of output is now discussed in turn.

6.2.1 Diagnostic information

Various diagnostic information is written to standard output by the model. This information largely consists of statistics generated by the atmosphere and ocean models, and can be controlled via the `namelist` parameters described in Sections 4.2 and 4.3. It is usually redirected to an output file, by running the model using a command such as

```
./model < input > output
```

6.2.2 Atmosphere model output

The output of the atmosphere model is controlled via the `namelist` parameters described in Section 4.2. Although a variety of different statistics can be generated, the user will generally only specify that monthly-mean model variables be saved. Table 4.7 lists the variables that are available.

The data is saved in netCDF, and so no processing of the model output is required. One file is generated for each variable; the filenames are of the form `svvv_xxxxx.nc`, where `vvv` is the variable name and `xxxxx` the experiment name.

6.2.3 Ocean model output

The ocean model writes monthly-mean variables to the binary file `fort.40`[1]. This needs to be converted into a more portable and user-friendly format before it can be analysed, and a number of utilities are therefore provided with Mk3L for the processing of ocean model output. These utilities are described in Section 6.3.

When using the `crelax_flag` option (Section 4.2.4) to derive flux adjustments for use within the coupled model, monthly-mean surface fluxes are also written to the binary file `fort.41`.

6.2.4 Restart files

The atmosphere model, ocean model and coupled model each generate restart files at the end of a simulation; these files are described in Section 5.2.

6.3 Processing of ocean model output

Mk3L is supplied with two utilities, intended for runtime processing of ocean model output: `convert_averages` and `annual_averages`.

6.3.1 `convert_averages`

Two slightly different versions of the utility `convert_averages` are supplied: `convert_averages`, which processes the output of the coupled model, and `convert_averages_ogcm`, which processes the output of the stand-alone ocean model. The need for these different versions arises from the fact that the coupled model can only be run for one year at a time, in which case the ocean model output file will only contain data for one year, whereas the stand-alone ocean model can be run for multiple years at a time, in which case the output file will contain data for multiple years.

The two versions of `convert_averages` are called differently:

```
./convert_averages <input_file> <output_file>
```

[1] Mk3L relies upon Fortran's implicit file naming whereby, if data is written to unit `nn` and this unit has not been connected to an external file using the `open` statement, data is written to the file `fort.nn`. It is dangerous to rely upon this behaviour, however, as it does not form part of the Fortran standard. This will be rectified in future versions of the model.

converts one year of ocean model output to netCDF, while

```
./convert_averages_ogcm <run> <start_year> <end_year>
```

takes the output of ocean model run `run`, for years `start_year` to `end_year`, and generates one netCDF file for each year of the run.

The files produced by the two versions of `convert_averages` are identical, with one netCDF file being generated for each year of model output. The variables that this file contains are listed in Table 6.1.

6.3.2 `annual_averages`

The utility `annual_averages` reads monthly-mean ocean model output from the netCDF files generated by `convert_averages`, and calculates the annual means of each of the fields. (The variable `cdepthm` is an exception, with the annual maximum being calculated instead.) The data is then written to a single netCDF file.

`annual_averages` is called as follows:

```
./annual_averages <run> <start_year> <end_year>
```

This reads the output of run `run`, for years `start_year` to `end_year`, and generates a single netCDF file containing annual-mean model output.

6.4 Analysis

Some programs, written in either the IDL programming language (ITT Visual Information Solutions, 2010) or Fortran 90, are provided in the directory `post/`. These utilities are intended to assist with the analysis of model output.

`average_fcor.pro`

Reads the monthly-mean output that is generated by the atmosphere model when the `namelist` variable `savefcor` is set to true, derives climatological surface fluxes, and writes the values to a netCDF file.

This program requires the data file `csiro_ogcm_ts_landsea.nc`, which is also provided.

`average_ocuv.pro`

Reads monthly-mean output from the low-resolution version of the ocean model, derives climatological surface velocities, and writes the values to a netCDF file.

`average_ocuv_128_112.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, derives climatological surface velocities, and writes the values to a netCDF file.

Variable	Description	Units
`itt`	Timestep counter	-
`dtts`	Tracer timestep duration	s
`relyr`	Year counter	years
`kmt`	Ocean depth on tracer grid	model levels
`kmu`	Ocean depth on velocity grid	model levels
`smfzon`	Zonal component of surface wind stress	Nm^{-2}
`smfmer`	Meridional component of surface wind stress	Nm^{-2}
`stfht`	Surface heat flux	Wm^{-2}
`stfsal`	Surface salinity tendency	kg/kg s^{-1}
`temp`	Potential temperature	$^{\circ}C$
`sal`	Salinity	psu
`rho`	Density	kgm^{-3}
`u`	Zonal component of velocity	ms^{-1}
`v`	Meridional component of velocity	ms^{-1}
`w`	Vertical component of velocity	ms^{-1}
`uedd`	Zonal component of eddy-induced velocity	ms^{-1}
`vedd`	Meridional component of eddy-induced velocity	ms^{-1}
`wedd`	Vertical component of eddy-induced velocity	ms^{-1}
`res`	Barotropic streamfunction	Sv
`cdepthm`	Maximum depth of convection	m
`mola`	Large-scale meridional overturning streamfunction (Atlantic Ocean)	Sv
`molp`	Large-scale meridional overturning streamfunction (Pacific Ocean)	Sv
`moli`	Large-scale meridional overturning streamfunction (Indian Ocean)	Sv
`molg`	Large-scale meridional overturning streamfunction (World Ocean)	Sv
`moea`	Eddy-induced meridional overturning streamfunction (Atlantic Ocean)	Sv
`moep`	Eddy-induced meridional overturning streamfunction (Pacific Ocean)	Sv
`moei`	Eddy-induced meridional overturning streamfunction (Indian Ocean)	Sv
`moeg`	Eddy-induced meridional overturning streamfunction (World Ocean)	Sv
`mota`	Total meridional overturning streamfunction (Atlantic Ocean)	Sv
`motp`	Total meridional overturning streamfunction (Pacific Ocean)	Sv
`moti`	Total meridional overturning streamfunction (Indian Ocean)	Sv
`motg`	Total meridional overturning streamfunction (World Ocean)	Sv

Table 6.1: The variables that can be contained in the file generated by the utilities `convert_averages` and `convert_averages_ogcm`. However, the actual variables that will be present will depend upon the values of the `namelist` parameters that are specified at runtime.

`average_sss.pro`

Reads monthly-mean output from the low-resolution version of the ocean model, derives climatological sea surface salinities, and writes the values to a netCDF file.

`average_sss_128_112.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, derives climatological sea surface salinities, and writes the values to a netCDF file.

`average_sst.pro`

Reads monthly-mean output from the low-resolution version of the ocean model, derives climatological sea surface temperatures, and writes the values to a netCDF file.

`average_sst_128_112.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, derives climatological sea surface temperatures, and writes the values to a netCDF file.

`average_stfht.pro`

Reads monthly-mean output from the low-resolution version of the ocean model, derives the climatological surface heat flux, and writes the values to a netCDF file.

`average_stfht_128_112.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, derives the climatological surface heat flux, and writes the values to a netCDF file.

`average_stfsal.pro`

Reads monthly-mean output from the low-resolution version of the ocean model, derives the climatological surface salinity tendency, and writes the values to a netCDF file.

`average_stfsal_128_112.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, derives the climatological surface salinity tendency, and writes the values to a netCDF file.

`calc_dmsl.pro`

Using the output of `rho_annual.pro`, this program calculates the change in mean sea level arising from changes in the density of the ocean.

This program requires the data file `csiro_ogcm_ts_area_volume.nc`, which is also provided.

`cdepthm_annual.pro`

Reads annual-mean output from the low-resolution version of the ocean model, and produces a single netCDF output file containing the data for the maximum depth of convection.

`cdepthm_annual_128_112.pro`

Reads annual-mean output from the high-resolution version of the ocean model, and produces a single netCDF output file containing the data for the maximum depth of convection.

`csiro_annual_climat.pro`

For a given atmosphere model variable, this program reads monthly-mean output from multiple netCDF files, and generates a single netCDF file containing annual means.

`csiro_annual_extent.pro`

Reads monthly-mean sea ice concentrations from multiple netCDF files, and generates a single netCDF file containing annual-mean sea ice extent.

`csiro_annual_maximum.pro`

For a given atmosphere model variable, this program reads monthly-mean output from multiple netCDF files, and generates a single netCDF file containing annual maxima.

`csiro_annual_minimum.pro`

For a given atmosphere model variable, this program reads monthly-mean output from multiple netCDF files, and generates a single netCDF file containing annual minima.

`csiro_climat_agcm_stats_multi.pro`

For a given atmosphere model variable, this program reads monthly-mean output from multiple netCDF files, derives a climatology, and writes the values to a netCDF file.

`csiro_detrend_climat.pro`

Using the output of `csiro_annual_climat.pro`, this program calculates two timeseries: one high-pass filtered, and one low-pass filtered.

This program requires the function `lowpass_3d.pro`, which is also provided.

`csiro_detrend_mth_climat.pro`

Using the output of `csiro_monthly_climat.pro`, this program calculates two timeseries: one high-pass filtered, and one low-pass filtered.

This program requires the function `lowpass_3d.pro`, which is also provided.

`csiro_detrend_mth_sst.pro`

Using the output of `sst_monthly.pro`, this program calculates two timeseries of monthly-mean sea surface temperature: one high-pass filtered, and one low-pass filtered.

This program requires the function `lowpass_3d.pro`, which is also provided.

`csiro_detrend_sst.pro`

Using the output of `ts_annual.pro`, this program calculates two timeseries of annual-mean sea surface temperature: one high-pass filtered, and one low-pass filtered.

This program requires the function `lowpass_3d.pro`, which is also provided.

`csiro_month_climat.pro`

For a given atmosphere model variable, this program reads monthly-mean output from multiple netCDF files, and generates a single netCDF file containing the data for a particular calendar month.

`csiro_monthly_climat.pro`

For a given atmosphere model variable, this program reads monthly-mean output from multiple netCDF files, and writes the data to a single netCDF file.

`enso_monthly.pro`

Using high-pass filtered mean sea level pressure and sea surface temperature data, this program calculates various El Niño-Southern Oscillation statistics.

`find_elnino.pro`

Using the output of `enso_monthly.pro`, this program detects El Niño events. The definition of Trenberth (1997) is employed, with an El Niño event being defined as a period of at least six consecutive months when the five-month running mean of the sea surface temperature anomaly in the Niño 3.4 region (170–120°W, 5°S–5°N) exceeds +0.4°C.

`nino3_monthly_128_112.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, derives a timeseries of the sea surface temperature anomaly in the Niño 3 region (150–90°W, 5°S–5°N), and writes the data to a netCDF file.

This program requires the data file `grid_spec_mk3l_128_112_21_v2.nc`, which is provided in the directory `data/grids/ocean/`.

`nino34_monthly_128_112.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, derives a timeseries of the sea surface temperature anomaly in the Niño 3.4 region (170–120°W, 5°S–5°N), and writes the data to a netCDF file.

This program requires the data file `grid_spec_mk3l_128_112_21_v2.nc`, which is provided in the directory `data/grids/ocean/`.

`res_annual.pro`

Reads annual-mean output from the low-resolution version of the ocean model, and produces a single netCDF output file containing the data for the barotropic streamfunction.

`res_annual_128_112.pro`

Reads annual-mean output from the high-resolution version of the ocean model, and produces a single netCDF output file containing the data for the barotropic streamfunction.

`rho_annual.pro`

Reads monthly-mean output from the low-resolution version of the ocean model, derives annual-mean density, and writes the values to a netCDF file.

This program requires the function `rho.pro`, which is also provided.

`rho_annual_128_112_21.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, derives annual-mean density, and writes the values to a netCDF file.

This program requires the function `rho.pro`, which is also provided.

`sigmat_annual.pro`

Reads monthly-mean output from the low-resolution version of the ocean model, derives annual-mean potential density, and writes the values to a netCDF file.

This program requires the function `sigma_t.pro` and the data file `csiro_ogcm_ts_area_volume.nc`, both of which are also provided.

`sigmat_annual_128_112_21.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, derives annual-mean potential density, and writes the values to a netCDF file.

This program requires the function `sigma_t.pro`, which is also provided, and the data file `grid_spec_mk3l_128_112_21_v2.nc`, which is provided in the directory `data/grids/ocean/`.

`sst_monthly.pro`

Reads monthly-mean output from the low-resolution version of the ocean model, and generates a single output file containing the sea surface temperature data.

`sst_monthly_128_112_21.pro`

Reads monthly-mean output from the high-resolution version of the ocean model, and generates a single output file containing the sea surface temperature data.

`sst_pcs_detrend.pro`

Using the output of `csiro_detrend_sst.pro`, this program derives the principal components of annual-mean sea surface temperature.

This program requires the data file `csiro_ogcm_ts_area_volume.nc`, which is also provided.

`ts_annual.pro`

Reads annual-mean output from the low-resolution version of the ocean model, and produces netCDF files containing the annual-mean temperature, salinity, sea surface temperature, sea surface salinity, surface heat flux and surface salinity tendency.

`ts_annual_128_112_21.pro`

Reads annual-mean output from the high-resolution version of the ocean model, and produces netCDF files containing the annual-mean temperature, salinity, sea surface temperature, sea surface salinity, surface heat flux and surface salinity tendency.

`ts_stats.pro`

Reads annual-mean output from the low-resolution version of the ocean model, and produces a single netCDF file containing various temperature and salinity statistics.

This program requires the data file `csiro_ogcm_ts_area_volume.nc`, which is also provided.

`ts_stats_128_112_21.f90`

Reads annual-mean output from the high-resolution version of the ocean model, and produces a single netCDF file containing various temperature and salinity statistics.

`tsc_pcs_detrend.pro`

Using high-pass filtered screen temperatures, this program derives the principal components of annual-mean screen temperature.

Appendix A

Release notes for version 1.1

A.1 Introduction

Version 1.1 features two major changes relative to version 1.0:

- The default horizontal resolution of the ocean has been doubled.
- Most of the restart and auxiliary files used by the model have been converted to netCDF.

A.2 Downloading the source code

Version 1.1 can be downloaded using the following subversion command:

```
svn checkout http://svn.tpac.org.au/repos/CSIRO_Mk3L/tags/version-1.1/
```

It is recommended that you create a directory to hold the source code (call it `CSIRO_Mk3L`, or whatever you like). You should change to this directory before entering the above command.

On the APAC National Facility, it may be necessary to enter the command `module load subversion` before you can use subversion.

If you have not previously downloaded the Mk3L source code, you will be prompted for a username and password.

If you do not have a username and password, you will have to apply for an account at

```
http://www.tpac.org.au/main/csiromk3l
```

A.3 Compiling and testing the model

In the directory

```
core/scripts/
```

there are two compile scripts:

```
compile
compile_low
```

The command `./compile` will compile the model with the new, high-resolution version of the ocean.

The command `./compile_low` will compile the model with the old, low-resolution version of the ocean.

In the same directory, there are scripts that will enable you to test both versions of the model.

A.4 Changes since version 1.0

A.4.1 Ocean model resolution

The default version of the ocean model now uses a 128 $\times$ 112 $\times$ 21 grid, giving a horizontal resolution of $\sim$2.8 $\times$ $\sim$1.6 degrees.

The old version of the ocean model is still available for reasons of backwards compatibility. This uses a 64 $\times$ 56 $\times$ 21 grid, giving a horizontal resolution of $\sim$5.6 $\times$ $\sim$3.2 degrees. It is not recommended that new experiments be begun using this version.

A.4.2 Auxiliary files

All the ocean model and coupled model auxiliary files have now been converted to netCDF, as have most atmosphere model auxiliary files.

In the process, the auxiliary files have been renamed as follows:

Atmosphere model

```
albnew21f    ->  albedo.nc
clim3f.sss   ->  sssa.nc
clim3f.sst   ->  ssta.nc
icedivl.R21  ->  icedivl.nc
ocuv.3st     ->  ocuv.nc
psrk21f.dat  ->  psrk.nc
sibrs.dat    ->  sibrs.nc
sibsig.dat   ->  sibsig.nc
sibsoil.dat  ->  sibsoil.nc
sibvegt.dat  ->  sibvegt.nc
sibz0.dat    ->  sibz0.nc
```

The files `amip2o3.dat` and `landrun21` remain in plain text, as does the file containing the CO_2 transmission coefficients.

Ocean model

```
sss.dat      ->  sss.nc
sst.dat      ->  sst.nc
stress.dat   ->  stress.nc
```

The file `sttop.bot_ind` is now obsolete, and is no longer required. The topography information is contained within the restart file.

Coupled model

```
dtm1v        ->  dtm.nc
hfcor.dat12  ->  hfcor.nc
s1coravth    ->  ssscor.nc
sfcor.dat12  ->  sfcor.nc
t1coravth    ->  sstcor.nc
txcor.dat12  ->  txcor.nc
tycor.dat12  ->  tycor.nc
```

Utilities which convert the auxiliary files from the old to the new formats are available upon request.

A.4.3 Restart files

The ocean model and coupled model restart files have been converted to netCDF.

In the process, the restart files have been renamed as follows:

Ocean model

```
fort.21  ->  orest.nc
```

Coupled model

```
fort.23  ->  oflux.nc
```

The atmosphere model restart file remains in unformatted binary for the time being. However, it is anticipated that this will converted to netCDF in a future release.

Utilities which convert the restart files from the old to the new formats are available upon request.

A.4.4 Namelist input

The following ocean model parameters are obsolete, and have been removed from the namelist input:

```
&CONTRL:   NLAST, NWRITE, NDW, NB, NC
&EDDY:     AHF, FKPHF
&ETRANS:   IGM
&ICPLE:    ISYNC, NATO
&PLTG:     NDIAG, ITDB
&COEFS:    URAT, DIFRAT
```

Three new ocean model parameters have been added:

`&EDDY: COS_AMF`

When set to `T`, the horizontal viscosity varies as the cosine of the latitude. In the new version of the model, this improves the ocean climate, reduces numerical noise, and enables longer timesteps to be used.

The default value is `T` for the new version of the model, and `F` for the old version of the model. It is recommended that these values be left unchanged.

`&ETRANS: NO_GM_ARCTIC`

When set to `T`, Gent-McWilliams eddy diffusion is disabled within the high-latitude Arctic Ocean. This reduces numerical noise, while having little impact upon the ocean climate.

The default value is `T` for the new version of the model, and `F` for the old version of the model. It is recommended that these values be left unchanged.

`&PLTG: JPLOT`

This indicates the latitude row for which diagnostic information is written to standard output. This feature exists primarily for debugging purposes, and hence most users can neglect it.

The default value is `25` for the new version of the model, and `13` for the old version of the model.

A.5 Performance

The performance of the coupled model (with the new, high-resolution version of the ocean model) on the APAC National Facility is as follows:

Number of CPUs	Speed (years/day)
1	6.8
2	11.3
4	15.9

It is not recommended to run on more than 4 processors, as relatively little extra performance is gained.

Steven Phipps
10 March 2008

Appendix B

Release notes for version 1.2

B.1 Introduction

Version 1.2 features the following changes since version 1.1:

- A new equation of state for the ocean model.
- A new time filter for the ocean model.
- A new bathymetry for the ocean model, as well as new default parameter settings.
- Implementation of a freshwater hosing scheme.
- A new compile mechanism, making it much easier to port the model to new machines.
- Enhancements to the output of both the atmosphere and ocean models.
- Fixes to a number of known bugs.
- Numerous other minor enhancements.

Mk3L-1.2 on the new SGI XE Cluster at the NCI National facility (`xe.nci.org.au`) runs approximately 50% faster than Mk3L-1.1 on the old SGI Altix AC (`ac.apac.edu.au`).

The differences between the climatologies of Mk3L-1.1 and Mk3L-1.2 are modest. However, users are encouraged to upgrade in order to take advantage of the above features.

B.2 Downloading the source code

Version 1.2 can be downloaded using the following subversion command:

```
svn checkout http://svn.tpac.org.au/repos/CSIRO_Mk3L/tags/version-1.2/
```

It is recommended that you create a directory to hold the source code (call it `CSIRO_Mk3L`, or whatever you like). You should change to this directory before entering the above command.

On the NCI National Facility, it may be necessary to enter the command `module load subversion` before you can use subversion.

If you have not previously downloaded the Mk3L source code, you will be prompted for a username and password.

If you do not have a username and password, you should first apply for an account at

```
http://www.tpac.org.au/main/csiromk3l
```

B.3 Compiling and testing the model

To compile the model and associated utilities, change to the directory

```
core/scripts/
```

and enter the command

```
./compile
```

To test that the model has compiled successfully, enter any of the following three commands:

`./test_atm`	Runs the stand-alone atmosphere model for one day
`./test_cpl`	Runs the coupled model for one day
`./test_oce`	Runs the stand-alone ocean model for one month

See the model documentation for further information.

B.4 Changes since version 1.1

B.4.1 Ocean model equation of state

The equation of state of McDougall et al. (2003) has been implemented.

This has negligible impact upon either performance or the climatology of the model, but it does have two key advantages:

- it allows the density to be saved as an output variable
- it allows the user to vary the vertical resolution

Neither of these were possible with the old Knudsen equation of state.

This change has introduced a new namelist option `M2003_EOS`. When `true`, the new equation of state is used; when `false`, the old Knudsen equation of state is used.

The McDougall et al. (2003) equation of state is enabled by default in version 1.2. The old equation of state is now deprecated, and may be removed in a future version.

B.4.2 Ocean model time filter

A Robert time filter has now been implemented. This has no performance impact, but improves both the conservation and noise characteristics of the model.

This change has introduced a new namelist option `ROBERT_TIME_FILTER`. When `true`, the new time filter is used; when `false`, the old Euler backward mixing timesteps are used.

The Robert time filter is enabled by default in version 1.2. The old time filter is now deprecated, and may be removed in a future version.

B.4.3 Ocean model bathymetry and parameter settings

The default bathymetry in version 1.1 was found to be a little bit too rough, giving rise to ocean model fields that could be spatially noisy. There was also a minor problem with numerical noise at depth in the Arctic Ocean.

The default bathymetry in version 1.2 is smoother. The ocean model has also been re-tuned slightly, with an increase in the default value of `AMF` (the horizontal viscosity at the equator) from 2.4×10^9 to 3.2×10^9 cm^{2}s^{-1}, and a reduction in the default value of `ACORF` (the Coriolis forward weighting parameter) from 0.67 to 0.5.

The combined effect of these changes is to give rise to smoother ocean model fields, and to resolve the problem with numerical noise. Most ocean model statistics are also now in better agreement with observations, although the Indonesian Throughflow is significantly too strong.

B.4.4 Freshwater hosing

A new freshwater hosing scheme has been implemented, thanks to Jess Trevena.

This introduces two new namelist options, as follows:

`HOSING_FLAG`	If `true`, apply freshwater hosing
`HOSING_RATE`	The freshwater hosing rate [Sv]

The default values of these parameters are `false` and `1.0` respectively.

When freshwater hosing is being used, a new auxiliary file `hosemask` must be provided. This is a plain text file and contains a 64×56 array, corresponding to the atmosphere model grid. Freshwater hosing is applied at all gridpoints at which this array is equal to 1.

A template is provided in the directory

```
core/data/atmosphere/hosing/
```

and can be manipulated using any text editor.

B.4.5 Compile mechanism

In previous versions of Mk3L, porting the model to a new machine required the user to modify ten separate makefiles.

In version 1.2, all the machine-specific configuration information has been consolidated into a single macro definition file.

The macro definition files can be found in the following directory:

```
core/bld/
```

Macro definition files are provided for the following machines:

`ac.apac.edu.au`	The SGI Altix AC at the NCI National Facility
`linux`	Linux (generic)
`shine-cl.nexus.csiro.au`	An Intel Xeon machine at CSIRO Marine and Atmospheric Research
`xe.nci.org.au`	The SGI XE Cluster at the NCI National Facility

By default, the model is configured for compilation on `xe.nci.org.au`. To compile the model on one of the other machines in the above table, make the following changes:

1. Remove the symbolic link `macros`
2. Create a new symbolic link `macros`, pointing to the appropriate macro definition file

To port the model to a new machine, the following changes are required:

1. Copy one of the existing macro definition files
2. Update the parameter definitions within the new file, as necessary
3. Remove the symbolic link `macros`
4. Create a new symbolic link `macros`, pointing to the new file

B.4.6 Atmosphere model output

In previous versions of Mk3L, all atmosphere model variables were saved as 16-bit integers. There were two problems with this approach:

- Excessive loss of precision
- The possibility that variables could exceed the specified valid range, leading to incorrect results and/or loss of data

In version 1.2, all atmosphere model variables are saved as 32-bit real values. Although this doubles the volume of data generated by the atmosphere model, it resolves both of the above problems and is therefore considered to be a price worth paying. Furthermore, the volume of data generated by the atmosphere model is still less than that generated by the ocean model.

The output of the atmosphere model is always now saved as netCDF. The option of saving the data in CIF (an obscure, pre-netCDF binary format) has been removed. This renders the namelist variable `NETCDF` obsolete, and so this has been removed.

B.4.7 Ocean model output

In previous versions of Mk3L, all ocean model variables were automatically saved to file. This resulted in very large volumes of data being generated, much of which would never be required by the user.

In version 1.2, user control over the ocean model output has been implemented. The following namelist options have been introduced:

`SAVE_SMFZON`	If `true`, save the zonal wind stress
`SAVE_SMFMER`	If `true`, save the meridional wind stress
`SAVE_STFHT`	If `true`, save the surface heat flux
`SAVE_STFSAL`	If `true`, save the surface salinity tendency
`SAVE_TEMP`	If `true`, save the potential temperature
`SAVE_SAL`	If `true`, save the salinity
`SAVE_RHO`	If `true`, save the density
`SAVE_U`	If `true`, save the zonal velocity
`SAVE_V`	If `true`, save the meridional velocity
`SAVE_W`	If `true`, save the vertical velocity
`SAVE_UEDD`	If `true`, save the eddy-induced zonal velocity
`SAVE_VEDD`	If `true`, save the eddy-induced meridional velocity
`SAVE_WEDD`	If `true`, save the eddy-induced vertical velocity
`SAVE_RES`	If `true`, save the barotropic streamfunction
`SAVE_CDEPTHM`	If `true`, save the maximum depth of convection
`SAVE_OVER`	If `true`, save the meridional overturning streamfunctions

The default behaviour is the same as in previous versions i.e. all variables apart from the density are saved to file. However, users are encouraged to consider carefully which variables they require. In particular, it will generally not be necessary to save the eddy-induced velocities (`UEDD`, `VEDD` and `WEDD`). Disabling these variables reduces the volume of data generated by the ocean model by around a third.

Notes:

- Saving all ocean model variables causes the model to generate around 14 GB of data for every 100 model years.
- Saving all ocean model variables also incurs a performance penalty of several percent.
- The meridional overturning streamfunctions are now saved in the same file as the rest of the ocean model output, reducing the number of output files from two to one. As a result of this change, the post-processing utilities `overturning` and `annual_overturning` are now obsolete, and have been removed from the model source code.

- These changes render the namelist option `IYES` obsolete, and this has therefore been removed.

B.4.8 Bug fixes

The following known bugs have been fixed:

- a bug in the handling of vegetation fractions by the land surface scheme
- a numerical instability in the soil moisture solver within the land surface scheme
- a bug in the calculation of the latitudes within the sea ice model
- a bug in the application of the "limited free slip" boundary condition within the sea ice model
- a bug in the calculation of monthly-mean statistics by the ocean model
- a bug whereby at least one of the namelist variables `LASTMONTH` or `MONTHS` had to be greater than zero; now it is only necessary for any one of `NSSTOP`, `NDSTOP`, `LASTMONTH` or `MONTHS` to be greater than zero

It should be emphasised that none of these bugs had major impacts upon the climatology of the model, or upon the output files that it generated.

B.4.9 Miscellaneous minor enhancements

The following miscellaneous changes have also been made to the model since version 1.1:

- Code has been inserted into the ocean model which checks for negative salinities. If these are detected, the simulation is aborted.
- Various syntax errors have been fixed, such that the model can now be compiled using the g95 Fortran compiler.
- The optional "McDougall" enhancement to Gent-McWilliams eddy diffusion has been removed from the ocean model. This option was experimental, and has been found to significantly degrade the climatology of the model. Removing it renders the namelist variable `ITM` obsolete, and this has therefore been removed.

B.5 Namelist input

There have been some significant changes to the namelist input since version 1.1. Existing control files will therefore need to be adapted before they can be used with version 1.2. In particular, the following changes will need to be made:

- any obsolete namelist variables (see Section B.5.1 below) will need to be removed
- the namelist groups `&COUPLING` and `&OSAVE` (see Sections B.5.2 and B.5.3 below) will need to be added to the control file, even if these groups are empty

- some variables may need to be moved from `&CONTROL` to `&COUPLING` (see Section B.5.4 below)
- the length of `runtype` will need to be increased from three to five characters (see Section B.5.4 below)

The sample control files provided in the directory

```
core/control/
```

can be used as a guide.

B.5.1 Obsolete variables

The following namelist variables are now obsolete, and have therefore been removed:

```
&DIAGNOSTICS: NETCDF
&PLTG: IYES
&ETRANS: ITM
```

B.5.2 New groups

Two new namelist groups have been added in version 1.2:

```
&COUPLING
&OSAVE
```

`&COUPLING` is only read if either `LCOUPLE` or `SAVEFCOR` are `true` i.e. it is only read within the coupled model, or within atmosphere model spin-up runs where the surface fluxes are being saved for the purposes of diagnosing flux adjustments.

B.5.3 New variables

The following namelist variables have been added in version 1.2:

```
&COUPLING: ISYNC
```

If equal to `0`, employ concurrent [asynchronous] coupling between the atmosphere and ocean. If equal to `1`, employ sequential [synchronous] coupling. The default value is `1`.

```
&COUPLING: OVOLUME
```

The volume of the ocean (m^3). This variable only has meaning within atmosphere model spin-up runs, and should be set equal to the volume of the ocean within the model to which it will be coupled. However, the default value of 1.27×10^{18} m^3 should be accurate enough for most purposes. Within the coupled model, the value of `OVOLUME` is overwritten with the actual volume of the ocean.

`&COUPLING: HOSING_FLAG, HOSING_RATE`

See Section B.4.4 above.

`&CONTRL: ROBERT_TIME_FILTER, PNU`

See Section B.4.2 above. `PNU` is the smoothing coefficient for the time filter. The default values of `ROBERT_TIME_FILTER` and `PNU` are `true` and `0.005` respectively.

`&CONTRL: CHECK_CONSERVATION`

If `true`, perform checks for conservation of heat and salt within the ocean. This option significantly diminishes performance, and causes a large volume of diagnostic information to be written to standard output. It should therefore be used during model development only. The default value is `false`.

`&CONTRL: M2003_EOS`

See Section B.4.1 above.

```
&OSAVE: SAVE_SMFZON, SAVE_SMFMER, SAVE_STFHT, SAVE_STFSAL, SAVE_TEMP,
        SAVE_SAL, SAVE_RHO, SAVE_U, SAVE_V, SAVE_W, SAVE_UEDD, SAVE_VEDD,
        SAVE_WEDD, SAVE_RES, SAVE_CDEPTHM, SAVE_OVER
```

See Section B.4.7 above.

B.5.4 Changes to existing groups and variables

`&CONTROL: RUNTYPE`

The length of this variable, which contains the experiment name, has been increased from three to five characters. This change has been made so as to avoid duplication of experiment names between different users.

It is recommended that you use your initials (or those of your group) as the first two characters of the experiment name. For example:

- if your name is Jane Smith, you should call your experiments `js001`, `jsa01` or similar
- if your group is the CCRC, you should call your experiments `cc001`, `cca01` or similar

`&CONTROL: CRELAX_FLAG, CRELAX_TAU, FLUXADJ, SUBICE`

These namelist variables have been moved from `&CONTROL` to `&COUPLING`.

B.6 Performance

The performance of the coupled model on `xe.nci.org.au` (the SGI XE Cluster at the NCI National Facility) is as follows:

Number of cores	Speed (years/day)
1	9.9
2	16.5
4	24.0
8	31.7

This represents a gain of approximately 50% over the performance of Mk3L-1.1 on `ac.apac.edu.au` (the SGI Altix AC at the NCI National Facility).

Note that it is NOT recommended to run on more than 4 cores, as the small additional performance gain does not justify the extra cost.

B.7 Acknowledgements

Thanks to Jess Trevena for implementing the freshwater hosing scheme.

Thanks also to everyone — and particularly Agus Santoso — who put Mk3L-1.1 through its paces, and who offered feedback on their experiences. Mk3L-1.2 is a better model as a result.

Steven Phipps
7 August 2009

Appendix C

Auxiliary files

C.1 Introduction

Mk3L must be supplied with auxiliary files, which specify the boundary conditions on the model. These files are described in detail in Chapter 5. This appendix documents the procedures which were followed to generate the default auxiliary files that are distributed with the model. These processes are summarised in Section C.2, while the exact procedures followed to generate the auxiliary files required by the ocean, atmosphere and coupled models are described in Sections C.3, C.4 and C.5 respectively.

To enable intercomparison with other climate system models, the default spin-up procedure for Mk3L is consistent with PMIP2 experimental design (Paleoclimate Modelling Intercomparison Project, 2009). For coupled model experiments, it is specified that a control simulation be conducted for pre-industrial conditions, which are taken as being those which existed around the year AD 1750. The precise experimental design is summarised in Table C.1.

C.2 Generation of auxiliary files

This section summarises the process whereby the auxiliary files were generated: the sources of the data, the software packages which were used, and the principles which were followed. The precise steps taken to generate each auxiliary file are documented in the sections which follow.

C.2.1 Datasets

World Ocean Atlas 1998

The World Ocean Atlas 1998 (National Oceanographic Data Center, 2010) was used to provide the initial state for the ocean model, as well as to provide the sea surface temperatures and salinities prescribed as the upper boundary condition during spin-up runs.

The World Ocean Atlas 1998 dataset contains analysed ocean temperatures and salinities, on a $1^\circ\times1^\circ$ latitude-longitude grid in the horizontal direction, and on 33 levels in the vertical direction, at depths ranging

Boundary condition	Value
Vegetation	Fixed
Ice sheets	Modern
Topography/coastlines	Modern
CO_2 concentration [ppm]	280
CH_4 concentration [ppb]	760
N_2O concentration [ppb]	270
Chlorofluorocarbons	None
O_3 concentration	Modern
Solar constant [Wm^{-2}]	1365
Epoch [years BP]	0
Eccentricity of Earth's orbit	0.016724
Obliquity of Earth's axis [°]	23.446
Longitude of perihelion [°]	102.04
Initial ocean state	World Ocean Atlas 1998

Table C.1: PMIP2 experimental design for coupled model control simulations.

from 0 to 5500 m. Annual means are available for all vertical levels, while monthly means are available for the uppermost 24 levels (which range in depth from 0 to 1500 m). The World Ocean Atlas 1998 dataset was obtained in netCDF (Unidata, 2010) from the NOAA/OAR/ESRL Physical Sciences Division (Physical Sciences Division, 2010).

NCEP-DOE Reanalysis 2

The wind stresses used to spin up the ocean model were derived from the NCEP-DOE Reanalysis 2 (Kanamitsu et al., 2002). Monthly-mean wind stresses for the period 1979-2003 were obtained in netCDF from the NOAA/OAR/ESRL Physical Sciences Division.

NOAA Optimum Interpolation Sea Surface Temperature Analysis v2

The sea surface temperatures used to spin up the atmosphere model were obtained from the NOAA Optimum Interpolation sea surface temperature analysis v2 (Reynolds et al., 2002). Weekly sea surface temperatures for the period 1982-2001 were obtained in netCDF from the NOAA/OAR/ESRL Physical Sciences Division.

C.2.2 The definition of "surface"

The upper layer of the Mk3L ocean model has a thickness of 25 m. The temperature and salinity of this layer therefore simulate the average temperature and salinity of the upper 25 m of the water column, and not the sea surface temperature (SST) and sea surface salinity (SSS) *per se*.

It is therefore inappropriate to use the observed SST and SSS to spin up the ocean model. Relaxing the temperature and salinity of a 25 m-thick layer of water towards these values, rather than towards an equivalent observational quantity, would result in unrealistic surface fluxes. In turn, this would influence the magnitude of the flux adjustments diagnosed for the coupled model.

The surface boundary conditions on the ocean model are *not* therefore the observed SST and SSS, but are instead the averages of the World Ocean Atlas 1998 temperature and salinity over the upper 25 m of the water column.

C.2.3 Software

Two software packages were used to generate the auxiliary files that are supplied with Mk3L: Ferret (Pacific Marine Environmental Laboratory, 2010) and IDL (ITT Visual Information Solutions, 2010).

Ferret was used to perform the interpolation operations on the data. The `@AVE` transformation, which calculates length-, area- and volume-weighted averages (in one, two and three dimensions respectively), was used to interpolate the observational datasets onto the Mk3L atmosphere and ocean model grids.

Ferret was also used to fill any missing values in the observational datasets. This was necessary because of differences between the positions of the coastlines on the Mk3L grid and on the grids on which the observational datasets were supplied. By using spatial interpolation to fill missing values over land, it could be ensured that the interpolation onto the model grid would generate values for all ocean gridpoints.

The `@FAV` transformation, which replaces missing values with the average of the values for the adjacent gridpoints, was used to fill the observational datasets over land. It was necessary to apply the `@FAV` transformation repeatedly in order to fill all the missing values.

IDL and Fortran 90 were used to perform all the other operations on the data, including the generation of auxiliary files in the formats read by Mk3L.

C.3 Ocean model spin-up

C.3.1 Sea surface temperature and salinity

The steps taken to generate the auxiliary files `sss.nc` and `sst.nc` were as follows:

1. The monthly-mean World Ocean Atlas 1998 ocean temperatures and salinities were averaged over the upper 25 m of the water column.
2. The missing values over land were filled.
3. The values were interpolated onto the Mk3L ocean model grid.
4. The data was written to file in the format read by the Mk3L ocean model.

C.3.2 Surface wind stress

The steps taken to generate the auxiliary file `stress.nc` were as follows:

1. Climatological monthly-mean NCEP-DOE Reanalysis 2 surface wind stresses were calculated for the period 1979–2003.
2. The values over land were masked out.
3. Interpolation was used to generate “pseudo-data” over land.
4. The values were interpolated onto the Mk3L ocean model grid.
5. The data was written to file in the format read by the Mk3L ocean model.

The values over land were masked out because of the differences in the positions of the coastlines on the NCEP-DOE Reanalysis 2 and Mk3L ocean model grids. If no masking had been carried out, then observational wind stresses for land gridpoints would have contributed towards the values used to force the ocean model. As the surface wind stresses can be much larger in magnitude over land than over the ocean, as a result both of topography and of the greater surface roughness lengths, this would be undesirable.

C.4 Atmosphere model spin-up

C.4.1 Sea surface temperature

The steps taken to generate the auxiliary file `ssta.nc` were as follows:

1. Climatological monthly sea surface temperatures for the *start* of each month were calculated using the NOAA OI SST analysis v2; the climatology was calculated using the data for 1982–2001.
2. The missing values over land were filled.
3. The values were interpolated onto the Mk3L atmosphere model grid.
4. The data was written to file in the format read by the Mk3L atmosphere model.

C.4.2 Sea surface salinity

The sea surface salinity is required by the Mk3L atmosphere model to convert the surface freshwater fluxes to equivalent surface salinity tendencies. In order to eliminate the need to apply adjustments to the sea surface salinities within the coupled model, climatological sea surface salinities diagnosed from an ocean model spin-up run are used to spin up the atmosphere model.

The steps taken to generate the auxiliary file `sssa.nc` were as follows:

1. Climatological monthly-mean sea surface salinities were diagnosed from the final 100 years of ocean model spin-up run k28.
2. The values were interpolated onto the Mk3L atmosphere model grid.
3. Climatological sea surface salinities for the *start* of each month were estimated, by averaging the climatological means for consecutive months.
4. The data was written to file in the format read by the Mk3L atmosphere model.

C.4.3 Ocean currents

The ocean currents used to spin up the atmosphere model are derived from ocean model spin-up runs, avoiding any need to apply flux adjustments to the ocean currents within the coupled model.

The following steps were taken to generate the auxiliary file `ocuv.nc`:

1. Climatological monthly-mean ocean currents were diagnosed from the final 100 years of ocean model spin-up run k28.
2. The values were interpolated onto the Mk3L atmosphere model grid.
3. Climatological ocean currents for the start of each month were estimated, by averaging the climatological means for consecutive months.
4. The data was written to file in the format read by the Mk3L atmosphere model.

C.5 Flux adjustments

C.5.1 Fields passed from the atmosphere model to the ocean model

Flux adjustments are applied to each of the four fields which are passed from the atmosphere model to the ocean model: the heat flux, the surface salinity tendency, and the zonal and meridional components of the surface momentum flux.

The derivation and application of the flux adjustments is outlined in Section 2.5. If F_A and F_O are the climatological surface fluxes diagnosed from atmosphere and ocean model spin-up runs respectively — in the case of the surface momentum fluxes, F_O is equal to the climatological fluxes applied to the ocean model during the spin-up run — then the flux adjustments ΔF are given by:

$$\Delta F = F_A - F_O \tag{C.1}$$

The flux adjustments are applied within the ocean model; as with the boundary conditions on the stand-alone ocean model, the coupled model requires that the flux adjustments supplied be climatological values for the midpoint of each month. The model than uses linear interpolation in time to estimate values at each timestep.

The steps taken to generate the auxiliary files `hfcor.nc`, `sfcor.nc`, `txcor.nc` and `tycor.nc` were therefore as follows:

1. Climatological monthly-mean surface fluxes were diagnosed from atmosphere and ocean model spin-up runs.
2. Monthly-mean flux adjustments were diagnosed, by subtracting the ocean model fluxes from the atmosphere model fluxes.
3. The data was written to file in the format read by the Mk3L coupled model.

C.5.2 Fields passed from the ocean model to the atmosphere model

Four fields are passed from the ocean model to the atmosphere model: the sea surface temperature (SST), the sea surface salinity (SSS), and the zonal and meridional components of the surface velocity. Of these, the coupled model applies adjustments to the SST and the SSS.

The derivation and application of the adjustments is outlined in Section 2.5. The adjustments which are applied to the SST are given by:

$$\Delta T = T_{obs} + \Delta T_{mlo} - T_O \tag{C.2}$$

while the adjustments which are applied to the SSS are given by:

$$\Delta S = S_{obs} - S_O \tag{C.3}$$

The adjustments to the SST and the SSS are applied within the atmosphere model; as with the boundary conditions on the stand-alone atmosphere model, the coupled model requires that the adjustments supplied be climatological values for the *start* of each month. The model then uses linear interpolation in time to estimate values at each timestep.

The steps taken to generate the auxiliary file `sstcor.nc` were therefore as follows:

1. Climatological monthly-mean SSTs were diagnosed from an ocean model spin-up run, while climatological monthly-mean mixed-layer ocean temperature anomalies (ΔT_{mlo}) were diagnosed from an atmosphere model spin-up run.
2. The ocean model SSTs were interpolated onto the atmosphere model grid, in exactly the same rigorously-conserving fashion as takes place within the Mk3L coupled model.
3. Monthly-mean adjustments were diagnosed, using Equation C.2.
4. Climatological adjustments for the start of each month were estimated, by averaging the climatological means for consecutive months.
5. The data was written to file in the format read by the Mk3L coupled model.

The sea surface salinities used to spin up the atmosphere model are derived from ocean model spin-up runs, avoiding any need to apply adjustments to the sea surface salinities within the coupled model.

Appendix D

Control files and run scripts

D.1 Introduction

This appendix reproduces control files and run scripts that have been used to spin up the atmosphere and ocean models, and to conduct a coupled model control simulation. The control files are provided in Section D.2, and the run scripts in Section D.3.

D.2 Control files

D.2.1 Atmosphere model spin-up

The following control file was used to carry out Mk3L atmosphere model spin-up run spc38. The parameters `lcouple` and `locean`, contained within the `namelist` group `control`, are both set to `.false.`, indicating that the model is to run in stand-alone atmosphere mode.

The parameter `bpyear` is set to 0, and `csolar` is set to 1365.0, specifying a solar constant of 1365 Wm^{-2}. The model is instructed to read the CO_2 transmission coefficients from the file `co2_data.280ppm.18l`, which contains the coefficients corresponding to an atmospheric CO_2 concentration of 280 ppm. These settings configure the atmosphere model for pre-industrial conditions, consistent with PMIP2 experimental design (Section C.1).

The parameter `savefcor`, contained within the group `diagnostics`, is set to `.true.`, indicating that the surface fluxes should be calculated and saved to file. This enables flux adjustments to be diagnosed for use within the coupled model (Section 2.5). The parameter `ovolume`, contained within the group `coupling`, is set to `1.28064907370741e18`. This indicates that, within the coupled model, the volume of the ocean will be $1.28064907370741\times10^{18}$ m^3; this is the volume of the ocean model in version 1.2 of Mk3L.

The parameter `lastmonth`, contained within the group `control`, is set to 12, indicating that the model is to run for one calendar year at a time.

```
&control
  lcouple=F
  locean=F
```

```
  mstep=20
  nsstop=0
  ndstop=0
  lastmonth=12
  months=0
  nrad=6
  co2_datafile='co2_data.280ppm.18l'
  o3_datafile='o3_data.18l'
  filewrflag=T
  irfilename='rest.start'
  orfilename='rest.end'
  runtype='spc38'
  qflux=F
  ncarpbl=T
  naerosol_d=0
  csolar=1365.0
  bpyear=0
  rcritl=0.75
  rcrits=0.85
  refac1=0.595
  refac2=0.865
&end

&diagnostics
  dynfp=F, minw=480
  iener=F
  ispec=F
  zavgp=T, dynzp=T, phz1p=T, phz2p=T, conzp=T, plotheat=T, plotclds=T,
    plotnetr=T, plotevrn=T
  gmap1=F, cvrnm=F, gwicm=F, rhnmm=F, cldm=F
  gmap2=F, rainm=F, evapm=F, pmslm=F, surfm=F
  cdmap=F
  mlomap=F
  idayp=0
  glmean_interval=240
  statsflag=T
  saveqflux=T
  savefcor=T
  clforflag=T
&end

&statvars
  evp_sflg=T, pev_sflg=T, sev_sflg=T, rnd_sflg=T, rnc_sflg=T, hfl_sflg=T,
  wfg_sflg=T, wfb_sflg=T, run_sflg=T, per_sflg=T, int_sflg=T, psl_sflg=T,
  vmo_sflg=T, tax_sflg=T, tay_sflg=T, tsu_sflg=T, tsc_sflg=T, tb2_sflg=T,
  tb3_sflg=T, tgg_sflg=T, tgf_sflg=T, thd_sflg=T, tld_sflg=T, thg_sflg=T,
  tlg_sflg=T, thf_sflg=T, tlf_sflg=T, thm_sflg=T, tlm_sflg=T, dtm_sflg=T,
  rsv_sflg=F,
  cld_sflg=T, cll_sflg=T, clm_sflg=T, clh_sflg=T,
```

```
  rgn_sflg=T, rgd_sflg=T, rgc_sflg=T, sgn_sflg=T, sgd_sflg=T, sgc_sflg=T,
  rtu_sflg=T, rtc_sflg=T, sot_sflg=T, soc_sflg=T, als_sflg=T,
  snd_sflg=T, sid_sflg=T, ico_sflg=T, itf_sflg=T, isf_sflg=T, icu_sflg=T,
  icv_sflg=T, div_sflg=T, gro_sflg=T, ire_sflg=T, ich_sflg=T,
  fwf_sflg=T,
  sno_sflg=T, rev_sflg=T, ssb_sflg=T, clc_sflg=T, lwp_sflg=T, pwc_sflg=T,
  ref_sflg=T,
    u_sflg=T,   v_sflg=T,   t_sflg=T,   q_sflg=T,  rh_sflg=T,   g_sflg=T,
    c_sflg=T,   l_sflg=T
&end

&histvars
&end

&params
&end

&coupling
  subice=T
  ovolume=1.28064907370741e18
&end
```

D.2.2 Ocean model spin-up

The following control file was used for the asynchronous stage of Mk3L ocean model spin-up run spk36. The parameter `locean`, contained within the `namelist` group `control`, is set to `.true.`, indicating that the model is to run in stand-alone ocean mode.

The parameters `dttsf`, `dtuvf` and `dtsff`, contained within the group `tsteps`, set the tracer timestep to 1 day, and the velocity and streamfunction timesteps to 20 minutes.

Otherwise, no values are specified for most of the parameters, indicating that the default values are to be used. In the case of `iocyr` and `iocmn`, the default values are 50 and 12 respectively, indicating that the model is to run for 50 calendar years at a time.

```
&control
  locean=T
  runtype='spk36'
&end
&diagnostics
&end
&statvars
&end
&histvars
&end
&params
&end

&contrl
```

```
  nnergy=3650
  ntsi=30
&end

&eddy
&end

&eddy2
&end

&etrans
&end

&tsteps
  dttsf=86400.0
  dtuvf=1200.0
  dtsff=1200.0
&end

&parms
&end

&icple
&end

&pltg
&end

&coefs
&end

&accel
&end

&osave
  save_rho=T
&end
```

For the synchronous stage of the run, the contents of the `namelist` groups `contrl` and `tsteps` were replaced with the following. The values of the parameters `nnergy`, `ntsi`, `dttsf`, `dtuvf` and `dtsff` were removed, indicating that the default values should be used; in the case of the timesteps, this indicates that each timestep should be set to 1 hour.

```
&contrl
&end

&tsteps
&end
```

D.2.3 Coupled model

The following control file was used to carry out Mk3L coupled model control simulation spi62. The parameter `lcouple`, contained within the `namelist` group `control`, is set to `.true.`, indicating that the model is to run in coupled mode.

The parameter `lastmonth`, also contained within the group `control`, is set to 12, indicating that the model is to run for one year at a time. The ocean model parameters `iocyr` and `iocmn` have no effect in the coupled model.

The atmosphere and ocean models are configured as for the respective spin-up runs. Within the group `coupling`, the parameter `fluxadj` is now set to `.true.`, indicating that flux adjustments should be applied; the parameter `ovolume` has been removed, as this has no effect within the coupled model.

```
&control
  lcouple=T
  locean=F
  mstep=20
  ndstop=0
  months=0
  lastmonth=12
  nsstop=0
  nrad=6
  co2_datafile='co2_data.280ppm.18l'
  o3_datafile='o3_data.18l'
  filewrflag=T
  irfilename='rest.start'
  orfilename='rest.end'
  runtype='spi62'
  qflux=F
  ncarpbl=T
  naerosol_d=0
  csolar=1365.0
  bpyear=0
  rcritl=0.75
  rcrits=0.85
  refac1=0.595
  refac2=0.865
&end

&diagnostics
  dynfp=F, minw=480
  iener=F
  ispec=F
  zavgp=T, dynzp=T, phz1p=T, phz2p=T, conzp=T, plotheat=T, plotclds=T,
    plotnetr=T, plotevrn=T
  gmap1=F, cvrnm=F, gwicm=F, rhnmm=F, cldm=F
  gmap2=F, rainm=F, evapm=F, pmslm=F, surfm=F
  cdmap=F
  mlomap=F
```

```
  idayp=0
  glmean_interval=240
  statsflag=T
  saveqflux=F
  savefcor=F
  clforflag=T
&end

&statvars
  evp_sflg=T, pev_sflg=T, sev_sflg=T, rnd_sflg=T, rnc_sflg=T, hfl_sflg=T,
  wfg_sflg=T, wfb_sflg=T, run_sflg=T, per_sflg=T, int_sflg=T, psl_sflg=T,
  vmo_sflg=T, tax_sflg=T, tay_sflg=T, tsu_sflg=T, tsc_sflg=T, tb2_sflg=T,
  tb3_sflg=T, tgg_sflg=T, tgf_sflg=T, thd_sflg=T, tld_sflg=T, thg_sflg=T,
  tlg_sflg=T, thf_sflg=T, tlf_sflg=T, thm_sflg=T, tlm_sflg=T, dtm_sflg=F,
  rsv_sflg=F,
  cld_sflg=T, cll_sflg=T, clm_sflg=T, clh_sflg=T,
  rgn_sflg=T, rgd_sflg=T, rgc_sflg=T, sgn_sflg=T, sgd_sflg=T, sgc_sflg=T,
  rtu_sflg=T, rtc_sflg=T, sot_sflg=T, soc_sflg=T, als_sflg=T,
  snd_sflg=T, sid_sflg=T, ico_sflg=T, itf_sflg=T, isf_sflg=T, icu_sflg=T,
  icv_sflg=T, div_sflg=T, gro_sflg=T, ire_sflg=T, ich_sflg=T,
  fwf_sflg=T,
  sno_sflg=T, rev_sflg=T, ssb_sflg=T, clc_sflg=T, lwp_sflg=T, pwc_sflg=T,
  ref_sflg=T,
    u_sflg=T,   v_sflg=T,   t_sflg=T,   q_sflg=T,  rh_sflg=T,   g_sflg=T,
    c_sflg=T,   l_sflg=T
&end

&histvars
&end

&params
&end

&coupling
  fluxadj=T
  subice=T
&end

&contrl
&end

&eddy
&end

&eddy2
&end

&etrans
&end
```

```
 &tsteps
 &end

 &parms
 &end

 &icple
 &end

 &pltg
 &end

 &coefs
 &end

 &accel
 &end

 &osave
   save_rho=T
 &end
```

D.3 Run scripts

D.3.1 Atmosphere model spin-up

The following script was used to carry out Mk3L atmosphere model spin-up run spc39 on vayu, a Sun Constellation Cluster located at the NCI National Facility (National Computational Infrastructure, 2010). It submits a job to the queueing system, and runs the atmosphere model for one year at a time. The model runs on eight processors.

The script performs the following tasks:

- The model is executed for one year, and a check is performed to ensure that the run completed successfully.
- At an interval specified by the value of `SAVE_INTERVAL`, the restart files and model output are archived to tape, using the `netmv` command (see below).
- If the run is not complete — the total duration of the run is specified by the value of `LASTYR` — the script re-submits itself, and the run continues for another year.

```
#!/bin/tcsh
#PBS -P n33
#PBS -q normal
#PBS -l walltime=1:00:00
#PBS -l vmem=1gb
```

```
#PBS -l ncpus=8
#PBS -m a
#PBS -M s.phipps@unsw.edu.au
#PBS -N spc39
#PBS -wd
#
# Purpose
# -------
# Runs the Mk3L atmosphere model for one year at a time on vayu.
#
# History
# -------
# 2010 Mar 8 Steven Phipps Original version

########################################################
#                                                      #
#                    USER INTERFACE                    #
#                                                      #
#  Set the following variables to the required values  #
#                                                      #
########################################################

# Run name
set run = spc39

# Duration of the run, in years
set LASTYR = 00100

# Interval over which to archive model output, in years
set SAVE_INTERVAL = 100

# Address to which to send emails
set ADDRESS = s.phipps@unsw.edu.au

######################################################
#                                                    #
#                   RUN THE MODEL                    #
#                                                    #
#  You shouldn’t have to change anything after here  #
#                                                    #
######################################################

# Display the node on which we’re running
echo This job is running on node ‘hostname‘.

# Set the stack sizes
limit stacksize unlimited
setenv KMP_STACKSIZE 10M
```

```
# Set the number of threads
setenv OMP_NUM_THREADS $PBS_NCPUS

# Set names of directories on vayu
set copydir = /short/n33/${run}/copy
set rundir = /short/n33/${run}/run
set tmpdir = /short/n33/${run}/tmp

# Set names of directories on the MDSS
set atdir = ${run}/atmos
set fcordir = ${run}/fcor
set outdir = ${run}/out
set qfluxdir = ${run}/qflux
set restdir = ${run}/restart

# Set the year number - $year may have leading zeroes, whereas $yr will not
set year = ‘cat year‘
set yr = ‘expr $year + 0‘

# Change to the run directory
cd $rundir

# Tidy up from the previous run
/bin/mv ${run}.[eo]* $tmpdir

# Save temporary copy of restart file
/bin/cp -p rest.start $copydir

# Run the model for one year
./model < input > out.$year

# Check that the run was OK
set MESSAGE = ‘tail out.$year | grep termination‘
if ("$MESSAGE" != ’’) then
  echo "Year $year terminated normally."
else
  echo "Abnormal termination of run."
  echo "Mk3L run $run stopped - abnormal termination." | mail $ADDRESS
  exit
endif

# Save restart file every SAVE_INTERVAL years
if (‘expr $yr % $SAVE_INTERVAL‘ == 0) then
  /bin/cp -p rest.end rest.start_${run}_$year
  chmod 400 rest.start_${run}_$year
  gzip rest.start_${run}_$year
  /bin/mv rest.start_${run}_${year}.gz $tmpdir
endif
```

```
# Rename the output restart file as the new input restart file
/bin/mv rest.end rest.start

# Save the standard output of the model
gzip out.$year
chmod 400 out.${year}.gz
/bin/mv out.${year}.gz $tmpdir

# Save the Q-flux output of the model
tar cf qflx${year}.${run}.tar qflx*.$run
gzip qflx${year}.${run}.tar
chmod 400 qflx${year}.${run}.tar.gz
/bin/mv qflx${year}.${run}.tar.gz $tmpdir
/bin/rm qflx*.$run

# Save the surface flux output of the model
tar cf fcor${year}.${run}.tar fcor*.$run
gzip fcor${year}.${run}.tar
chmod 400 fcor${year}.${run}.tar.gz
/bin/mv fcor${year}.${run}.tar.gz $tmpdir
/bin/rm fcor*.$run

# Every SAVE_INTERVAL years, save all the model output to the MDSS
if (‘expr $yr % $SAVE_INTERVAL‘ == 0) then
  set yr2 = $year
  set year1 = ‘expr $yr - $SAVE_INTERVAL + 1‘
  set yr1 = $year1
  if ($year1 <= 9999) set yr1 = 0$year1
  if ($year1 <= 999) set yr1 = 00$year1
  if ($year1 <= 99) set yr1 = 000$year1
  if ($year1 <= 9) set yr1 = 0000$year1

  # Compress and tar the atmosphere model output, and then save it to the MDSS
  gzip s*${run}.nc
  chmod 400 s*${run}.nc.gz
  tar cf netcdf.${run}.${yr1}-${yr2}.tar s*${run}.nc.gz
  /bin/mv netcdf.${run}.${yr1}-${yr2}.tar $tmpdir
  chmod 600 s*${run}.nc.gz
  /bin/rm s*${run}.nc.gz
  cd $tmpdir
  chmod 400 netcdf.${run}.${yr1}-${yr2}.tar
  netmv -P n33 -N netcdf.$run -l walltime=1:00:00 \
        netcdf.${run}.${yr1}-${yr2}.tar $atdir

  # Tar the restart files, and save them to the MDSS
  tar cf restart.${run}.${yr2}.tar rest.start_${run}_*.gz
  chmod 400 restart.${run}.${yr2}.tar
  netmv -P n33 -N restart.$run -l walltime=1:00:00 restart.${run}.${yr2}.tar \
                                                   $restdir
```

```
  chmod 600 rest.start_${run}_*.gz
  /bin/rm rest.start_${run}_*.gz

  # Tar the standard output of the model, and save it to the MDSS
  tar cf out.${run}.${yr1}-${yr2}.tar out.?????.gz
  chmod 400 out.${run}.${yr1}-${yr2}.tar
  netmv -P n33 -N out.$run -l walltime=1:00:00 out.${run}.${yr1}-${yr2}.tar \
                                               $outdir
  chmod 600 out.?????.gz
  /bin/rm out.?????.gz

  # Tar the Q-flux output, and save it to the MDSS
  tar cf qflx.${run}.${yr1}-${yr2}.tar qflx*.${run}.tar.gz
  chmod 400 qflx.${run}.${yr1}-${yr2}.tar
  netmv -P n33 -N qflx.$run -l walltime=1:00:00 qflx.${run}.${yr1}-${yr2}.tar \
                                                $qfluxdir
  chmod 600 qflx*.${run}.tar.gz
  /bin/rm qflx*.${run}.tar.gz

  # Tar the surface flux output, and save it to the MDSS
  tar cf fcor.${run}.${yr1}-${yr2}.tar fcor*.${run}.tar.gz
  chmod 400 fcor.${run}.${yr1}-${yr2}.tar
  netmv -P n33 -N fcor.$run -l walltime=1:00:00 fcor.${run}.${yr1}-${yr2}.tar \
                                                $fcordir
  chmod 600 fcor*.${run}.tar.gz
  /bin/rm fcor*.${run}.tar.gz

endif

# Change to the run directory
cd $rundir

# Increment the year number
set yrnext = ‘expr $year + 1‘
set yrp1 = $yrnext
if ($yrnext <= 9999) set yrp1 = 0$yrnext
if ($yrnext <= 999) set yrp1 = 00$yrnext
if ($yrnext <= 99) set yrp1 = 000$yrnext
if ($yrnext <= 9) set yrp1 = 0000$yrnext
/bin/rm year
echo $yrp1 > year

# Stop the run if the file stop_run exists
if (-e ${rundir}/stop_run) then
  echo "Model stopped - stop_run exists."
  echo "Mk3L run $run stopped - stop_run exists." | mail $ADDRESS
  exit
endif
```

```
# Continue the run as necessary
if ($year != $LASTYR) then
  qsub RUN
  set errstat = $?
  @ n = 1
  while (($errstat != 0) && ($n <= 10))
    echo "qsub error - trying again in 60 seconds..."
    sleep 60
    qsub RUN
    set errstat = $?
    @ n ++
  end
endif
```

D.3.2 Ocean model spin-up

The following script was used to conduct the asynchronous stage of Mk3L ocean model spin-up run spk37 on vayu, a Sun Constellation Cluster located at the NCI National Facility (National Computational Infrastructure, 2010). It exhibits the following differences from the script used to run the atmosphere model:

- The model is executed on a single processor.
- The model is executed for 50 years at a time, rather than one.
- The utility `convert_averages` is used to convert the model output to netCDF. (The script assumes that the raw ocean model output is written to the binary file `fort.40` - see Section 6.2.3.)
- The utility `annual_averages` is used to calculate annual-mean model statistics.
- To reduce the amount of model output, the variable `MONTHYR` allows the user to specify the model year from which to begin saving monthly-mean model output; prior to this year only annual-mean output is archived to tape. The following script specifies that monthly-mean output is only to be saved during the final 100 years of the run (from model year 06401, the value of `MONTHYR`, to model year 06500, the value of `LASTYR`).
- The standard output of the model is only archived to tape once every 500 model years (the value of `TAR_INTERVAL`); otherwise the archive files are excessivly small.

The script used to conduct the synchronous stage of the run differed only in that the values of `MONTHYR` and `LASTYR` were changed to 06901 and 07000 respectively, and the amount of walltime requested per job was increased from 1.25 hours to 18 hours (i.e. `#PBS -l walltime=1:15:00` was replaced with `#PBS -l walltime=18:00:00`).

```
#!/bin/tcsh
#PBS -P n33
#PBS -q normal
#PBS -l walltime=1:15:00
#PBS -l vmem=1gb
#PBS -l ncpus=1
```

```
#PBS -m a
#PBS -M s.phipps@unsw.edu.au
#PBS -N spk37
#PBS -wd
#
# Purpose
# -------
# Runs the Mk3L-1.2 ocean model on vayu.
#
# History
# -------
# 2010 Feb 19 Steven Phipps Original version

########################################################
#                                                      #
#                    USER INTERFACE                    #
#                                                      #
#  Set the following variables to the required values  #
#                                                      #
########################################################

# Run name
set run = spk37

# Duration of the run, in years
set LASTYR = 06500

# Year from which to begin saving monthly output
set MONTHYR = 06401

# Length of each job, in model years
set RUN_LENGTH = 50

# Interval over which to tar standard output, in years
set TAR_INTERVAL = 500

# Address to which to send emails
set ADDRESS = s.phipps@unsw.edu.au

######################################################
#                                                    #
#                   RUN THE MODEL                    #
#                                                    #
#  You shouldn't have to change anything after here  #
#                                                    #
######################################################

# Display the node on which we're running
echo This job is running on node `hostname`.
```

```
# Set the stacksize to unlimited
limit stacksize unlimited

# Set names of directories on vayu
set tmpdir = /short/n33/${run}/tmp
set rundir = /short/n33/${run}/run

# Set names of directories on the MDSS
set comdir = ${run}/com
set outdir = ${run}/out
set restdir = ${run}/restart

# Set the year number for the first year of the run - $year1 may have leading
# zeroes, whereas $yr1 will not
set year1 = ‘cat year‘
set yr1 = ‘expr $year1 + 0‘

# Set the year number for the last year of the run
set yr2 = ‘expr $yr1 + $RUN_LENGTH - 1‘
set year2 = $yr2
if ($yr2 <= 9999) set year2 = 0$yr2
if ($yr2 <= 999) set year2 = 00$yr2
if ($yr2 <= 99) set year2 = 000$yr2
if ($yr2 <= 9) set year2 = 0000$yr2

# Change to the run directory
cd $rundir

# Tidy up from the previous run
/bin/mv ${run}.[eo]* $tmpdir

# Run the model
./model < input > out.${year1}-${year2}

# Check that the run was OK
set MESSAGE = ‘tail out.${year1}-${year2} | grep termination‘
if ("$MESSAGE" != ’’) then
  echo "Years $year1 to $year2 terminated normally."
else
  echo "Abnormal termination of run."
  echo "Mk3L run $run stopped - abnormal termination." | mail $ADDRESS
  exit
endif

# Convert the model output to netCDF
/bin/mv fort.40 fort.40.${year1}-${year2}
./convert_averages_ogcm $run $yr1 $yr2
```

```
# Delete the original model output
/bin/rm fort.40.${year1}-${year2}

# Calculate the annual averages
./annual_averages $run $yr1 $yr2

# If necessary, compress and tar the monthly output
set comtar = com.${run}.${year1}-${year2}.tar
if (‘expr $year1 \>= $MONTHYR‘ == 1) then
  chmod 444 com.${run}.?????.nc
  gzip com.${run}.?????.nc
  tar cf $comtar com.${run}.?????.nc.gz
  chmod 444 $comtar
endif

# Delete the monthly output
if (‘expr $year1 \>= $MONTHYR‘ == 1) then
  chmod 600 com.${run}.?????.nc.gz
  /bin/rm com.${run}.?????.nc.gz
else
  /bin/rm com.${run}.?????.nc
endif

# Compress the annual averages
chmod 444 com.ann.${run}.${year1}-${year2}.nc
gzip com.ann.${run}.${year1}-${year2}.nc

# Save the restart file
/bin/cp -p orest.nc orest.nc_${run}_${year2}
chmod 444 orest.nc_${run}_${year2}
gzip orest.nc_${run}_${year2}

# Save standard output
chmod 444 out.${year1}-${year2}
gzip out.${year1}-${year2}

# Move the output to the temporary directory
/bin/mv com.ann.${run}.${year1}-${year2}.nc.gz \
  orest.nc_${run}_${year2}.gz out.${year1}-${year2}.gz $tmpdir
if (‘expr $year1 \>= $MONTHYR‘ == 1) /bin/mv $comtar $tmpdir

# Change to the temporary directory, and save the output to the MDSS
cd $tmpdir
netmv -P n33 -N com.ann.$run -l walltime=1:00:00 \
      com.ann.${run}.${year1}-${year2}.nc.gz $comdir
netmv -P n33 -N rest.$run -l walltime=1:00:00 orest.nc_${run}_${year2}.gz \
                                              $restdir
if (‘expr $year1 \>= $MONTHYR‘ == 1) netmv -P n33 -N com.$run \
                                    -l walltime=1:00:00 $comtar $comdir
```

```
# Save standard output to the MDSS
if (‘expr $yr2 % $TAR_INTERVAL‘ == 0) then
  set yr0 = ‘expr $yr2 - $TAR_INTERVAL + 1‘
  set year0 = $yr0
  if ($yr0 <= 9999) set year0 = 0$yr0
  if ($yr0 <= 999) set year0 = 00$yr0
  if ($yr0 <= 99) set year0 = 000$yr0
  if ($yr0 <= 9) set year0 = 0000$yr0
  tar cf out.${run}.${year0}-${year2}.tar out.?????-?????.gz
  chmod 444 out.${run}.${year0}-${year2}.tar
  netmv -P n33 -N out.$run -l walltime=1:00:00 \
        out.${run}.${year0}-${year2}.tar $outdir
  chmod 600 out.?????-?????.gz
  /bin/rm out.?????-?????.gz
endif

# Change back to the run directory
cd $rundir

# Increment the year number
set yrnext = ‘expr $year2 + 1‘
set yrp1 = $yrnext
if ($yrnext <= 9999) set yrp1 = 0$yrnext
if ($yrnext <= 999) set yrp1 = 00$yrnext
if ($yrnext <= 99) set yrp1 = 000$yrnext
if ($yrnext <= 9) set yrp1 = 0000$yrnext
/bin/rm year
echo $yrp1 > year

# Stop the run if the file stop_run exists
if (-e ${rundir}/stop_run) then
  echo "Model stopped - stop_run exists."
  echo "Mk3L run $run stopped - stop_run exists." | mail $ADDRESS
  exit
endif

# Continue the run as necessary
if ($year2 != $LASTYR) then
  qsub RUN
  set errstat = $?
  @ n = 1
  while (($errstat != 0) && ($n <= 10))
    echo "qsub error - trying again in 60 seconds..."
    sleep 60
    qsub RUN
    set errstat = $?
    @ n ++
  end
```

```
endif
```

D.3.3 Coupled model

The following script was used to conduct Mk3L coupled model control simulation spi65 on vayu, a Sun Constellation Cluster located at the NCI National Facility (National Computational Infrastructure, 2010). It combines the features of the scripts used to conduct the atmosphere and ocean model spin-up runs, executing the coupled model for one year at a time on eight processors, and archiving the restart files and model output to tape once every 100 years.

```
#!/bin/tcsh
#PBS -P n33
#PBS -q normal
#PBS -l walltime=1:00:00
#PBS -l vmem=1gb
#PBS -l ncpus=8
#PBS -m a
#PBS -M s.phipps@unsw.edu.au
#PBS -N spi65
#PBS -wd
#
# Purpose
# -------
# Runs the Mk3L-1.2 coupled model for one year at a time on vayu.
#
# History
# -------
# 2010 Mar 10 Steven Phipps Original version

#########################################################
#                                                       #
#                    USER INTERFACE                     #
#                                                       #
#  Set the following variables to the required values  #
#                                                       #
#########################################################

# Run name
set run = spi65

# Duration of the run, in years
set LASTYR = 10000

# Interval over which to archive restart files, in years
set REST_INTERVAL = 100

# Interval over which to archive model output, in years
set SAVE_INTERVAL = 100
```

```
# Address to which to send emails
set ADDRESS = s.phipps@unsw.edu.au

######################################################
#                                                    #
#                   RUN THE MODEL                    #
#                                                    #
#  You shouldn’t have to change anything after here  #
#                                                    #
######################################################

# Display the node on which we’re running
echo This job is running on node ‘hostname‘.

# Set the stack sizes
limit stacksize unlimited
setenv KMP_STACKSIZE 10M

# Set the number of threads
setenv OMP_NUM_THREADS $PBS_NCPUS

# Set names of directories on vayu
set copydir = /short/n33/${run}/copy
set rundir = /short/n33/${run}/run
set tmpdir = /short/n33/${run}/tmp

# Set names of directories on the MDSS
set atdir = ${run}/atmos
set comdir = ${run}/com
set outdir = ${run}/out
set restdir = ${run}/restart

# Set the year number - $year may have leading zeroes, whereas $yr will not
set year = ‘cat year‘
set yr = ‘expr $year + 0‘

# Change to the run directory
cd $rundir

# Tidy up from the previous run
/bin/mv ${run}.[eo]* $tmpdir

# Save temporary copies of restart files
/bin/cp -p oflux.nc $copydir
/bin/cp -p orest.nc $copydir
/bin/cp -p rest.start $copydir

# Run the model for one year
```

```
./model < input > out.$year

# Check that the run was OK
set MESSAGE = ‘tail out.$year | grep termination‘
if ("$MESSAGE" != ’’) then
  echo "Year $year terminated normally."
else
  echo "Abnormal termination of run."
  echo "Mk3L run $run stopped - abnormal termination." | mail $ADDRESS
  exit
endif

# Save restart files every REST_INTERVAL years
if (‘expr $yr % $REST_INTERVAL‘ == 0) then
  /bin/cp -p oflux.nc oflux.nc_${run}_$year
  /bin/cp -p orest.nc orest.nc_${run}_$year
  /bin/cp -p rest.end rest.start_${run}_$year
  chmod 444 oflux.nc_${run}_$year orest.nc_${run}_$year rest.start_${run}_$year
  gzip oflux.nc_${run}_$year orest.nc_${run}_$year rest.start_${run}_$year
  /bin/mv oflux.nc_${run}_${year}.gz orest.nc_${run}_${year}.gz \
          rest.start_${run}_${year}.gz $tmpdir
endif

# Rename the output atmosphere model restart file as the new input restart file
/bin/mv rest.end rest.start

# Save the standard output of the model
gzip out.$year
chmod 444 out.${year}.gz
/bin/mv out.${year}.gz $tmpdir

# Convert the ocean model output to netCDF
./convert_averages fort.40 com.${run}.${year}.nc
/bin/rm fort.40

# Save the output of the ocean model
chmod 444 com.${run}.${year}.nc
/bin/mv com.${run}.${year}.nc $tmpdir

# Every SAVE_INTERVAL years, calculate the annual means of the ocean model
# output, and save all the model output to the MDSS
if (‘expr $yr % $SAVE_INTERVAL‘ == 0) then
  set yr2 = $year
  set year1 = ‘expr $yr - $SAVE_INTERVAL + 1‘
  set yr1 = $year1
  if ($year1 <= 9999) set yr1 = 0$year1
  if ($year1 <= 999) set yr1 = 00$year1
  if ($year1 <= 99) set yr1 = 000$year1
  if ($year1 <= 9) set yr1 = 0000$year1
```

```
# Compress and tar the atmosphere model output, copy it to /short and then
# save it to the MDSS
gzip s*${run}.nc
chmod 444 s*${run}.nc.gz
tar cf netcdf.${run}.${yr1}-${yr2}.tar s*${run}.nc.gz
/bin/mv netcdf.${run}.${yr1}-${yr2}.tar $tmpdir
chmod 600 s*${run}.nc.gz
/bin/rm s*${run}.nc.gz
cd $tmpdir
chmod 444 netcdf.${run}.${yr1}-${yr2}.tar
netmv -P n33 -N netcdf.$run -l walltime=1:00:00 \
      netcdf.${run}.${yr1}-${yr2}.tar $atdir

# Calculate the annual means of the ocean model output, compress them and
# save them to the MDSS
./annual_averages $run $yr1 $yr2
chmod 444 com.ann.${run}.${yr1}-${yr2}.nc
gzip com.ann.${run}.${yr1}-${yr2}.nc
netmv -P n33 -N com.ann.$run -l walltime=1:00:00 \
      com.ann.${run}.${yr1}-${yr2}.nc.gz $comdir

# Compress and tar the ocean model output, and save it to the MDSS
chmod 444 com.${run}.?????.nc
gzip com.${run}.?????.nc
set comtar = com.${run}.${yr1}-${yr2}.tar
tar cf $comtar com.${run}.?????.nc.gz
chmod 444 $comtar
netmv -P n33 -N com.$run -l walltime=1:00:00 $comtar $comdir
chmod 600 com.${run}.?????.nc.gz
/bin/rm com.${run}.?????.nc.gz

# Tar the restart files, and save them to the MDSS
tar cf restart.${run}.${yr2}.tar oflux.nc_${run}_?????.gz \
       orest.nc_${run}_?????.gz rest.start_${run}_?????.gz
chmod 444 restart.${run}.${yr2}.tar
netmv -P n33 -N restart.$run -l walltime=1:00:00 restart.${run}.${yr2}.tar \
                                                 $restdir
chmod 600 oflux.nc_${run}_?????.gz orest.nc_${run}_?????.gz \
          rest.start_${run}_?????.gz
/bin/rm oflux.nc_${run}_?????.gz orest.nc_${run}_?????.gz \
        rest.start_${run}_?????.gz

# Tar the standard output of the model, and save it to the MDSS
tar cf out.${run}.${yr1}-${yr2}.tar out.?????.gz
chmod 444 out.${run}.${yr1}-${yr2}.tar
netmv -P n33 -N out.$run -l walltime=1:00:00 out.${run}.${yr1}-${yr2}.tar \
                                             $outdir
chmod 600 out.?????.gz
```

```
  /bin/rm out.?????.gz

endif

# Change to the run directory
cd $rundir

# Increment the year number
set yrnext = ‘expr $year + 1‘
set yrp1 = $yrnext
if ($yrnext <= 9999) set yrp1 = 0$yrnext
if ($yrnext <= 999) set yrp1 = 00$yrnext
if ($yrnext <= 99) set yrp1 = 000$yrnext
if ($yrnext <= 9) set yrp1 = 0000$yrnext
/bin/rm year
echo $yrp1 > year

# Stop the run if the file stop_run exists
if (-e ${rundir}/stop_run) then
  echo "Model stopped - stop_run exists."
  echo "Mk3L run $run stopped - stop_run exists." | mail $ADDRESS
  exit
endif

# Continue the run as necessary
if ($year != $LASTYR) then
  qsub RUN
  set errstat = $?
  @ n = 1
  while (($errstat != 0) && ($n <= 10))
    echo "qsub error - trying again in 60 seconds..."
    sleep 60
    qsub RUN
    set errstat = $?
    @ n ++
  end
endif
```

Bibliography

Arakawa, A., and V. R. Lamb, Computational design of the basic dynamical processes of the UCLA general circulation model, in J. Chang, editor, *General Circulation Models of the Atmosphere*, volume 17 of *Methods in Computational Physics*, pages 173–265, Academic Press, 1977.

Bi, D., *Transient and Long-Term Behaviour of the World Ocean Under Global Warming*, PhD thesis, University of Tasmania, 2002.

Bryan, K., A numerical method for the study of the circulation of the world ocean, *Journal of Computational Physics*, 4:347–376, 1969.

Bryan, K., Accelerating the convergence to equilibrium of ocean-climate models, *Journal of Physical Oceanography*, 14:666–673, 1984.

Cess, R. D., and G. L. Potter, Exploratory studies of cloud radiative forcing with a general circulation model, *Tellus*, 39A:460–473, 1987.

Chouinard, C., M. Béland, and N. McFarlane, A simple gravity wave drag parameterization for use in medium-range weather forecast models, *Atmosphere-Ocean*, 24(2):91–110, 1986.

CollabNet, 2009, URL `http://subversion.tigris.org/`, accessed 26 April 2010.

Cox, M. D., A primitive equation, 3-dimensional model of the ocean, Technical Report 1, Geophysical Fluid Dynamics Laboratory Ocean Group, 1984.

Cox, M. D., Isopycnal diffusion in a z-coordinate ocean model, *Ocean Modelling*, 74:1–5, 1987.

Fels, S. B., and M. D. Schwarzkopf, The simplified exchange approximation: A new method for radiative transfer calculations, *Journal of the Atmospheric Sciences*, 32:1475–1488, 1975.

Fels, S. B., and M. D. Schwarzkopf, An efficient, accurate algorithm for calculating CO_2 15μm band cooling rates, *Journal of Geophysical Research*, 86(C2):1205–1232, 1981.

FFTW, FFTW Home Page, 2010, URL `http://fftw.org/`, accessed 26 April 2010.

Flato, G. M., and W. D. Hibler, III, On a simple sea-ice dynamics model for climate studies, *Annals of Glaciology*, 14:72–77, 1990.

Flato, G. M., and W. D. Hibler, III, Modeling pack ice as a cavitating fluid, *Journal of Physical Oceanography*, 22:626–651, 1992.

Gargett, A. E., Vertical eddy diffusivity in the ocean interior, *Journal of Marine Research*, 42(2):359–393, 1984.

Gates, W. L., and A. B. Nelson, A new (revised) tabulation of the Scripps topography on a 1 degree global grid: Part I, Terrain heights, Technical Report R-1276-1-ARPA, The Rand Corporation, 1975.

Gent, P. R., and J. C. McWilliams, Isopycnal mixing in ocean circulation models, *Journal of Physical Oceanography*, 20:150–155, 1990.

Gent, P. R., J. Willebrand, T. J. McDougall, and J. C. McWilliams, Parameterizing eddy-induced tracer transports in ocean circulation models, *Journal of Physical Oceanography*, 25:463–474, 1995.

Gordon, H. B., A flux formulation of the spectral atmospheric equations suitable for use in long-term climate modeling, *Monthly Weather Review*, 109:56–64, 1981.

Gordon, H. B., and S. P. O'Farrell, Transient climate change in the CSIRO coupled model with dynamic sea ice, *Monthly Weather Review*, 125(5):875–907, 1997.

Gordon, H. B., L. D. Rotstayn, J. L. McGregor, M. R. Dix, E. A. Kowalczyk, S. P. O'Farrell, L. J. Waterman, A. C. Hirst, S. G. Wilson, M. A. Collier, I. G. Watterson, and T. I. Elliott, The CSIRO Mk3 climate system model, Technical Report 60, CSIRO Atmospheric Research, 2002.

Gregory, D., and P. R. Rowntree, A mass flux convection scheme with representation of cloud ensemble characteristics and stability-dependent closure, *Monthly Weather Review*, 118:1483–1506, 1990.

Hirst, A. C., S. P. O'Farrell, and H. B. Gordon, Comparison of a coupled ocean-atmosphere model with and without oceanic eddy-induced advection. Part I: Ocean spinup and control integration, *Journal of Climate*, 13:139–163, 2000.

ITT Visual Information Solutions, IDL - Data Visualization Solutions, 2010, URL `http://www.ittvis.com/ProductServices/IDL.aspx`, accessed 26 April 2010.

Kanamitsu, M., W. Ebisuzaki, J. Woollen, S.-K. Yang, J. J. Hnilo, M. Fiorino, and G. L. Potter, NCEP-DOE AMIP-II Reanalysis (R-2), *Bulletin of the American Meteorological Society*, 83(11):1631–1643, 2002.

Kowalczyk, E. A., J. R. Garratt, and P. B. Krummel, A soil-canopy scheme for use in a numerical model of the atmosphere - 1D stand-alone model, Technical Report 23, CSIRO Division of Atmospheric Research, 1991.

Kowalczyk, E. A., J. R. Garratt, and P. B. Krummel, Implementation of a soil-canopy scheme into the CSIRO GCM - regional aspects of the model response, Technical Report 32, CSIRO Division of Atmospheric Research, 1994.

Lacis, A. A., and J. E. Hansen, A parameterization for the absorption of solar radiation in the earth's atmosphere, *Journal of the Atmospheric Sciences*, 31:118–133, 1974.

McDougall, T. J., D. R. Jackett, D. G. Wright, and R. Feistel, Accurate and computationally efficient algorithms for potential temperature and density of seawater, *Journal of Atmospheric and Oceanic Technology*, 20:730–741, 2003.

McGregor, J. L., Economical determination of departure points for semi-Lagrangian models, *Monthly Weather Review*, 121:221–230, 1993.

National Computational Infrastructure, NCI National Facility, 2010, URL `http://nf.nci.org.au/`, accessed 26 April 2010.

National Geophysical Data Center, 2-minute Gridded Global Relief Data (ETOPO2v2), 2006, URL `http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html`, accessed 26 April 2010.

National Oceanographic Data Center, Ocean Climate Laboratory Products, 2010, URL `http://www.nodc.noaa.gov/OC5/indprod.html`, accessed 26 April 2010.

O'Farrell, S. P., Investigation of the dynamic sea ice component of a coupled atmosphere-sea ice general circulation model, *Journal of Geophysical Research*, 103(C8):15751–15782, 1998.

Pacific Marine Environmental Laboratory, Data Visualization and Analysis – Portal, 2010, URL `http://ferret.wrc.noaa.gov/Ferret/`, accessed 26 April 2010.

Paleoclimate Modelling Intercomparison Project, PMIP 2 Project Home Page, 2009, URL `http://pmip2.lsce.ipsl.fr/`, accessed 26 April 2010.

Phipps, S. J., The CSIRO Mk3L climate system model, Technical Report No. 3, Antarctic Climate & Ecosystems Cooperative Research Centre, Hobart, Tasmania, Australia, 236pp., 2006, ISBN 1-921197-03-X.

Physical Sciences Division, ESRL : PSD : Physical Sciences Division, 2010, URL `http://www.esrl.noaa.gov/psd/`, accessed 26 April 2010.

Reynolds, R. W., N. A. Rayner, T. M. Smith, D. C. Stokes, and W. Wang, An improved in situ and satellite SST analysis for climate, *Journal of Climate*, 15:1609–1625, 2002.

Robert, A. J., The integration of a low order spectral form of the primitive meteorological equations, *Journal of the Meteorological Society of Japan*, 44(5):237–244, 1966.

Rotstayn, L. D., A physically based scheme for the treatment of stratiform clouds and precipitation in large-scale models. I: Description and evaluation of the microphysical processes, *Quarterly Journal of the Royal Meteorological Society*, 123:1227–1282, 1997.

Rotstayn, L. D., A physically based scheme for the treatment of stratiform clouds and precipitation in large-scale models. II: Comparison of modelled and observed climatological fields, *Quarterly Journal of the Royal Meteorological Society*, 124:389–415, 1998.

Rotstayn, L. D., On the "tuning" of autoconversion parameterizations in climate models, *Journal of Geophysical Research*, 105(D12):15495–15507, 2000.

Schwarzkopf, M. D., and S. B. Fels, Improvements to the algorithm for computing CO_2 transmissivities and cooling rates, *Journal of Geophysical Research*, 90(D6):10541–10550, 1985.

Schwarzkopf, M. D., and S. B. Fels, The simplified exchange method revisited: An accurate, rapid method for computation of infrared cooling rates and fluxes, *Journal of Geophysical Research*, 96(D5):9075–9096, 1991.

Semtner, Jr, A. J., A model for the thermodynamic growth of sea ice in numerical investigations of climate, *Journal of Physical Oceanography*, 6:379–389, 1976.

Trenberth, K. E., The definition of El Niño, *Bulletin of the American Meteorological Society*, 78(12):2771–2777, 1997.

Unidata, NetCDF (network Common Data Form), 2010, URL `http://www.unidata.ucar.edu/software/netcdf/`, accessed 26 April 2010.

Wang, W.-C., X.-Z. Liang, M. P. Dudek, D. Pollard, and S. L. Thompson, Atmospheric ozone as a climate gas, *Atmospheric Research*, 37:247–256, 1995.

Washington, W. M., and C. L. Parkinson, *An Introduction to Three-Dimensional Climate Modeling*, Oxford University Press, 1986.

WWW.ACECRC.ORG.AU