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AusCOM: The Australian Climate Ocean Model

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ABSTRACT

The Australian Climate Ocean Model (AusCOM) is an initiative by the Australian climate science community (including governmental and academic research laboratories) towards a unified coupled ocean-ice model for climate applications. The technical configuration and details of the sub-models are presented here. Initial results, including the development of a displaced pole bipolar ocean grid, are also discussed. An outlook for future model development and of further community model systems are reported on.

1 Introduction

The AusCOM (Australian Climate Ocean Model) is an initiative of Australian government and university research groups to standardise ocean and sea-ice model activities for climate applications. This development will result in many benefits to this research community including, reducing the number of large complex codes requiring support, having a broader range of local expertise available, having simulation output distributed amongst a variety of institutions - potentially reducing the computational cost of a series of simulations as some of the simulations might have been conducted elsewhere, simplifying the ability to use the computational and data grids to conduct simulations - as only one main code needs to be modified to run in these environments. Additional benefit may, for example, arise from sharing of data analysis and graphical handling tools, scripts. This standardisation is non-exclusive in nature, some simulations require a model configuration outside the AusCOM specification (in fact may require a completely different model), but the research community is encouraged to use an AusCOM conforming specification when appropriate to allow for direct intercomparision between simulations.

2 Model Description

The AusCOM model consists of three components, an ocean model, a sea-ice model and a numerical coupler. Details for each of these components are given below.

2.1 Ocean Model

The ocean component is the Modular Ocean Model (MOM) version 4p0d supplied by Geophysical Fluid Dynamics Laboratory (GFDL/NOAA Department of Commerce). This model is a finite difference, z coordinate model with generalised orthogonal horizontal coordinates, and an Arakawa B-Grid [Griffies et al., 2004]. Time evolution of the baroclinic velocity and tracers is via either a leap-frog scheme with an associated Robert-Asselin time filter, or a newly introduced predictor-corrector scheme. The predictor-corrector scheme allows for a longer time step (frequently double that of the leap-frog scheme) whilst maintaining stability and accuracy. Furthermore, the elimination of the time-filter when using the predictor-corrector method, significantly improves the conservation of tracers to within numerical roundoff error.

The default grid for the AusCOM ocean component is a nominal $1^\circ \times 1^\circ$ horizontal grid (see Figure 1) with equatorial latitudinal refinement to $\frac{1}{3}^\circ$, Southern Hemisphere latitudinal refinement to maintain cell isotropy with meridional grid convergence and the North Pole relocated into Siberia, as per Roberts et al. [2005] to reduce Courant-Friedrichs-Levy limitations on the time stepping. The vertical grid has 46 levels covering the depth range 0–5050 m with a resolution ranging from 5 m at the surface to 250 m for the abysal ocean, Table 1 lists the vertical grid details.

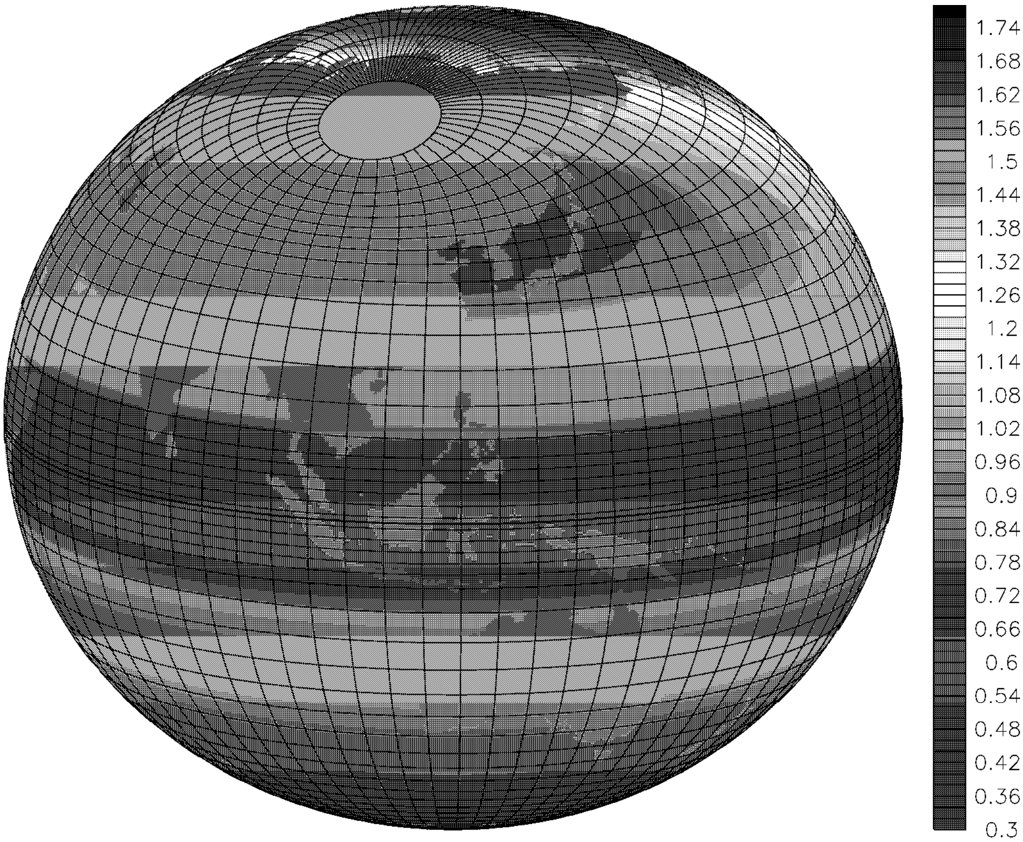

Figure 1: The default AusCOM ocean model horizontal grid is shown with its latitudinal grid spacing (°, in colour). Note that for clarity only every 5^{th} grid line is shown.

2.2 Sea-ice Model

The sea-ice model used here has been designed with numerical coupling in mind, so that it can be integrated into a larger framework for climate mod-

Table 1: AusCOM ocean vertical grid distribution, showing the node depth for tracers (z_t) and vertical velocity (z_w).

Level	z_t (m)	z_w (m)	Level	z_t (m)	z_w (m)	Level	z_t (m)	z_w (m)
1	2.50	5.07	16	190.00	200.00	31	1743.06	1825.38
2	7.64	10.43	17	210.00	221.59	32	1907.71	1993.01
3	13.22	16.35	18	233.18	249.39	33	2078.32	2166.97
4	19.48	23.08	19	265.60	288.99	34	2255.62	2347.89
5	26.68	30.84	20	312.39	344.85	35	2440.17	2536.26
6	35.01	39.82	21	377.30	419.80	36	2632.34	2732.34
7	44.64	50.16	22	462.30	514.85	37	2832.34	2936.26
8	55.68	61.93	23	567.39	628.99	38	3040.17	3147.89
9	68.18	75.16	24	690.60	759.39	39	3255.62	3366.97
10	82.14	89.82	25	828.18	901.59	40	3478.32	3593.01
11	97.51	105.84	26	975.00	1050.00	41	3707.71	3825.38
12	114.18	123.08	27	1125.00	1200.31	42	3943.06	4063.29
13	131.98	141.35	28	1275.62	1351.84	43	4183.51	4305.79
14	150.72	160.43	29	1428.06	1505.79	44	4428.06	4551.84
15	170.14	180.07	30	1583.51	1663.29	45	4675.62	4800.31
						46	4925.00	5050.00

elling. The model is written in Fortran90 and is MPI1-enabled. The internal global MPI communicator within the sea-ice model is called *MPI_COMM_ICE*. The sea-ice model includes explicit calculations of the ice dynamics, ice-thickness redistribution, ice advection, ice thermodynamics and radiation budget. The user may select alternative parameterisations, where available.

In the model, sea ice is represented as a finite number of ice-thickness categories. As such the ice pack is modelled as a large-scale continuum within an Eulerian framework. A set of fundamental equations describes the spatio-temporal evolution of the sea-ice cover by evolving the variables of state. A plastic-yield surface is used to describe the constitutive response of the sea-ice aggregate, which can be divided into ridged and rafted ice, level (or undeformed) ice, leads and open-water areas.

2.3 Numerical Coupler

The Ocean Atmosphere Sea Ice Soil (OASIS) coupler version 3.2.2 (courtesy CERFACS) is used to exchange information between, and synchronise execution of the model components [Valcke et al., 2003]. Data exchange is via MPI communicators, and conservative two-dimensional interpolation is available for differing source and destination model grids. OASIS 3.2.2 has been enhanced to provide restart capabilities (see Heil et al. [2005] for details) so that long simulations can be performed as a sequence of shorter simulations (suitable for execution under a queue management system). This restart capability captures any information that would be exchanged via the coupler if the simulation were to precede to the next time-step, and stores the information on disk for subsequent use at the start of the next simulation in the sequence.

Information exchange between the coupler and the sub-models is serial in the current release on OASIS, so that each parallel sub-model has to gather/scatter distributed information from/to parallel processes before exchanging the unified data with the coupler. This is inefficient, as the information is communicated twice, once between the coupler and the sub-model and once between the communication process and the other processes. Version 4 of the OASIS coupler (due for release late 2005) will overcome this limitation.

Advantages associated with the use of a numerical coupler include:

- Grid independence:

  The ability of the numerical coupler to conservatively interpolate between different grids at the two-dimensional (in spherical coordinates) interface between the sub-model domains means that each sub-model can use the most physically, numerically and computational appropriate grid for simulations. This is particularly relevant when AusCOM is coupled to a numerical atmosphere model. The grid singularity associated with the North Pole (and the associated severe restriction on the size of the time-step for solution) can be removed for the ocean model by transforming the grid to relocate the pole over land, and hence outside the computational domain. This is not possible with an atmospheric model and other grids (such as spectral or cubic conformal grids) are more appropriate.

- Individual sub-model executables:

  Using MPI communication to exchange information means that each model can be separately compiled into its own executable. All that is required is that all of the executables are launched with the same "mpirun" command. This greatly simplifies the compilation process and means that a code developer only needs to be familiar with a single code (providing that none of the development work changes the inter-model communications).

- Modular architecture:

  The ability to have individual sub-model executables and model grids means that any sub-model can be replaced by an alternative sub-model of differing complexity easily. This allows for sensitivity studies: For example how sensitive is the coupled model to a particular sea-ice model.

- Expandability:

  Additional models can be (relatively) easily added. For example, land surface models or river run-off models may be added to improve the ocean simulations by introducing realistic sources of fresh water. In fact while AusCOM consists of ocean and sea-ice models and the numerical coupler, boundary conditions are suppled through a data atmosphere model, which includes an atmospheric boundary layer model (see Section 2.4), so that inclusion of a numerical atmosphere model is easily achieved by replacing this data model.

The numerical coupler also simplifies the time-stepping used to evolve the governing equations for the various sub-models. This allows for asynchronous time stepping between models, with the restriction that all models that are exchanging information at a prescribed time must have a time-step such that the model reaches that particular time. For example, in the current set-up the ocean model has multiple time-steps. The ocean model has two internal time-steps, 60 seconds for the evolution of the barotropic system and 1800 seconds for the baroclinic system and tracers. The ocean model exchanges boundary condition data with the coupler every 6 hours.

2.4 Boundary Conditions

The TPAC Atmosphere Model (TPACAM) provides the surface boundary conditions to the ocean and sea-ice models via the OASIS coupler. It may be run in either an active or a passive mode. In the passive mode, TPACAM obtains the surface fluxes from the NCEP-DOE Reanalysis 2, and passes them directly to the coupler. In the active mode, however, it makes use of a simple boundary layer model (see Heil et al. [2005]) to calculate the surface fluxes interactively. Surface properties are obtained from the ocean and sea-ice models via the OASIS coupler, while the boundary layer model is forced from above by the NCEP-DOE Reanalysis 2.

2.5 Load Balancing

Both the ocean and sea-ice models are MPI enabled for parallel execution, and use two-dimensional domain decomposition to obtain good scalability for the moderate grid resolution and hence problem size. Figure 2 shows the parallelisation efficiency of the ocean component on a 1.3GHz SGI Altix platform. The ocean code may run on any integer number of processors, while the sea-ice code requires the number of processors be exactly divisible by four for parallel operation. Both the coupler and data atmosphere model are uni-processor tasks. Load balancing is achieved through selection of an appropriate number of processors for each sub-model, to ensure that each sub-model reaches the synchronisation point of data exchange within approximately the same time. Both the numerical coupler and data atmosphere codes are computationally inexpensive to run, and the dedicated processors for each of these codes is relatively idle. Parallel efficiency could be improved by having these two tasks share a processor.

3 Initial Results

Figures 3–5 show initial results (all daily averages for 31 December) for the ocean only component of AusCOM, initialised with the data from the World Ocean Atlas [Stephens et al., 2002; Boyer et al., 2002], and forced with the

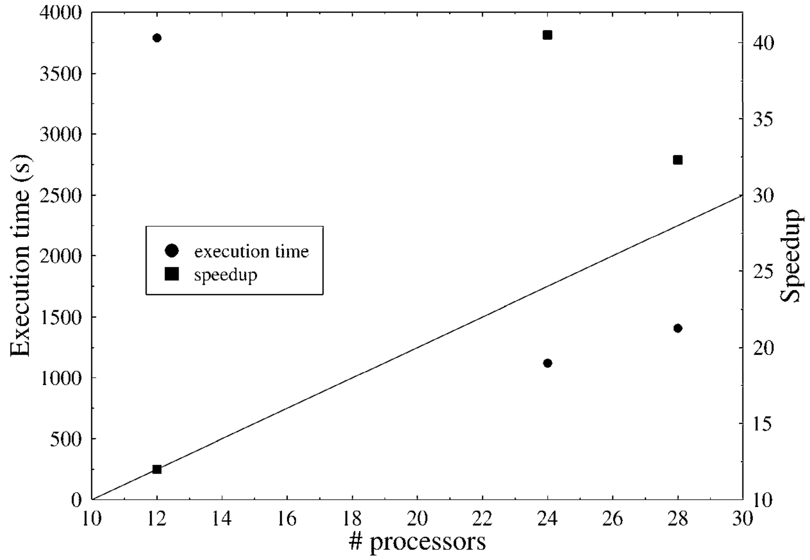

Figure 2: Parallel performance of ocean component of AusCOM on 1.3GHz SGI Altix platform, speedup is relative to 12 processors.

mean daily fields from ERA40 (1990-1999). The natural variability in the tropics and the Southern Ocean is readily apparent, as is the relative strength of western boundary currents (the strong boundary currents along the western edges of the ocean basins). The distribution at 97.5 m shows the large scale subtropical gyres ($\approx 30°$S and 30°N) and in the equatorial band where the grid has higher resolution there is strong wave activity (Figure 4). This strong wave activity is also reflected in the salinity field (Figure 5).

4 Discussion

The technical development of the Australian Climate Ocean Model (AusCOM) has progressed well, with initial spin-up runs completed for the ocean

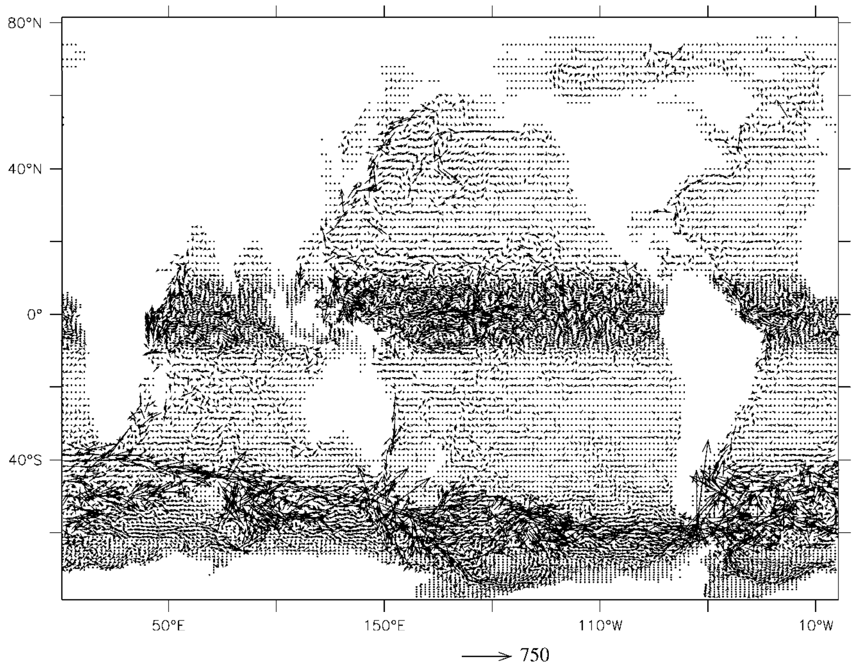

Figure 3: AusCOM ocean-only spin-up, depth integrated velocity (m^2/s).

component and coarse resolution runs completed for the sea-ice model. Significant improvements have been carried out on the OASIS3.2.2 coupler. The information science component of the joining of these two sub-models through the numerical coupler has been completed, and tested with previous versions of both the ocean and sea-ice models. The remaining tasks are adoption of a AusCOM compatible resolution for the sea-ice model and tuning the model physics in response to the interactive coupling.

Project planning of AusCOM has seen a consensus being reached by the members of the involved Australian research community to jointly support a single ocean and sea-ice model as the model of choice. This consensus has been expanded to include specifications of the model grid and physics, and a joint set of experiments of mutual interest. This approach has been

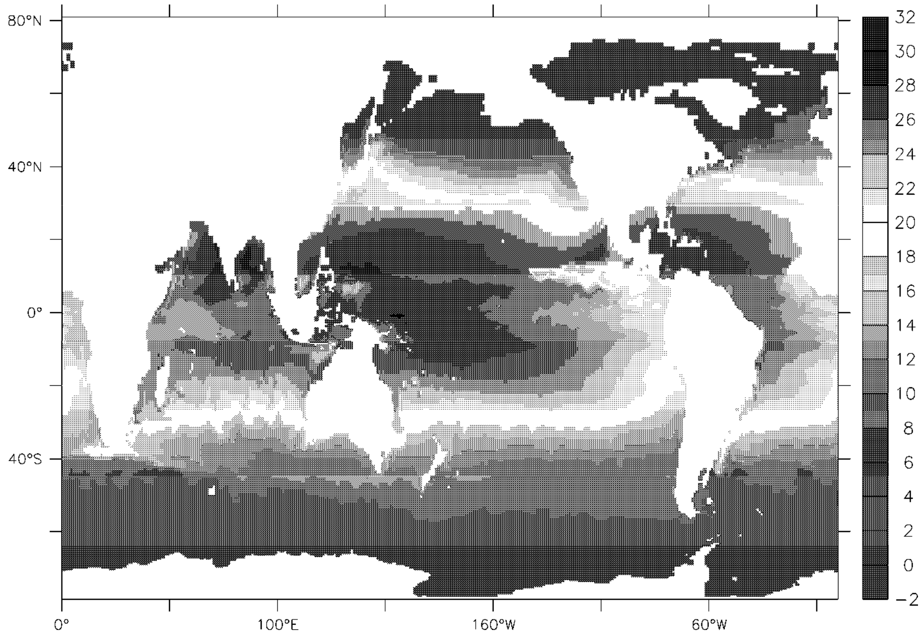

Figure 4: AusCOM ocean-only spin-up, temperature (°C) at 97.5 m.

grown with the development of the Australian Community Climate Earth System Simulator (ACCESS) as a joint venture between CSIRO Marine and Atmospheric Research, Bureau of Meteorology and Australian University's. This joint venture is going to create a state-of-the-art coupled Earth System Model and associated framework for Australia, using model components in the AusCOM project plus a new atmosphere code, ocean carbon cycle, terrestrial land scheme and dynamic vegetation all coupled together into a single dynamic model. Coupled climate simulations to be credible are of scale that demand a level of community agreed standards for any one component. It is more critical that each component model's behaviour be well defined and understood than to place effort in further untested developments. Analysis of a system as complex as the earth's climate can only be achieved with a

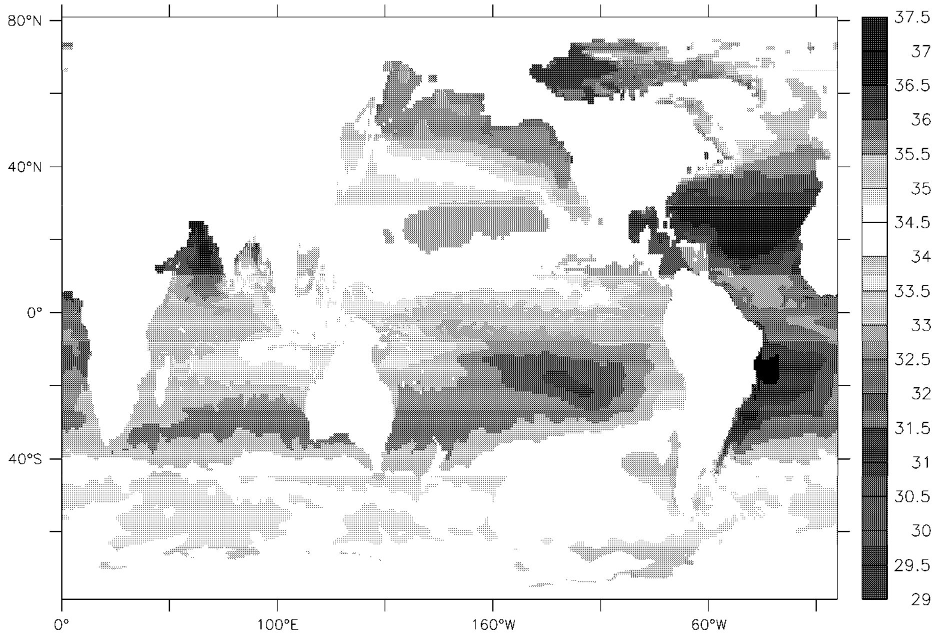

Figure 5: AusCOM ocean-only spin-up, salinity (PSU) at 97.5 m.

large team of scientists working together on a common modelling framework. For Australia, this requires a multi-institutional highly distributed approach that is well served by community model with an agreed configuration.

Acknowledgements

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have been for this project.

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