Contribution to a WMO Report

Submitted by

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The logo of the Lawrence Livermore National Laboratory, featuring a stylized 'L' and the text 'Lawrence Livermore National Laboratory' arranged in a chevron shape.

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**Coupled Oceanic-Atmospheric General Circulation Modeling at
Lawrence Livermore National Laboratory**

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The Climate Systems Modeling group at LLNL has developed a portable coupled oceanic-atmospheric general circulation model (OAGCM) suitable for use on a variety of massively parallel (MPP) computers of the multiple instruction, multiple data (MIMD) class. The model is composed of parallel versions of the UCLA atmospheric general circulation model [1], an enhanced version of the GFDL modular ocean model (MOM1)[2] and a dynamic and thermodynamic sea ice model based on the Hibler formulation extracted from the OPYC ocean model [3]. The strategy to achieve parallelism is twofold [4]. One level of parallelism is accomplished by applying two dimensional domain decomposition techniques to each of the three constituent submodels. A second level of parallelism is attained by a concurrent execution of AGCM and OGCM/sea ice components on separate sets of processors. For this functional decomposition scheme, a flux coupling module has been written to calculate the heat, moisture and momentum fluxes independent of either the AGCM or the OGCM modules. The flux coupler's other roles are to facilitate the transfer of data between subsystem components and processors via message passing techniques and to interpolate and aggregate between the possibly incommensurate meshes.

We have completed several multi-year simulations of the OAGCM using 64 processors of a Cray T3D. On this machine, the model's optimally load balanced processor configuration is to assign 15 processors to the oceanic/sea ice submodel in a 3 by 5 domain decomposition and 48 processors to the atmospheric submodel in a 6 by 8 domain decomposition. A remaining processor is reserved for output purposes. The resolution of these simulations is 4° by 5° by 9 vertical levels in the atmosphere and 3° by 3° by 15 vertical levels in the ocean. We are currently analyzing these runs to quantify and reduce the model's climate drift. Preliminary analysis suggests that the cold, dry bias of the UCLA AGCM is causing the oceans to cool too much in the tropical west Pacific and Indian oceans. On the other hand, the sea ice thickness and extent in the coupled OAGCM simulations compare reasonably with stand alone OGCM calculations. Present efforts are focused on removing the model biases causing the simulated climate to drift.

- [1] M.F. Wehner, *et al.*, Performance of a distributed memory finite difference atmospheric general circulation model, To appear in *Parallel Computing* 21(10) 1995.
- [2] R. Pacanowski, K. Dixon and A. Rosati, The GFDL modular ocean model user guide, version 1.0, *GFDL Ocean Group Tech. Report No. 2*, GFDL/NOAA Princeton (1991)
- [3] D. Holland, L. Mysak, D. Manak, J. Oberhuber (1993), *J. Geophys. Res.* 98 C2, 2561-2586.
- [4] M.F. Wehner, A.J. Bourgeois, P.G. Eltgroth, P.B. Duffy, W.P. Dannevik, Parallel Coupled Oceanic-Atmospheric General Circulation Model, *Coming of Age: Proc. sixth Workshop on use of Parallel Computers in Meteorology*. ECMWF, Reading, England, 1994

The Coupled Atmosphere River flow Simulation (CARS) System

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As part of an effort to investigate regional-scale atmospheric flows, precipitation, surface energy budget, hydrology, and river flow at various spatial and temporal scales, we have developed a Coupled Atmosphere River Flow Simulation (CARS) system (Fig. 1). This unique system has the ability to run simulations from the global scale down to the watershed catchment scale and can be used to forecast or diagnose both atmospheric conditions and land surface hydrology at regional to catchment scales. We applied the CARS system to a preliminary numerical prediction study over the Russian River basin (Fig. 2) in the northern California Coastal Range from January 1 to March 30, 1995. This includes 48 hour numerical predictions during a flooding period in early January 1995.

The CARS system consists of three uni-directionally coupled numerical models; (1) the Mesoscale Atmospheric Simulation (MAS) model, (2) the Automated Land Analysis System (ALAS), and (3) a modified version of the physically based hydrology model known as TOPMODEL. Within MAS there is a interactively coupled land surface soil-plant-snow model (Kim and Ek 1995). As illustrated in figure 1, the CARS system can be nested within either a large-scale forecast or analysis data. Hence, the CARS system may be employed for predictions of regional weather and river flow or for simulating regional climatology, depending on the choice of the large scale input data.

This prototype system successfully modeled the Winter 1995 storms that caused severe flooding along the Russian River watershed in the northern California Coastal Range (Miller and Kim 1995, Soong and Kim 1995). The simulated area mean precipitation which is in good agreement with the observed precipitation is shown along with the observed upstream dam release from Lake Mendocino (Fig. 3). The simulated river flow, which includes the dam release, is also in good agreement with the observed river flow value at the Hopland gauge station along the Russian River (Fig. 4), as the simulated river flow during the flooding period differs from the observed value by ten percent.

The CARS system is currently being employed for experimental numerical weather prediction for the southwestern United States. The hydrologic simulation component of the CARS system is being extended to include several other major river systems within California, including the Lake Shasta inflow, the American River, and the Feather River. Sub-catchment scale response, sensitivity, and climate variability are being investigated through the use of the CARS system and several related tools (Miller 1995).

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Kim, J. and M. Ek, 1995: A simulation of the surface energy budget and soil water content over the Hydrologic Atmospheric Pilot Experiments-Modelisation du Bilan Hydrique forest Site. *J. Geophys. Res.*, 100, D10, 20845-20854.

Miller, N. L., 1995: Sensitivity of surface heat and moisture fluxes due to topographic slope and azimuth. *J. Geophys. Res.*, 100, D9, 18669-18685.

Miller, N. L. and J. Kim, 1995: Numerical prediction of precipitation and river flow over the Russian River watershed during the January 1995 California storms. *Bull. Am. Meteor. Soc.*, In Press.

Soong, S.-T. and J. Kim, 1995: Simulation of a heavy precipitation event in California. *Climatic Change*, In Press.

Carbon-cycle Modeling at LLNL

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The Biogeochemical Cycles Group at LLNL has an active program in modeling the global carbon cycle as a part of LLNL's effort to predict climate change and its impacts. We are developing models of both the terrestrial and marine aspects of the carbon cycle.

Main Goals of Carbon-Cycle Research at LLNL

The primary goals of carbon cycle research at LLNL are to:

- understand observed variation in atmospheric CO_2 , $^{13}\text{CO}_2$ and $^{14}\text{CO}_2$ concentrations over the past decade (or more) on the seasonal time scale;
- understand observed variation in atmospheric CO_2 , $^{13}\text{CO}_2$ and $^{14}\text{CO}_2$ concentrations from pre-industrial times to the present on the interannual time scale;
- predict anthropogenic CO_2 fluxes implied by the various IPCC scenarios, taking into account relevant feedbacks (climate, ocean circulation, biological);
- predict future atmospheric CO_2 concentrations considering relevant feedbacks (climate, ocean circulation, biological);
- predict impacts on natural and managed ecosystems (land and marine, natural and agricultural).

Terrestrial Carbon-cycle Research at LLNL

We are developing a detailed model capable of simulating ecosystem response to changing weather, hydrological, CO_2 , and insolation parameters. This model includes a physiologically-based representation of photosynthesis, and has been used to simulate diurnal and seasonal cycles at various sites. Considerable effort is being placed on collaborating with data collection efforts to ensure that this model is as physically realistic as possible.

Because this detailed model is computationally expensive to run for long integrations, and because appropriate parameter values are not known for all areas of the world, we have also developed a simpler terrestrial carbon cycle model that can be used for long time-scale global integrations.

Ocean Carbon-cycle Research at LLNL

The ocean carbon cycle modeling work at LLNL falls into two basic areas:

Greg Rau is leading the effort to develop models of biological carbon isotope fractionation by marine phytoplankton (Rau, Riebesell and Wolf-Gladrow, 1996). This work has the goal of developing physiologically based isotope fractionation models that can be used when modeling marine biogeochemistry.

Ken Caldeira is leading the effort to develop a model of marine biogeochemical processes, including air-sea gas transfer, biological productivity in the surface ocean, regeneration of organic matter in the deep ocean, and the production of siliceous and carbonate sediments. The model was originally based on that of Maier-Reimer and

colleagues, but every parameterization has been replaced and only the model architecture of Maier-Reimer's original model remains. This model incorporates the carbon-isotope models being developed by Greg Rau and colleagues, and runs on MPP machines.

At the time of this writing, we have spun up an initial version of the model for 2000 surface years (10000 deep ocean years), using our version of the GFDL MOM model with the Gent-McWilliams parameterization for the effect of subgrid-scale eddies on tracer transport, and with Oberhuber's dynamic/thermodynamic sea-ice model. We are now analyzing this initial spinup so that we may improve the model. This task is complicated due to the fact that departures from observations could be due either to deficiencies in modeled ocean circulation or modeled ocean biogeochemistry. Our preliminary results for Pacific total dissolved inorganic carbon concentration are shown below:

Selected Recent Publications

- Amthor JS (1995) Predicting effects of atmospheric CO₂ partial pressure on forest photosynthesis. *Journal of Biogeography* 22, 1273-1284
- Amthor JS (1995) Terrestrial higher-plant response to increasing atmospheric [CO₂] in relation to the global carbon cycle. *Global Change Biology* 1, 243-274
- Amthor JS (1996) Plant respiratory responses to elevated CO₂ partial pressure. In: Allen LH Jr et al. (eds) *Advances in Carbon Dioxide Effects Research*. American Society of Agronomy, Madison, WI, in press
- Amthor JS, Koch GW (1996) Biota growth factor: stimulation of terrestrial ecosystem net primary production by elevated atmospheric CO₂. In: Koch GW, Mooney HA (eds) *Carbon Dioxide and Terrestrial Ecosystems*. Academic Press, San Diego, pp 399-414
- Amthor JS, Loomis RS (1996) Integrating knowledge of crop responses to elevated CO₂ and temperature with mechanistic simulation models: model components and research needs. In: Koch GW, Mooney HA (eds) *Carbon Dioxide and Terrestrial Ecosystems*. Academic Press, San Diego, pp 317-345
- Caldeira, K., (1995) Long-term control of atmospheric carbon dioxide: low temperature sea-floor alteration or terrestrial silicate-rock weathering, *American Journal of Science*, 295, 1077-1114.
- Rau GH, Riebesell U, Wolf-Gladrow D (1996) A model of photosynthetic ¹³C fractionation by marine phytoplankton based on diffusive molecular CO₂ uptake. *Marine Ecology--Progress Series* 128, in press

Ocean Circulation Modeling at LLNL

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The Climate System Modeling Group at LLNL has an active program in ocean model development and in the use of global ocean models to study climate, ocean turbulence, and the ocean carbon cycle. (Our ocean carbon cycle research is described in a separate contribution.) I will describe first our model development activities, and then our application studies.

Our ocean general circulation model is closely based on the widely-used GFDL model. We have coupled our ocean model to the dynamic-thermodynamic sea ice model of Oberhuber (1993). In addition, we have added to the model several advanced parameterizations of the effects of subgrid scale eddies, including

- the "Gent-McWilliams" parameterization of tracer transport by eddies (Gent and McWilliams (1990);
- the "topographic stress" parameterization of mixing of momentum by subgrid scale eddies (Holloway, 1992);
- a parameterization of vertical turbulent mixing in which the vertical diffusivity is inversely proportional to the local Brunt-Vaisala frequency.

We are currently working on implementing the Kantha and Clayson mixed layer model in our ocean GCM.

Our ocean model runs on a wide variety of computers, including workstations, traditional vector supercomputers, and massively parallel processors (MPPs). Our code is portable enough that we have been able to rapidly port our model to several new generations of MPPs; we expect to continue moving to the newest machines as they become available. We are presently doing production runs on several Cray T3Ds. By speeding up interprocessor communication and the execution of the model's Fourier filters, we have achieved both near-perfect parallel efficiency and excellent overall throughput on these machines.

The main research interest to which we are applying our ocean GCM is the prediction of climate on century time scales. For this purpose, we are coupling our OGCM to an atmospheric GCM. (That model, and our coupling effort, are described in separate contributions.) In addition, we are using the model to investigate

- effects of climate change on the large-scale ocean circulation, and effects of circulation changes on climate;
- effects of different parameterization of subgrid eddies on simulated distributions of temperature, salinity and natural radiocarbon;
- ocean uptake and transport of bomb ^{14}C , and the global budget of bomb ^{14}C ;

In addition, we are investigating other aspects of the ocean carbon using our OGCM coupled to a complete ocean carbon cycle model; these activities are described in a separate contribution.

References

- P. R. Gent and J. C. McWilliams, "Isopycnal mixing in ocean general circulation models", *J. Phys. Oceanogr.*, **20**, pp. 150 - 155 (1990).
- G. Holloway, "Representing topographic stress for large-scale ocean models", *J. Phys. Oceanogr.*, **22**, pp. 1033-1046 (1992)
- L. Kantha and C. A. Clayson, "An improved mixed layer model for geophysical applications", *J. Geophys. Res.*, **99**, pp. 25,235-25,266 (1994)
- J. M. Oberhuber, "Simulation of the Atlantic circulation with a Coupled Sea Ice-Mixed Layer-Isopycnal General Circulation Model. Part II: Model Experiment", *J. Phys. Oceanogr.*, **23**, pp. 830-845, 1993b.

Selected Recent Publications

- A. A. Mirin, J. J. Ambrosiano, J. H. Bolstad, A. J. Bourgeois, J. C. Brown, B. Chan, W. P. Dannevik, P. B. Duffy, P. G. Eltgroth, C. Matarazzo, and M. F. Wehner, "Climate System Modeling using a Domain and Task Decomposition Message-Passing Approach", *Computer Physics Communications.*, **84**, pp. 278-296. (1994).
- P. B. Duffy, P. Eltgroth, A. J. Bourgeois, and K. Caldeira, "Effect of Improved Subgrid Scale Transport of Tracers on Uptake of Bomb Radiocarbon in the GFDL Ocean General Circulation Model", *Geophysical Research Letters*, **22**, pp. 1065-1068 (1995).
- P. B. Duffy, J. Amthor, K. Caldeira, P. S. Connell, D. E. Kinnison, J. Southon, and D. J. Wuebbles, "The Global Budget of Bomb ^{14}C ", submitted to *Climatic Change*
- P. B. Duffy, and K. Caldeira, "A Three-Dimensional Model Calculation of Ocean Uptake of Bomb ^{14}C and Implications for the Global Budget of Bomb ^{14}C ", *Global Biogeochemical Cycles.*, **9**, pp. 373-375 (1995).
- P. B. Duffy, D. Eliason, A. J. Bourgeois, and C. Covey, "Simulation of Bomb Radiocarbon in Two Ocean General Circulation Models", *J. Geophys. Research*, **100**, pp. 22,545-22,565.
- K. Caldeira and P. B. Duffy "An evaluation of the Gent-McWilliams Eddy Transport Parameterization Using a New Method for Diagnosing Ocean Models" submitted to *J. Geophys. Res.*
- G. Perry, P. B. Duffy, and N. Miller, "An Extended Dataset of River Discharges for Validation of Climate Models", submitted to *J. Geophys. Res.*
- P. B. Duffy and K. Caldeira, "Effect of Fossil Fuel Carbon on Estimates of Bomb Radiocarbon Inventories in the Ocean", submitted to *Geophys. Res. Letters*.

Analyzing climate model variability with an ensemble of AMIP simulations

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The chaotic nature of the climate system leads to significant variability, both in nature and in models. This variability, as represented in an atmospheric general circulation model (AGCM), may be quantified by performing and analyzing ensembles of simulations. A practical limitation to this procedure is the high computational cost of obtaining enough realizations in the ensemble to provide significant statistics. Recently, we have developed an implementation of the UCLA AGCM designed to exploit massively parallel processing (MPP) computers [1]. This technology has allowed us to construct an ensemble of twenty realizations of the 10 year Atmospheric Model Intercomparison Project (AMIP) period. Each member of the ensemble was executed using the same version of the model but with slightly different initial conditions. The initial conditions were generated by collecting restart data at simulated 12:00 Universal Coordinated Time (UCT) each day of the first January of the AMIP period. A different day's worth of this data was then used to initialize each of the realizations by turning only the simulated calendar back to day one of the AMIP integration period.

Most of the monthly mean climate statistics as specified by AMIP were collected. However, due to limitations of the output systems on MPP systems, it was not feasible to efficiently gather the six hour history data as specified by AMIP. Nonetheless, this volume of monthly mean data reveals much about the variability of this AGCM. Although the simulated climate produced by this model has a cold and dry bias, especially at the surface [2], the standard deviation of a particular field about its mean may still be used to address the issue of potential predictability [3]. The period of time over which the standard deviation is calculated affects the magnitude and nature of the pattern of variability. The seasonal extremes offer a duration long enough to reduce some of the weather noise yet reveal some insights into the climate statistics. Furthermore, since the sea surface temperature is specified differently for each of the 120 months, we analyze the ensemble standard deviation for each season of the ten year period and then perform a decadal average. In figure 1, the mean standard deviation of the northern hemisphere winter surface temperature is shown. Over the oceans, the surface temperature is specified by AMIP, thus the standard deviation is identically zero. Inspection of this figure reveals the highest variability occurs over sea ice and land areas covered with significant amounts of snow. Other land areas with high surface albedo, such as the Sahara and Australia, show moderate variability ($0.5K < \sigma < 1.0K$) suggesting a radiative feedback. In figure 2, the same field is shown for southern hemisphere winter. Again, the sea ice exhibits the greatest variability. Analysis of other monthly averaged climate statistics is ongoing. It is anticipated that this data will be made available to the atmospheric modeling community by the Program for Climate Model Diagnosis and Intercomparison (PCMDI) in 1996.

[1] M.F. Wehner, *et al.*, Performance of a distributed memory finite difference atmospheric general circulation model, To appear in *Parallel Computing* 21(10) 1995.

[2] M.F. Wehner and C. Covey, Description and validation of the LLNL/UCLA parallel atmospheric GCM, Lawrence Livermore National Laboratory Internal Document, UCRL-ID-xxxx, (in press).

[3] K. Sperber and T.N. Palmer, Interannual tropical rainfall variability in general circulation model simulations associated with the Atmospheric Model Intercomparison Project, UCRL-JC-121725, submitted to *J. Climate*

Figure 1 Mean standard deviation of the DJF mean surface temperature (degree K)

Figure 2. Mean standard deviation of the JJA mean surface temperature (degrees K)