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PCCM2: A GCM ADAPTED FOR SCALABLE PARALLEL COMPUTERS

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1. INTRODUCTION

The Computer Hardware, Advanced Mathematics, and Model Physics (CHAMMP) program (Department of Energy 1990) seeks to provide climate researchers with an advanced modeling capability for the study of global change issues. Current general circulation models are usually applied at coarse spatial resolution with minimal coupling between ocean, atmosphere, and biosphere. As a first goal in the program, state-of-the-art models are being adapted for execution on scalable parallel computers. (A parallel computer is said to be *scalable* if its performance can be increased by adding processors. The Intel Paragon, IBM SP1, Thinking Machines Corporation CM5, and Cray T3D are examples: each can incorporate $10 - 10^3$ microprocessors.) Accomplishment of this task will lay the groundwork for the coupling of oceanic and atmospheric models to produce advanced climate models with improved process representations and capable of exploiting the teraflops computers that are expected to become available later this decade.

One of the more ambitious projects being undertaken in the CHAMMP program is the development of PCCM2, an adaption of the Community Climate Model (CCM2) for scalable parallel computers. This project involves a team of computer scientists, applied mathematicians, and climate modelers at Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), and the National Center for Atmospheric Research (NCAR). In September 1993, a significant milestone was reached when PCCM2 was validated with respect to the CRAY version of CCM2 and a five-month simulation was performed successfully on the 512-processor Intel Delta computer. This is believed to be the first validated implementation of a global atmospheric circulation model on a scalable parallel computer.

Development of PCCM2 serves two objectives. First, it makes the computational capabilities of scalable parallel computers available to scientists using CCM2 for global change studies, allowing increases in spatial resolution, incorporation of improved process models, and longer simulations. For example, the 16 gigabytes of memory on a 128-processor IBM SP1 allows simulations at spectral resolutions greater than T200 (0.6 degrees by 0.6 degrees transform grid). Second, it provides a testbed that can be used to compare the performance of current scalable computers and conventional vector computers and to investigate issues such as load balancing, parallel I/O, and coupling that are important for future parallel models.

PCCM2 uses a message-passing, domain-decomposition approach, in which each processor is allocated responsibility for computation on one part of the computational grid, and messages are generated to communicate data between processors. Much of the research effort associated with development of a parallel code of this sort is concerned with identifying efficient decomposition and communication strategies. In PCCM2, this task is complicated by the need to support both semi-Lagrangian transport (for moisture) and spectral transport (for other fields). Load balancing and parallel I/O techniques are also required. In this paper, we review the various parallel algorithms used in PCCM2 and the work done to arrive at a validated model.

2. THE NCAR CCM

Over the past decade, the NCAR Climate and Global Dynamics Division has provided a comprehensive, three-dimensional global atmospheric model to university and NCAR scientists for use in the analysis and understanding of global climate. Because of its widespread use, the model was designated a Community Climate Model (CCM).

The most recent version of the CCM, CCM2, was released to the research community in October 1992 (Hack et al. 1992; Bath, Rosinski, and Olson 1992). This incorporates improved physical representations of a wide range of key climate processes, including clouds, ra-

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