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The fastest supercomputer of the world, the Earth Simulator (total peak performance 40TFLOPS) has recently been available for climate researches in Yokohama, Japan. We are planning to conduct a series of future climate change projection experiments on the Earth Simulator with a high-resolution coupled ocean-atmosphere climate model.

The main scientific aims for the experiments are to investigate 1) the change in global ocean circulation with an eddy-permitting ocean model, 2) the regional details of the climate change including Asian monsoon rainfall pattern, tropical cyclones and so on, and 3) the change in natural climate variability with a high-resolution model of the coupled ocean-atmosphere system.

To meet these aims, an atmospheric GCM, CCSR/NIES AGCM, with T106($\sim$1.1°) horizontal resolution and 56 vertical layers is to be coupled with an oceanic GCM, COCO, with $\sim 0.28^\circ \times 0.19^\circ$ horizontal resolution and 48 vertical layers. This coupled ocean-atmosphere climate model, named MIROC, also includes a land-surface model, a dynamic-thermodynamic seaice model, and a river routing model. The poles of the oceanic model grid system are rotated from the geographic poles so that they are placed in Greenland and Antarctic land masses to avoild the singularity of the grid system.

Each of the atmospheric and the oceanic parts of the model is parallelized with the Message Passing Interface (MPI) technique. The coupling of the two is to be done with a Multi Program Multi Data (MPMD) fashion. A 100-model-year integration will be possible in one actual month with 720 vector processors (which is only 14% of the full resources of the Earth Simulator).

A61C-0089 0830h POSTER

Thermodynamic Efficiency of a General Circulation Model

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The thermodynamic efficiency is a fundamental number that allows us to compare numerical models of the general circulation. In this study, we use the heat engine framework to evaluate the atmospheric circulations, both global and regional, generated in the idealized GCM from GFDL (Held and Suarez 1994). We will demonstrate that this theoretical framework can be applied to both closed systems (the general circulation) and open systems (the Hadley circulation). We have calculated the thermodynamic efficiency in 3 different ways for the closed system. One is based on mechanical dissipation of energy, the other based on net heating, and the third is the Carnot efficiency. For the open system, we calculate the the thermodynamic efficiency in 2 ways, the first based on mechanical dissipation of energy and the second based net heating. For the closed system, the efficiencies are calculated in the tradition manner. However, for open systems such as the Hadley circulation, it is necessary to take into account the energy fluxes that enter or leave the control volume. We will present the mathematical description of these efficiencies.

In a numerical model without error or irreversible processes, the efficiencies based on dissipation of mechanical energy and net heating are identical, while the Carnot efficiency is the maximum possible. Therefore, by comparing these efficiencies, we can ascertain the irreversibilities present in the model. The results for various experiments demonstrate that the efficiencies based on dissipation and net heating are sensitive to model resolution. T42 appears to be an adequate resolution. Model experiments give efficiencies based on dissipation, net heating and Carnot of 9.5%, 11.2% and 12.5%, respectively for the general circulation. Although the model is reversible in terms of its parameterization, they are irreversibilities associated with the numerics. For the Hadley cell, the efficiency based on mechanical dissipation of energy is 6.2%, while that based on net heating is 7.4%. The decrease in efficiency compared to the global values results for the fact that the Hadley cell exports thermal energy to higher latitudes.

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Using Clustering to Establish Climate Regimes from PCM Output

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A multivariate statistical clustering technique–based on the k-means algorithm of Hartigan–has been used to extract patterns of climatological significance from 200 years of general circulation model (GCM) output. Originally developed and implemented on a Beowulf-style parallel computer constructed by Hoffman and Hargrove from surplus commodity desktop PCs, the high performance parallel clustering algorithm was previously applied to the derivation of ecoregions from map stacks of 9 and 25 geophysical conditions or variables for the conterminous U.S. at a resolution of 1 sq km. Now applied both across space and through time, the clustering technique yields temporally-varying climate regimes predicted by transient runs of the Parallel Climate Model (PCM). Using a business-as-usual (BAU) scenario and clustering four fields of significance to the global water cycle (surface temperature, precipitation, soil moisture, and snow depth) from 1871 through 2098, the authors' analysis shows an increase in spatial area occupied by the cluster or climate regime which typifies desert regions (i.e., an increase in desertification) and a decrease in the spatial area occupied by the climate regime typifying winter-time high latitude perma-frost regions. The patterns of cluster changes have been analyzed to understand the predicted variability in the water cycle on global and continental scales. In addition, representative climate regimes were determined by taking three 10-year averages of the fields 100 years apart for northern hemisphere winter (December, January, and February) and summer (June, July, and August). The result is global maps of typical seasonal climate regimes for 100 years in the past, for the present, and for 100 years into the future.

Using three-dimensional data or phase space representations of these climate regimes (i.e., the cluster centroids), the authors demonstrate the portion of this phase space occupied by the land surface at all points in space and time. Any single spot on the globe will exist in one of these climate regimes at any single point in time. By incrementing time, that same spot will trace out a trajectory or orbit between and among these climate regimes (or atmospheric states) in phase (or state) space. When a geographic region enters a state it never previously visited, a climatic change is said to have occurred. Tracing out the entire trajectory of a single spot on the globe yields a "manifold" in state space representing the shape of its predicted climate occupancy. This sort of analysis enables a researcher to more easily grasp the multivariate behavior of the climate system.

URL: http://climate.esd.ornl.gov/

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Uncertainty Propagation in Earth System Models

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One of the major challenges of climate prediction is the estimation of uncertainty related to the modeling results. Various assumptions about the model structure and different settings of parameters and initial conditions can alter the model output crucially - especially in the case of model inherent thresholds and other consequences of non-linearities within the model equations.

General Circulation Models (GCMs) - used for climate prediction- are not suited for a sufficient uncertainty analysis because the computational costs are too demanding through the highly complex model structure. The model class of EMICs (Earth System Models of Intermediate Complexity) can serve as a tool to investigate different aspects of model performance by realizing Multi-Run experiments (e.g. for scanning the phase space of possible solutions for different input parameter settings). We use a model of this class (CLIMBER-2) for the propagation of probability densitiy functions (PDFs) of the uncertain model input parameters by applying a Latin-Hypercube-Sampling scheme.

Our aim is to restrict the parameter space, and hence the space of possible solutions. We compare model simulations with observational data to reject model input parameters, which will result in simulation of climate states inconsistent with climatologies.

Enlarging the number of uncertain model parameters or rerunning the experiment in different modes (e.g. with interactive vegetation module) would be too time demanding. This problem can be circumvented if the comprehensive original climate model can be emulated by a fit model. The low variability and the smooth model response of CLIMBER with respect to parameter changes might allow to construct a reduced form model using an approximation procedure by orthogonal polynomials. This model will be very time effective (compared to the original climate model) if the order for the approximation will be low and if the dimensionality of the problem (i.e. the number of uncertain parameters) will be mathematically tractable. Having constructed such a computationally efficient polynomial model, extensive uncertainty analyses are feasible for various parameters of interest.

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A61C-0092 0830h POSTER

The Role of Ocean General Circulation in Climate Assessed With Coupled Climate Models

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Integrations of coupled climate models with fixed ocean currents are used to explore the climatic response to varying magnitude of ocean circulation. A trio of 100 year integrations are made with control currents from a GFDL R30 ocean simulation, same currents reduced by half, and same currents increased by half. This suite is performed with two coupled models employing different atmospheric components, the new GFDL AM2 atmospheric model and the GFDL Manabe Climate Model atmosphere (MCM), for a total of six experiments. Both models show a large sensitivity of the sea ice extent to the magnitude of currents with increased currents reducing the extent and warming the high latitudes. Cloud short wave forcing over the ocean also responds to circulation changes in both models but in the opposite sense. In the AM2-based model, low cloudiness decreases as ocean circulation increases, reinforcing the sea ice changes in reducing the planetary reflectivity, and warming the climate. This cloudiness change is associated with a reduction in lower atmospheric stability over the ocean. The MCM-based model has a smaller sensitivity of lower atmospheric stability with the same sign but the cloud cover becomes more reflective as the circulation is increased, offsetting the changes due to sea ice cover and reducing the change in global mean temperature.

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Analysis of the Polar Amplification Pattern of Global Warming in an Atmospheric GCM Coupled to an Oceanic Mixed Layer

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The sensitivity of an idealized climate system model consisting of an atmospheric GCM coupled to an oceanic upper mixed layer on an aquaplanet is analyzed. There is no seasonal cycle and the solar radiation is taken to be symmetric about the equator. The system is integrated with the observed CO_2 (330 ppm) until it reaches a quasi-equilibrium climate. To study the sensitivity we double the CO_2 and again integrate until the system reaches a new equilibrium climate. To simplify the linear analysis we assume that the atmosphere is always in quasi-equilibrium (typical atmospheric adjustment times being much shorter than that of the oceanic upper mixed layer). We introduce a linear surface energy budget sensitivity (or response) operator consisting of a Jacobian matrix of the surface budget with respect to the surface temperature. The operator is used to construct a linear estimate of the surface temperature change that results from the CO_2 doubling. It is found that the temperature response obtained from the linear extimate compares well with the results of the full 3D run. The shape of the response looks very similar to that of the least stable mode of the linear surface budget sensitivity operator. The importance of different components of the initial forcing at the surface is discussed. The role of individual components of the system in determining the typical polar amplification pattern is studied.