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**Modeling and Analysis of Global and Regional Climate Change in  
Relation to Atmospheric Hydrologic Processes**

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## MODELING AND ANALYSIS OF GLOBAL AND REGIONAL CLIMATE CHANGE IN RELATION TO ATMOSPHERIC HYDROLOGIC PROCESSES

### Research Objectives

The goal of this research is the continued development and application of global isentropic modeling and analysis capabilities to describe hydrologic processes and energy exchange in the climate system, and discern regional climate change. This work involves a combination of modeling and analysis efforts involving 4DDA datasets and simulations from the University of Wisconsin (UW) hybrid isentropic-sigma ( $\theta$ - $\sigma$ ) coordinate model and the GEOS GCM.

An additional objective of this research is to investigate the accuracy and theoretical limits of global climate predictability which are imposed by the inherent limitations of simulating trace constituent transport and the hydrologic processes of condensation, precipitation and cloud life cycles.

### Current Research

Research is directed to continued development and application of global versions of the UW isentropic coordinate models. The full suite of physical parameterizations from the NCAR CCM3, including a land surface model and optional slab ocean model, has been incorporated into a version of the model. Multitasking capabilities have also been implemented in the dynamical core and physical parameterizations of the UW models. Global five day simulations have been run daily for a period exceeding 5 months. These simulations are being validated as part of the development for seasonal and annual simulation. Realistic integrations exceeding one year have been completed. Validation efforts continue with an emphasis on simulations of hydrologic processes.

Development also continues on a generalized coordinate ( $\eta$ ) global model which has a smooth transition from sigma to isentropic coordinates in the middle troposphere. Daily five day simulations for the same 5 month period as above have been performed and are currently being validated. Realistic simulations exceeding one year have been completed with the UW  $\theta$ - $\eta$  model over the past six months. Numerical experiments similar to those in Zapotocny et al. (1996, 1997a and b) have been performed to examine the capability of the  $\eta$  model to simulate trace constituent transport and hydrologic processes. The experiments document that this model along with the UW  $\theta$ - $\sigma$  model appropriately conserves dry and moist entropy to a high degree of accuracy during transport and therefore simulates reversible processes within the atmosphere's hydrologic cycle involving condensation, evaporation and transport of clouds with increased accuracy over sigma based models.

In a theoretical study Johnson (1997) established for a model without drift that a positive definite source of entropy requires that the simulated climate state be biased cold, and that sigma coordinate model simulations are subject to positive definite aphysical sources of entropy in association with the numerical diffusion/dispersion of energy. Also, since the implicit source of entropy in a sigma coordinate model is determined from a calculation of heating that is separate from the prognostic calculation of temperature, a prognostic error in temperature induces an erroneous aphysical source of entropy. Johnson (1997) further established that a similar positive definite source of entropy does not occur in a model based on isentropic or specific entropy coordinates since the vertical mass and entropy transport is a direct function of the Lagrangian entropy source itself.

In a follow on study entitled "Entropy, the Lorenz Energy Cycle and Climate" Johnson (1998) reconciled the theoretical concepts of available potential energy with the classical thermodynamic concepts of thermodynamic efficiency, the Carnot cycle, and verified that a climate model atmosphere must become cold, thus becoming more efficient in order to simulate a climate state without drift in the presence of spurious positive definite sources of entropy. Globally, an aphysical source of entropy from numerical diffusion/dispersion and other inadequacies of parameterization equivalent to 4% of the entropy source from kinetic energy dissipation corresponds with a biased temperature error of 10° C, thus limiting the accuracy of climate model simulations. Increasing the accuracy of climate model simulations through

reducing apophysical sources of entropy and cold temperature biases is exceedingly difficult to realize. Theory substantiates that a major source of the positive definite source of entropy comes from the numerical diffusion of water substances and the spurious mixing of moist static energy.

In a two part paper entitled "Entropy, Numerical Uncertainties and Modeling of Atmospheric Hydrologic Processes: Part A and Part B", Johnson et al. (1998a, 1998b) set forth a strategy to assess pure error in numerical predictions and to isolate bias and random components. This strategy was applied to 10 day simulations by the UW  $\theta$ - $\sigma$  model and NCAR's CCM2 and CCM3 to investigate bias and random error growth in simulations of reversible moist processes.

### Future Plans

Model development and application of the UW  $\theta$ - $\sigma$  and  $\theta$ - $\eta$  models to advance the accuracy of global energy balance and the understanding of global and regional climate change will continue over the next six months. This work will emphasize investigation and validation of extended simulations of the UW  $\theta$ - $\sigma$  and UW  $\theta$ - $\eta$  models with emphasis on simulation of hydrologic processes. Investigation of the relative capabilities of models based on different numerical schemes and vertical coordinates to simulated processes essential to the hydrologic cycle will also continue.

### Publications under previous grant NAG5-1330 and the continuing NAG5-4398

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