Paper No. 26

SOME ASPECTS OF THE NEW UCLA GENERAL CIRCULATION MODEL

M. J. Suarez, *Department of Atmospheric Sciences, UCLA*

ABSTRACT

A potential enstrophy conserving scheme and a modified σ-coordinate have been coded in the UCLA general circulation model. The new model is being tested with global simulation experiments.

Introduction

During the past year we have modified several aspects of the UCLA general circulation model. Major changes are:

---- The inclusion of a potential enstrophy conserving advection scheme in the equation of motion;

---- reformulation of the vertical differencing based on a modified σ-coordinate in which the predicted PBL top is a coordinate surface;

---- the inclusion of the turbulent entrainment parameterization reported by Randall at the Third NASA Weather and Climate Program Review.

Other changes include: a potential temperature conserving horizontal advection scheme, a modified upstream scheme for advection of moisture, and inclusion of the ice phase in the cloud model used in the cumulus convection parameterization.

The potential enstrophy conserving scheme

Large truncation errors produced by poorly resolved steep topography can in a non-linear system affect large-scale waves. The convergence of the solution as the grid size is reduced will be slow unless the numerical scheme can prevent the false cascade of energy to small scales. In a purely two dimensional flow, governed by conservation of absolute vorticity, η, a false cascade may be prevented by using a scheme that conserves enstrophy, $\frac{1}{2}\eta^2$, and kinetic energy. In the presence of topography

a two-dimensional barotropic flow is governed by conservation of absolute potential vorticity, $q = \eta/\pi$, where π is the surface pressure. In this case a numerical scheme that conserves potential enstrophy and total energy will guarantee an upper bound on the absolute enstrophy and once again prevent the cascade to small scales.

As reported by Arakawa at last year's NASA Weather and Climate Program Review, a preliminary study using shallow water equations with steep topography showed that a potential enstrophy conserving scheme was superior to a conventional scheme when the grid size was comparable to the scale of variation of the topography. These ideas have been extended to the general circulation model equations in the folowing way: The equation of motion and continuity in a σ-coordinate may be written in the form

$$\frac{\partial \vec{V}}{\partial t} = \eta \vec{k} \times \vec{V} - \dot{\sigma} \frac{\partial \vec{V}}{\partial \sigma} - \nabla(\phi + \tfrac{1}{2} \vec{V} \cdot \vec{V}) - \sigma \alpha \nabla \pi$$

$$\frac{\partial \pi}{\partial t} = - \nabla \cdot (\pi \vec{V}) - \frac{\partial}{\partial \sigma} (\pi \dot{\sigma})$$

These equations guarantee conservation of $\overline{\tfrac{1}{2} q^2 \pi \Delta\sigma} = \overline{\tfrac{1}{2} \eta^2 / \pi \Delta\sigma}$ for a layer between two material surfaces separated by an amount $\Delta\sigma$, provided V is independent of σ within the layer, $\nabla\alpha \times \nabla\pi = 0$, and the vorticity is defined in terms of gradients at constant σ. The numerical scheme guarantees conservation under these constraints when the material surfaces coincide with its σ-coordinate surfaces.

The modified σ-coordinate system

A major deficiency noted in the previous version of the UCLA general circulation model was a lack of organization in fields strongly influenced by the planetary boundary layer. Precipitation in the tropics, for example, was less sensitive to sea surface temperature than in either nature or earlier versions of the model. This was thought to be due to the indirect way in which the general circulation and the parameterized PBL were coupled.

In the old model layers were defined by conventional σ-coordinate surfaces, as indicated by the heavy lines in the upper half of figure 1. The well-mixed planetary boundary layer, whose depth was predicted, was then allowed to occupy any fraction of the lower atmosphere. Typically, it was confined to a part of the lowest general circulation layer, as shown on the right of the figure, but it could also penetrate to higher

layers, as shown on the left. Coupling between this PBL and the general circulation model was handled by writing prognostic equations for the magnitude of the discontinuities at the top of the PBL and diagnostic relations for PBL properties.

We felt that the difficulties arising from the weak coupling between PBL and general circulation model in this scheme may be overcome by making the top of the PBL a coordinate surface. We therefore redefined the vertical coordinate as follows:

$$\sigma = \frac{p - p_I}{p_B - p_I} \qquad p_I \leq p \leq p_B$$

$$\sigma = \frac{p - p_B}{p_s - p_B} + 1 \qquad p_B \leq p \leq p_s$$

where p_I is a constant pressure above which we use pressure coordinates, p_B is the pressure at the PBL top, and p_s is the surface pressure. The PBL top then corresponds to $\sigma = 1$ and the earth's surface to $\sigma = 2$. This coordinate allows us to make the PBL the lowest GCM layer, and PBL quantities become the prognostic variables from which the jumps at the PBL top are defined. To improve the accuracy of the jumps, vertical resolution is increased immediately above the PBL. The model is being run with the 9-level (15-level when the stratosphere is included) structure shown in figure 2.

These changes have been coded into the new version of the UCLA general circulation model. The model has been tested for an idealized limited domain and is now being tested with global simulation experiments.

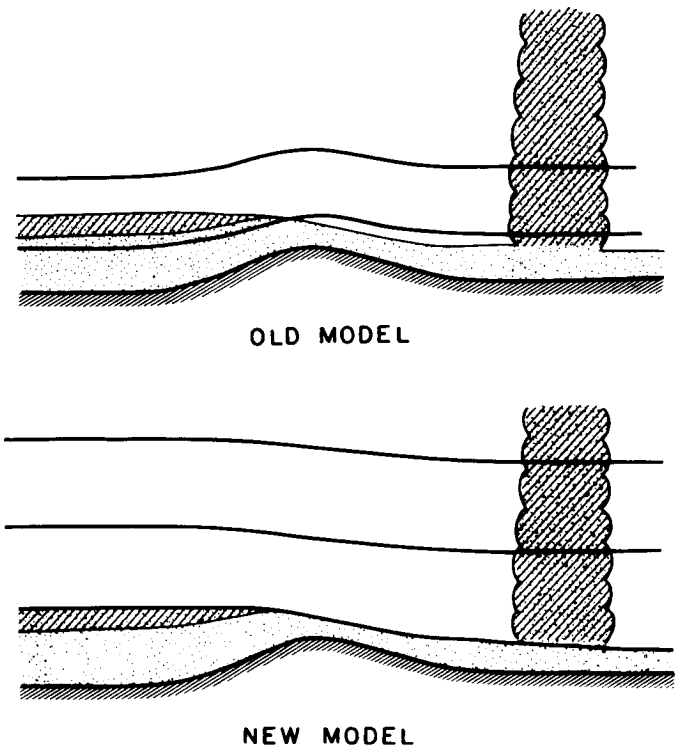

Figure 1 - Schematic of the model's layers near the ground in the old and new σ-coordinates. Note that in the new version the PBL coincides with the lowest layer

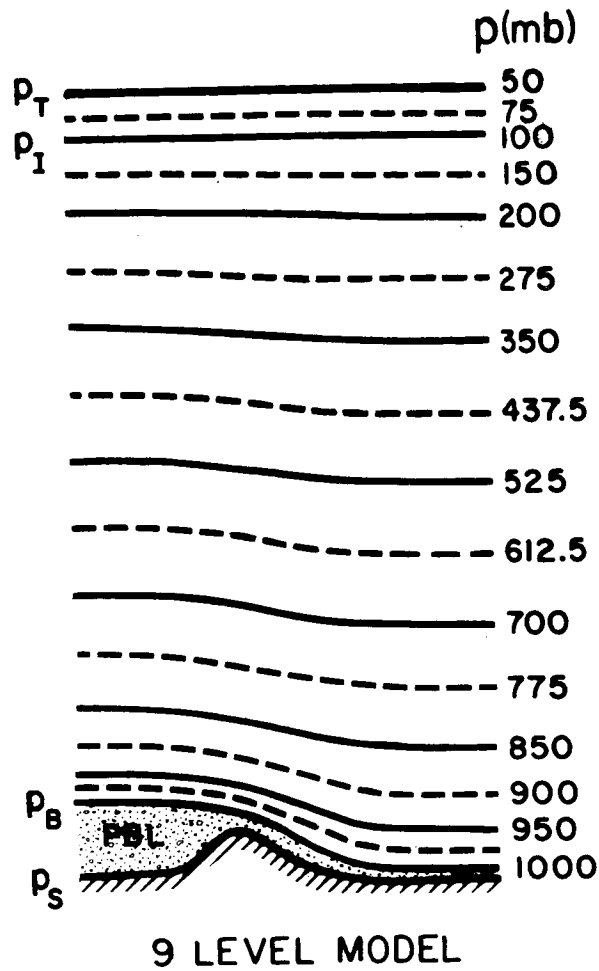

Figure 2 - Vertical structure of the new 9-level model. Pressures refer to the case when the PBL top is at 1000mb.