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Title: Theoretical and Experimental Studies of Baroclinic Processes

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Significant Accomplishments in the Past Year:

The fully nonlinear, nonhydrostatic, three-dimensional geophysical fluid flow simulation code, GEOSIM, has been developed, validated, and exercised for several problems. The code is cast in spherical coordinates and is finite difference in the meridional plane (latitude and height) and spectral in the azimuthal. This formulation allows the modeling of a full sphere or any axisymmetric part thereof (i.e., latitudinal walls may be inserted), which permits the use of the code for cylindrical or channel configurations. The code has been validated by comparing with previous numerical results and with experimental observations.

A paper by Miller and Fehribach was accepted and published in the past year which uses the axisymmetric and linear wave options of GEOSIM. This paper studies the onset of baroclinic wave instabilities in the GFFC apparatus. The results of the study show that there is a large region of parameter space which is accessible using the existing hardware which would result in baroclinic wave flow. Interestingly, the results indicate an advantage with the capability to heat the pole rather than the equator; in the equatorially-heated case, centrifugally-induced convection would occur which complicates the dynamics and which is non-Earth-like.

A paper by Miller and Butler has been accepted and is awaiting publication. This work was part of the validation process for GEOSIM in that it computes the transition curves for both rigid lid and free surface baroclinic experiments, agreeing with the observations for most of parameter space. The primary scientific contribution of this paper, however, is the study of hysteresis of the upper transition curve for the free-surface case. For large thermal Rossby numbers, it has been found experimentally that the flow may include baroclinic waves or not for a given set of external parameters, depending upon whether the waves were previously established before moving to that set of parameters. The calculations show that the hysteresis is due to a jump in wave amplitude when the external parameters are changed, and this jump is due to the presence of a positive feedback between the wave and mean state. That is, while it is usually considered that the waves act to stabilize the mean flow (negative feedback), there is the capability for a destabilization involving the combination of baroclinic and barotropic feedbacks. More details will be given at the review.

GEOSIM has been used for fully nonlinear simulations which have been animated on the Division's Stellar and Stardent computers. Cases have been completed for the traditional baroclinic annulus, the MSFC bottom-heated annulus, the GFFC, and for channel calculations. The most striking of these are the GFFC cases, which are simulations of Spacelab 3 experiments. These cases are with heating from below in addition to latitudinal temperature gradients, and the flow, while laminar, is quite chaotic and complex. Examples will be shown at the review.

A version of GEOSIM was used to study nonhydrostatic vertical and slantwise convection on the small scale. This work was motivated by results using the mesoscale model LAMPS which indicated that symmetric instability in the atmosphere may be quite sensitive to vertical convection from below. These results were shown at the 4th Conference on Mesoscale Processes last month.

Focus of Current Research:

GEOSIM is being used to study the phenomenon of vacillation in the baroclinic annulus. Having verified that the code predicts vacillation for the same points as the experiments, the work is aiming toward explaining the mechanics of vacillation and pointing out some of the sensitivities of the results to the numerical method. We are finding that there is a structural change associated with "amplitude vacillation", where the structural changes are in the vertical. Our results disagree with the premise of Lindzen et al. that the vacillation is due to constructive and destructive interference of neutral modes with different phase speeds.

We are continuing to study the Spacelab 3 GFFC results with horizontal temperature gradients and heating from below. GEOSIM has been used to compute a wide range of cases, and these are being compared with the observations. The computations and observations compare well, and the model is being used to extend the results beyond cases studied in the experiments and to study the mechanics and predictability of the flows.

The study of fully nonlinear baroclinic instability using the GFFC apparatus is proceeding with the numerical code. While the first instability that occurs is of planetary scale, secondary instabilities consisting of small-scale, penetrative convection occurs where cold fluid flows over a warm surface. The simultaneous modeling of the planetary scale and the convective scale is possible because of the nonhydrostatic formulation of the model. Some of these results have been animated on the Stardent computer, which shows the explosive nature of the small-scale convection.

Plans for Next Year:

We will be continuing the work in the preceding section. Our goals include a publication on each of the three paragraphs above.

The laboratory work will be revived. We have constructed a new lid for the annulus which is outfitted with thermistors. We are developing the software for an IBM PC which will allow the acquisition and recording of thermal data at the top of the flow cell. This will allow us to better study the dynamics of the flow and to compare it more quantitatively with the numerical model.

Publications:

Miller, T. L., and J. D. Fehribach, 1990: A numerical study of the onset of baroclinic instabilities in spherical geometry. Geophys. Astrophys. Fluid Dyn., 52, 25-43.

Miller, T. L., and K. A. Butler, 1990: Hysteresis and the transition between axisymmetric flow and wave flow in the baroclinic annulus. J. Atmos. Sci., accepted.

Miller, T. L., and S.-H. Chou, 1990: Numerical experiments on the interaction between vertical and slantwise convection. Fourth Conference on Mesoscale Processes, June, 1990, Boulder, CO.