Basic Studies of Baroclinic Flows

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Significant Accomplishments During the Past Year:

1. Computations were completed of transition curves in the conventional annulus, including hysteresis effects. A paper has been published by T. L. Miller and K. A. Butler on the use of the model GEOSIM (developed by this investigator group) to compute the transition between axisymmetric flow and baroclinic wave flow in the conventional annulus experiments of Fein (Geophys. Fluid Dyn., 1973). Results agree very well with the experiments, including the prediction of hysteresis for the extreme upper transition curve in the free-surface case. The only nonlinearity required to accurately predict the hysteresis is feedback between a single wave and the azimuthal mean state. It was found that there is a small region of parameter space in which the steady axisymmetric solution is stable to infinitesimal disturbances, but a finite-amplitude wave can be maintained indefinitely. The mechanics of this process have to do with the reduction of the mean azimuthal jet by baroclinic energy conversion from the mean state to the wave (reducing the thermal wind, hence the jet itself) which in turn causes a reduction in the barotropic energy conversion and normalized friction (both energy sinks with respect to the wave), thereby allowing the wave to be maintained. It was found that the wave state in this region can be obtained either by first obtaining a wave state in the non-hysteresis region and then slowly changing parameters to those of the hysteresis region, or by perturbing the axisymmetric solution by a baroclinic wave disturbance of large enough amplitude.
2. Thorough testing and documentation of the GEOSIM code has been completed. A paper has been submitted to the Journal of Computational Physics. The main result given in that paper is the benchmarking of the code on the steady-amplitude baroclinic wave case of Williams (JFM, 1971). While the code obtains Williams' results when at least one harmonic is used in addition to the fundamental wave 5, the use of a single wave 5 results in a significant underprediction of the wave amplitude and its effects upon the mean state. It is pointed out that the latter result disagrees with that of Quon (J. Comput. Phys., 1976).
3. Drs. Miller and Leslie are continuing to review the Spacelab 3 results from the Geophysical Fluid Flow Cell (GFFC), and numerical modeling has been performed of many of the cases with horizontal temperature gradients as well as heating from below, with different rates of rotation. A new flow regime has been identified, with "banana cells" in the equatorial region and nearly axisymmetric rings in the polar region.
4. A numerical study of the lower transition to axisymmetric flow in the baroclinic annulus of Lewis and Koschmieder (Geophys. Astrophys. Fluid Dyn., 1988) was performed using GEOSIM. A paper was accepted by GAFD which challenges Lewis & Koschmieder's conclusions that hysteresis exists in that transition. The numerical results indicate that the apparent hysteresis is due to the experimenters not waiting long enough before concluding that the flow had equilibrated.
5. The first phase of the laboratory experiments using the MSFC annulus which imposes the horizontal temperature gradient on the lower surface was completed. A journal article documenting those results as well as numerical calculations on various aspects of the experiments has been accepted by the Journal of Fluid Mechanics.
6. A study of amplitude vacillation in the annulus experiments of Pfeffer et al. (JAS, 1980) has been started. The model GEOSIM is decidedly capable of simulating both amplitude

and structural vacillation. Analysis of the model's output indicates that the amplitude vacillation is actually a kind of structural vacillation, in which the structural changes are in the vertical rather than the horizontal and hence have not been identified by the experimenters. The structural changes are a result of interactions between the wave and mean flow which result in drastic changes in the preferred mode of instability. A survey of parameter space has also found hysteresis in this phenomenon, including hysteresis in the amplitude of the vacillation, a very surprising result.

7. The study of the effect of topography on supercritical baroclinic disturbances has been completed. The resultant paper by S.-H. Chou and A. Z. Loesch has been accepted for publication in J. Atmos. Sci. This study uses a simple quasi-geostrophic model to investigate, analytically and numerically, the nonlinear evolution of baroclinic waves in the presence of surface topography. The topographic form drag competes with baroclinicity for the control of amplitude evolution and propagation characteristics of the various disturbance modes. The effectiveness of the topography to phase lock and equilibrate a given mode versus that of baroclinicity to propagate and vacillate that mode depends on the topographic height, its zonal structure and the level of superciticality.

Focus of Current Research and Plans for Next Year:

1. The analysis of the Spacelab 3 GFFC results and numerical modeling of that configuration will be completed. A paper will be written documenting the results and analyzing the fluid dynamics.
2. The model GEOSIM will be used to study flows in GFFC that may be more Earth-atmosphere-like in basic character. Experiments to be conducted in the future reflight of the apparatus will be suggested.
3. The model GEOSIM will be used to study increasingly nonlinear phenomena in baroclinic flows, concentrating on the conventional annulus configuration. A paper will be written on amplitude vacillation, and the relationship between hysteresis in wavenumber selection and time-dependent behavior will be studied.
4. Further laboratory experiments will be conducted in which we make quantitative measurements of the temperature field at the top of the MSFC baroclinic annulus. These measurements will provide a more quantitative comparison with the numerical model, and they will allow the study of long-term temporal behavior such as vacillation. Currently, the hardware for these experiments is being developed. Furthermore, a small amount of software development is required for the data acquisition system.

Publications:

1. "A numerical study of the onset of baroclinic instabilities in spherical geometry" by T. L. Miller and J. D. Fehribach, Geophys. Astrophys. Fluid Dyn., 52, 25-43 (1990).
2. "Hysteresis and the transition between axisymmetric flow and wave flow in the baroclinic annulus" by T. L. Miller and K. A. Butler, J. Atmos. Sci., 48, 811-823 (1991).
3. "A laboratory and numerical study of baroclinic instability in a cylindrical annulus with the temperature gradient imposed on the lower surface" by T. L. Miller and N. D. Reynolds, accepted in J. Fluid Mech. (1991).
4. "Comments on 'Convection in a rotating, laterally-heated annulus: Transition to lower symmetry' by Lewis and Koschmieder" by T. L. Miller, accepted in Geophys. Astrophys. Fluid Dyn. (1991).
5. "A fully nonlinear, mixed spectral and finite difference model for thermally-driven, rotating flows" by T. L. Miller, H.-I. Lu, and K. A. Butler, submitted to J. Comput. Phys. (1991).
6. "Supercritical baroclinic disturbances under the influence of topography" by S.-H. Chou and A. Z. Loesch, accepted in J. Atmos. Sci. (1991).