THEORETICAL AND EXPERIMENTAL STUDIES IN SUPPORT OF THE GEOPHYSICAL FLUID FLOW EXPERIMENT

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Meteorologists and astrophysicist interested in global planetary and solar circulations have long recognized the importance of rotation and stratification in constraining the character of these flows. In particular, the effect of latitude-dependent Coriolis force, the so-called beta-effect, is thought to play a crucial role in such phenomena as differential rotation on the Sun, cloud band orientation on Jupiter, and the generation of magnetic fields in thermally driven dynamos. Most theoretical works and all laboratory studies on these problems to date have treated the curvature effects only locally, and the laboratory efforts have only been able to study beta effects in layered quasi-geostrophic models. The continuous low-g environment of the orbiting space shuttle offers a unique setting for conducting geophysical fluid model experiments with a completely consistent representation of sphericity and the resultant radial gravity found on astro-geophysical objects. This is possible because in zero gravity one can construct an experiment that has its own radial buoyancy forces. The dielectric forces in a liquid, which are linearly dependent on fluid temperature, give rise to an effectively radial buoyancy force when a radial electrostatic field is applied. The Geophysical Fluid Flow Cell (GFFC) is an implementation of this idea in which fluid is contained between two rotating hemispheres that are differentially heated and stressed with a large a-c voltage. Our group has developed a facility to analyze the temeprature and velocity data that will come out of the GFFC experiment on spacelab III. In addition we have been working on many theoretical and laboratory problems which serve as models of expected GFFC motions, or bridges between the idealized situation of the GFFC and terrestrial, planetary, and solar circulations.

Research Accomplishments in the time period May 1983 - April 1984.

1) GFFC Data Analysis and Programming

Programming for digital acquisition of thermal maps and fluid velocities from the 16mm GFFC data films was completed. One remaining task is to attach our camera to the VAX-11 computer so that faster processing of each data frame can be effected.

On the basis of computer modeling and linear stability theory a set of scenarios (on-board programs that run the GFFC during the Spacelab III mission) were generated. The runs cover studies of basic electro-hydrodynamic instability, highly supercritical convection with isothermal boundaries, convection with imposed thermal forcing that has both radial <u>and</u> latitudinal structure, and some stably stratified runs to look at some very simple questions concerning large-scale thermohaline ocean circulations.

2) Studies of Compressible Convection.

To apply the Boussinesq results from GFFC to planetary and solar flows, some ideas about the effects of compressibility are needed. Hurlburt and Toomre have studied the effects of compressibility on thermal convection that is allowed to penetrate into stable surroundings, as is often typical of deep planetary or solar convection. Fully non-linear simulations of two-dimensional flows have been carried out on the Cyber 205 and on the VAX. These studies allow us to assess to what extent the GFFC experimental results without penetration may apply to more complicated circumstances within the Sun or the giant planets. For motions spanning several scale heights the cellular structure obtained in the compressible models are qualitatively similar to those predicted by our earlier incompressible studies. However, compressibility leads to distinctive asymmetries between the strengths of the upflow and downflow: pressure fluctuations cause stronger downward directed plumes. On encountering a stable layer these plumes can excite internal gravity waves and these in turn can couple back into the convecting layer and modulate its efficiency. The penetration effect is stronger in compressible models than Boussinesq ones because of the faster pressure-augmented plumes. The full numerical simulations of penetrative convection have been complemented by anelastic modal solutions by Toomre and co-workers.

3) Laboratory experiments on multiple equilibria and chaotic oscillators.

In 1979 Charney proposed that the atmosphere may contain multiple quasi-stable states. Since then Hart, Ghil and many others have looked for multi-equilibria in models of the Earth's atmosphere, of low Prandtl number Jovian convection, and of GFFC type convection. Hart and students have recently been studying a simple laboratory experiment that contains a convection front. This very simple experiment exhibits extremely complex dynamics including persistent states (hysteresis), frontal oscillations, intermittency in frontal formation, quasi-periodic oscillations and chaos. Some of the motions may be interpreted by simple convection loop theory. Others can be described by simple one-dimensional mappings (which unfortunately don't get at the underlying internal physics). As several of the GFFC experiments are designed to look for hysteresis and transition, these terrestrial laboratory studies are useful in building our intuition about how convective flows with competing instabilities work, and how to best analyse complex time series.

4) Transition to chaos in numerical models of double diffusive convection.

Toomre, Knobloch, Moore, and Weiss have performed some numerical calculations on 2-dimensional but many degree-of-freedom thermohaline convection. Remarkably the results show period doubling sequences (a la Feigenbaum) to chaos. The results are of interest to GFFC and to atmospheric dynamicists because they illustrate how period doubling can arise in relatively unconstrained fluid systems. Period doubling has been observed in laboratory models of baroclinic instability, and may occur in GFFC.

Plans for FY-85 (Including May 84 - Oct. 84)

1) Provide science support for the Spacelab III flight of GFFC.
2) Complete high-speed film-to-digital translator, and all data analysis programs.
3) Get linear convective instability and non-linear GFFC hydrodynamic codes up and running on the Cyber 205.

4) Analyse the GFFC data film and compare results with theories of hydrodynamic stability, non-linear numerical models, and terrestrial laboratory experiments.
5) Continue our laboratory study of oscillations in convecting systems, as well as theoretical and numerical studies of diffusive and compressible convection.

List of publications and submissions supported wholly or partially by NASA contract NAS-8-31958

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Knobloch E., D.R. Moore, J. Toomre, and N.O. Weiss, "Transitions to chaos in two-dimensional double-diffusive convection", J. Fluid Mech., to be submitted, 1984.