

CONVECTION PROCESSES IN THE OCEAN--LABORATORY AND THEORETICAL STUDIES

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LONG TERM GOALS

To make observations in the laboratory and conduct associated theory of a number of processes important in the ocean.

OBJECTIVES

To produce a design for laboratory experiments or to theoretically answer questions raised in trying to understand two processes: a. Multiple state problems in Geophysical Fluid Dynamics and b. Boundary layers in rotating stratified fluid.

APPROACH

First we try to find a way to develop prototype experiments and generate simple theories. The theories will, if successful, indicate the feasibility of an experiment, but in some cases the theory itself is sufficient to answer the questions. In other cases, the theory remains difficult to solve but the struggle indicates what experimental measurements might be sought to make some progress at understanding the problem. From this emerges a picture of the sort of laboratory configuration needed.

WORK COMPLETED

In the multiple states problems, most theories to date involve drastic simplifications with either simple box models or frictionally regulated flow. In some cases the friction is of a special nature. We have now developed one theory which indicates multiple states can be produced in a continuous region with small viscosity. To get a feasible analytical model for temperature-salinity problems was not terribly difficult, but to get this for temperature-wind driven problems has been difficult, since one of the states (the wind-driven one) involves having light water being forced to flow under dense water, which leads to vertical mixing which leads to turbulence. This situation makes one of the two states invalid for the simple laminar flow equations we can solve. The box models, with tubes separating the inflowing and outflowing water in the vertical, did not have this difficulty. One theory for wind-driven multiple states is successful, but it requires an elaborate combination of temperature, salinity, and wind forcing. Another approach, using temperature and wind in a rotating fluid is being investigated now. In another project, a laboratory experiment indicates that double diffusion tends to erase the multiple state effect in experiments. It seems that

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a preferred state instead is a three layer flow which is quite robust. Thus there must be some important dimensionless numbers which are not yet clear, that govern the multiple state processes. In exploring different formulations of such problems, a number of simple theories have been produced. One model of deep water formation illustrates that a layer of low salinity water can suppress deep convection. Once this layer is penetrated the convection can continue for the rest of the winter and into the spring. In addition, it is simple to see that fresh water, with its nonlinear equation of state, could have two states in a shallow freshwater bay in a lake. The laboratory experiments for this cycle of projects are now being moved from the prototype to the operational stage. b. For boundary layer processes in rotating stratified fluid, boundary layers produced by heating from the side have been compared successfully with calculations by Joseph Pedlosky during this past year. In one region of parameter space the agreement between experiment and theory is quite good. The experiment undergoes instability in another parametric region. The stability problem is not yet developed. In a second laboratory study of flow in rotating stratified fluid, new numerical calculations for a very simplified model of circulation in the Black Sea by G. Korotaev compare very well with laboratory measurements from an older project.

RESULTS

It is now clear that multiple states can be found in a variety of simple analytical numerical model problems in the general area of GFD. Some examples are now formulated and isolated for scientific study in problems which are more realistic than the very simplified models. The first laboratory experiments, which were finished about two years ago, mimicked the box models. But recent improved experiments and attempts to formulate these problems in continuous regions i.e in the absence of different "boxes" indicate that the problems are not always robust. Mixing and diffusive processes may sometimes interfere with sharp differentiation between the two states. Possibly one can create hybrid states which span the two extreme states at the same time, so that in some cases the box models are not accurate. b. Boundary layers and flow in stratified rotating fluids are now displayed so that their sizes, predicted many years ago, are now confirmed by physical measurements. Such structure seems apparent in some ocean observations.

IMPACT / APPLICATIONS

Multiple states could be very troublesome to forecasters if not properly anticipated or understood. Models which forecast environmental conditions for operations at sea could predict the wrong state at times. If a model, for instance, were constructed so that one of the numerous assumptions in the model excluded one of the states the real situation might suddenly undergo a transition to a state which the model could not reach. The problems considered in this project will more clearly show whether localized mixing effects produced by either turbulence or double diffusion tend to strongly erase the possibility of the system having multiple states. b. Length and velocity scales are found which depend on both advection and diffusion. They are likely to be experienced by a stratified rotating fluid subjected to differential temperature and wind forcing. It is unlikely that numerical models would properly resolve these scales since such models use large values of diffusion to remain stable.

TRANSITIONS

None known directly. Work continues to locate direct observations of catastrophic transitions from a fresh water mode to a cold water mode in winter, or a salt water mode to a hot water mode in an estuary in a monsoonal region.

RELATED PROJECTS

There are no projects directly related to this research. Deep measurements in the Sea of Japan may agree with predicted scales and flow patterns that have been found in the laboratory which is that the deep flow will have weak vertical shear because of the small amount of stratification in the Sea of Japan.