Abstract View

Volume 10, Issue 4 (April 1980)

Journal of Physical Oceanography
Article: pp. 483–492 | Abstract | PDF (770K)

The Dynamics of Oceanic Fronts. Part I: The Gulf Stream

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(Manuscript received August 6, 1979, in final form November 8, 1979)

DOI: 10.1175/1520-0485(1980)010<0483:TDOOFP>2.0.CO;2

ABSTRACT

The establishment and maintenance of the mean hydrographic properties of large-scale density fronts in the upper ocean is considered. The dynamics is studied by posing an initial value problem starring with a near-surface discharge of buoyant water with a prescribed density deficit into an ambient stationary fluid of uniform density. The full time-dependent diffusion and Navier-Stokes equations with constant eddy diffusion and viscosity coefficients and for a constant Coriolis parameter are used in this study. Scaling analysis reveals three independent length scales of the problem, *viz*., a radius of deformation or inertial length scale L_0, a buoyancy length scale h_0 and a diffusive length scale h_v. Two basic dimensionless parameters are formed from these length scales: the thermal (or more precisely, the densimetric) Rossby number, $Ro=L_0/h_0$ and the Ekman number $E=(h_v/h_0)^2$. The governing equations are then suitably scaled and the resulting normalized equations are shown to depend on E alone for problems of oceanic interest. Under this scaling, the solutions are similar for all Ro sufficiently large. It is also shown that 1/Ro is a measure of the frontal slope, so that Ro is large for all oceanic density fronts. The governing equations, in the form used in a previous paper by Kao *el al*. (1978), are solved numerically and the scaling analysis is confirmed. The solution indicates that an equilibrium state is established. The front can then be rendered stationary by a barotropic current from a larger scale alongfront pressure gradient. In that quasi-steady state and for small values of E, the main thermocline and the inclined isopycnics forming the front have evolved, together with an intense alongfront jet and a crossfront (or cross-stream) circulation with surface discharge toward the front and return flow at greater depth. Conservation of potential vorticity is also obtained in the light water pool. The surface jet exhibits anticyclonic shear in the light water pool and cyclonic shear across the front. It is also shown that horizontal diffusive effects are unimportant. Comparisons with known hydrographic features of the Gulf Stream are made, showing good agreement, especially on the major features. It is thus seen the mean Gulf Stream dynamics can indeed be interpreted in terms of a solution of the Navier-Stokes and diffusion equations, with the cross-stream circulation responsible for the maintenance of the front. This mechanism is thus suggested in this paper as a mechanism for the maintenance of the Gulf Stream dynamics.

For large values of E, it will be shown that another type of scaling is required. That result will be shown in a

subsequent paper as Part II of this series, and is relevant to the study of density and current structure on the East Coast continental shelf of North America from Newfoundland to Chesapeake Bay, a region subject to forcing by freshwater river discharges.

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