Salt Finger Convection under the Effect of Steady Wind Shear

Ray-Yeng Yang and Hwung-Hweng Hwung

Tainan Hydraulics Laboratory, Research Center of Ocean Environment and Technology, National Cheng Kung University
Tainan, TAIWAN, China

ABSTRACT

In oceanographic situations where salt fingers may be an important mechanism for the transport of heat and salt in the vertical, velocity shears may also be present. Salt finger convection is analogous to Bénard convection in that the kinetic energy of the motions is obtained from the potential energy stored in the unstable distribution of a stratifying component. On the basis of the thermal analogy it is of interest to discover whether salt fingers are converted into two-dimensional sheets by the wind shear, and how the vertical fluxes of heat and salt are changed by the wind shear. Salt finger convection under the effect of steady wind shear is theoretically examined in this paper. The evolution of instability developing in the presence of a vertical density gradient disturbance and the horizontal Couette flow is considered near the onset of salt fingers under a moderate rate of shear. We use velocity as the basic variable and solve the pressure Poisson equation in terms of the associated Green function. Growth competition between the longitudinal rolls (LR) and the transverse rolls (TR), whose axes are respectively in the direction parallel to and perpendicular to the direction of the mean shear, is investigated by the weakly nonlinear analysis of coupled-mode equations. The results show that the TR mode is characterized in some range of the effective Rayleigh number, and that the stability is dominated by the LR mode in the system.

KEY WORDS: Salt finger convection, wind shear, growth competition, longitudinal rolls, transverse rolls, coupled-mode equations.

INTRODUCTION

Since the discover of double-diffusive convection by Stommel, Arons & Blanchard (1956), “evidence has accumulated for the widespread presence of double-diffusion throughout the ocean” and for “its significant effects on global water-mass structure and the thermohaline convection” (Schmitt, 1998). The salt-fingering form of double-diffusion has particularly attracted interest because of salt-finger convection being now widely recognized as an important mechanism for mixing heat and salt both vertically and laterally in the ocean. Kluikov and Karlin (1995) suggested that two-thirds of world ocean is favorable for fingering convection. For example, in the tropics, surface evaporation exceeds precipitation and heating exceeds cooling, producing these conditions. In contrast, the diffusive convection form of double-diffusion is commonly found in polar water where cool fresh water overlies warmer saltier water. Salt-finger convection is analogous to Bénard convection in that the kinetic energy of the motions is obtained from the potential energy stored in the unstable distribution of a stratifying component.

In oceanographic situations where salt-fingers may be an important mechanism for the transport of heat and salt in the vertical, wind shear may also be present. In 1928 Jeffreys suggested that a steady shear in an unstably stratified fluid stabilizes all perturbations except the one mode of infinite length in the direction of the shear flow, and hence that the convective disturbance takes the form of rolls aligned along the direction of the shear. The later studies by Kuo (1963), Asai (1964, 1970a,b) and Linden (1974) have also confirmed Jeffreys’ conclusion. These studies have also provided neutral stability curves for various ranges of the non-dimensional parameters of the problem namely the Reynolds number, the Rayleigh number and the Prandtl number. Meanwhile, the Rayleigh-Bénard convection in the presence of plane Couette flow (or horizontal flow with vertical shear) has also received considerable experimental and theoretical interest particularly motivated by a meteorological interest in cloud formation (Lipps, 1971; Kimura et al., 1971). A considerable amount of evidence has thus far been amassed that convection occurs for most cases in the form of the longitudinal rolls (LR), i. e., an assembly of the parallel rolls whose axes are in the direction of the shear flow. The subject of the present study is, however, much more modest: it is concerned with dominant pattern of convection rolls developing in the presence of salt-fingers and horizontal Couette flow near the onset of convection for a small rate of wind shear (to see Fig.1). The amplitude equations are derived near the onset of convection to study growth competition between the longitudinal rolls (LR) and the transverse rolls (TR) whose axes are respectively in the direction parallel to and perpendicular to the direction of the shear. Since convection in the form of the TR was observed under certain conditions in early experiments on air (Chandra 1938; Brunt 1951). Therefore, the purpose of the present paper is also to ascertain whether the TR can stably persist if some suitable