Mixing Processes and Hydraulic Control in a Highly Stratified Estuary

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ABSTRACT

This thesis utilizes field data from the Fraser River Estuary, a highly stratified system located in southwestern British Columbia, Canada, to investigate the nature of mixing processes in a highly stratified environment, and to extend two-dimensional hydraulic theory to a three dimensional environment.

During the late ebb, a stationary front exists at the Fraser mouth. Although densimetric Froude numbers in the vicinity of the front are supercritical in a frame of reference parallel to the local streamlines, the front itself is oriented such that the value of the Froude number is equal to the critical value of unity when taken in a frame of reference perpendicular to the front. This observation presents a robust extension of established two-dimensional, two-layer hydraulic theory to three dimensions, and implies similarity with trans-sonic flows, in that a Froude angle can be used to identify critical conditions in a manner similar to the Mach angle.

Mixing processes were evaluated at the mouth during the late ebb using a control volume approach to isolate mean vertical entrainment processes from turbulent processes, and quantify the vertical turbulent salt and momentum fluxes. Observed turbulent dissipation rates are high, on the order of 10^{-3} m^2s^{-3}, with vertical entrainment velocities on the order of 2×10^{-3} $m \cdot s^{-1}$. Mixing efficiencies, expressed as flux Richardson numbers, are confined within a range from 0.15 to 0.2, at gradient Richardson number values between 0.2 and 0.25. These results are consistent with previous laboratory studies, but represent energetic conditions that are several orders of magnitude higher.

In the estuarine channel, the variability of mixing processes was investigated through the tidal cycle using control volume and overturn scale methods. Spatially, mixing was observed to be more intense near a width constriction on the order of 25%. Temporally, more dominant mixing was observed during ebbs, due to increases in both vertical shear and stratification. Mixing is active and important throughout the tidal cycle, and was found to be the dominant process responsible for removing salt from the estuarine channel during the ebb.

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Chapter 1

Introduction

1.1 The Physical Significance of Estuaries

The discharge of fresh river water represents a significant source of nutrients, sediments, pollutants and other terrestrially derived material to the world's oceans (Yin et al., 1995; Caspers, 1967; Sommerfield and Nittrouer, 1999). During its journey to the sea, the fresh river discharge first interacts with ocean water within an estuary situated at or near the river mouth. Because very different water masses are colliding within an estuary, estuaries can often be characterized by strong gradients, of which the most dynamically important are density and velocity. Strong gradients of dissolved and suspended constituents such as nutrients, pollutants, and suspended sediment are also typically present, and it is the ultimate disposition of these components that provides much of the motivation for understanding the local physics.

The nature and intensity of the mixing processes within an estuary are driven, to a large extent, by the dynamically important gradients of density and velocity. Shear instabilities resulting from perturbations in the velocity profile large enough to overcome the ambient density stratification provide the primary mechanism for turbulence generation and mixing (Thorpe, 1973). At the seaward end of the estuary, the density difference between the discharge and the ambient coastal water has been greatly reduced, but the brackish residual that remains can continue to persist in the coastal ocean and be carried great distances, sometimes on the order of 10^2 to 10^3 kilometers, as the plume forms a coastal current (Yankovsky and Chapman, 1997). Eventually, through the action of external forcing mechanisms, such as wind and wave action, the signal of the plume is diluted by mixing with ocean water (Fong, 1998; Lentz, 2001).