Computational Modeling of the Evolution of a Submerged Laminar Round Jet in Shallow Water

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ABSTRACT

The evolution mechanism and characteristics of the submerged laminar round jet in a viscous homogenous shallow water layer is investigated through computational modeling. The model was run through rigorous mesh independence check to ensure the reliability of the simulation data. Two major simultaneous flow mechanisms during the evolution process are discovered and to quantify the observed flow patterns, three non-dimensional parameters \( L_n \), \( R_n \) and \( d_n \) are introduced as functions of the non-dimensional time \( t_n \). This research further discovered that major influence of injection duration only exists during the developing stage and has no influence on the functional relationships.

KEY WORDS: laminar round jet; shallow water; vortex structure; evolution characteristic

INTRODUCTION

In late 20th century, a class of ocean surface flow structures was frequently observed by using satellite-based remote sensing instruments. When a tracer technique is adopted, their basic configuration usually manifests a feature with a pair of counter-rotating vortices at the front. It looks like a sliced mushroom, as shown in Fig. 1, thus being termed as a “mushroom-like pattern” (Mied, 1991; Voropayev, 1994). Generally, such a pattern has a horizontal scale of 1-200km, a vertical scale of 10-100m, and a decaying period of 1-30 days (Ivanov, 2002). Due to its large spatial scale and persistence, such flow structure has a remarkable influence on the mass, momentum and energy transport processes in the ocean. A series of reports in literature has documented the mysteries of this pattern. The observation on the meanders in the west coasts of Oregon and northern California (Ikeda, 1984) indicates that the interaction between the mean current and the coastal topography excited the initial structure of this pattern, and the baroclinic instability caused by the vertical shear was responsible for its following growth. Fedorov further claimed that this pattern was the reaction of ocean rotating fluid to certain impulses which introduced relative angular momentum into both signs of this paired eddy structure in the upper ocean (Fedorov, 1986). Voropayev concluded that, in essence, the mushroom-like pattern was a class of flow structure caused by certain momentum sources under the action of stratification, and suggested that such flow pattern could be reproduced in laboratory by adopting a continual round jet as the momentum source in a stratified fluid (Voropayev, 1994). Voropayev’s suggestion was proved by his own experimental studies (Voropayev, 1994; 2007). The momentum jet collapsed and its vertical scale was limited to a certain thickness due to the confinement induced by gravitational force.

Fig. 1 Mushroom-like pattern on ocean surface (Mied, 1991)

Another example appears in the formation of rip currents in a surf zone. A strong current is sometimes formed by the water driven by the waves coming into the shallow water. This current separates from the shore and generated some off-shore directed jets which have typical ‘hats’ on their leading edge and are named rip currents (Massel, 1989). A reasonably simplified physical model of this case can be described as low speed momentum jets acting under the vertical suppression produced by the shallowness. Such model may also be applicable to problems like rivers entering the lakes or currents acting in coastal areas. Therefore we numerically investigate this model and present some of the preliminary work in this paper. The aim is to reveal the evolution of the flow structure generated by a submerged round laminar jet in shallow water and describe the influence of the shallow water effect.

COMPUTATIONAL MODELLING