A new empirical model of vertical profile of velocity and suspended sediment concentration of steady-state turbidity currents

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The importance of a turbidity current is characterized by its role as a dominant sediment transport mechanism from shallow to deep ocean at continental margins. Turbidity currents create one of the biggest sediment architectures on our planet, called submarine fans. During their flow processes, they running down more than 100s to 1000s km along the sinuous submarine channel, destroying and recreating the deep marine systems. The understanding of a whole flow event of a turbidity current from initiation to the deposition and the evolution of resultant deposits provides us a various kind of scientific information such as the historical records of huge earthquakes, the better risk management of submarine infrastructures, and the better understanding of potential contamination of deep marine due to the human activities (e.g. microplastics). Despite those high demands of understanding flow mechanics of turbidity currents, we actually do not understand how a turbidity current can run out such an ultra-long distance without dissipation. Although we have high-resolution numerical models to predict the flow behavior in high precision, the computational cost is too expensive to simulate the natural scale flow event. A shallow water scheme that assumes the vertically uniform flow is often used as an alternative model but is too simple to predict a turbidity current’s flow dynamics. To tackle this dilemma of computational cost and model performance, recent studies are focusing on introducing appropriate stratification effects into shallow water models considering the vertical flow stratification of equilibrium turbidity currents assuming the Rouse profile of suspended sediment concentration. One of the problems of traditional Rouse profile and other Rouse-based vertical stratification models is that they cannot capture the flow stratification due to the strong shear between ambient fluid. Those models, therefore, cannot predict the wide variety of density and concentration profile that has been observed and predicted by both past flume experiments and direct measurements. Here, we compiled past flume experiments of steady-state turbidity currents to establish the new vertical flow profile model which is able to predict a wide variety of flow stratification. Firstly, we found a relationship between vertical velocity and concentration profiles; the ratio between normalized velocity and concentration at each height is almost constant regardless of other flow parameters. Secondly, instead of the traditional Rouse-type equations, we introduced the generalized Schlick’s bias and gain function to describe the vertical concentration profile. Then from the results of curve fitting, we conducted model selection to describe the parameters in Schlick’s function by characteristic flow parameters, using K-fold cross-validation method. From the obtained model of vertical concentration profile and the constant relationships between velocity and concentration profile, we readily obtained the new model of vertical flow velocity profile as well. In short, the obtained model implies that the flow stratification of turbidity currents can be well approximated by the flow concentration, densimetric Froude number, Rouse number, and drag coefficient. Within the dataset we gathered, the developed model shows quite good agreement and it depicts the basic trends of flow stratification which have been reported previously (e.g. high stratification with high Froude number). The flexibility of the developed model was highlighted by that they can demonstrate the various types of flow stratification which has been reported from both experiments and direct measurements such as traditional Rouse profile and highly-contrasted two-layer type profile which is often observed in saline flows or low Rouse number flow. As a future study, it is expected to introduce this model into shallow water model to validate the developed model’s applicability.

Keywords: turbidity currents, sediment transport, vertical stratification, cross validation, flume experiment