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Three-dimensional numerical simulation of the turbidity current on a flume slope

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Density-driven gravity flows frequently occur in nature, due to density difference between inflowing and ambient water. When a sediment-laden flow reaches the backwater zone of a reservoir, with a greater density than the ambient waters, an underflow can occur along steep bottom slopes. The formation and evolution of an underflow depend on various natural conditions. It is necessary and crucial for reservoir management to understand the dynamics and prediction of the turbidity currents. In addition to field investigation and laboratory experiments, numerical models are gaining popularity for solving open-channel flows and sediment transport processes such as turbidity currents in reservoirs.

SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model) is a 3D seamless cross-scale model grounded on unstructured grids for hydrodynamics and ecosystem dynamics. A general set of governing equations are used for the flow and tracer transport, and a new higher-order implicit advection scheme for transport (TVD^2) is proposed. A mixed triangular-quadrangular horizontal grid and a highly flexible vertical grid system are developed in the model to faithfully represent complex geometry and topography of environmental flows in open channel cases. SCHISM has found a wide range of cross-scale applications worldwide including general circulation, storm surges, sediment transport and so on. However, the feasibility of simulating turbidity currents caused by sediment-laden flows in a reservoir is rarely validated. In this study, SCHISM is applied to a lab experiment to simulate the turbidity currents on a flume slope to examine how the model predicts the hydraulic characteristics of turbidity currents in a reservoir.

Model results can describe the process of the turbidity current plunging beneath the free surface with the time step of 0.1s. It is relatively uncommon in previous studies to clearly show the evolution of the velocity and sediment concentration profiles in such a short time step. The simulated velocity and sediment concentration profiles of the turbidity currents match well with the measured profiles at the cross section downstream of the plunge point. The calculated depth-averaged velocity, thickness, and depth-averaged concentration of the turbidity current all agree well with the measured values. The correlation coefficient between the measured and calculated values is 0.92, 0.95, and 0.94, respectively. Also, the densimetric Froude number of the stable plunge point is found to be approximately 0.54 in this study, which is between 0.5 and 0.8 based on previous research. The plunge depth is smaller with higher sediment concentration and smaller discharge of the inflow. Besides, the ratio of plunge depth to inlet depth is proportional to the densimetric Froude number of inflow conditions. This finding can be used to predict the depth and location of the plunge point based on the inflow conditions in a reservoir, which has great practical implications in reservoir management. Our results demonstrated that SCHISM is generally applicable to simulate the turbidity currents in small-scale water environments, and has the potential to be adopted in large-scale open water environments.