Numerical characteristics study on Delft3D for simulating the density flow caused by temperature difference in a reservoir flume

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Introduction

Generally, there are two vertical coordinate type to construct a three dimensional model of D3D, one is z-coordinate, the other is σ-coordinate. The existing improvement methods of D3D such as anti-creep correction and bottom grid redistribution cannot completely quantitatively eliminate this error. Therefore, how to choose a suitable vertical coordinate system in the simulation of temperature stratified density flow in reservoir bay is still need a specific study for specific problem.

Based on the physical model experiments conducted by Johnson different types of vertical grid coordinate were employed to establish the numerical models using D3D software. By comparing the modeling results, general suggestions on coordinate selection for simulating reservoir bay temperature stratified density flow using D3D model are given.

Model

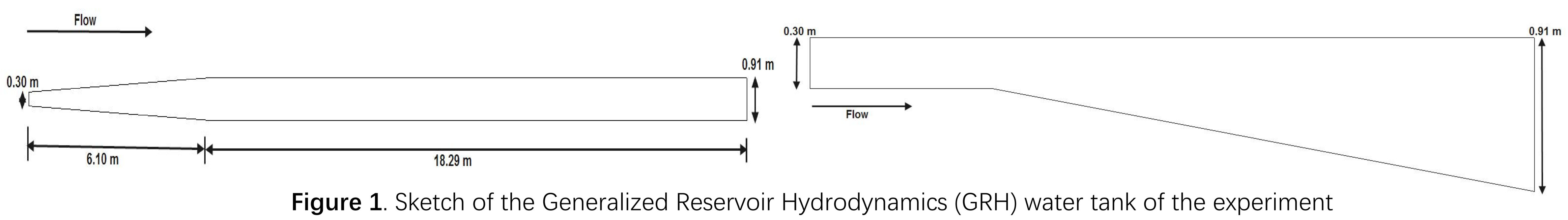

Figure 1. Sketch of the Generalized Reservoir Hydrodynamics (GRH) water tank of the experiment

Sketch of the experiment tank is shown in Figure 1. Its length is 24.39 m, the downstream section size is 0.91 m × 0.91 m, and the upstream section size is 0.30 m × 0.30 m. The water tank can be divided into two sections. The upstream section is 6.10 m in length, 0.30 m in depth, and the width changes linearly from 0.30 m to 0.91 m. The downstream section is 18.29 m in length, 0.91 m in width, and linearly changes from 0.30 m to 0.91 m in depth. At the initial moment, the model reservoir is in a stationary and uniform state with a water temperature of 21.44 °C. During the experiment, cold water at 16.67 °C was introduced from 0.46 m from the upstream section, and the baffle restricted cold water from entering 0.15 m above the bottom. The inflow and outflow discharge are both 0.00063 m3/s. The downstream section is an orifice with a diameter of 2.54 cm, 0.15 m from the bottom and in the middle of the section.

Table 1. Settings of σ-coordinate and z-coordinate model.

Simulation conditions		σ-coordinate	z-coordinate
Plane grid	Longitudinal/horizontal scale ratio	3:1	
	Longitudinal grid number	80	
	Horizontal grid number	9	
Vertical grid		36	
parameters	Manning number（$m^{-1/3}s$）	0.009	
	Background horizontal eddy viscosity coefficient（m^2/s）	0.01	
	Background horizontal eddy diffusion coefficient（m^2/s）	0.01	
Turbulence model		Constant model	

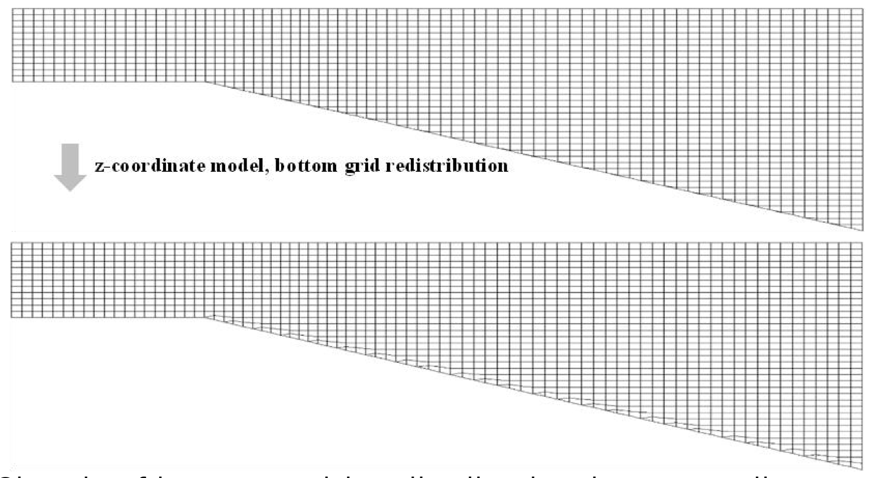

Figure 2. Sketch of bottom grid redistribution in z-coordinate model.

Results

According to Figure 3, the time when the outlet water temperature starts to fall is t = 15 min, and the time when the outlet water temperature calculated by the z is 9 minutes later than the observed value. At the end of the z-coordinate model, the outlet water temperature is also much higher than the observed value.

According to Figure 4, the thickness of the submerged density current in cold water is 0.12 m, while the thickness of which in the z-coordinate model is about 0.24 m. Moreover, the reverse velocity of the upper layer is also significantly larger than the observed value, which indicates that the vertical velocity gradient of the z-coordinate model is small, which causes the speed of the submerged cold water to be small, while the reverse velocity of the upper layer is increased.

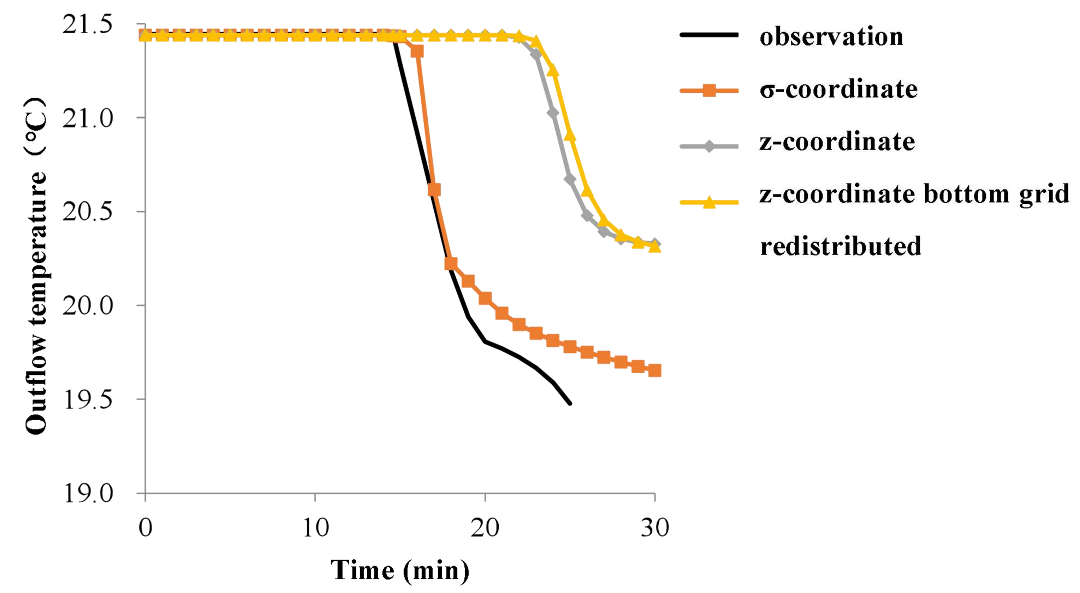

Figure 3. Water temperature change at the outlet over time of different vertical coordinate models.

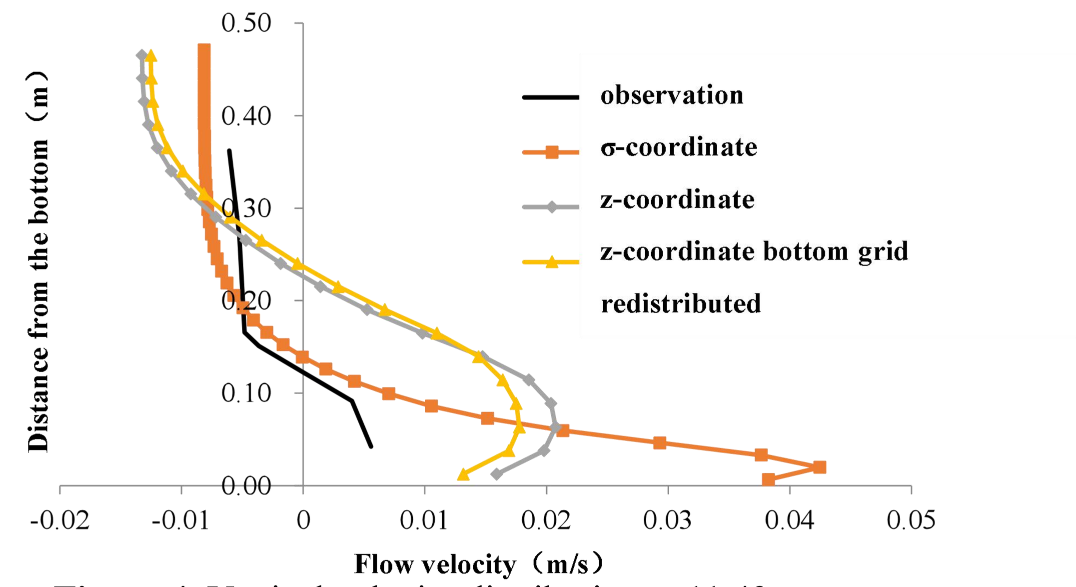

Figure 4. Vertical velocity distribution at 11.43 m upstream at t = 11 min of different coordinate models.

Table 2. Simulation cases with different numbers of vertical grids based on z-coordinates

Simulation cases		B1	B2	B3
Plane grid	Longitudinal grid number		80	
	Horizontal grid number		9	
Vertical grid number		36	72	100

Table 3. Simulation cases set up to study the influence of bottom slopes in different coordinate systems on results of density flow characteristics.

Simulation cases	C1	C2	C3	C4	C5
Bottom slop	1‰	2‰	3‰	4‰	5‰
Water depth in front of the downstream boundary（m）	0.318	0.337	0.355	0.373	0.392
Height of the downstream outflow（m）	0.053	0.056	0.059	0.062	0.065

- The vertical grid resolution is important to accurately simulate the cold submerged flow of the reservoir, but it is not the main cause of the calculation errors of the z-coordinate reservoir model.
- The bottom slope is larger than 4 ‰, the simulation results of the z-coordinate model are affected by the step approximation, resulting in a large calculation error, and the error also increases as the bottom slope increases.

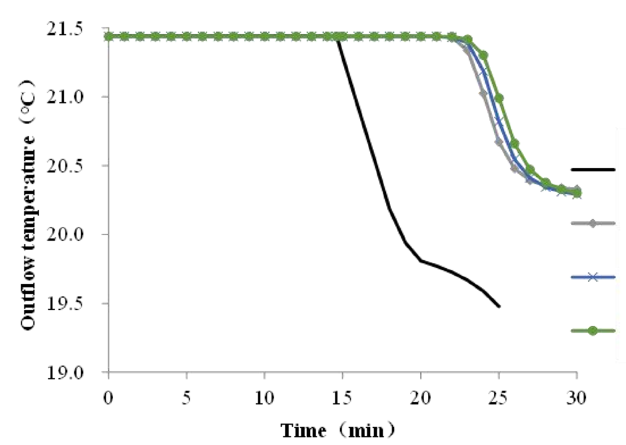

Figure 6. Water temperature at the outlet of z-coordinate model with different vertical grid numbers

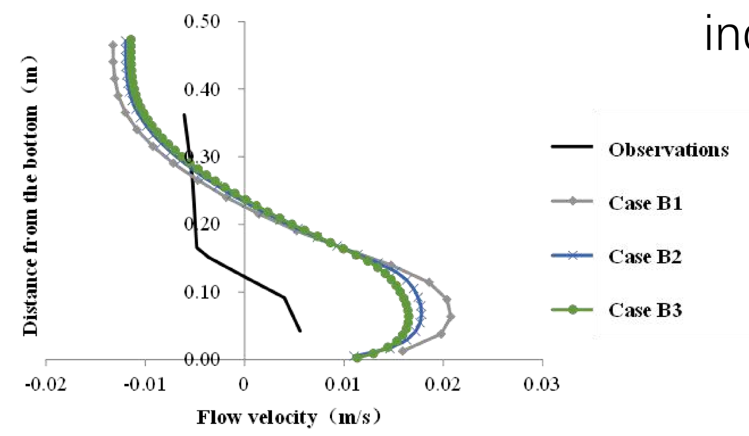

Figure 7. Vertical velocity distribution at 11.43 m upstream at t = 11 min of z-coordinate model with different vertical grid numbers.

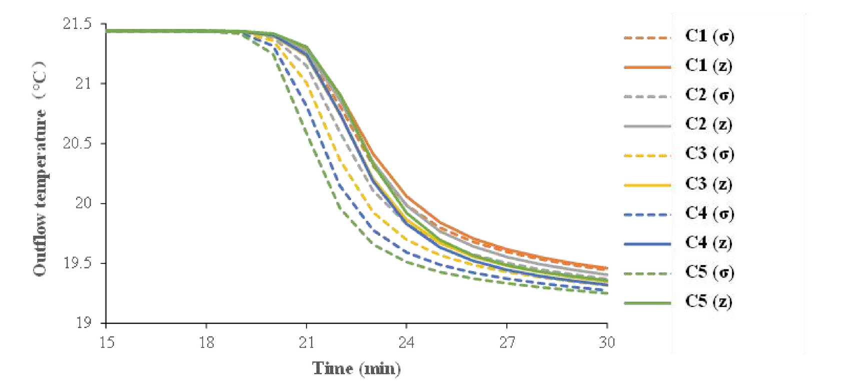

Figure 8. Comparison results of σ-coordinate and z-coordinate model outlet water temperature under different bottom slope conditions

Conclusion

- ✓ The selection of the vertical coordinate system has a large impact on the accuracy of the temperature stratification flow simulation.
- ✓ When the density currents is along the bottom of the reservoir, the model accuracy using the σ-coordinate is obviously better than the model using the z-coordinate
- ✓ When the slope is less than 3 ‰, the difference between the two vertical coordinate systems becomes very small.