Estuarine Circulation Modeling Framework

Core Components and Initialization

The model represents an estuary with a length $L = 10,000$ m and depth $H = 10$ m, discretized into $N = 100$ grid points with a spatial step $\Delta x = L/N$. The time step is $\Delta t = 10$ s. Key parameters include:

- River inflow: $Q_r = 0.1\,\text{m}^3/\text{s}$
- Tidal amplitude: $A = 1.0$ m
- Tidal period: $T = 43,200$ s (12 hours)
- Ocean salinity: $S_o = 35$ PSU
- Ocean temperature: $T_o = 20\,°\text{C}$

The model initializes salinity and temperature profiles (`salinityProfile`, `temperaturePro` across the grid. The salinity profile starts at zero (freshwater), and the temperature is set to the ocean temperature. A `HydrodynamicSolver` object handles velocity and eddy viscosity calculations, with options for a Reynolds-Averaged Navier-Stokes (RANS) solver or a simplified velocity model.

Functioning Logic

The `Update` method advances the simulation by one time step:

1. Updates the current time: $t \leftarrow t + \Delta t$.
2. Computes tidal velocity: $u_t = A \cos\left(\frac{2\pi t}{T}\right)$.
3. Computes water level: $\eta = A \sin\left(\frac{2\pi t}{T}\right)$.
4. Determines effective velocity, either via the RANS solver or a simplified model: $u_{\text{eff}} = u_t - \frac{Q_r}{H \cdot \Delta x}$.
5. Updates the salt wedge position: $x_s \leftarrow x_s + u_{\text{eff}} \Delta t$.
6. Updates salinity and temperature profiles using advection-diffusion equations.

Salt Wedge Dynamics

The salt wedge position x_s marks the boundary between freshwater and saline water, updated as:

$$x_s(t + \Delta t) = x_s(t) + u_{\text{eff}} \Delta t \quad (1)$$

The position is constrained within $[0, L]$.

Salinity and Temperature Profiles

The salinity $S(x,t)$ and temperature $T(x,t)$ profiles are updated using an advection-diffusion model:

$$\frac{\partial S}{\partial t} = -u_{\text{eff}}\frac{\partial S}{\partial x} + K\frac{\partial^2 S}{\partial x^2} \tag{2}$$

$$\frac{\partial T}{\partial t} = -u_{\text{eff}}\frac{\partial T}{\partial x} + K\frac{\partial^2 T}{\partial x^2} \tag{3}$$

where K is the diffusion coefficient (eddy viscosity from the RANS solver or a default 0.1 m^2/s). These are discretized using finite differences:

$$\text{Advection: } \frac{S_{i+1} - S_{i-1}}{2\Delta x} \tag{4}$$

$$\text{Diffusion: } K\frac{S_{i+1} - 2S_i + S_{i-1}}{\Delta x^2} \tag{5}$$

The profiles are constrained: $0 \leq S \leq S_o$, $0 \leq T \leq T_o$.

Hydrodynamic Solver

The `HydrodynamicSolver` computes velocity and eddy viscosity. When `UseRANSSolver` is enabled, it employs a RANS model, optionally with non-hydrostatic corrections. Otherwise, a simplified velocity is used. The solver provides velocity profiles and eddy viscosity at specific points, influencing mixing processes.

Key Outputs

The model provides:

- Salinity at a point: $S(x)$, interpolated from the profile.
- Temperature at a point: $T(x)$.
- Maximum salinity: max(S_i).
- Velocity and salinity/temperature profiles.
- Eddy viscosity and non-hydrostatic status.

Physical and Mathematical Models

The model simulates estuarine circulation driven by tidal forcing and river inflow. The tidal velocity and water level follow harmonic functions:

$$u_t = A\cos\left(\frac{2\pi t}{T}\right) \tag{6}$$

$$\eta = A\sin\left(\frac{2\pi t}{T}\right) \tag{7}$$

The salt wedge dynamics reflect the balance between river outflow and tidal inflow, while salinity and temperature evolve via advection-diffusion, capturing mixing processes. The RANS solver enhances realism by modeling turbulent mixing.