Wind Forcing

Core Components and Initialization

The `WindForcing` class, implemented in C#, models wind-induced stress on an estuarine surface, incorporating the effects of wind speed, direction, and wave height. The class is initialized with the following parameters:

- Air density: $\rho_{\text{air}} = 1.225\,\text{kg/m}^3$
- Wind speed at 10 m height: U_{10} (m/s, non-negative)
- Wind direction: θ_w (degrees, normalized to $[0, 360)$)
- Significant wave height: H_s (m, non-negative)

The constructor enforces $U_{10} \geq 0$, $H_s \geq 0$, and normalizes θ_w using modulo 360. The `UpdateParameters` method allows dynamic updates of these parameters during simulation.

Functioning Logic

The class provides two primary methods to compute wind effects:

1. `ComputeDragCoefficient`: Calculates the wind drag coefficient based on wind speed and wave height.
2. `ComputeWindStress`: Computes wind stress components (τ_x, τ_y) in N/m², resolved along the x- and y-axes.

Drag Coefficient Computation

The `ComputeDragCoefficient` method uses a simplified parameterization:

$$C_d = (0.75 + 0.067U_{10} + 0.1H_s) \times 10^{-3} \tag{1}$$

The drag coefficient is bounded for physical realism:

$$C_d \in [0.001, 0.003] \tag{2}$$

This accounts for the influence of wind speed and sea state (via wave height) on surface drag.

Wind Stress Computation

The `ComputeWindStress` method calculates the wind stress components:

$$\tau_x = \rho_{\text{air}} C_d U_{10}^2 \cos\left(\theta_w \frac{\pi}{180}\right) \tag{3}$$

$$\tau_y = \rho_{\text{air}} C_d U_{10}^2 \sin\left(\theta_w \frac{\pi}{180}\right) \tag{4}$$

where C_d is obtained from `ComputeDragCoefficient`. The stress components represent the force per unit area exerted by the wind on the water surface, resolved in the x- and y-directions based on the wind direction.

Physical and Mathematical Models

The `WindForcing` class employs the following models:

- **Drag Coefficient**:

$$C_d = (0.75 + 0.067U_{10} + 0.1H_s) \times 10^{-3}, \quad C_d \in [0.001, 0.003] \tag{5}$$

- **Wind Stress**:

$$\tau_x = \rho_{\text{air}} C_d U_{10}^2 \cos\left(\theta_w \frac{\pi}{180}\right) \tag{6}$$

$$\tau_y = \rho_{\text{air}} C_d U_{10}^2 \sin\left(\theta_w \frac{\pi}{180}\right) \tag{7}$$

These models capture the wind-induced momentum transfer to the estuarine surface, accounting for variations in wind speed, direction, and sea state, and are designed for integration with broader estuarine circulation models.