Supporting Information for "Flow Separation and Increased Drag Coefficient in Estuarine Channels with Curvature"

Tong Bo[1,2], David K. Ralston[2]

[1]MIT-WHOI Joint Program, Cambridge, MA 02139, United States

[2]Woods Hole Oceanographic Institution, Applied Ocean Physics and Engineering, Woods Hole, MA 02543, United States

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Introduction This supporting information includes additional details on the extra dissipation contributed by secondary circulation.

Text S1. Extra energy loss associated with secondary circulation

The energy loss associated with secondary circulation includes two parts: additional bottom dissipation due to lateral velocity and the enhanced bed shear stress, and increased internal frictional loss associated with lateral shear. The total energy dissipation and the energy loss due to lateral circulation are calculated in section 3.4. The total dissipation ϵ_t is same as the right side of equation (5).

$$\epsilon_t A_b = \int_{A_b} \vec{u}_b \cdot \vec{\tau}_b \mathrm{d}A + \int_V \rho_0 K_V \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right] \mathrm{d}V, \tag{S1}$$

where we have dropped the horizontal dissipation term as it is negligible (section 3.4). The control volume V with bottom area A_b is built on slices across the channel, and the energy dissipation is calculated as depth-integrated and laterally-averaged result. $\vec{u}_b$ and $\vec{\tau}_b$ are vectors of the bottom velocity and bottom shear stress. u is the along-channel velocity and v is the lateral velocity. K_V is the vertical viscosity. Likewise, ϵ_l — the dissipation contributed by lateral circulation — is calculated as

$$\epsilon_l A_b = \int_{A_b} v_b \tau_{bl} \mathrm{d}A + \int_V \rho_0 K_V \left(\frac{\partial v}{\partial z} \right)^2 \mathrm{d}V. \tag{S2}$$

v_b is the lateral bottom velocity and τ_{bl} is the lateral component of bottom shear stress. The terms in equation (S2) are also contained in equation (S1). The calculation is based on the average over two tidal cycles. We converted the energy dissipation to a corresponding drag coefficient $C_{D,energy}$ (Figure S1) by using

$$\epsilon = \rho_0 C_{D,energy} U^3 \tag{S3}$$

with U being the cross-sectionally averaged along-channel velocity. $C_{D,energy}$ represents the corresponding energy loss at each cross-section along the channel.

The drag coefficient in Figure S1 is consistent with the drag coefficient from the momentum balance (Figure 2), because the energy loss and momentum loss are correlated. In the straight channel, the energy loss associated with lateral circulation is almost zero because lateral circulation is weak without the channel curvature effect. In the sinuous channel, the energy loss associated with lateral circulation generally accounts for $10-20\%$ of the total energy dissipation. By comparing the lateral circulation energy loss in the sinuous channel with the total energy loss in the straight channel, the maximum drag increase contributed by secondary circulation is about 30%. The 30% increase appears at the seaward bends, where form drag is also largest. In the shallower landward bends where flow separation is weaker, the drag increase due to secondary circulation is also smaller. Therefore, secondary circulation is a less dominant source of increased drag compared to that of flow separation in these relatively sharp bend models (section 3.4).

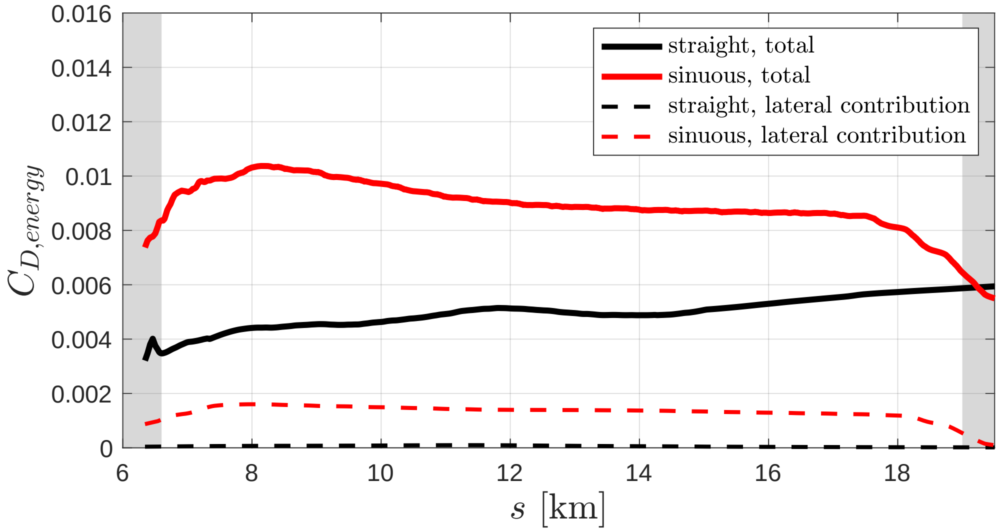

Figure S1. Total energy dissipation and the lateral contribution. Red lines represent the sinuous model and black lines represent the straight model. Solid lines are the total energy dissipation and dashed lines are the energy loss due to lateral circulation. The energy loss is converted to a corresponding drag coefficient. The results are smoothed over the bend scale.