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Tide-induced suspended sediment transport: depth-averaged concentrations and horizontal residual fluxes

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Depth-averaged suspended sediment concentrations (DASSC) and horizontal residual fluxes (HRF) are derived analytically in order to distinguish the relative contributions of different forcing factors (and their interactions), including tidal currents, tidal heights, and horizontal DASSC gradients. On this basis the effect of horizontal advection and local resuspension and deposition processes can be clarified.

The analytical solution of the temporal evolution of the DASSC is obtained based on three main assumptions: (1) the effect of vertical circulation on the suspended sediment transport is small, this being associated with the well-mixed nature of the water body; (2) sediment resuspension is proportional to the square of the depth-averaged velocity multiplied by a constant resuspension capacity, this being associated with an erosion constant, the drag coefficient and a critical shear stress, deposition resulting from the vertical sediment inventory multiplied by a constant deposition capacity, which is related to the sediment settling velocity and the ratio between the near-bed SSC and the sediment inventory; and (3) the DASSC gradient is constant over time. If the tidal current velocities and tidal heights are decomposed to non-periodic M2 and M4 compositions at the study site, and neglecting the high-order (>1) trivial terms, the analytical solution can be written as the sum of eight components.

The eight components (E1 to E8) of the analytical solution indicate different processes affecting the DASSC. The non-periodic E1 component corresponds to the SSC averaged over depth and tidal cycle, being controlled by the suspension capacity and the combined effect of the DASSC gradient and the residual velocity. The E2, E3 and E4 components show the M2 variations. The E5 and E6 components represent the M4 variations, whereas the E7 and E8 components demonstrate the M6 variations of the DASSC. The E6 component is caused by the M2 velocity, and is considered to contribute most to the total DASSC variation. All the components are balanced by the deposition capacity, which is associated with the settling lag effect of the DASSC.

The HRF can be expressed empirically in the decomposed form on the basis of observations (F1 to F5), where F1 represents the Eulerian flux, F2 the Stokes' drift, and F3 to F5 stand for the effect of tidal pumping. In accordance with the solution of the DASSC, F1 to F5 can be formulated such that the phase differences between the M2 and M4 currents and the settling lag effect play an important role in determining the direction and magnitude of tidal pumping.

In-situ observations in a deep channel of a macro-tidal embayment, Yangkou Harbor, Jiangsu coast, China, are used to validate the analytical solution. The tidal currents and the SSC were observed by a ship-mounted ADCP at a fixed station. The analytically predicted DASSC is fitted to the observations by means of three calibrated parameters, including the resuspension and deposition capacity and the DASSC gradient because these are difficult to estimate in the field. The fitted curve shows reasonably good agreement, which is indicated by the fact that the E2, E3 and E6 components contribute 29.8 %, 12.3 % and 42.7% to the total DASSC variations, respectively. The E2 component is mainly related to the DASSC gradient and the M2 tidal heights, the E3 component is caused by the interaction between the M2 and M4 velocities, and the E6 component is induced by the M2 velocity.