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Role of space-time-dependent eddy viscosity on the spatial pattern of tidal and residual flow in estuaries

Wei Chen and Huib de Swart
Institute for Marine and Atmospheric research, Utrecht, Utrecht University, the Netherlands (w.chen4@uu.nl)

Several field studies in estuaries show non-logarithmic profiles of the tidal flow amplitude over the water column and complex patterns of residual flow. To gain fundamental understanding about these phenomena, a semi-analytical 3D model is designed and analysed, with focus on the sensitivity of the spatial pattern of tidal (semi-diurnal) and residual (tidally-averaged) flow to formulations of eddy viscosity that account for spatial and temporal variations. To allow comparison of model results with field observations measured in sigma-levels, the model is formulated in sigma-coordinates. The residual flow is decomposed into individual contributions induced by river discharge (including discharge due to Stokes return flow), horizontal density gradient, tidal rectification, wind, depth-dependent friction and asymmetric tidal mixing due to temporal covariance between eddy viscosity and velocity shear.

By using scaling and perturbation techniques, new analytical solutions for semi-diurnal tide and residual flows are found for space-time-dependent eddy viscosity. The model reveals that “Surface Velocity Jumps” (tidal flow amplitude non-logarithmically increasing near the surface of water column) and “Subsurface Velocity Jets” (maximum tidal flow amplitude shows at subsurface of water column) occur for relatively low mixing conditions. Model output is subsequently compared with field data collected at an estuarine cross-section in the North Passage of the Yangtze (Changjiang) estuary.

It is found that the modelled tidal velocity shear agrees better with observations when using space-time-dependent eddy viscosity instead of a constant eddy viscosity. Moreover, the spatial patterns of individual residual flow components on along-estuary direction are more spread over the cross section, which agrees with observations. With space-time-dependent eddy viscosity, it turns out that density gradient and time-varying mixing are key forcing agents of residual flow.