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A semi-analytical study on the residual transport of salinity and sediment trapping in well-mixed estuaries

Xiaoyan Wei [1] and Mohit Kumar [2] and Henk M. Schuttelaars [3]

Keywords: lateral circulation, residual transport, sediment, baroclinic forcing, estuaries.

Abstract

Along-channel and cross-channel sediment transport in tidal estuaries is usually driven by tides, density gradients, Coriolis's force, wind stress, channel curvature and bathymetric variations. Since the water motion is influenced by density-induced gravitational circulation which in turn affects the salinity distribution, the coupled water motion and salinity has a potentially strong effect on the residual sediment transport, and thus the trapping of fine sediment. To better understand the dynamical effects of water motion and salinity on sediment transport, the salinity field has to be computed consistently.

In this work, the water density is assumed to be a function of salinity only, thus ignoring the influence of temperature and assuming the sediment concentration to be low. To obtain the coupled water motion and salinity, the three-dimensional shallow water equations and the salinity equation are solved simultaneously using a perturbation method together with an iterative finite element method (Kumar et al., 2016; Wei et al, in preparation), resulting in a consistent water motion and salinity field. This information is then used to calculate the sediment concentrations, so that the influence of the salt dynamics on sediment transport is prognostically calculated. Owing to the adopted perturbation method, the contribution of various physical processes to residual sediment transport can be studied separately, which allows for a full investigation on individual contribution of each process to longitudinal/lateral transport of salinity and sediment. Moreover, as wind is another important forcing of estuarine circulation (Chen et al., 2009, de Jonge and van Beusekom 1995, Ridderinkhof et al., 2000), the influence of wind stress on estuarine sediment transport will be studied. The present work will bring insights into sediment transport and trapping mechanisms in real estuaries, for example, the Delaware estuary.

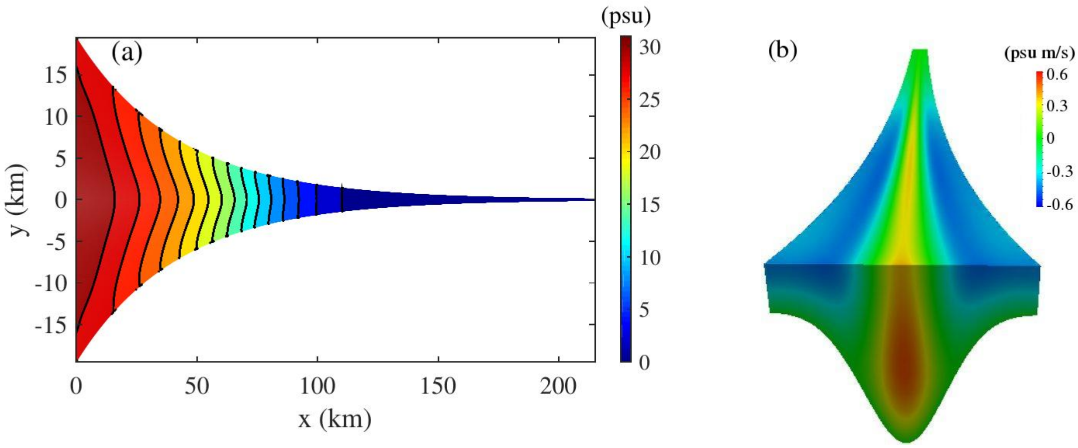

Figure 1: (a) Residual salinity distribution, and (b) the along-channel salt flux induced by gravitational circulation for an exponentially convergent channel with a laterally varying bathymetry.

We assume the estuary to be well-mixed, and the width is exponentially convergent with a laterally Gaussian-shaped bathymetry (ignoring Coriolis and wind), representative for the Delaware estuary. The residual salinity in leading order is vertically homogeneous and time-independent. Higher salinity is found in deeper channels than on the shoals (see Fig. 1a), symmetric with respect to the mid-axis of the channel. The residual salinity transport by gravitational circulation shows not only significant longitudinal circulations, but also remarkable lateral patterns (see Fig. 1b), with the salt transported landward from the deep channel and seaward from the shoals.

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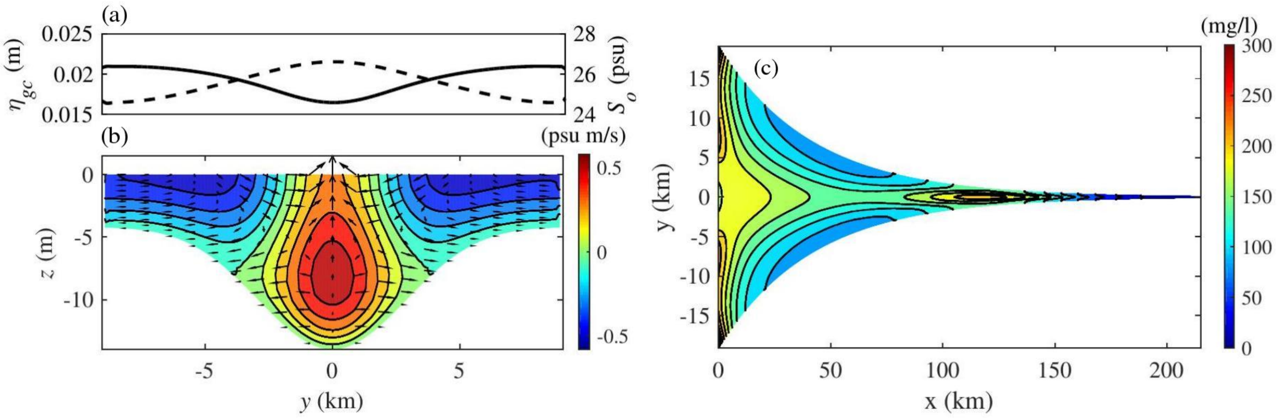

Figure 2: (a) The lateral distribution of the residual water level induced by gravitational circulation (η_{gc}, solid line) and salinity (S_o, dashed line) at x=32 km. (b) The cross-sectional distribution of salt flux induced by gravitational circulation. Positive values shows landward flux induced by gravitational circulation, and vice versa. The arrows show the direction of cross-sectional salt flux, with the perspective looking seaward. (c) The depth-averaged residual sediment concentration.

Requiring the normal (depth-integrated) salt transport to vanish at both banks, a counter-gradient residual water level is induced by gravitational circulation, with higher water levels near the shoals than in the deep channel (see solid line in Fig. 2a). The lateral salinity difference drives bankwards flow on both sides in the direction of the density pressure gradient, while the free surface slope drives return flow towards the mid-axis of the estuary, as is reported by Huzzey et al (1988). This results in a divergent salt flux near the bottom and a convergent flux near the surface, since the impact of the salinity gradient increases towards the bed (see arrows in Fig. 2b). This lateral and longitudinal process of gravitational circulation, together with other residual contributions (not shown) results in a much higher depth-averaged sediment concentration in the deeper channel, and an estuarine turbidity maximum (ETM) at around 120 km from the mouth, as shown in Fig. 2c.

The lateral structure of salinity and sediment as shown above are mainly associated with the estuarine bathymetry and geometry, and the magnitude and location of ETM are expected to change under influence of non-negligible wind forcing or earth's rotation, which significantly affects the lateral exchange of momentum, thus altering the along-channel momentum. In the presentation, the influence of cross-channel wind and Coriolis' effect on residual salt transport and sediment-trapping mechanisms will be shown in more detail.

References

Chen, S.N. and Sanford, L.P., 2009. Axial Wind Effects on Stratification and Longitudinal Salt Transport in an Idealized, Partially Mixed Estuary. Journal of Physical Oceanography, 39(8), pp.1905-1920.

De Jonge, V.N. and Van Beusekom, J.E.E., 1995. Wind-and tide-induced resuspension of sediment and microphytobenthos from tidal flats in the Ems estuary. Limnology and oceanography, 40(4), pp.766-778.

Huzzey, L. M., 1988. The lateral density distribution in a partially mixed estuary. Estuarine, Coastal and Shelf Science, 26(4), pp.351-358.

Kumar, M., Schuttelaars, H.M., Roos, P.C. and Möller, M., 2016. Three-dimensional semi-idealized model for tidal motion in tidal estuaries. Ocean Dynamics, 66(1), pp.99-118.

Ridderinkhof, H., van der Ham, R. and van der Lee, W., 2000. Temporal variations in concentration and transport of suspended sediments in a channel-flat system in the Ems-Dollard estuary. Continental Shelf Research, 20(12), pp.1479-1493.

Wei, X., Kumar, M., and Schuttelaars, H.M., in preparation. The impact of bathymetry and geometry on salt dynamics in well-mixed estuaries.