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Linkage of vertically differentiated unidirectional freshwater flux and suspended sediment transport in the Abukuma river mouth

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The objective of this study is to give more detailed insight into fate of sediment particles when they approach the interface layer between fluvial and oceanic water in order to better understand transportation mechanisms of pollutants in estuaries.

The purpose of this theoretical concept and applied general ocean circulation numerical model MSSG is to show the application of vertically differentiated unidirectional freshwater flux $dQdz = \partial(v*s)/\partial z$ as useful for explaining the suspended sediment transport in the middle of the water column at the river mouth. It is used as a link between hydrodynamic phase and suspended sediment transport phase in strongly stratified estuaries as a consequence of fluvial forcing during high discharge in combination with stable salt wedge formation (hereafter referred as "high discharge").

During field observations in March and September 2013, distributions of radionuclides, salinity, temperature and turbidity within the coastal zone near the Abukuma river mouth were observed (Yamashiki et al., 2013). The particular motivation for the study was an unexpected vertical turbidity distribution which showed peaks 500 m downstream of the river mouth towards the ocean at depths that correspond to the middle river water column, while freshwater inflow at those depths was not simultaneously observed. We tried to find the specific mechanism which led to the observed peak of turbidity on station 1 at a depth of 4.5 m, while freshwater intrusion was not observed at the same depth (Figure 1).

We suggest that for highly stratified estuaries where a stable salt wedge forms, peak suspended load transport rate will take place in river mouth vicinity on the internal interface shear layer between fluvial and oceanic water. The reason for that is that dQdz has its maximum at that depth.

We used z-leveled general ocean circulation numerical model MSSG (Kida, 2011) solving incompressible Navier-Stokes equations to predict the flow field. The turbulent-sediment transporting flow was based on the observed turbidity data (Figure 1) and joined with the model outputs by comparing the modeled dQdz with both its theoretical concept and the observed turbidity quantities. As our major intention was to consider influence of fluvial inflow towards the ocean, we defined various boundary conditions mostly from the river side and only briefly from the ocean in order to find an oceanic response to diverse fluvial conditions. Major emphasis was put on diverse hydrodynamic processes during rising limb

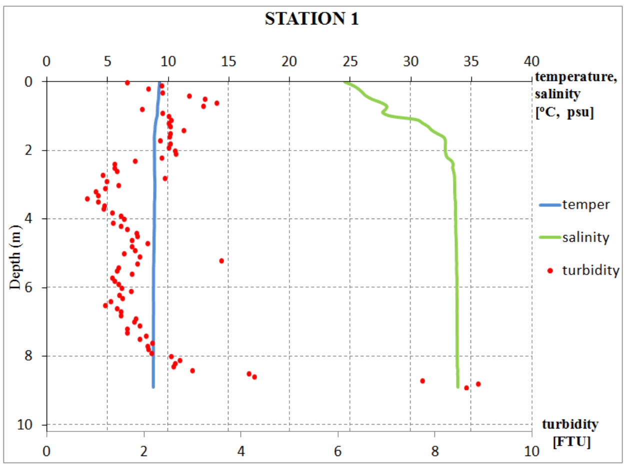

Figure 1. Observed temperature, salinity and turbidity data over the water column at Station 1 (Yamashiki et al., 2013)

stage of an extreme fluvial discharge event, with the biggest focus on high discharge. We also modeled a low discharge case and compared the results with a high discharge case.

We used the ETOPO1 (Amante and Eakins, 2009), 1 Arc Minute Global Relief Model for initial bathymetry conditions and the World Ocean Atlas 2005 (NODC, 2007) for initial temperature, salinity and pressure data. The domain was discretized with rectangular 100×100 cells with 200 m resolution and 35 depth layers of 1 m resolution each, with time increments of 1 h from the start of the simulation. Horizontal domain was from 140.89E to 141.07E longitude and 37.96N to 38.14N latitude. The river outlet was 800 m wide and 7 m deep for high discharge and 6 m deep for low discharge. It was positioned in the central west point of the model from 140.89E to 140.92E, so the river channel was simulated to be 2.6 km long. The middle of the river channel was placed at 38.045N latitude, which corresponds to the position where all modeled results will be shown. Northern, southern and eastern boundaries were closed. At the beginning of the simulation the whole domain including the river channel was full of saltwater and afterwards freshwater is entering to the domain with constant unidirectional velocity v. Thus, the simulation needed some time to obtain realistic results, defined as the time from the beginning of the simulation until equilibrium state establishment between saltwater and incoming freshwater.

Figure 2 shows the most important result of the study, dQdz 8 hours after starting the simulation for high unidirectional velocity v = 1 m/s. The maximum dQdz value is located in the river mouth vicinity in the middle of the water column due to the high discharge. The positive peak in the middle of the water column in the vicinity of river mouth is an extension of dQdz peaks from lower layers of the water column. The internal interface shear layer acts as a boundary where sediment settling velocities decrease and therefore its concentration in upper columns increase. It is similar to place in the middle of the water column where was observed (Yamashiki et al., 2013) an unexpected peak in turbidity data (Figure 1).

We conclude that dQdz can be used to solve the mechanism for occurrence of the middle water column turbidity peaks in a stratified estuary with occurrence of a stable salt wedge. The salt wedge type of estuarine circulation for the given high discharge causes a strong vertical stratification of freshwater and saltwater fluid densities. We neglected the tidal effect in order to isolate the specific mechanism of turbulence suppression by stratification to focus solely on fluvial influence to suspended sediment transport. Modeled results of dQdz for high discharge have positive peak in the middle of the water column in vicinity of the river mouth on the internal interface shear layer between fluvial and oceanic water. This corresponds to the same depth where the turbidity peak was found by field observations (Figure 1).

Although we did not quantitatively solved the linkage between phases, we discussed meanings of dQdz results and qualitatively approached theoretical governing mechanisms about how they may influence suspended sediment phase flow.

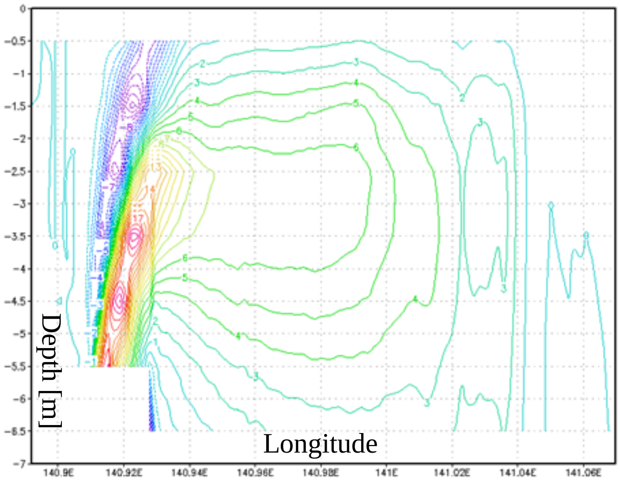

Figure 2. Vertically differentiated unidirectional freshwater flux dQdz = ∂(v*s)/∂z [m/(s*psu)/m'] on river mouth longitudinal section 38.045N for t = 8 hours and high unidirectional velocity v = 1m/s