Intertidal Sediment Transport and Morphological Response in San Francisco Bay using Modified Princeton Ocean Model

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1. Introduction

A wetting and drying scheme (WDS) has recently been developed and incorporated into the Princeton Ocean Model (POM; Blumberg and Mellor, 1983) to simulate tidal currents in San Francisco Bay, CA, USA (WD-POM; Uchiyama, 2004). An extended logarithmic law was newly introduced into WDS so as to accurately estimate bed shear stresses and resultant sediment resuspension and deposition in extremely shallow basins. San Francisco Bay (**Figure 1 (a)**) is a tidally-forced, semi-enclosed estuary encompassed by huge intertidal area including mudflats and salt marshes where flooding and draining are predominant for hydrodynamics. In the present study, cohesive sediment transport and bed elevation changes are modeled and adapted to WD-POM to assess intertidal morphodynamics in San Francisco Bay.

2. Numerical Modeling

POM consists of a set of the primitive equations, Mellor-Yamada level 2.5 (vertical) and a Smagorinsky-type (horizontal) turbulence closure models with the Boussinesq approximation and hydrostatic assumption. The governing equations are transformed from the 3D Cartesian coordinate into the orthogonal curvilinear coordinate (horizontal) and σ coordinate (vertical) to smoothly follow complex terrain geometries and marine bathymetries as shown in **Figure 1 (b)**. A wetting and drying feature is implemented by Uchiyama (2004) to deal with hydrodynamics in extremely shallow basins including intertidal flats and salt marshes. The cohesive sediment transport submodel is coupled with WD-POM as expressed in Eqn. (1).

$$\frac{\partial CD}{\partial t}+\frac{\partial UCD}{\partial x}+\frac{\partial VCD}{\partial y}+\frac{\partial(\omega-W_s)C}{\partial\sigma}=\frac{\partial}{\partial\sigma}\left[\frac{K_H}{D}\frac{\partial C}{\partial\sigma}\right]+F_C \qquad (1)$$

where D: total depth ($=H+\eta$, H: depth, η: surface elevation), C: cohesive sediment concentration, W_s: settling velocity, K_H: vertical eddy diffusivity, and F_C: horizontal diffusion term. Equation (1) is transformed from the regular Cartesian coordinate into the horizontal curvilinear and vertical sigma coordinate as used in WD-POM. The boundary conditions at surface and seabed are:

$$\frac{K_H}{D}\left(\frac{\partial C}{\partial\sigma}\right)=0, \quad \sigma\to 0 \qquad \text{at sea surface} \qquad (2)$$

$$\frac{K_H}{D}\left(\frac{\partial C}{\partial\sigma}\right)=E_r-D_p, \quad \sigma\to -1 \qquad \text{at seabed} \qquad (3)$$

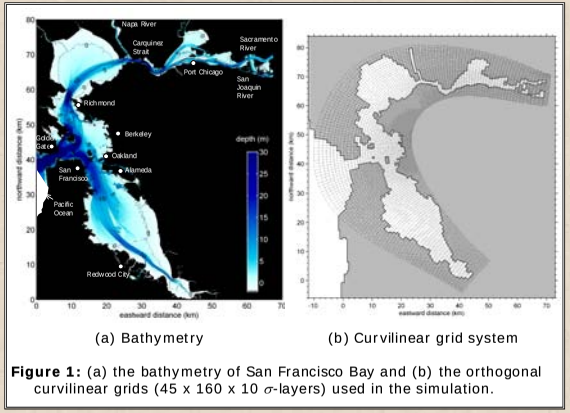
Where E_r, D_p: erosion and deposition rates at the seabed empirically formulated. The source term, E_r, is evaluated to represent resuspension of cohesive sediments from the bed in accordance with the conventional formulation using the threshold τ_{ce} for the bed shear stress τ_b (Krone, 1962). Similarly, the sink term, D_p, is calculated with the parameterization by Partheniades (1992). Settling velocity, W_s, of cohesive flocs is calculated with the parameterization by Burban *et al.* (1990) in which flocculation is assumed to be related to the local concentration and vertical shear stress in water column. Shear stress at the seabed is formulated with consideration of the extended logarithmic law (Uchiyama, 2004) to be:

$$\tau_b=\rho u^{*2}=\rho\left[\kappa u/\ln(z/z_0+1)\right]^2 \qquad (4)$$

in which κ: the von Karman constant, u^*: friction velocity, z_0: roughness height. Bathymetry change can be evaluated based upon the volume conservation of the bed sediments expressed as:

$$\frac{d\,h_b}{d\,t}=\lambda_s\left(E_r-D_p\right) \qquad (5)$$

where h_b: bed elevation, λ_s: porosity of the bed sediments.



(a) Bathymetry (b) Curvilinear grid system

Figure 1: (a) the bathymetry of San Francisco Bay and (b) the orthogonal curvilinear grids (45 x 160 x 10 σ-layers) used in the simulation.

3. Results and Discussions

Astronomical tidal oscillations are imposed on the open boundary condition off Golden Gate (the bay mouth). Neither fluvial sediments nor surface wind stresses are assumed in the computation for the simplicity. The starting date of the simulation is March 29, 2003 (the 88th Julian day in 2003) and simulation *spin-up* (McDonald and Cheng, 1997) is done for the first 14 days. The model outputs exhibit that during a spring tide cohesive sediments are suspended dominantly in the deeper channels while being transported and deposited on intertidal areas fringing the bay at ebbing phases (**Figure 2**). This tendency can also be observed during neap tides although the variations are small. The incoming tidal waves are propagating as anti-clockwise Kelvin waves but significantly refracted on the intertidal slopes (Uchiyama, 2004). Thus, once the bed cohesive sediments are resuspended in the channels, they are carried in the direction of ebb tidal currents during ebbs whereas transported onto the intertidal areas owing to the rising tides approaching the shore during floods.

The morphological change due to the tidal currents during two spring-neap cycles (28 days) shows that intertidal mudflats tend to slightly be accreted whereas channels seem rather eroded (**Figure 3**). This result is obviously consistent with the temporal development of the cohesive sediment concentrations (**Figure 2**). Similar morphological behavior is found in a simplified topography with a monochromatic sinusoidal tide (**Figure 4**). The flooding tides evidently cause the shoreward sediment transport to be deposited near the shoreline, and enhance the accretion in the intertidal areas.

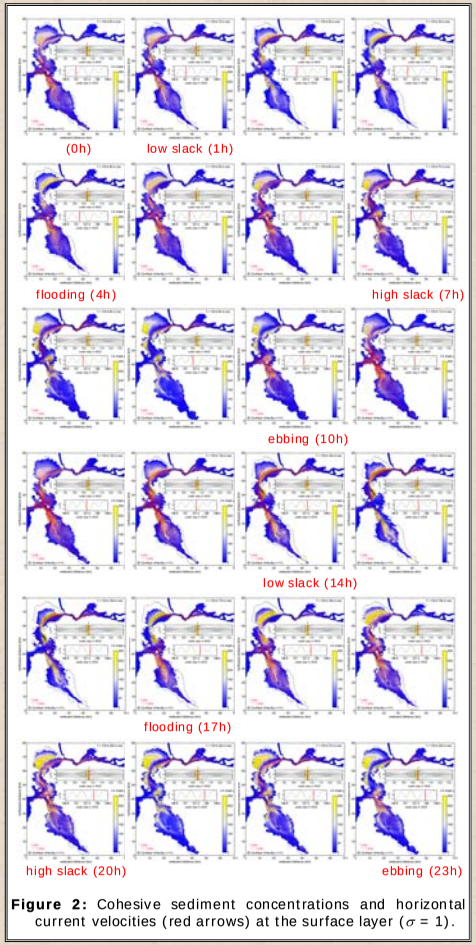


Figure 2: Cohesive sediment concentrations and horizontal current velocities (red arrows) at the surface layer (σ = 1).

4. Summary

Cohesive sediment transport and resultant bathymetry change in estuaries encompassed by intertidal area are developed on the basis of WD-POM and applied to San Francisco Bay. The simulated results indicate that the sediments are remarkably suspended (erosion) in the deeper channels while deposited (accretion) on the intertidal fringes. The intertidal areas play an important role in the sediment budgets in the estuary, acting as 'sink' of the suspended cohesive sediments under action of the tidal currents.

References

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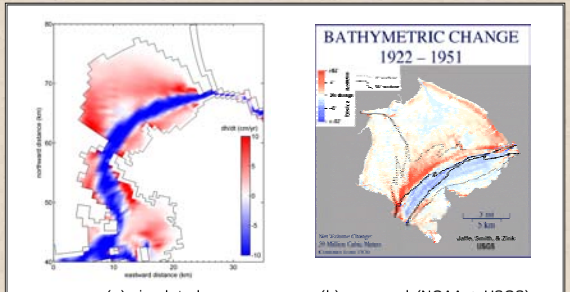

(a) simulated (b) surveyed (NOAA + USGS)

Figure 3: Bathymetry change in San Pablo Bay (north of SF Bay) evaluated by the (a) simulation and (b) bathymetry surveys conducted by NOAA and visualized by USGS (http://sfbay.wr.usgs.gov/access/Bathy/).

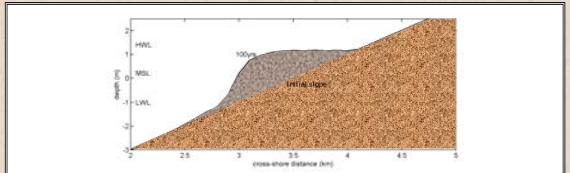

Figure 4: Long-term accretion on an intertidal sloping topography. Only a sinusoidal tidal oscillation is considered at the open boundary (left side).