Assessment of benthic flux of dissolved organic carbon in estuaries using the eddy-correlation technique

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1. Introduction
Estuarine sediments release significant amounts of dissolved organic carbon (DOC) due to high levels of microbial activity. Changes in climate and hydrologic conditions have a potential to alter DOC release as well. This is a concern, as high levels of DOC can lead to mobilization of toxic metals and organics in natural waters. In addition, source waters high in DOC produce undesirable disinfection byproducts in water treatment. Various in situ methods, such as equilibrium dialysis samplers and sediment core centrifugation, exist to quantify vertical benthic fluxes of DOC and other dissolved species from the sediment–water interface (SWI). These techniques, however, are intrusive and involve disturbance of the sediment environment. They are also based on the calculation of the passive diffusive flux, which is known to underestimate the benthic flux in most cases. In this work, we have used the eddy-correlation technique, which allows for real-time, non-intrusive, in situ flux measurement of important analytes, such as DOC (4-5) and DOC, as well as groundwater discharge (6). An acoustic Doppler velocimeter (ADV) is used to obtain three-dimensional fluid velocity measurements. The eddy-correlation technique employs the mathematical separation of fluid velocity into mean and fluctuating velocity components, with the latter representing turbulent eddy velocity. DOC concentrations are measured using a colored dissolved organic matter (CDOM) fluorometer, and instantaneous vertical flux is determined from the correlated data. We have used the eddy-correlation technique to assess the DOC flux from a mudflat in Kittery, Maine, USA. The results are compared to the diffusive flux calculated from sediment pore-water concentrations.

2. Instrumentation
A Vector ADV (Nortek AS, Rud, Norway) was used to obtain water velocity measurements. The ADV uses Doppler principles to measure particle velocities, as a proxy for water velocity, in three dimensions via acoustic backscattering. Velocity measurements are accurate to within a small, cylindrical volume located 15.7 cm from the instrument’s transmit transducer. An ECO-FL CDOM fluorimeter (WETLabs, Philomath, OR, USA) was used to measure in situ DOC concentration, which is an indicator of DOC concentration. The ECO-FL utilizes excitation and emission wavelengths of 370 nm and 460 nm, respectively, corresponding to the fluoresence characteristics of CDOM. The fluorometer measures CDOM concentration at approximately 2 cm from the face of the optics head. Unlike many of the fluorometers used in other studies, the ECO-FL is not a flow-through device, thus reducing the chance of contamination of the water column. Eddy-correlation measurements were done at a frequency of 8 Hz for about 5 hours during flow, high, and ebb tides. The ADV and the ECO-FL were mounted vertically to an A-frame ladder.

3. Deployment
The instrumentation was deployed on September 3, 2009 at a mudflat in a sheltered tidal inlet of the Piscataqua River in Kittery, Maine, USA, near Portsmouth Naval Shipyard (see figures 1 and 3). The site was characterized by fine-grained, cohesive sediments, and the overlying water had an average DOC concentration of 1.8 ppm over the length of the deployment. The ADV and the ECO-FL were mounted vertically to an A-frame ladder (see figure 2). Continuous sampling was done at a frequency of 8 Hz for about 5 hours during flow, high, and ebb tides.

4. Data Analysis
The instantaneous velocity values collected by the ADV can be separated into two components: mean vertical velocity $\bar{w}$ and vertical turbulent fluctuating velocity $w'$ (1). Similarly, fluorescence voltage values obtained with the ECO-FL, once converted into DOC concentrations, can be separated into $\bar{C}$ and $C'$. Both $\bar{w}$ and $C'$ were determined using least squares linear fitting of 10-min. bursts. Values of $w'$ were then obtained, as $w' = w - \bar{w}$. The same process was applied to the concentration data. Since advection is assumed to be the dominant process in the water column in the vertical direction, instantaneous vertical velocity due to turbulent eddies was estimated as $J = w' C$ (1). Continuous flux values were integrated over time to obtain cumulative flux for a given period, and average daily flux was then calculated. Velocity, concentration, and flux data for a sample 10-min. burst are shown in figure 5.

Variations in CDOM concentration can occur due to large scale advective currents, which cannot effectively be evaluated by eddy-correlation and linear trending, so flux calculations were only applied to portions of the data characterized by steady CDOM concentration. This resulted in flux calculations for six 10-min. bursts during the tidal flow and three 10-min. bursts during the ebb tide.

5. Results
Figure 6a shows the net cumulative flux over six 10-min. bursts in the tidal flow period and over three bursts in the tidal ebb period. Based on these measurements, the following average daily fluxes were estimated:

Flux (flow period) = 60.2 mg m$^{-2}$ d$^{-1}$
Flux (ebb period) = 58.5 mg m$^{-2}$ d$^{-1}$

Pore water centrifugation done at the same site in August 2008 yielded diffuse carbon flux values of 4 – 10 mg m$^{-2}$ d$^{-1}$ (7), which are an order of magnitude lower than the eddy correlation fluxes. This difference in magnitude is to be expected other processes, such as bioirrigation and pressure-induced, small advective currents, are considered to be the dominant processes for carbon flux from the sediment.

References:

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