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

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Michael P. Swett[1], Aria Amirbahman[1], Emmanuel Boss[2], Gregory P. Gerbi[3]

[1]Department of Civil & Environmental Engineering, University of Maine, Orono, ME 04469-5711 (michael.swett@umit.maine.edu)
[2]School of Marine Sciences, University of Maine, Orono, ME 04469-5607
[3]Institute of Marine & Coastal Sciences, Rutgers University, New Brunswick, NJ 08901-8521

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 O_2 (*1-5*) 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.

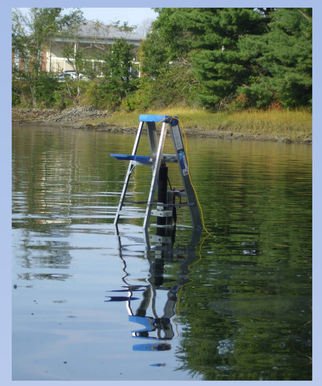

Figure 1 – Eddy correlation device deployed in Kittery, Maine.

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 taken within a small, cylindrical volume located 15.7 cm from the instrument's transmit transducer.

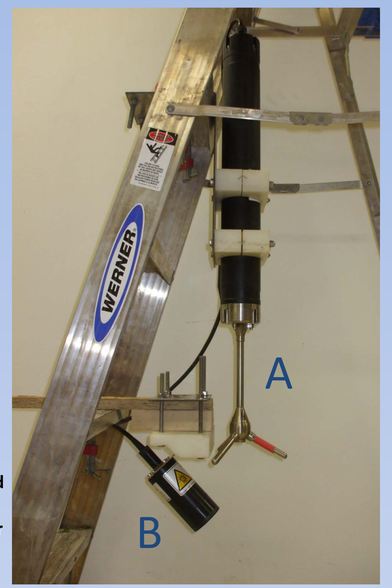

Figure 2 – Nortek Vector ADV (A) and WETLabs ECO-FL CDOM fluorometer (B) mounted on ladder.

An ECO-FL CDOM fluorometer (WETLabs, Philomath, OR, USA) was used to measure in situ CDOM 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 fluorescence 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 velocity measurements.

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 1.80 ppm over the length of the deployment. The ADV and the ECO-FL were mounted vertically to an A-frame ladder (see figure 2) ~0.3 m above the SWI. Continuous sampling was done at a frequency of 8 Hz for about 5 hours during flow, high, and ebb tides.

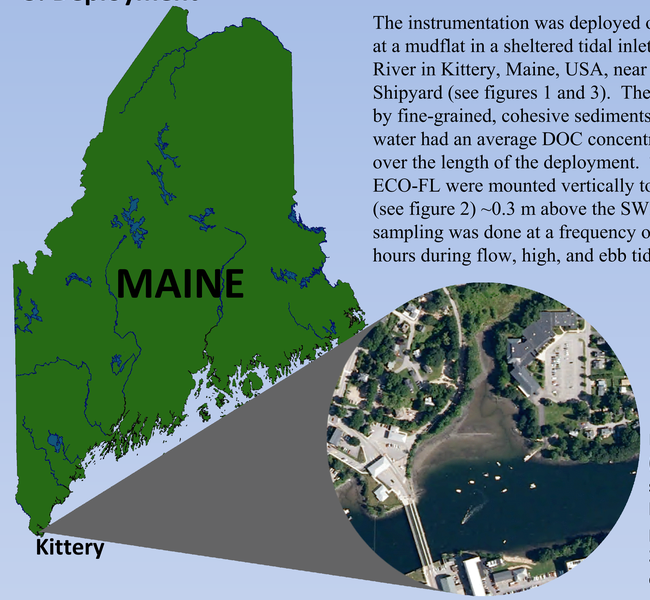

Figure 3 – Map of Maine (ME Office of GIS) showing project site location and aerial photograph (NAIP, 2009) showing tidal inlet on Piscataqua River.

4. Data Analysis

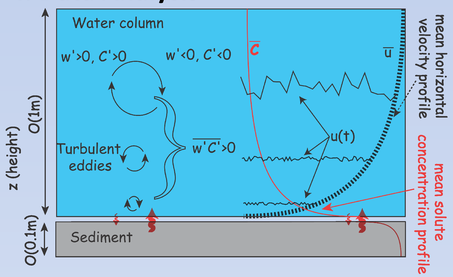

Figure 4 – Conceptual model of turbulence associated with horizontal flow (*u*) over the SWI, coupled with a mean gradient of *C*, enhancing flux of DOC into the water column.

The instantaneous velocity values collected by the ADV can be separated into two components: mean vertical velocity $\overline{w}$ 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 $\overline{C}$ and C'. Both $\overline{w}$ and $\overline{C}$ were determined using least squares linear fitting of 10-min. bursts. Values of w' were then obtained, as $w' = w - \overline{w}$. 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 flux 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 tidal ebb.

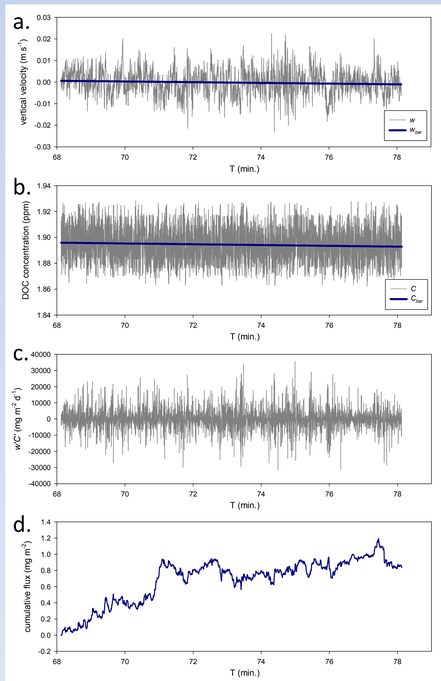

Figure 5 – Example data from a 10-min. burst: (a) vertical velocity and linear fit; (b) DOC concentration and linear fit; (c) instantaneous flux; and (d) cumulative flux.

5. Results

Figure 6.a 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:

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

Pore water centrifugation done at the same site in August 2008 yielded diffusive 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, since other processes, such as bioirrigation and pressure-induced, small advective currents, are considered to be the dominant processes for carbon flux from the sediment.

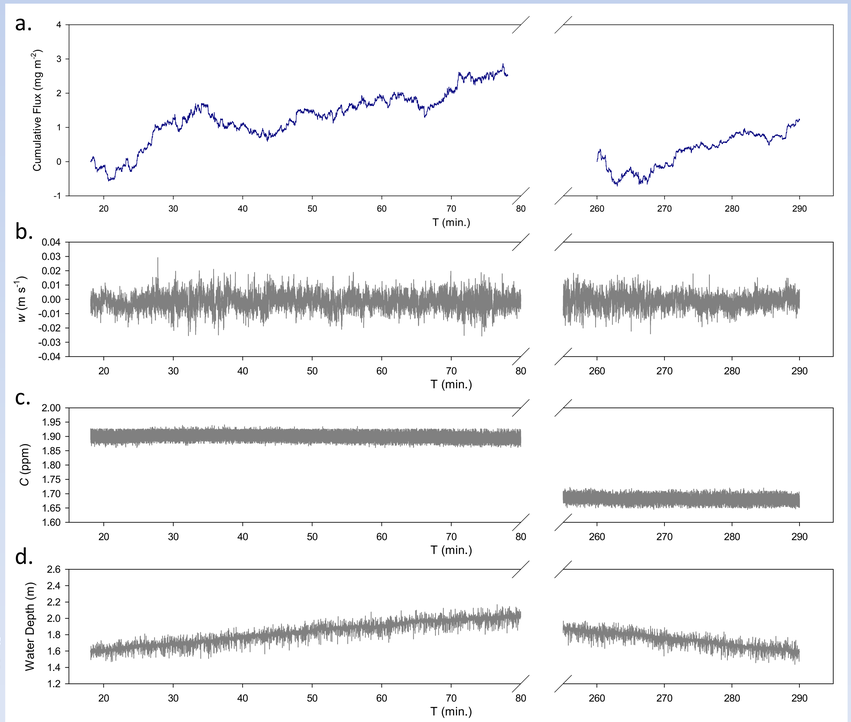

Figure 6 – (a) Cumulative flux; (b) vertical velocity; (c) DOC concentration; and (d) water depth.

References:
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