P4.6 AN ALTERNATIVE APPROACH OF WPL: CONTRIBUTION FROM WATER VAPOR

Heping Liu
Jackson State University, Jackson, MS, USA

1 INTRODUCTION

Energy and CO_2 fluxes are commonly measured above plant canopies using an eddy covariance system that consists of a three-dimensional sonic anemometer and an H_2O/CO_2 infrared gas analyzer. By assuming that the dry air is conserved and inducing mean vertical velocity, Webb et al. (1980) obtained two equations to account for density effects due to heat and water vapor transfer on H_2O/CO_2 fluxes.

Directly starting with physical consideration of air-parcel expansion/compression, Liu (2005) derived two alternative equations to correct for these effects, which do not require the assumption (i.e., the dry-air is conserved) and the use of the mean vertical velocity.

In this study, we extensively tested and compared these two alternative equations proposed by Liu (2005) with those by Webb et al. (1980) using data collected over three boreal ecosystems. Over these three different ecosystems, the equations developed by Liu (2005) led to consistently increased estimates of CO_2 uptake by the vegetation during the day (up to about 24%), and decreased estimates of CO_2 respiration by the ecosystem during the night (approximately 4%) as compared with estimates obtained using the Webb et al. approach.

* *Corresponding author's address:* Heping Liu, Jackson State University, Dept. of Physics & Atmospheric Sciences, P. O. Box 17660, Jackson, MS 39217, USA; e-mail: Heping.Liu@jsums.edu

2 FIELD SITES

The data used in this study were collected in three sites near Delta Junction in interior Alaska (63^o 54'N, 145 ^{o}40'W). More detail site information can be found in Liu et al. (2005).

Grass

Grass and shrub in this site established after the Donnelly Flats fire that occurred in June of 1999 just south of Delta Junction (63^{o}55'N, 145^{o}44'W). The boles of the black spruce remained standing three years after the fire with a mean height of 4 m and a stand density of 2691 ± 778 dead trees per ha (M.C. Mack, unpublished data).

In 2002, approximately 30% of the surface was covered by bunch grasses (*Festuca altaica*) and deciduous shrubs (that had a height less than 1 m). The other 70% of the surface was not covered by vascular plants. A uniform fetch from the tower extended for more than 1 km in all directions. Moss cover expanded in each consecutive year since the burn, and consisted of *Polytrichum* and *Ceratodon* species.

Aspen

The aspen site was located southeast of Delta Junction (63^{o}56'N, 145^{o}37'W). The canopy developed after the Granite Creek fire occurred in 1987. In 2002, heterogeneous aspen and willow species dominated the overstory (*Populus tremuloides* and *Salix* spp.). Aspen had a mean canopy height of 5 m. The sparse understory vegetation included shrubs (*Salix* spp., *Ledum paustre*, *Rosa acicularis, Vaccinium uliginosum,* and *Vaccinium vitis-idaea*), black spruce (*Picea mariana*), and grasses (*Festuca* spp. and *Calamagrostis lapponica*), separated by patches of moss in open areas (*Polytrichum* spp.). The burn scar from the tower extended for more than 1 km to the south, west and north, and approximately 500 m to the east.

Black spruce

The black spruce site was located approximately 5 km to the south of the grass site (63°53'N, 145°44'W). The canopy overstory consisted of homogeneous stands of black spruce (*Picea mariana*) with a mean canopy height of 4 m and a mean age of 80 years based on tree ring measurements. The sparse understory consisted primarily of shrubs (*Ledum palustre*, *Vaccinium uliginosum*, and *V. vitis-idaea*). The dominant ground cover species were feathermoss (*Pleurozium schreberi* and *Rhytidium rugosum*) and lichen (*Cladonia* spp. and *Stereocaulon spp.*). Moss and soil organic layers had a mean depth of approximately 11 cm to mineral soil. The site extended from the tower for more than 1 km to the south, west and north, with the shortest fetch to the east (approximately 200 m).

3. INSTRUMENTS

Turbulent fluxes of sensible heat (H), latent heat (LE), and carbon dioxide (CO_2) were measured at each site with an eddy covariance system that consisted of a three-dimensional sonic anemometer (CSAT3, Campbell Scientific, Inc.) and an open-path carbon dioxide/water vapor (CO_2/H_2O) infrared gas analyzer (IRGA; LI 7500, LI-COR, Inc.). The sonic anemometers measured fluctuations of the three components of wind velocity and fluctuations of sonic temperature of the atmosphere. IRGAs measured fluctuations of densities of water vapor and carbon dioxide. At each site, the eddy covariance system was mounted at a height approximately 2 times that of the mean canopy on an aluminum tower (Climatronics Corp.).

Sensor signals were recorded by dataloggers (CR5000, Campbell Scientific, Inc.) at a rate of 10 Hz. Vertical fluxes of sensible (H) and latent heat (LE) were obtained via 30-min mean covariance between vertical velocity (w') and the respective scalar (c') fluctuation. Turbulent fluctuations were calculated as the difference between the instantaneous and the 30-min mean quantities. Because the temperature obtained from the sonic anemometer is the sonic temperature and because the crosswind effect should be taken into account (Kaimal and Finnigan, 1994), we applied a correction following that established by Liu et al. (2001). We checked the original 10 Hz time series of temperature, H_2O, and CO_2 for spiking/noise. Data points were replaced through linear interpolation when their magnitudes exceeded 5σ of the half hour mean (where σ denotes standard deviation). Some flux data were rejected when winds were blowing through the towers and when the data did not pass a quality check (Foken and Wichura, 1996). In addition, in our analysis and site comparisons, we only included flux data from each site during periods when all three sites were simultaneously active.

Along with the turbulent fluxes, a variety of micrometeorological variables were also measured as 30-min averages of 1 s readings at our three sites. Net radiation (Rn) was measured with net radiometers (Q-7.1, Radiation and Energy Balance Systems [REBS], Inc.) at all three sites. Incoming and reflected global solar radiation were measured with Precision Spectral Pyranometers (Eppley Lab., Inc.) at the grass and black spruce sites. Air temperature and relative humidity were measured at three heights at all three sites with temperature/humidity probes (HMP45C, Vaisala, Inc.). A wind sentry unit (model 03001, RM Young, Inc.) was mounted at the top of the tower to measure wind speed and wind direction while another wind speed sensor (model 03101, RM Young, Inc.) was mounted on each tower at an intermediate height.

At three sites within 2 to 4 m of the tower base we measured soil temperature profiles. In each profile, thermocouples were placed at 0, 2.5, 5, 10, and 20 cm depths below the surface. In 2 of the 3 profiles at each site we also measured the soil heat flux (G_{10}) at a depth of 10 cm using soil heat flux plates (model

HFT3, REBS, Inc.). Precipitation totals were measured at half-hourly intervals at both the grass and aspen sites with an automated tipping-bucket rain gauge (model TE525, Campbell Scientific, Inc.). More detail information about the towers can be found in Liu et al. (2005).

4. METHODS

For comparison, we rewrote the equations from Webb et al. (1980) and Liu (2005) as following

- Webb et al. (1980):

$$E_{WPL} = \overline{w'\rho_v'}(1+\mu\sigma) + \overline{\rho}_v(1+\mu\sigma)\frac{\overline{w'T'}}{\overline{T}}$$

$$F_{cWPL} = \overline{w'\rho_c'} + \frac{\overline{\rho}_c}{\overline{\rho}_a}\mu\,\overline{w'\rho_v'} + \overline{\rho}_c(1+\mu\sigma)\frac{\overline{w'T'}}{\overline{T}}$$

- Liu (2005):

$$E_{Liu} = \overline{w'\rho_v'}\{\frac{\overline{\rho}_v}{\overline{\rho}}(\mu-1)+1\} + \frac{\overline{\rho}_a}{\overline{\rho}}\overline{\rho}_v(1+\mu\sigma)\frac{\overline{w'T'}}{\overline{T}}$$

$$F_{cLiu} = \overline{w'\rho_c'} + \frac{\overline{\rho}_c}{\overline{\rho}}(\mu-1)\overline{w'\rho_v'} + \frac{\overline{\rho}_a}{\overline{\rho}}\overline{\rho}_c(1+\mu\sigma)\frac{\overline{w'T'}}{\overline{T}}$$

where $\mu = m_a / m_v$ and $\sigma = \overline{\rho}_v / \overline{\rho}_a$ and m_a and m_v are the molecular mass of dry air and water vapour, respectively. ρ_a, ρ_v and ρ are the respective densities of dry air, water, and moist air ($\rho = \rho_a + \rho_v$); T is the absolute air temperature. $\overline{w'\rho_v'}$, $\overline{w'T'}$, and $\overline{w'\rho_c'}$ are the respective fluxes of water vapor, sensible heat and CO_2 measured by eddy covariance systems. E_{WPL} and F_{cWPL} are the respective latent heat flux and CO_2 flux after the correction following Webb et al. (1980). E_{Liu} and F_{cLiu} are the respective latent heat flux and CO_2 flux after the correction following Liu (2005).

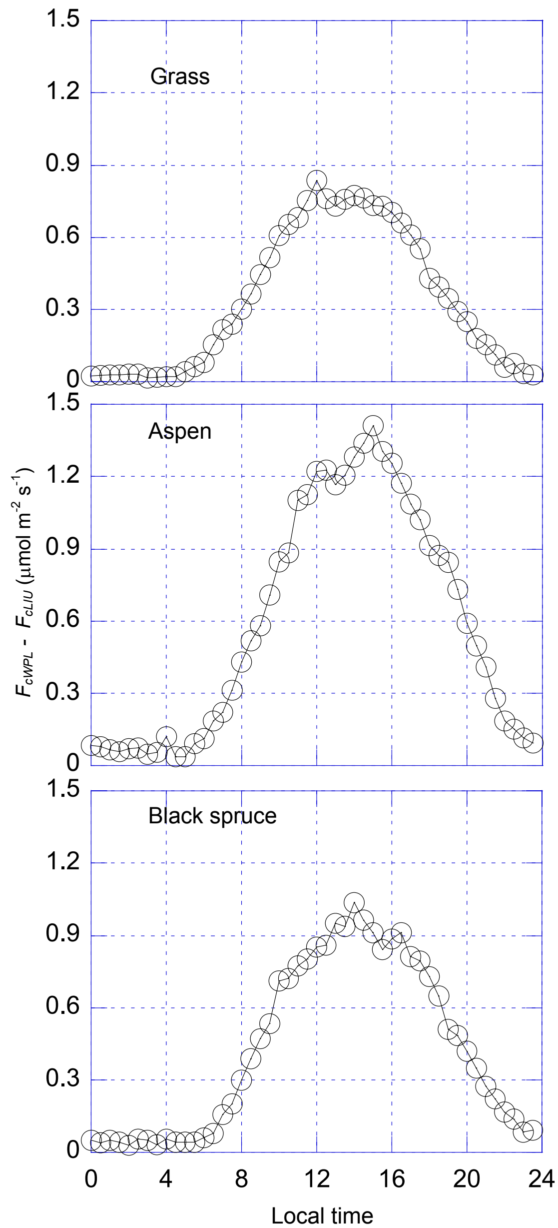

Fig. 1. Comparison of diurnal variations of CO_2 flux difference [$F_{cWPL} - F_{cLIU}$ where F_{cWPL}: CO_2 flux obtained by WPL; F_{cLIU}: CO_2 flux obtained by the Liu (2005) approach] over grass, aspen, and black spruce stands in interior Alaska. Data cover the period from June 17 to August 5, 2003. Total half-hour data numbers are 1,695, 1,793, and 1,895 for the grass, aspen, and black spruce sites, respectively.

5. RESULTS

We obtained the difference in CO_2 fluxes calculated by WPL and the Liu (2005) approach over the three ecosystems. In general, the magnitudes of CO_2 fluxes with the Liu (2005) approach are consistently on average about 10 - 25% more negative than those obtained by using WPL, indicating up to about 0.8, 1.4, and 1.0 μmol m^{-2} s^{-1} more CO_2 uptake by vegetation over the grass, aspen, and black spruce ecosystems, repectively. During the night, the CO_2 flux estimated using the Liu (2005) gives consistently about 3-4% (or about 0.1-0.2 μmol m^{-2} s^{-1}) lower respiration flux than that obtained from WPL.

For the implication of long term NEE estimation, the Liu (2005) approach gives consistently more negative NEE than the WPL correction, implying a larger carbon sink during the growing season. We used the data measured over the growing season in 2003, the difference in total integral of NEE from June 17 to August 5 between WPL and the Liu (2005) approach is 18, 31, and 22 g C m^{-2}, over the grass, aspen, and black spruce ecosystems, indicating more carbon sink when the Liu (2005) approach is applied.

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