P2.1 TURBULENT TRANSPORT ABOVE A MIXED NORTHERN FOREST

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1. INTRODUCION

The eddy-covariance (EC) method is often used to measure the exchange of chemical compounds such as CO_2. Transport is calculated using the covariance of two high frequency measurements. There are problems with the EC method, particularly under light wind conditions. Surface-layer EC measurements represent relatively small flux footprints (~1Km^2). It is difficult to assess the representativeness of single-tower EC fluxes.

In this paper, we compare NEE (net ecosystem-atmosphere exchange) of CO_2 from two nearby sites in Wisconsin using the EC method. Different transport scales of CO_2 are analyzed, and we propose and test a new parameterization of counter-gradient transport in the atmospheric surface layer over a forest canopy. The parameterization describes the observations very well. Finally, we discuss problems that occur under light wind and low turbulence conditions during the morning transition.

2. DESCRIPTION OF STUDY SITE AND DATA

EC measurements were collected from a 30m above-canopy tower (Willow Creek) and a 400m tower (WLEF) in northern Wisconsin. Both are part of the Chequamegon Ecosystem-Atmosphere Study (ChEAS, http://cheas.umn.edu). WLEF represents a wetland-forest mix, while WC observations isolate the contribution of mature hardwood forests to the NEE of the region. Bakwin et al (1998) and Berger et al (J Tech, submitted, 2000) describe the site and instrumentation at WLEF. The WC system can be divided into two parts: a flux system where data(velocities, temperature, vapor and CO_2) are recorded at 10 Hz, and a profile system where CO_2 data are recorded at a slow rate to determine mean mixing ratio profiles and the rate of change of storage term in the NEE budget equation. Flux data are collected just above the canopy, and profile data are collected within and above the canopy.

3. METHODS AND RESULTS

3.1 Comparison of NEE from WLEF and WC

NEE of CO_2 was calculated as the sum of turbulent and storage fluxes measured from the EC towers (Yi et al, 2000). In general, there is a good correlation(r=0.89) between the two sites during the growing season (June through August). The monthly diurnal averages for 1999 show that uptake at WC far exceeds WLEF during mid-summer, but WLEF may have a longer period of uptake (including the months of April and October). The longer period of uptake is probably due to the fact that the WLEF footprint includes conifers, but WC does not. As an example, figure 1 presents the diurnal average comparison of NEE in July of 1999. Table 1 presents the averaged NEE in Apr./Oct. and June/July. In WLEF (wetland-forest mix), NEE is close to half of that in WC (mature hardwood forests). The lower mid-summer NEE at WLEF is probably due to extensive wetlands in its flux footprint, NEE at WC is similar to other temperate deciduous forests.

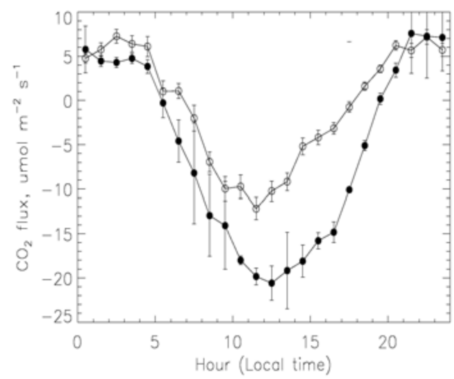

Fig.1 Diurnal average of NEE from WLEF (open circles) and WC (filled circles) in 1999.

Table 1 Averaged NEE (gC/m^2/day) in 1999

	April	June	July	October
WC	1.58	-4.31	-5.34	1.75
WLEF	0.04	-2.16	-0.49	0.27

3.2 Transport scales of CO_2

Figure 2 shows the decomposed scales of CO_2 vertical transport at morning, noon, late afternoon and midnight, respectively. Transport processes are dominated by eddies with the frequency of 0.002 to 0.1Hz. During the morning transition (0600), uptake of CO_2 begins with large eddies, while in the later afternoon, small eddies firstly carry CO_2 upwards.

3.3 Flux-gradient Relationship and Similarity Theory

Traditional flux-gradient relationships cannot work when counter-gradient transport occurs within a canopy or just

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above the canopy. Here, we attempt to introduce a resistance into the flux-gradient relationship to solve the problem of counter-gradient transport. Following Deardorff(1966), let γ be the resistance. γ can be estimated from the maximum gradient value when counter-gradient transport occurs. Based on WC data, γ is roughly equal to 3ppm/m. The relationship between flux and gradient with counter-gradient transport can then be written as,

$$\overline{w'c'} = -K(\frac{\partial C}{\partial z}+\gamma) = -\frac{u_*\kappa(z-d)}{\phi}(\frac{\partial C}{\partial z}+\gamma) \quad (1)$$

Where $\overline{w'c'}$ is the vertical flux of CO_2, u_* is friction velocity, *d* is the displacement depth. Summer data are used to fit the ϕ. The data are broken into three groups according to friction velocity. Figure 3 presents the fitted results. We hypothesize that ϕ can be described by,

$$\phi = \alpha\left|1-\beta\frac{z-d}{L}\right|^{\lambda} \quad (2)$$

where *L* is Monin-Obukhov length. α=30; β= 0.7; λ=-0.8, When $u_* \leq$ 0.2 m/s; α=25; β=3.0; λ= -0.72, when 0.2< $u_* \leq$0.6m/s; α=34; β=20; λ=-0.82, when u_* >0.6m/s. Note that ϕ varies with stability and u_*. This suggests that (2) must be modified further to find a universal ϕ. This dependence of ϕ on u_* maybe a by-product of the apparent drainage of CO_2 that occurs at low u_* values. If this hypothesis is correct, the relationship may change from site-to-site as a function of the local topography.

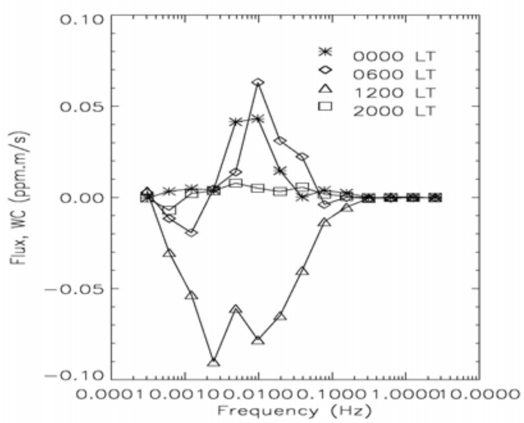

Fig.2 Vertical Transport spectrum obtained from a wavelet method on different times of day 231,1999

3.4 Morning transition issues

Often there is a large discrepancy between the turbulent flux and the RCS (rate of change of storage) of CO_2 in the early morning after very stable, calm nights. Anthoni, et al (1999) show for their site that this cannot be explained biologically. We find similar behavor at WC and WLEF, though not severe. Possible reasons for the quick depletion of CO_2 occurring at the onset of convective turbulence could be that (1) EC technique has large error when flow and turbulence are significantly nonstationary; and (2) other processes such as horizontal flux divergence and advection are neglected (Yi et al, 2000). In the NEE equation, it is not clear that horizontal flux divergence can always be neglected relative to vertical flux divergence (Finnigan, 1999). We estimated horizontal flux divergence using WLEF data in May 1998, and it had values that could explain the discrepancy in some but not all cases.

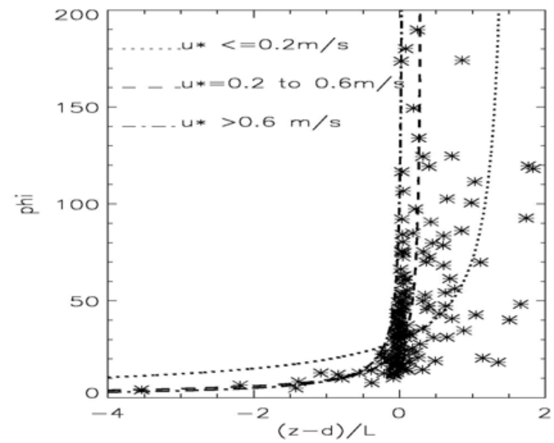

Fig.3 The fitted curve of ϕ, asterisks are observed data

Another issue possibly related to the morning transition problem is slow CO_2 leakage (during the entire night) into low-lying areas. To examine the spatial distribution of CO_2 during stable nighttime and early morning conditions, an experiment was performed where a portable infrared gas analyzer (IRGA) and a GPS receiver were carried along transects near our research sites just before and after sunrise. The experiment confirmed that low-lying areas have CO_2 concentrations that can be at least twice as high as adjacent upland areas (altitude difference of the topography, 60ft at WC, 30 ft at WLEF). Under these conditions it is clear that a one-dimensional surface-layer budget approach to NEE is not appropriate.

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