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2.7 IS FLUX DIVERGENCE IN THE TOWER LAYER IMPORTANT IN ESTIMATING ANNUAL NEE USING EDDY-COVARIANCE MEASUREMENTS?

Hong-Bing Su [*1], Hans Peter Schmid [2], C. S. B. Grimmond [2], Christoph S. Vogel [3], Peter S. Curtis [4]
[1] East Carolina University, Greenville, NC; [2] Indiana University, Bloomington, IN;
[3] University of Michigan Biological Station Pellston, MI; [4] Ohio State University, Columbus, OH

1. INTRODUCTION

Carbon and energy fluxes measured at the University of Michigan Biological Station AmeriFlux site (UMBS~Flux) in the first three years (1999-2001) were published recently (Schmid et al. 2003). It was discussed that annual net ecosystem production (NEP) estimates based on long-term eddy-covariance measurements are sensitive to criteria used for data quality control (e.g., friction velocity threshold) and gap-filling methods. It was also reported that annual NEP (>0) estimates based on measurements at a higher level (46 m, or 2.1h_c, where h_c = 22 m is the mean canopy height) are consistently smaller by 0.56 to 0.86 ton C ha^{-1} (25.2% to 51.7%) than those observed at a lower level (34 m, 1.5h_c) over each of the three years. In that study, CO_2 fluxes in periods of measurement gaps or low friction velocity (u_* <0.35 m s^{-1}) were estimated by parametric models of ecosystem respiration and gross photosynthetic uptake (Schmid et al. 2003) and accounted for in the annual sums.

In this study, we examine the characteristics of vertical flux divergence, and define the sign of net ecosystem exchange (NEE) as the same of vertical flux, negative for a downward flux and positive for an upward flux. In the following, we used "Cumulative NEE" to represent the annual sum (a time integral) of measured CO_2 fluxes, although periods of missing measurements at either height were excluded. Also, the "vertical divergence" is actually a vertical difference (e.g., fluxes at 46 m minus those at 34 m).

At the UMBS site, cumulative NEE (<0) are smaller in absolute values at the higher level by 0.23 to 0.35 ton C ha^{-1} (Figure 1). Similarly, differences in cumulative NEE between the two heights (46 m and 34 m, or 1.8h_c and 1.3h_c, h_c = 26 m) at the Morgan Monroe State Forest (MMSF) site (Schmid et al. 2000) for the same three-year period ranged from 0.37 to 1.0 ton C ha^{-1} (Figure 2). Note that at MMSF, the smaller absolute values in 1999 and 2000, compared to 2001, are in part due to greater gaps of missing measurements during the growing season.

In the following, using measurements at the UMBS site in 2001 as an example, we first examine effects of different choices of coordinate rotation, varying block average time length and sampling frequency on cumulative NEE. Then, we compare vertical divergences of carbon, sensible and latent heat, as well as momentum fluxes.

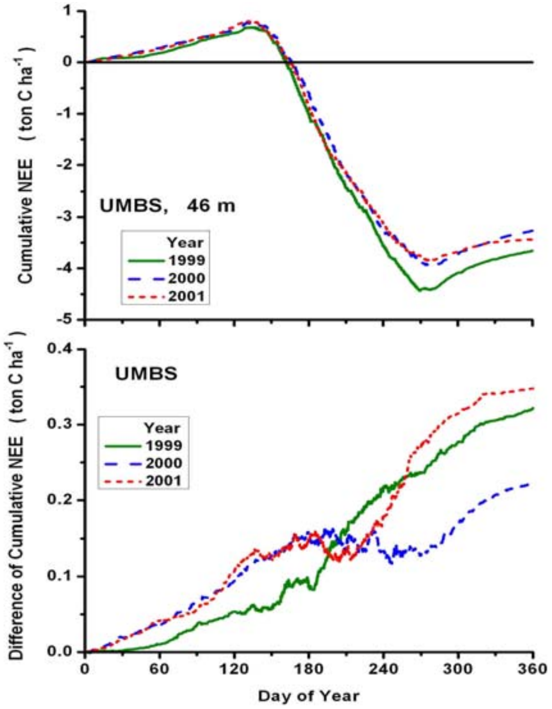

Figure 1: Cumulative NEE measured at 46 m (top panel), and cumulative NEE at 46 m minus that at 34 m (bottom panel), at the UMBS site.

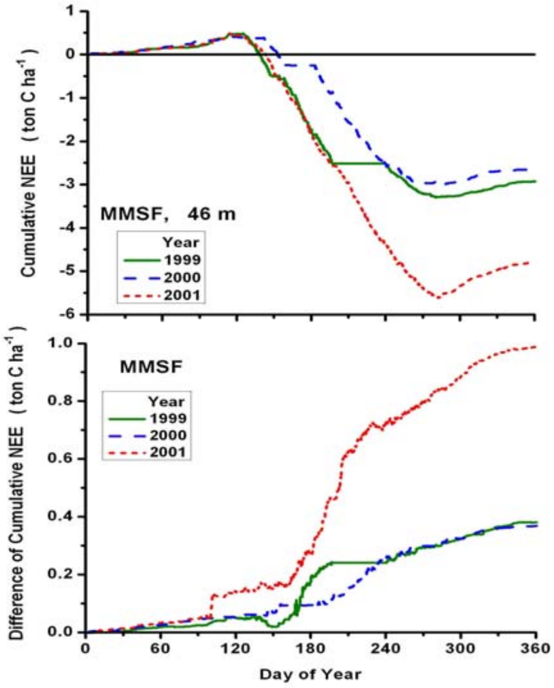

Figure 2: Similar to Figure 1 but for the MMSF site.

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* Corresponding author: Department of Geography, East Carolina University, Brewster A-227, Greenville, NC 27858. Email: suh@mail.ecu.edu

2. CHOICES OF COORDINATE ROTATION

Here we examine the differences among three methods of coordinate rotation. Method-1 is the run-to-run triple rotations (McMillen 1998, Kaimal and Finnign 1994) as applied in Schmid et al. (2003) and for the results in Figures 1 and 2. Method-2 uses ensemble-averaged vertical rotation angles varying with wind direction (Lee 1998, Baldocchi et al. 2000, Finnigan et al. 2003) which was applied in Su et al. (2004). Method-3 estimates the zero-offsets of the vertical component of the sonic anemometers using a modified planar fit method (Paw U et al. 2000, Wilczak et al. 2001) and then removes them from the respective vertical rotation angles at the two heights. The zero-offsets for the 46 m and 34 m CSAT3 sonic anemometers were determined to be 1.7 cm s^{-1} and -0.9 cm s^{-1}, respectively.

Method-1 yielded greater absolute magnitudes of cumulative annual NEE (<0) than method-2 at both heights. However, method-2 yielded greater at 46 m but smaller at 34 m cumulative annual NEE in absolute magnitudes than method-3, as expected from the opposite signs of the zero-offsets of the two sonic anemometers. These differences are an order of magnitude smaller than the vertical divergences between the two heights (Figure 1). When the zero-offsets of opposite signs were removed (method-3), the vertical divergence in cumulative annual NEE increased compared to method-2 (Figure 4). To a lesser extent, method-1 also yielded greater vertical divergence than method-2.

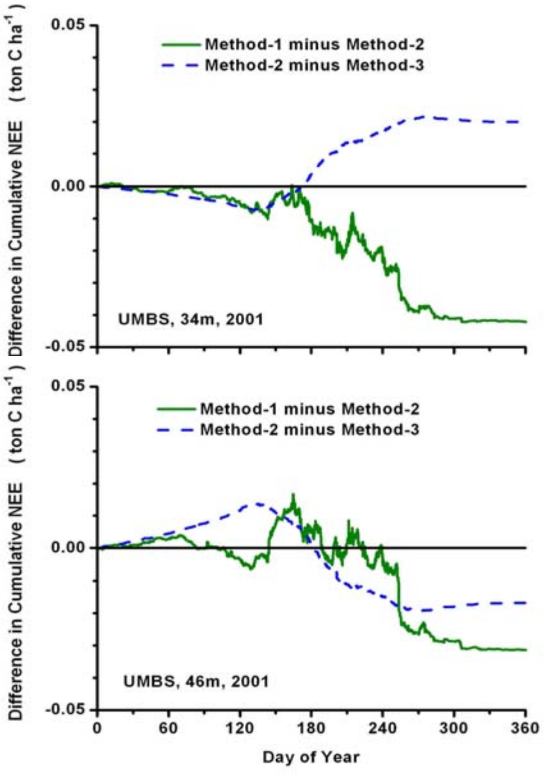

Figure 3: Differences in annual cumulative NEE between different coordinate rotation methods.

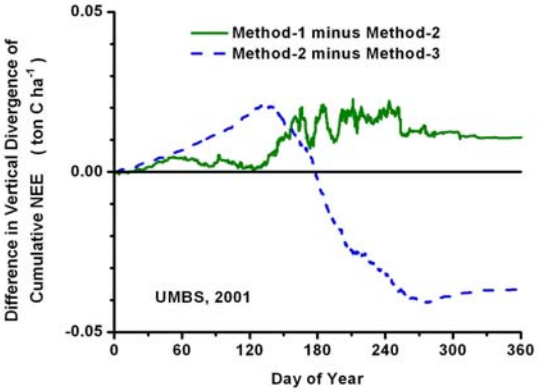

Figure 4: Differences in vertical divergences (46 m NEE minus 34 m NEE) of cumulative NEE between different coordinate rotation methods.

3. BLOCK AVERAGE TIME LENGTH AND SAMPLING FREQUENCY

Results shown so far used 1 hr block average time of 10 Hz data. In the following, method-3 was chosen for the coordinate rotation in evaluating the effects of varying lengths of block average time and sampling frequencies.

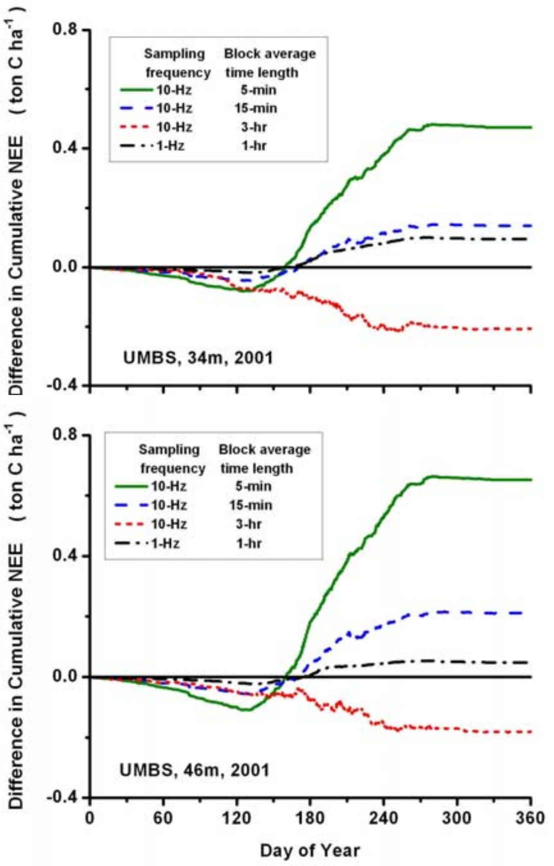

Figure 5: Differences in cumulative NEE of different block average time lengths and sampling frequencies relative to that of 1 hr block average time of 10 Hz data.

As expected, shorter or longer block average time would decrease or increase the absolute values of cumulative annual NEE (Figure 5). Relative to the 1 hr block average time, the differences due to as short as 15 min and as long as 3 hr block average time are in the same order of magnitude but smaller than vertical divergence (Figure 1). A block average time of 5 min yielded somewhat greater differences. Using non-overlapping block average of the 10 Hz data into 1 Hz yielded to even smaller differences (decrease). However, both shorter and longer block average time led to greater vertical divergence (>0) of measured cumulative annual NEE, with greatest increase from the shortest block average time of 5 min (Figure 6). The effect of non-overlapping block average of 10 Hz data into 1 Hz is the opposite, leading to smaller vertical divergence.

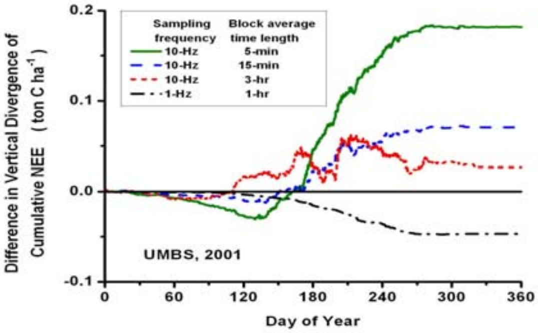

Figure 6: Differences in vertical divergences (46 m NEE minus 34 m NEE) of different block average time length and sampling frequency relative to that of 1 hr block average of 10 Hz data.

4. COMPARISON OF VERTICAL DIVERGENCES OF DIFFERENT FLUXES

To examine seasonal differences in vertical flux divergence, we used measurements in June through August to represent the growing season (leaf-on), and November to April for the dormant season (leaf-off), the same as in Su et al. (2004). Results shown below used method-3 for the coordinate rotation and a block average time of 1 hr of 10 Hz data.

In general, the ensemble averages of CO_2 fluxes are greater at the higher measurement level, more positive at night during the growing season as well as throughout the day in the dormant season, and more negative during the day in the growing season (Figure 7). Overall, the more negative fluxes are in lesser extent in terms of their portion in time over the entire year, which led to smaller absolute values of cumulative NEE at the higher measurement level.

Similarly, the ensemble averages of latent heat fluxes (Q_E) are generally greater at the 46 m level throughout the year (Figure 8). Note that Q_E is generally quite small during the dormant season and there were many more measurement gaps.

However, the ensemble averages of sensible heat fluxes (Q_H) are generally smaller at 46 m, less positive in the day throughout the year, and less negative at night in the growing season (Figure 9).

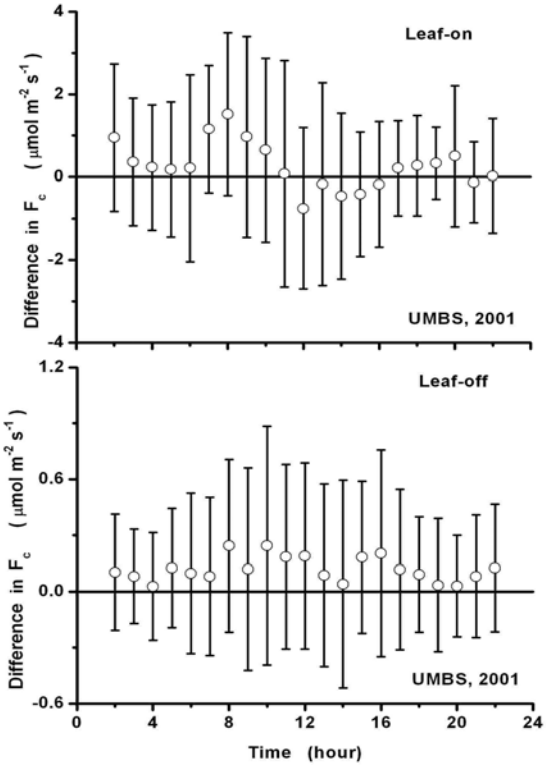

Figure 7: Ensemble average of diurnal courses of vertical CO_2 flux (F_c) divergences (46 m F_c minus 34 m F_c) during the growing (upper panel) and dormant (lower panel) seasons, respectively.

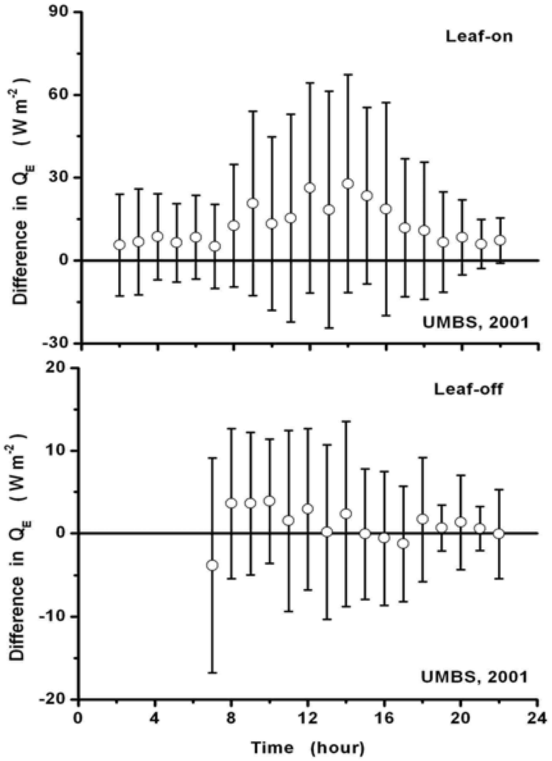

Figure 8: Similar to Figure 7 but for latent heat flux (Q_E).

On the contrary, the ensemble averages of the momentum fluxes ($\overline{u'w'}$) are greater in absolute magnitudes (more negative) at the 46 m level, except for the nighttime during the growing season when the opposite is true (Figure 10).

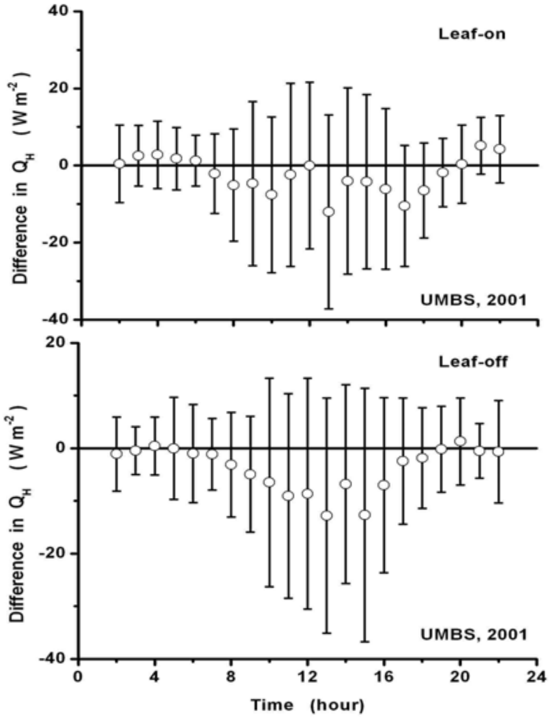

Figure 9: Similar to Figure 7 but for sensible heat flux (Q_H).

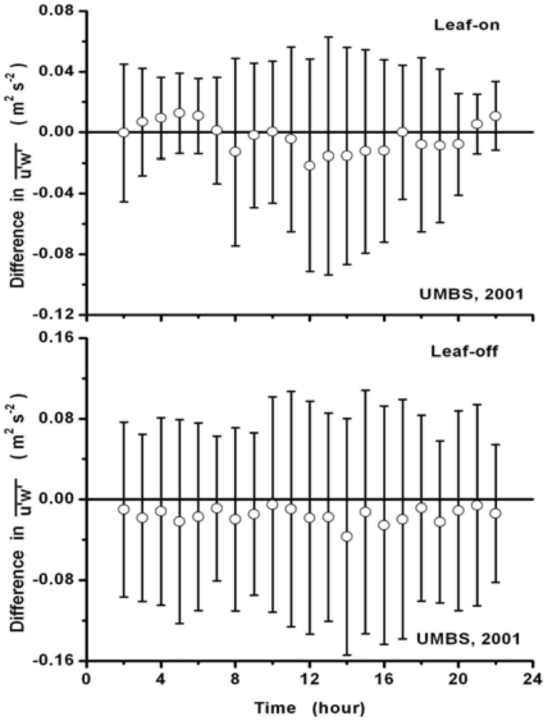

Figure 10: Similar to Figure 7 but for momentum flux $\overline{u'w'}$.

5. SUMMARY

Long-term eddy-covariance measurements over three years (1999-2001) at both the UMBS and the MMSF AmeriFlux sites demonstrated that cumulative NEE measured at a higher level was consistently smaller in absolute magnitude (or less negative). Different choices of coordinate rotation and varying block average time length and sampling frequency led to changes in the magnitude but not the sign of vertical divergence of measured cumulative NEE.

The vertical divergence in measured cumulative NEE is an order of magnitude greater than the differences among three methods of coordinate rotation, but on the same order of magnitude as the differences due to shorter (15 min) or longer (3 hr) relative to 1 hr block average time length.

The ensemble averages of both CO_2 and latent heat fluxes are generally greater in absolute magnitudes at the higher (46 m) observational level throughout the year. This is also the case for the momentum flux over most time of the year, except for the nighttime in the growing season. However, the ensemble averages of sensible heat fluxes are generally smaller over the year at the higher level.

Differences in vertical divergence of momentum, carbon, sensible and latent heat fluxes shown here call for further investigations of their causes. These may include source and sink areas and footprints of different fluxes which are likely to differ, as well as spatial heterogeneity of the forest ecosystem and complexity of underlying topography. Such work could also have implications for other studies, e.g., energy balance closure.

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