12.11 LINKING INTERANNUAL VARIABILITY OF CARBON EXCHANGE IN AN OLD-GROWTH FOREST TO SEASONAL AND INTERANNUAL VARIATIONS IN WATER AVAILABILITY

Sonia Wharton*, Liyi Xu[1], Eugenia Gonzalez[1], Matthias Falk[2],
Matt Schroeder[1], and Kyaw Tha Paw U[1]
[1]University of California, Davis, California
[2] University of California, Berkeley, California

1. INTRODUCTION

Carbon dioxide fluxes have been estimated at the top (70 m) of a 400-500 year old coniferous forest canopy in southern Washington using eddy-covariance techniques since July 1998. The old-growth forest canopy, composed primarily of Douglas-fir and western hemlock, is defined by a strongly seasonal precipitation pattern (5% falling during summer months) and transitional maritime-to-continental annual temperatures.

Eddy-covariance measurements have shown overall net uptake of carbon by the old-growth forest ecosystem, though the data also indicate high interannual variability of net ecosystem exchange (NEE). Three years (1999, 2000, and 2002) have shown significant carbon uptake by the forest sequestering 204 g C m^{-2} yr^{-1}, 74 g C m^{-2} yr^{-1}, and 80 g C m^{-2} yr^{-1}, respectively. 2003 was at equilibrium with carbon exchange and 2001 was a significant source year, with a loss of 49 g C m^{-2} yr^{-1}, for the old-growth canopy.

Here we analyzed the interannual variability of carbon exchange for this forest by closely examining interannual and seasonal variations in precipitation, primarily looking for temporal changes in ecosystem evapotranspiration, water balance, and water-use efficiency.

2. METHODS

The eddy-covariance (EC) system consisted of a closed path Infrared Gas Analyzer (LiCor 6262) and an ultrasonic anemometer (Gill HS), both mounted at 70 m on an 87 m crane at the Wind River Canopy Crane Research Facility (WRCCRF). The EC system measured fluxes of CO_2, H_2O, and turbulent velocities at 10 Hz.

Evapotranspiration was calculated from latent heat flux and summed over yearly, monthly, and weekly time scales. Daily precipitation measurements came from the nearby NOAA Carson Fish Hatchery (5.7 km north-northwest of the crane). A site water budget was calculated to be the difference between daily evapotranspiration (ET) and daily precipitation, summed monthly and yearly. A negative ∑ (ET - P) indicated a surplus of water in the ecosystem, while a positive water balance indicated that the ecosystem lost more water through evapotranspiration than it received.

Ecosystem water-use efficiency (WUE) was estimated for examination of year to year differences which may be explained by interannual variability in water availability. WUE has been defined by Chen (2002) to be the ratio of carbon dioxide flux to water vapor flux for times when CO_2 is negative (assimilation) and H_2O flux is positive (evaporation and transpiration).

3. RESULTS AND DISCUSSION

Precipitation measurements showed significant interannual variability at the old-growth forest canopy. Annual precipitation varied from a five-year high of 2669 mm in 1999 (a La Niña year) to a low of 1742 mm in the following year. Yearly water availability statistics are found in table 1.

	1999	2000	2001	2002	2003
ET (kg m^{-2} yr^{-1})	535	299*	433	428	549
∑ (ET -P)	-2134	-1443	-1475	-1542	-1681
precip. (mm yr^{-1})	2669	1742	1908	1970	2230
mean Ta (ºC)	9.3	8.8	9.1	9.3	10.0
dry season WUE (mg g^{-1})	1.8± 3.2	NA	3.3 ± 8.9	3.4 ± 10.6	3.9 ± 12.1

Table 1: *Total evapotranspiration, water balance, and precipitation, and average air temperature and dry season water-use efficiency by year at the WRCCRF. *ET estimates in 2000 are biased low partially due to water flux data gaps.*

Initial analysis found that annual net ecosystem exchange (NEE) was moderately correlated with annual precipitation (R^2 = 0.4). This correlation increased after a one month time-lag for precipitation was included (R^2 = 0.6). To further investigate the lagged relationship between precipitation and NEE, a cross-correlation was performed on weekly averages of both variables over the entire study period. Significant correlation values ($P < 0.05$) between NEE and precipitation were observed for lags 10 to 17, with the highest (ρ = -0.52) occurring at lag 15. In order to include the longer lag period for

* *Corresponding author address*: Sonia Wharton, Atmospheric Science, Univ. of California, Davis, One Shields Ave., Davis, CA 95616; email: swharton@ucdavis.edu

precipitation, the water budget year was redefined to include the entire rainy season (November-March). Accordingly, water balance estimates were cumulated starting in July and ending in June of the next year. The new (ET- P) estimates were regressed against monthly NEE for 1999-2000 in figure 1.

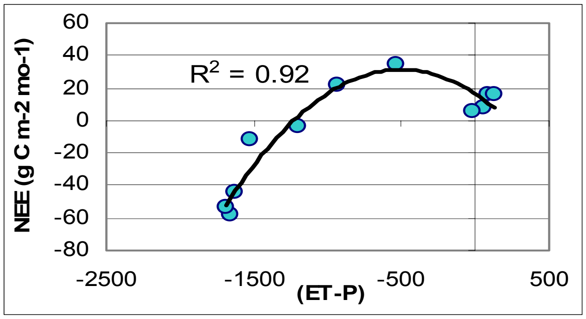

Figure 1. *The data show a strong nonlinear relationship between cumulative water balance and monthly NEE for the water budget year 1999-2000. R^2 values for 2001-2002 and 2002-2003 are 0.89 and 0.88.*

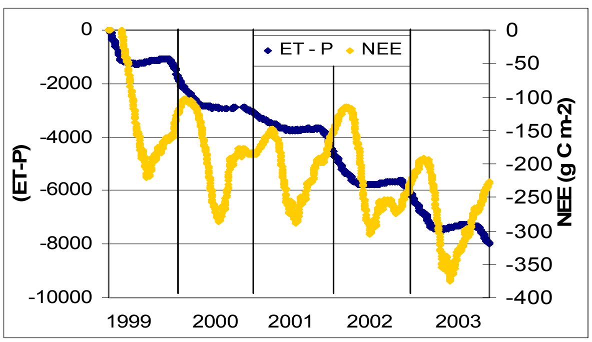

Figure 2. *Cumulative daily site water balance and NEE estimates from 1999-2003. An unusually dry autumn and winter in 2000-2001 (lower 5th percentile, 1949-2003) is apparent by the flatness of the (ET-P) curve.*

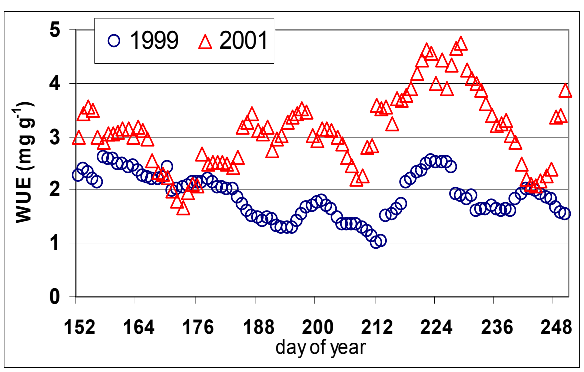

Figure 3. *Dry season WUE varied significantly between 1999 and 2001, indicating that the ecosystem was more efficient at uptaking carbon during the drought-stressed year, than it was when water was plentiful.*

Mean dry-season WUE varied from 1.8 mg g^{-1} in 1999 to 3.9 mg g^{-1} in 2003. WUE in 1999 was significantly lower than any other year ($P < 0.0001$). Figure 3 shows daily average dry-season WUE values in 1999 and 2001.

One caveat with interpreting ecosystem WUE is that it includes both evaporation and transpiration. Humphreys (2003) has shown for a Douglas-fir forest that high latent heat fluxes can at times be attributed primarily to evaporation of intercepted rainfall, creating the need to isolate individual ET components in the future.

4. CONCLUSION

Links between carbon exchange and precipitation suggest that water availability is an important factor in determining whether or not the old-growth forest becomes an annual carbon sink, source, or is at equilibrium. Precipitation received by the forest ecosystem during the winter season did not trigger an immediate response of enhanced photosynthesis, but instead was delayed roughly four months. Only when several factors such as mild air temperatures, moderate to high radiation levels and an adequate supply of water already stored in the ecosystem converge, the difference of carbon gain over ecosystem respiration reached its maximum value. Lack of an adequate water supply appears to enhance ecosystem stress if it is concurrent with high radiation and temperature, and consequently reduces photosynthetic activity. Seasonal to interannual variability in precipitation and consequent water balance appears to influence the timing of this switch from photosynthesis-dominance to respiration-dominance, ultimately determining whether the forest will be a net carbon sink or source.

5. REFERENCES

Chen, J, et al. 2002. Biophysical controls of carbon flows in three successional Douglas-fir stands based on eddy-covariance measurements. *Tree Physiology* **22**, 169-177.

Humphreys, E.R. et al. 2003. Annual and seasonal variability of sensible and latent heat fluxes above a coastal Douglas-fir forest, British Columbia, Canada. *Agric. For. Meteorol.* **115**, 109-125.

6. ACKNOWLEDGEMENTS

This research was funded by the Western Regional Center (WESTGEC) of the National Institute for Global Environmental Change (NIGEC) through the U.S. Department of Energy (Cooperative Agreement No. DE-FC03-90ER61010). WRCCRF is operated under joint sponsorship of the University of Washington and the USDA Forest Service/PNW Station and we acknowledge both for significant support. Any opinions, findings, and conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the view of DOE.