Partitioning Net Ecosystem Exchange in a Tennessee Deciduous Forest Using Stable Isotopes of CO_2

D. R. Bowling[1], D. D. Baldocchi[2], and R. K. Monson[1]

[1]Dept. of Environmental, Population, and Organismic Biology, University of Colorado, Boulder, CO

[2]Dept. of Environmental Science, Policy and Management, University of California, Berkeley, CA

Abstract

The combination of stable isotope measurements and micrometeorological flux measurements is a powerful new approach that is likely to lead to substantial new insight into the dynamics of carbon dioxide (CO_2) exchange between terrestrial ecosystems and the atmosphere. Through a number of national and international programs (e.g., AmeriFlux, EUROFLUX, LBA, FluxNet) considerable effort and research funding is being devoted to the measurement of net ecosystem carbon exchange (NEE). These studies rely largely on tower-mounted, eddy covariance systems to continuously monitor fluxes of CO_2. The eddy covariance approach alone does not allow the independent measurement of the component processes of NEE, photosynthesis and respiration, yet these are the processes we wish to understand. During summer 1998, we used two new techniques to measure canopy-level fluxes of $^{13}CO_2$ and $C^{18}OO$ over an oak-maple forest in eastern Tennessee. First, we used extensive flask sampling to define the local relationships between isotopic composition and atmospheric CO_2, and *combined this with the standard eddy covariance technique* to compute the isotopic fluxes. Second, we used a modified version of the *relaxed eddy accumulation (REA) technique* to directly measure $^{13}CO_2$ and $C^{18}OO$ fluxes. This was accomplished via a collection system that cryogenically concentrated the CO_2 in updrafts and downdrafts in separate traps. Our analytical precisions for isotopic composition with the REA technique were ±0.2 and ±0.3 ‰ for $\delta^{13}C$ and $\delta^{18}O$ in CO_2, respectively (based on repeated tests with WMO-calibrated isotope ratio standards), sufficient to discern small isotopic differences in updrafts and downdrafts. Results with the two techniques compared well, providing confidence that our methods are robust. We used our measured fluxes in an attempt to partition NEE into its component fluxes, net photosynthesis and ecosystem respiration, and to investigate the dynamics of CO_2 exchange in this deciduous forest canopy.

Eddy Covariance / Flask Sampling

standard eddy covariance:

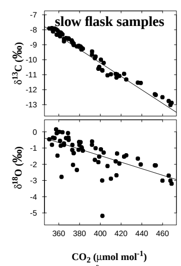
$$CO_2\ \text{flux} = \rho\overline{w'(CO_2)'}$$

"eddy covariance" for $^{13}CO_2$:

$$^{13}CO_2\ \text{flux} = \rho\overline{w'(^{13}CO_2)'}$$

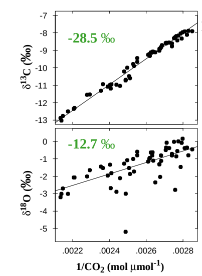
$$^{13}CO_2 = \delta^{13}C * CO_2$$

$$\delta^{13}C = m * CO_2 + b$$



Isotope Ratio of Respired CO_2

(Keeling 1958)

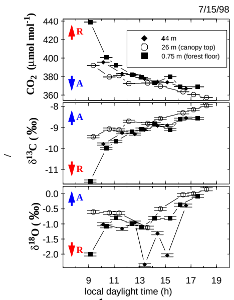


$CO_{2\,meas} = CO_{2\,back} + CO_{2\,resp}$

$\delta^{13}C_{meas}CO_{2\,meas} = \delta^{13}C_{back}CO_{2\,back} + \delta^{13}C_{resp}CO_{2\,resp}$

$\delta^{13}C_{meas} = \text{slope}*(1/CO_{2\,meas}) + \delta^{13}C_{resp}$

Isotope Ratio of Atmospheric CO_2

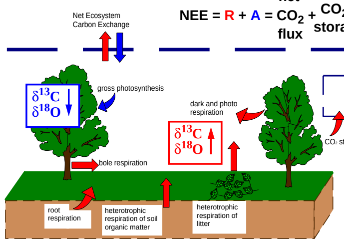


$\delta^{13}C_{resp}$, $\delta^{18}O_{resp}$

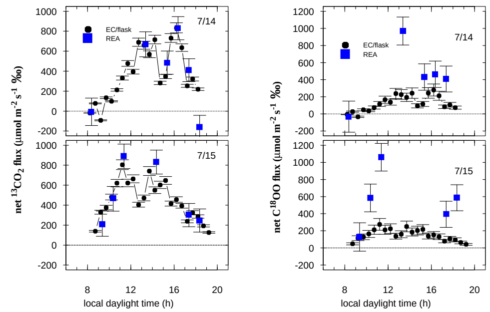
$\delta^{13}C_{atm}$, $\delta^{18}O_{atm}$

Canopy Carbon Balance

NEE = R + A = net CO_2 flux + CO_2 storage



Measured Isotopic Fluxes using Both Techniques



NEE, ^{13}NEE, ^{18}NEE

Partitioning Equations - Conservation of Mass

CO_2: NEE = R + A

$^{13}CO_2$: $^{13}NEE = \delta^{13}C_{resp}(R) + (\delta^{13}C_{atm} - \Delta_{13})A$

$C^{18}OO$: $^{18}NEE = \delta^{18}O_{resp}(R) + (\delta^{18}O_{atm} - \Delta_{18})A$

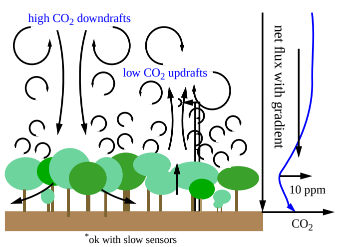
measured terms in green
modeled terms in purple
respiratory terms in red
photosynthetic (assimilation) terms in blue

R, A

Δ_{13}, Δ_{18}

Relaxed Eddy Accumulation (REA)

flux of $^{13}CO_2 = b\sigma_w(\delta^{13}C_{up}CO_{2up} - \delta^{13}C_{dn}CO_{2dn})$



*ok with slow sensors

Photosynthetic Discrimination Models

carbon isotope discrimination by photosynthesis (Farquhar et al. 1989)

$$\Delta_{13} = 4.4 + (29 - 4.4)\frac{c_i}{c_a}$$

oxygen isotope discrimination by "photosynthesis" (Farquhar et al. 1993)

$$\Delta_{18} = 7.4 + \frac{c_c/c_a}{1 - c_c/c_a}(\delta^{18}O_c - \delta^{18}O_a)$$

$\delta^{18}O_c$ is modeled via an evaporative enrichment model (Craig and Gordon 1965, Flanagan et al. 1991)

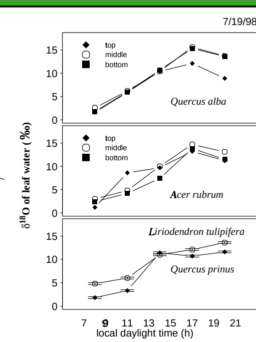
modeling leaf water isotope ratio (Craig and Gordon 1965, Flanagan et al. 1991)

$$R_l = \alpha_{eq}\left[\alpha_k R_x\left(\frac{e_i - e_b}{e_i}\right) + \alpha_{kb} R_x\left(\frac{e_b - e_a}{e_i}\right) + R_a\left(\frac{e_a}{e_i}\right)\right]$$

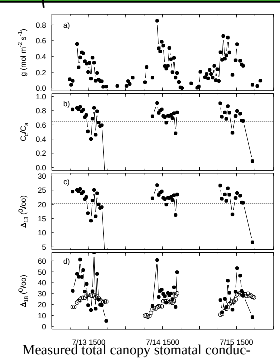
R	isotope ratio (D/H or $^{18}O/^{16}O$)
e	water vapor pressure
α_{eq}	liquid-vapor equilibrium fractionation factor
α_k	kinetic fractionation due to diffusion in air
α_{kb}	kinetic fractionation due to diffusion through leaf boundary layer

subscripts:

a	air
x	source (xylem)
l	leaf
i	intercellular air space
b	leaf surface (boundary layer)



Measured and modeled bulk leaf water oxygen isotope ratio.



Measured total canopy stomatal conductance, associated ci/ca ratio, and modeled carbon and oxygen isotope discriminations.

Results - Partitioning Net Ecosystem Exchange into Photosynthesis and Respiration

Expected Results

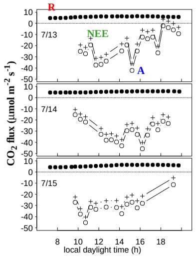
model respiration as a function of temperature:

Greco and Baldocchi (1996)

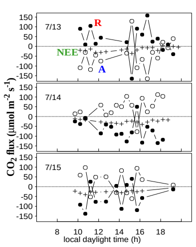
$R_{correct} = 0.067e^{(0.04859 Tair)}$

then solve for A using measured NEE:

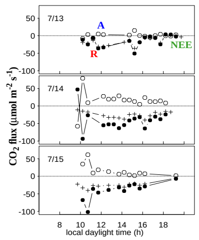
$NEE = R_{correct} + A$



Actual Results Using ^{13}C



Actual Results Using ^{18}O



Why Doesn't This Work?

1) Run-to-run variability in measured fluxes due to site topography suggests ensemble averages should be used instead (i.e., 15 days should be hourly-averaged to come up with diurnally representative fluxes of CO2, $^{13}CO_2$, and $C^{18}OO$, then do the partitioning). IRGA problems prevented such an approach in the present study - accurate measurements were only available for 5 days.

2) We don't know if these canopy-level discrimination (Δ_{13} and Δ_{18}) estimates are realistic. For example, there is variation in measured ^{13}NEE that is not accurately represented in modeled Δ_{13}. The processes controlling photosynthetic discrimination within a canopy are complex, including variation in such factors as stomatal conductance, light, CO_2 assimilation rate, leaf nitrogen, and intercellular CO_2 partial pressure. Detailed models of isotope discrimination that include these sources of variation may be required for accurate partitioning.

3) Spatial heterogeneity in the $\delta^{18}O$ signal may be a serious problem. The mass-balance approach used here assumes horizontal and vertical variation in isotope effects is minimal. Using a single $\delta^{18}O_{resp}$ or Δ_{18} may not be realistic if there is variation in soil water or leaf water isotope ratios due to slope aspect, variation with height in the canopy, species or community effects, isotopic exchange with liquid water in other pools, etc.

Conclusions

1)There is a useful stable isotope signal that contains independent information about photosynthesis and respiration.

2) Flux measurements can likely be trusted for $^{13}CO_2$, but not yet for $C^{18}OO$.

3) We cannot yet partition NEE into R and A because of the above factors.