How close is close enough? Evaluating uncertainties in forest carbon and water flux estimates.

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The Big Picture
The story so far...

Rapid Fluxes

Slow Growth
The story so far...

Rapid Fluxes

Constraining carbon cycle with water cycle.

A solution?
How close is close enough?

Components of carbon cycle (g m\(^{-2}\) yr\(^{-1}\)) in a pine forest


White: Ambient CO\(_2\)
Gray: +200 ppm CO\(_2\)

Left: Pine Overstory
Right: Hardwood Understory
Outline

• Questions
• Study Site, Data Sources
• Analytical Approach
• Transpiration: Hierarchical Model
• Photosynthesis: 4CA model
• Results: Transpiration
• Results: Assimilation
• Conclusions
• Future Directions
Questions

• How does variability in sap flux density \((J)\) data impact estimates of:
  • Canopy transpiration \((E)\)?
  • Canopy conductance \((G)\)?

• How does this variability in \(G\) effect estimates of photosynthesis \((A_{NET})\)?
  • Does this vary with environmental conditions?
Study Site (Duke FACE)

Loblolly pine planted 1983
Elevated CO₂ (+200 ppm) since 1996 (n=4)
Soil: clay loam to 30 cm

Study period: 2006-2007

Annual Precipitation:
• Mean: 1140 mm
• 2006: 1127 mm
• 2007: 800 mm
Sap Flux ($J$) Measurements

Thermal Dissipation Probes (Granier 1987)

Half-hourly values

Vary by tree size and radial position in tree.

Probe Depths:
- 0-20 mm ($n=33$)
- 20-40 mm ($n=11$)
- 40-60 mm ($n=11$)

Scaled by sapwood and leaf area of plot to $E$ and $G$. 

T. Motzer
Other Data Sources

- DBH measurements
- Estimates of LAI, LAD profile
- 3D digital imaging
  - Leaf angle
  - STAR
- Porometry
  - $A_{NET-C_i}$
  - $G_S-Q$
Analytical Approach

- Estimate $G$ response to $D$, $Q$ and $M$ from $J$ data
  - Hierarchical Bayesian state-space model
  - Multivariate posterior distribution of parameters
- Generate 100 time series of $G$
  - Monte Carlo simulation
- Estimate impact on $A_{NET}$
  - Mean simulated $G$ $\pm$ 2 standard deviations
  - Input to 4C-A model
    - Canopy Conductance-Constrained Carbon Assimilation
Hierarchical Model of Transpiration

Select set of parameters (Apply)

Process time series (Lather)

Data time series (Rinse)

(Repeat)

$\times 10^4$

Compare to observations
Hierarchical Model of Transpiration

Data: \( \{D_t, Q_t, T_t, M_t\} \) \( \rightarrow \) \( J_{tijk} \) \( \leftarrow \) \( \{L_t, S_{tij}\} \)

Process: \( G_{t-1}^{dy} \) \( \rightarrow \) \( G_t^{dy} \) \( \rightarrow \) \( G_{t+1}^{dy} \)

Parameters: \( a_{ijk} \) \( \{g_{Sref}, \lambda, \beta_{1-4}\} \) \( \sigma \) \( \tau \)

Priors: Truncated Normal Inverse Gamma Fixed
Photosynthesis: 4-CA Model

- Canopy Conductance Constrained Carbon Assimilation
  - (Schäfer et al. 2003, Kim et al. 2008)
- Light model
  - Estimates $Q$ at 1 m intervals
  - Includes tree and shoot clumping, penumbra
- Partitions $G_C$ based on light response curves
- Calculates $A_{NET}$ from leaf $A_{NET}-C_i$ curves
  - Farquhar-von Caemmerer-Berry model
  - $Q$, $G$, $V_{CMAX}$ and $J_{MAX}$
Photosynthesis: 4-CA Model

Stage 3
- Regeneration
  - ADP
  - ATP
  - Triose phosphate

Stage 1
- Carboxylation
  - CO₂ + H₂O
  - Ribulose-1,5-bisphosphate

Stage 2
- Reduction
  - 3-PGA
  - ATP + NADPH
  - ADP + Pi & NADP

Regenerated products
- Transferred from chloroplast to make glucose

Reactions
- H₂O
- CO₂

Components
- ATP
- NADPH
- ADP + Pi
- NADP
Environmental Data

Graphs showing:
- Mean Q (mmol/m²/s)
- Mean D (kPa)
- Mean M

Graphs for Jan 06, Jul 06, Jan 07, Jul 07, Dec 07
Results: Transpiration
Results: Transpiration

Modeled time course of transpiration ($E_C$) (ground area basis) for each year of study. Monthly sums (circles) are shown with those of $G_C$ +/- 2 standard deviations (dashed lines).
Conductance and Assimilation
Conclusion

• The impact of uncertainties in sap flux scaled canopy conductance on annual $A_{\text{NET}}$ estimates varied from 1 to 26%, depending on the degree of stomatal limitation caused by inter-annual weather variability.

• Elevated CO$_2$ plots had higher $E_C$ and $A_{\text{NET}}$, proportional to increased leaf area.

• This difference did not persist through intense drought, as a result of higher sensitivity to $M$ in elevated plots.
Future Directions

• Other years of data to extend environmental variability
• Analysis of fertilization-CO$_2$ treatments
• Monte Carlo simulations to test sensitivity of 4C-A to light & gas exchange parameters, interactions with $G_C$ estimates
• Cross-site comparison with ORNL FACE
• Couple with tree hydraulic model
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