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Impacts of leaf phenology and water table on interannual variability of regional carbon fluxes in mixed landscapes

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Introduction

- Regional scale (10^3-10^7 km^2) surface-atmosphere net ecosystem exchange of CO_2 (NEE) can be quantified with top-down and bottom-up approaches, but comparisons have been limited.
- Even if magnitudes differ, interannual variability (IAV) of regional fluxes from multiple methods might be coherent, allowing for analysis of climatic controls on regional fluxes.
- In the Upper Great Lakes USA region, we have observed consistent IAV at several flux tower sites (Fig. 1) and have shown that wetland IAV is sensitive to water table depth, while upland IAV is more sensitive to length of growing season and date of autumn senescence (Desai *et al*., in prep; Sulman *et al*., 2009).
- The region is a complex assemblage of subboreal mixed hardwood uplands and shrub and meadow wetlands (Fig. 2). Little is known about the magnitude and variation of regional NEE.

Key questions:

1.) What is the magnitude of regional (~10^4 km^2) NEE?

2.) Is there consistent IAV among methods?

3.) What are the controls on regional IAV?

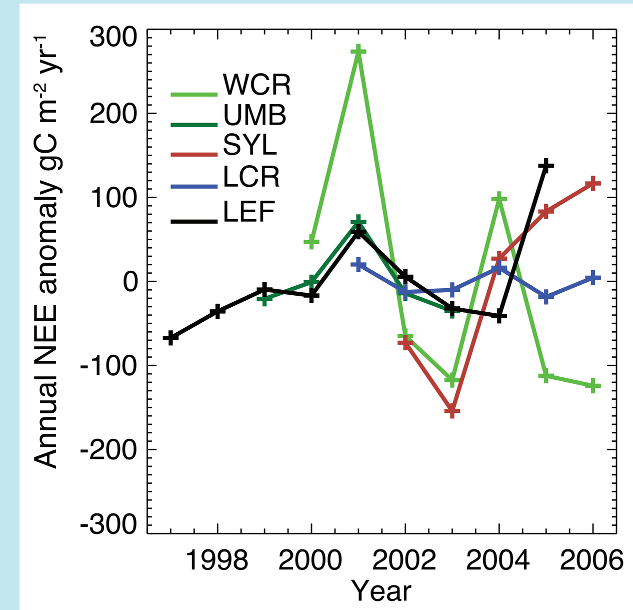

Figure 1. Annual eddy covariance observed NEE anomaly for three upland forests (WCR, UMB, SYL), one wetland (LCR), and one regional tower (LEF) in the Upper Great Lakes region.

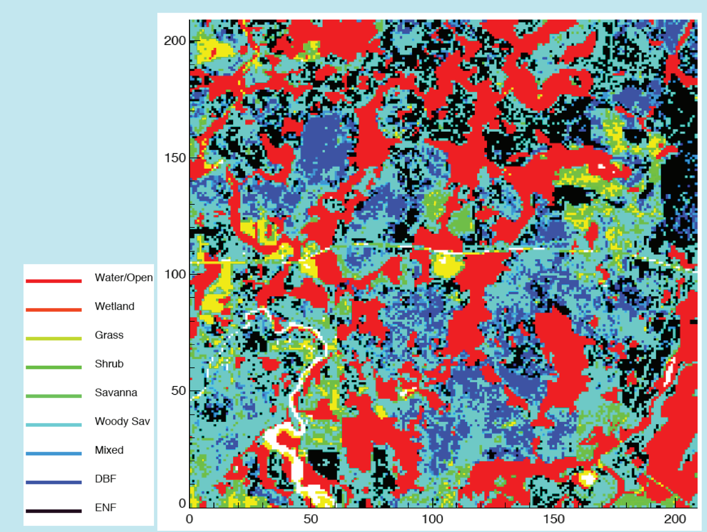

Figure 2. Supervised classification of 50 km^2 area around the LEF tall tower in Park Falls, WI showing complexity of region (courtesy of B. Cook, U. Minnesota).

Techniques

- Four *independent* bottom-up ecological scaling and top-down atmospheric budget techniques were used to estimate NEE from 1996-2006 for ~10^4 km^2 region around WLEF tall tower (Fig. 3).

Bottom-up methods

Interannual Flux-tower Up-Scaling Experiment (***IFUSE***)

A simple ecosystem model parameterized against 12 flux towers in region (Fig. 3) and upscaled by gap-filled climate and remotely sensed landcover (Desai *et al*., 2008, in prep)

Ecosystem Demography model (***ED***)

A height-and-age structured dynamic ecosystem model (Fig. 4) tuned to regional Forest Inventory Analysis (FIA) statistics (Desai *et al*., 2007; Moorcroft *et al*., 2001)

Top-down methods

Equilibrium Boundary Layer (***EBL***)

Synoptically-averaged (~14 day) 1-D boundary layer CO_2 budget at the WLEF tall tower (Eq. 1; Helliker *et al*., 2004)

CarbonTracker 2008 (***CT***)

Regional subset extracted from the NOAA ESRL global nested-grid atmospheric CO_2 inversion for 2000-2006 (Fig. 5; Peters *et al*., 2007)

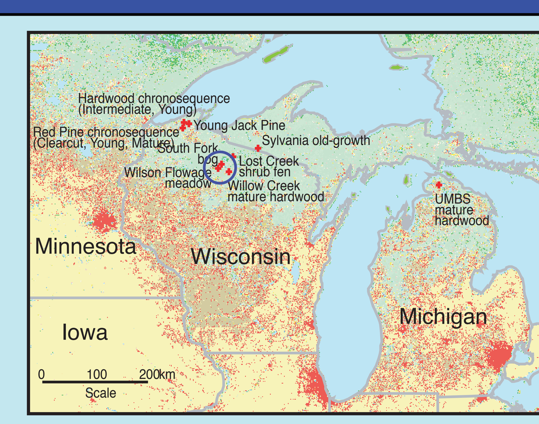

Figure 3. Map of flux towers used in IFUSE and area of upscaling region (blue circle).

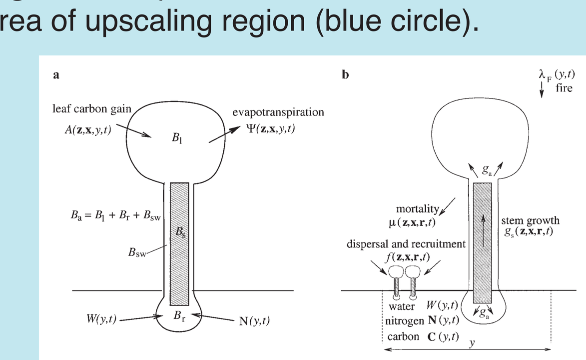

Figure 4. Visual representation of the structure of ED model (from Moorcroft *et al*., 2001).

$$\rho h \frac{\partial C_m}{\partial t} = F_{NEE} - \rho W (C_t - C_m)$$

Equation 1. Time-averaged 1-D boundary layer budget for CO_2 (from Helliker *et al*., 2004). Terms were estimated from reanalysis meteorology and flask and tower CO_2 observations.

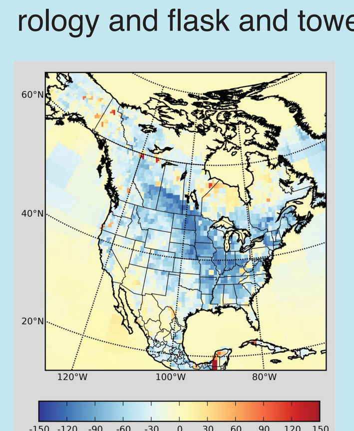

Figure 5. Estimate of mean net ecosystem production and fire fluxes (NEP) of North America over 2001-2005 from CT model in gC m^{-2} yr^{-1} (from Peters *et al*., 2007).

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Regional Fluxes

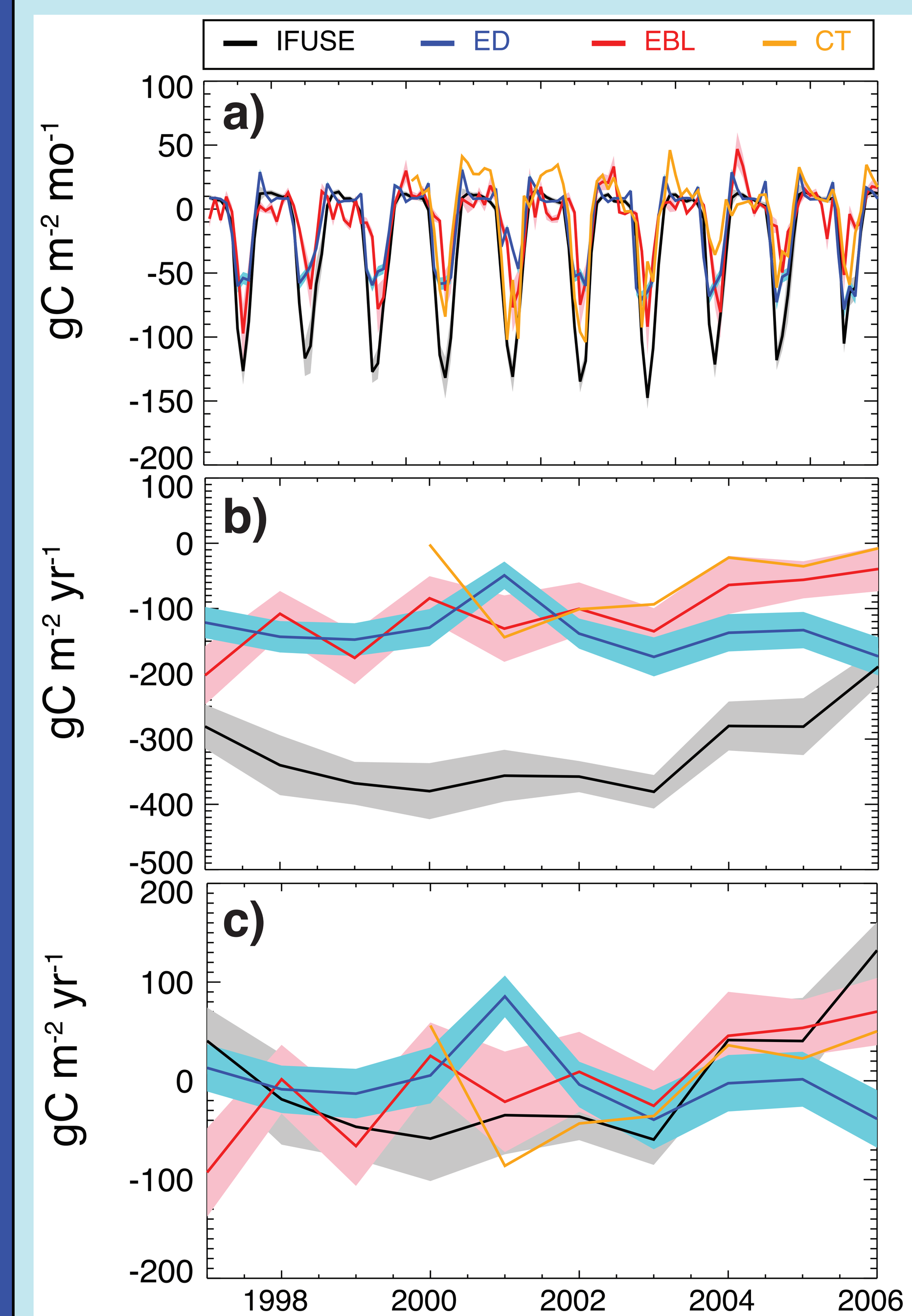

Figure 6. Comparison of regional NEE from the four methods at the a) monthly and b) annual timestep. Also shown is c) annual anomaly in NEE. Error bars were computed by model specific propagation of uncertainties in forcing, parameters, and scaling variables.

- Regional monthly NEE (Fig. 6a) shows strong consistency in typical pattern of winter buildup, spring drawdown, peak uptake, and autumn senescence. IFUSE model has strongest peak uptake, while top-down methods show larger winter respiration. Year-to-year variability in peak uptake is similar for all methods. Timing of spring uptake is often later in the top-down techniques.
- Larger differences are found in magnitude of regional NEE (Fig. 6b) with IFUSE as the largest outlier. The large NEE is likely due to biased sampling of mature hardwood forest NEE by the flux tower network and undersampling of young forest NEE. Top-down techniques in general agreement with each other on NEE trends.
- Annual anomalies of NEE shows general coherence among the four methods (Fig. 6c) with the ED model agreeing the least with the other three methods. IFUSE, CT, and EBL in strong agreement of a trend of decreasing NEE from 2003-2006. Insect defoliation in 2001 has conflicting results in top-down vs. bottom-up. All methods have similar amounts of IAV.
- Source area of top-down methods (especially EBL) are not well-constrained. Scaling of bottom-up methods limited by quality of upscaling data. Error bars attempt to constrain some of this, but more work is needed.

Controls on Regional Interannual Variability

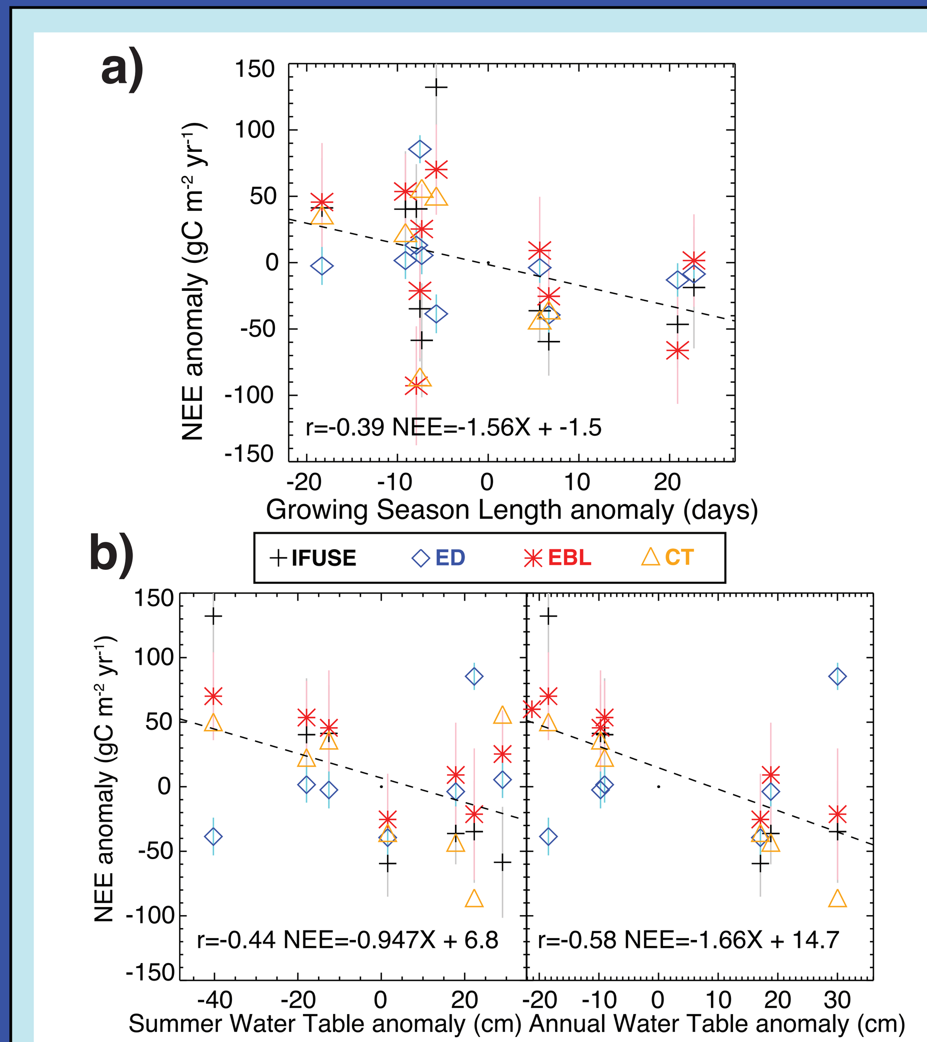

Figure 7. Relationship of climate factor anomalies to regional NEE anomalies for a) growing season length computed by IFUSE model and b) (left) summer minimum water table or (right) 1-yr lagged annual mean water table position observed at the Lost Creek fen.

- Many annual and seasonal controls compared to regional IAV including local climate, phenology, and hydrology variables and global climate indices.
- Best climatic controls included spring PAR, summer and fall soil temperature, and prior (lag 1) autumn precipitation. All tested climate indices (ENSO, PNA, PDO, etc...) were not strongly correlated with regional IAV.
- Both observed and modeled growing season length and date of autumn senescence were consistently negatively correlated with IAV, implying more uptake with later autumn/longer growing season (Fig. 7a)
- Surprisingly, summer water table depth and especially one year lagged annual water table were the strongest and most consistent predictors of IAV across all methods (Fig. 7b), suggesting a strong role for regional hydrology-carbon interaction.
- Coupled dynamic vegetation-hydrology models are being developed to further test mechanisms.

Conclusions

1.) Regional NEE from 1996-2006 shows uptake of carbon across four independent methods of approximately -160 gC m^{-2} yr^{-1}±112 gC/m^{-2} yr^{-1}. Flux tower model consistently shows largest uptake.

2.) Consistent IAV and trends are found in many years, but “footprints” require characterization.

3.) Growing season and lagged hydrologic controls on regional IAV suggest avenues for future research and coupled water-carbon model development.

Acknowledgments

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