12.10

Higher-order closure turbulence modeling of long term carbon exchange in an old-growth temperate forest: implications for land-use and climate changes.

R. David Pyles*, Sonia Wharton, Liyi Xu, Kyaw Tha Paw U, Matthias Falk,
and Matthew Schroeder
Dept. of Land, Air, and Water Resources
University of California, Davis

1. Introduction

The University of California, Davis Advanced Canopy-Atmosphere Soil Algorithm (ACASA) has been used to model net ecosystem exchange of carbon (NEE) at the Wind River Canopy Crane Research Facility (WRCCRF) betwixt June, 1998 and December, 2003. Preliminary results presented herein suggest that ACASA is able to capture main features of the diurnal cycle of NEE as well as seasonal and interannual variations in accumulated NEE at WRCCRF within observational uncertainty.

Eddy-covariance estimates of NEE every half hour were gathered within an old-growth temperate rainforest. This site is unique among AmeriFlux sites and provides a rare opportunity to investigate NEE as it relates to various climate forcings, both actual and potential.

The University of California, Davis Advanced Canopy-Atmosphere-Soil Algorithm (ACASA) was used for the simulations, which included both land use change and future climate change scenario sensitivity tests (see Pyles et al, 2000). ACASA was configured for WRCCRF and driven using half-hour feeds of observed above-canopy downward long- and short-wave radiation, air temperature, wind speed, humidity, pressure, precipitation rate, and CO_2 concentration. Default values of 365 ppm(v) when not otherwise available. ACASA estimates NEE based on simulated microenvironmental and physiological conditions in 10 above-canopy, 10 intra-canopy and 15 soil layers using 3rd-order, diabatic higher-order closure principles and a suite of physics and physiological packages designed to simulate canopy microenvironments and associated fluxes of energy, mass, and momentum. A more extensive description of ACASA can be found in Pyles et al. (2000).

Where insufficient data were available to drive ACASA, gaps were filled by adding in observed values. This gap filling was most extensively done in 1999 and 2003, where it totaled roughly +20 and +15 gC m^{-2} for the year, respectively. The effect of this on model-observed comparisons is negligible.

Corresponding Author Address: R. David Pyles, Dept. of Land, Air, and Water Resources, 1 Shields Ave., University of California, Davis, Davis, CA 95616; email: rdpyles@ucdavis.edu

2. Results

Results show excellent daily agreement between model and observed NEE (Fig. 1), with annual totals falling well within observational uncertainty (Table 1, Figs 2 &3).

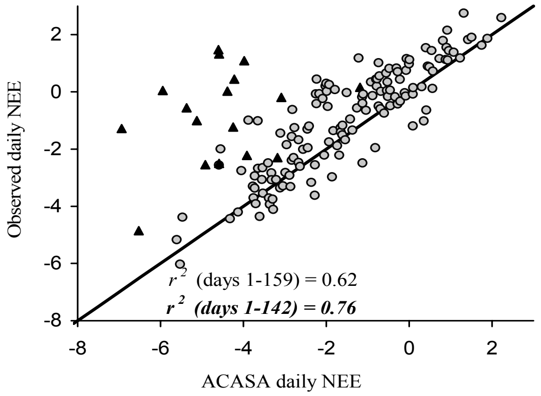

Figure 1: Scatter diagram showing ACASA vs. observed daily NEE for 2003. Units are in µmol m^{-2} s^{-1}. Triangular points denote the period 142-159, where observed daytime photosynthesis values indicated moisture stress, whereas ACASA moisture stress manifested after day 160.

There is some model-observed disagreement immediately after dry-season (roughly June-October) precipitation episodes (Fig. 2, upper panel). Here, observations show respiration spikes followed by enhanced photosynthesis lasting several days to two weeks following dry-season rain events. ACASA results do not show this (Fig 2, lower panel), as there is nothing in the model that serves to enhance respiration when rain falls on a moisture-limited canopy.

Cumulative NEE	1999	2000	2001	2002	2003
ACASA*	-87	-73	-17	-73	+79
Observed	-103	-73	-21	-76	+61
Logged	+116	+224	***+358***	+85	***+440***
Shift Precip by +30 days*	-78	-65	+19	-60	+113

Table 1 (previous page): Observed and modeled annual NEE totals for 1999-2003. All differences are within observational uncertainty for each year. An asterisk (*) denotes ACASA simulations). A negative value represents a net sink of carbon for the year. Note that all values are positive in the logged scenario. Italicized values indicate net loss of carbon from plant tissue (excluding soil).

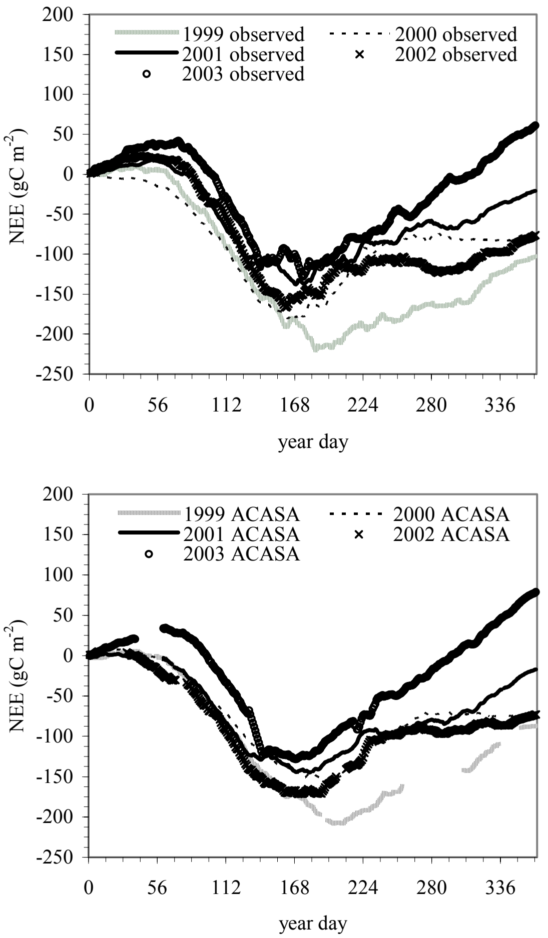

Figure 2: Observed (upper panel) and ACASA simulated (lower panel) annualized NEE for 1999-2003. Note the 1-2 week spikes in NEE during the dry season, most of which follow isolated but significant rain events, though 2003 spikes are mainly due to extremely warm conditions.

NEE changes arising from shifting the timing of wintertime rains by ±1 month are relatively subtle for 1999, 2000, and 2002, when the forest was a net sink of CO_2. Model NEE values for stress years 2001 and 2003, however, are more positive when the rains are shifted back one month, indicating that in these years the system is more sensitive to shifting precipitation patterns that may arise under future climate change scenarios. The implications of this are potentially worrisome, as ongoing and future climate changes may turn forests that are otherwise near equilibrium or are mild sinks of CO_2 to net sources as climate change continues.

There has been some indication that forests recovering from disturbances (Van Wijk *et al*. 2001; Morgenstern *et al*. 2004) are able to sink more carbon that their old-growth predecessors, which are thought to be at or near the equilibrium maximum of carbon storage (Smithwick et al. 2002). Information such as this has been used in policy debates as reason to enhance logging operations that would replace 'inefficient' old-growth ecosystems with more vigorous younger stands. Such conclusions are premature, since the recovery potential of logged forests will likely change in the future considering present and future climate change scenarios. Indeed, climate variability appears to be on the rise. The World Meteorological Organization (WMO) recently issued a rare statement warning the global community about an upswing of weather extremes around the globe in July, 2003 (WMO, 2003). At WRCCRF, 2003 was marked by a series of abnormally warm spells, with mean summertime temperatures running 5 ^{o}C above normal much of the time. Both observed and ACASA values show 2003 to be a net source year for WRCCRF.

Results from an additional sensitivity test, where ACASA was run with a canopy more resembling what would appear 5 years after clear cutting, assuming the seedlings and small saplings survive to this point. ACASA was run with the clear-cut canopy using the 1999-2003 data as before, but with a canopy height of 2 meters, a total LAI of 3.4, and a shallower root zone (0-0.4 m). It was assumed that soil moisture stress points were the same between the control and post-clear-cut simulations, and that soil carbon stores remain similar to what they are currently. Moisture stress was most pronounced in 2001 and especially 2003, where even the internal plant carbon balance (gross primary production, GPP) was positive for the year. This suggests that insufficient photosynthesis to fuel the reemerging vegetation may occur following a clear-cut during these or similar years, suggesting system mortality. The main driving mechanisms behind this imbalance is high temperatures leading to greater respiration needs, and moisture stress in the dry season attenuating photosynthetic uptake of CO_2. Moderate sink years (1999, 2000, and 2002) all became net source years in the clear-cut scenario, through increases in moisture stress due to enhanced soil surface evaporation and a shallower root zone. Increased dry season soil temperatures in the clear-cut scenario also served to increase NEE by driving up soil respiration.

3. Conclusions

NEE for an old-growth temperate rainforest has been measured and simulated for 5 continuous years. Broad agreement between model and observed estimates occurs throughout the period, with annual totals and daily values comparable to within observational uncertainty.

Model results are highly sensitive in 2001 and 2003 to shifts in the timing of wintertime precipitation, especially if the rainy season starts and ends 1 month early. Such findings suggest that changing precipitation patterns already underway may have an impact on carbon sequestration over this and perhaps other old-growth ecosystems.

Model results are also sensitive to severe reductions in canopy height and biomass after significant logging has occurred, especially for 2001 and 2003. If the frequency or severity of anomalous years like 2001 and 2003 are to increase in the future as suggested by the WMO and other research bodies, then the microclimate may not support regeneration after extensive logging without irrigation. Only in the years 1999, 2000, and 2002 was the simulated internal plant carbon balance negative, allowing for plant growth. Any advantages gained from clear cutting old growth vegetation to enhance NEE in such ecosystems are therefore suspect.

4. 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), and National Science Foundation award number ATM-0071377 . Any opinions, findings and conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the view of the DOE. The Authors would like to thank all the WRCCRF staff and affiliates for aid and support for this work.

5. References

Morgenstern, K., T. Andrew Black, E. R. Humphreys, et al., 2004: Sensitivity and uncertainty of the carbon balance of a Pacific Northwest Douglas-fir forest during an El Nino/La Nina cycle. *Agric. For. Meteorol.*, **123**, 201-219.

Pyles, R. D., B. C. Weare, and K. T. Paw U, 2000: The UCD Advanced-Canopy-Atmosphere-Soil Algorithm (ACASA): comparisons with observations from different climate and vegetation regimes. *Q. J. Roy. Meteorol. Soc.*, ***126,*** 2951-2980.

Smithwick, E. H., M. E. Harmon, S. M. Remillard, et al., 2002: potential upper bounds of carbon stores in forests of the pacific northwest. *Ecological Applications*, **12(5**), 1303-1317.

Van Wijk, M. T., S. C. Dekker, W. Bouten, et al., 2001: Simulation of carbon and water budgets of a Douglas-fir forest. Forest Ecology and Management, **145**, 229-241.

World Meteorological Organization (WMO), 2003: Extreme weather events might increase. WMO # 695, July 2, 2003, Geneva, Switzerland.