6.11 THE ROLE OF CLOUD COVER IN NET ECOSYSTEM EXCHANGE OF CO_2 OVER TWO MID-WESTERN MIXED HARDWOOD FORESTS.

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1. INTRODUCTION

The presence of clouds modifies surface environmental conditions both directly and indirect via atmospheric and hydrological processes. Since plant functioning is strongly linked with these processes, it is logical that the presence of clouds will also influence biophysical processes. One important relation that has emerged from field observations of net ecosystem exchange of CO_2 (NEE), links the presence of clouds with enhanced levels of canopy scale net CO_2 uptake (e.g. Price and Black 1990, Hollinger et al. 1994, Fitzjarrald et al. 1995). Several mechanisms have been suggested to explain this relation, including the enhancement of diffuse relative to direct beam photosynthetically active radiation (PAR), for which plant canopies have a higher use efficiency (Gu et al. 1999). Less direct influences include cooler leaf and soil temperatures under cloudy conditions which can lower respiration rates and decreases in vapor pressure deficit, enhancing stomatal openness.

In this study, we examine the relation between clouds and NEE observed over two different mid-latitude forest systems and over multiple growing seasons. By quantifying this relationship over different ecosystems with different climatic controls as well as inter-annual differences, we hope to improve a regional understanding for this role and potential responses in carbon sequestration to changing levels of cloudiness.

2. SITES AND METHODOLOGY

The two sites are located in mid-western USA and differ primarily by latitude and species composition. The southern site is located in the Morgan-Monroe State Forest (MMSF) in south central Indiana (38°N, 87°W), while the northern site is located at the University of Michigan Biological Station (UMBS), northern lower Michigan (45°N, 84°W). MMSF is a mixed hardwood forest comprised primarily of sugar maple, tulip poplar, sassafras, white oak and black oak. The UMBS forest is a northern hardwood forest with bigtooth and trembling aspen, red oak, sugar maple, white pine and eastern hemlock as the dominant species.

The two sites have identical eddy covariance measurement systems mounted at 46 m. The measurements utilized in this study include fluxes of CO_2 (NEE, μmols m^{-2} s^{-1}), using CSI CSAT3s and LiCor LI6262 closed path gas analyzers, and solar radiation (W m^{-2}) using LiCor LI200. Data presented for MMSF include the growing seasons of 1998 through 2001, while UMBS includes 1999 and 2000 and both datasets are comprised of hourly averages. A clearness index (K_t) is defined as the ratio K_{SH}:K_{OH}, where K_{SH} is the total downwelling solar radiation on a horizontal plane at the surface, while K_{OH} is the extraterrestrial radiation at a hypothetical horizontal surface at the top of the atmosphere. A cloudiness index (K_c) is defined as the ratio K_{SHobs}:K_{SHmod}, where the subscripts $_{obs}$ and $_{mod}$ refer to observed and modeled for the same time period but under clear skies respectively. K_{OH} is calculated using Whiteman and Allwine (1986), while K_{SH} is calculated by applying a locally determined optical transmissivity at 10-day intervals. Solar elevation angle (β) for each hour is also determined.

3. RESULTS

The relation between K_t, K_c and daylight NEE (a constraint of β > 10° was used) was examined using cubic regression for each growing season at both sites in bins of every 5° of β. An example of the relation between K_t and NEE at 40°-45° β is provided for all years at both sites (Figure 1).

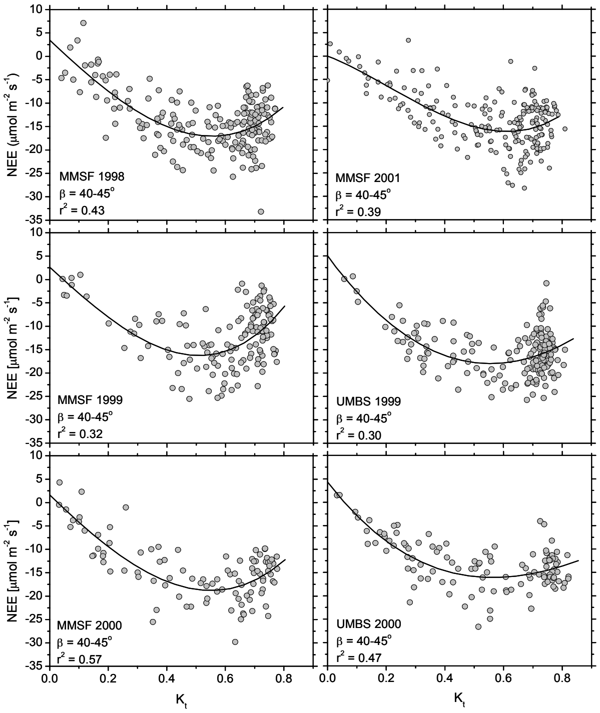

Figure 1. Relation between K_t and NEE for all years at MMSF and UMBS using the 40°-45° bin of β.

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These show clearly that the maximum NEE does not occur under clear skies but at a clearness index of between 40% and 60% of clear sky values and that a considerable amount of consistency exists between sites and between years.

For each site and each bin of β, the relation between K_c and NEE, determined in this way is presented in Figure 2. The values of K_c above 1 typically indicate cloud gap effects, which have a different relation with NEE (Gu et al. 1999) and have been removed from this analysis.

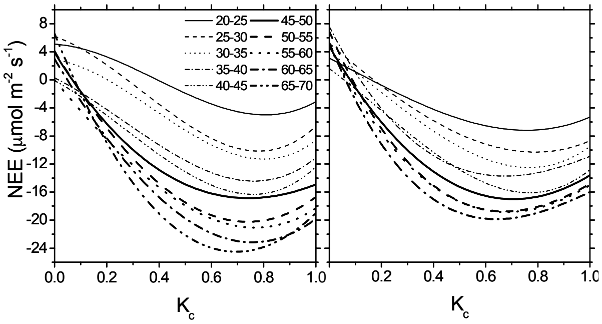

Figure 2. Cubic regression between K_c and NEE for each β bin for MMSF (left) and UMBS (right), 2000 data.

This figure shows the importance of binning the relation by β values because, while the relation is very similar in each case, the magnitude of NEE clearly increases with increasing β. This range also clearly varies between the two sites, indicating that β is more important at MMSF than UMBS for governing magnitudes of NEE. The mean r^2 value for each set of cubic regressions is 0.46 for MMSF and 0.57 for UMBS. Gu et al. (1999) defined an optimum K_c, the level of cloudiness at which carbon uptake is maximum and a critical K_c, the level of cloudiness below which CO_2 uptake is less than that of clear-sky conditions. The optimum and critical K_c values were determined by solving the polynomials derived from each regression for the maximum and the root at which NEE equals the clear-sky value ($K_c = 1$). The optimal and critical values (presented as percentages) for a range of β at both sites for 2000 are presented in Table 1.

Table 1. Optimal and critical values of K_c (percentage) for a range of β for MMSF and UMBS in 2000.

β	MMSF 2000		UMBS 2000	
intervals	Optimal	Critical	Optimal	Critical
25°-30°	81	58	76	48
35°-40°	80	57	77	50
45°-50°	76	47	77	50
55°-60°	74	47	67	39
65°-70°	76	50	64	36
Average	76	50	72	45

These values indicate that maximum NEE occurs when the relative irradiance of cloudy to clear skies is approximately 76% in the case of MMSF and 72% for UMBS. Furthermore, this measure of cloudiness could reach as low as 50% (MMSF) or 45% (UMBS) before an actual decrease in NEE would occur, compared with clear skies. It is interesting therefore, to examine the actual levels of cloudiness associated with these two sites to determine their levels of efficiency and the likely changes in NEE with inter-annual or longer scale changes in cloudiness (Figure 3).

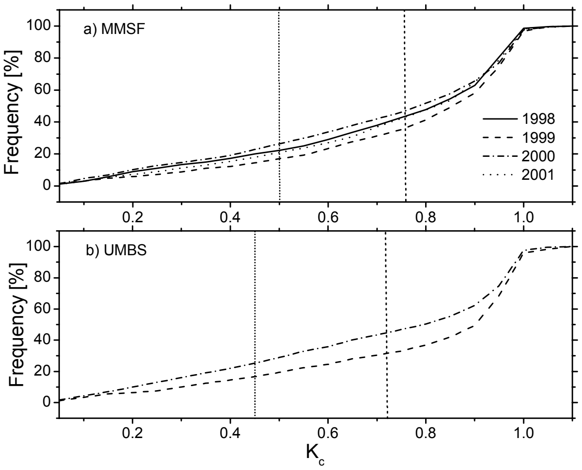

Figure 3. Cumulative frequency plots of K_c for each year. Vertical dashed lines show optimal K_c and dotted lines show critical K_c, both for 2000.

It is clear from Figure 3 that both sites experience lower cloudiness levels than is optimal for carbon uptake, and that a general increase in cloudiness would result in an enhancement of carbon sequestration. Furthermore, both sites would need to increase considerably in cloudiness before NEE would diminish to a level lower than that under clear skies.

5. ACKNOWLEDEMENTS

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