Carbon Dioxide and Methane Exchange in a Boreal Wetland

by

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GRADUATE COLLEGE
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Andrew E. Suyker, Ph.D.

University of Nebraska, 2000

Advisor: Shashi B. Verma

Detailed information on carbon exchange in northern wetlands is needed to improve our understanding of global carbon cycle and predictions of future climatic conditions. For this reason, fluxes of carbon dioxide and methane were measured in a boreal wetland in central Saskatchewan as part of the Boreal Ecosystem Atmosphere Study (BOREAS) in 1994 and 1995. Seasonal patterns of midday CO_2 flux were comparable in the two years. Peak midday CO_2 uptake (about 0.5 to 0.6 mg m^{-2} (ground area) s^{-1}) occurred in early July concurrent with peak LAI (≈ 1.3). The relationship between CO_2 flux (normalized by leaf area) and incident photosynthetically active radiation was similar in both years. High vapor pressure deficit ($1.5 < D < 3.2$ kPa) and air temperature ($20 < T_a < 30$ °C) reduced CO_2 flux significantly. Integrated net ecosystem CO_2 uptake was 89 and 108 g CO_2-C m^{-2} (890 and 1080 kg CO_2-C ha^{-1}) in the 1994 and 1995 growing seasons, respectively. Periods of high vapor pressure deficit and air temperature, a brief interval of cloudy/cool conditions, and a brief temporary rise of the water table in 1994 were likely associated with the lower carbon uptake.

Seasonal trends of methane emission showed some similarities in the two years. Maximum seasonal methane emission was of comparable magnitude (19.5 and 16.5 mg m^{-2} h^{-1} in 1994 and 1995, respectively) and occurred about the same time as the highest peat temperatures and water tables. However, peak methane emission occurred much earlier (5 to 6 weeks) in 1995: this was probably linked to the contrasting seasonal trends of peat temperature and water table between

years. Peat temperature and water table also reached their peak values later in the 1994 season. Sensitivity of methane emission to changes in peat temperature and water table was consistent between the two seasons. Seasonally integrated methane emission of 16.3 and 17.9 g CH_4-C m^{-2} (163 and 179 kg CH_4-C ha^{-1}) in 1994 and 1995 respectively, was 15-20% of the net ecosystem CO_2 exchange. Thus, for a productive wetland as studied here, carbon loss through methane emission is significant in the overall carbon budget.

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a,b,c,d,e	regression coefficients for relationship between methane and T_p and W where b is sensitivity to water table and c is a Q_{10} factor
D	midday (1130-1430 local time) average vapor pressure deficit at 4.2 m
F_c	carbon dioxide flux averaged over one half hour
F_c	midday average (1130-1430 local time) of carbon dioxide flux
F_{cL} (= F_c/LAI)	atmospheric CO_2 flux normalized by leaf area (mg m^{-2} (leaf area) s^{-1})
F_{cLM}	atmospheric CO_2 flux (mg m^{-2} (leaf area) s^{-1}) asymptote
$\mathbf{F}$	daily integrated carbon dioxide flux
$\mathbf{F}_{day}$	daytime integrated carbon dioxide flux
$\mathbf{F}_{night}$	nighttime integrated carbon dioxide flux
F_s	carbon dioxide flux measured from the soil surface using a chamber
F_m	methane emission averaged over one half hour
F_m	midday average (1130-1430 local time) of methane emission
G	soil heat flux (including energy storage in the peat)
$g(D)$	empirical term (function of D) to account for lower CO_2 flux due to high D
H	sensible heat flux
LAI	leaf area index
LE	latent heat flux
P = F_c+F_s	canopy photosynthesis for one half hour
P	midday (1130-1430 local time) average canopy photosynthesis
P_m	canopy photosynthesis asymptote in light response relationship
PAR	photosynthetically active radiation
PAR*	light compensation point (P=0) of the canopy
Q_{10}	relative change in item of interest for a 10 °C change in temperature
R_n	net radiation
R_s	y-intercept of light response curve
R_{sL}	y-intercept of light response curve normalized by leaf area
T_p	midday (1130-1430 local time) peat temperature 0.1m below a hollow bottom
T_a	midday (1130-1430 local time) average air temperature at 4.2m

W	midday (1130-1430 local time) average water table where the datum plane (i.e., *W*=0) is referenced to an "average" hollow bottom
α_L	apparent quantum yield (slope of curve at $F_{cL} = 0$)
η	slope of the photosynthesis-light response curve at P=0
NEE	net ecosystem exchange
BOREAS	Boreal Ecosystem Atmosphere Study
TDLS	Tunable diode laser sensor
DOY	Julian day of the year

List of Conversion Factors

F_c:	1 mg CO_2 m^{-2} s^{-1}	=	14.7 µmol CO_2 m^{-2} s^{-1}
F_c:	1 mg CO_2 m^{-2} s^{-1}	=	235.6 kg C ha^{-1} d^{-1}
F:	1 g CO_2-C m^{-2}	=	10.0 kg CO_2-C ha^{-1}
F_m:	1 mg CH_4 m^{-2} h^{-1}	=	24.0 mg CH_4 m^{-2} d^{-1}
F_m:	1 mg CH_4 m^{-2} h^{-1}	=	0.180 kg C ha^{-1} d^{-1}

Chapter 1. Introduction

Wetlands in boreal zones are extensive, covering more than 25% of the landscape in Canada and greater than 50% of the landscape in western Siberia (National Wetlands Working Group, 1988; Gorham, 1991). Boreal wetlands store a significant amount of global soil carbon (possibly between 20-33 %: Gorham, 1991; Billings, 1987; Schlesinger, 1996), and produce methane from anaerobic respiration in inundated peat soils. Carbon dynamics in wetlands involve a balance between carbon uptake in photosynthesis or sequestration below the water table and release from microbial and root respiration and methane emission. On a short term basis, day to day variations in environmental parameters (e.g., light, air temperature) have profound effects on carbon exchange via photosynthesis. On a long-term basis, other environmental parameters (e.g., height of the water table, peat temperature) affect carbon exchange via changes in soil/microbial respiration and plant phenology/productivity (Oechel *et al.*, 1998).

Atmospheric concentration of methane has doubled since the industrial revolution (e.g., Pearman *et al.*, 1986, Mitchell *et al.*, 1990) and it continues to increase although at a slower rate since about 1980 (Dlugokencky *et al.*, 1998, Steele *et al.*, 1992). Methane is a potentially important greenhouse gas both directly (efficiently traps outgoing tropospheric radiation: Lashof and Ahuja, 1990, Rodhe, 1990) and indirectly (affects concentrations of O_3 and H_2O - other greenhouse gases: Khalil and Rasmussen, 1992).

Wetlands produce methane from the anaerobic microbial decomposition of organic matter. Methane emission from northern (40-80°N) wetlands contributes an estimated 4-7% of the *global* sources (Bolin, 1994; Vourlitis and Oechel, 1997; Aselmann and Crutzen, 1989), with some

estimates as high as 13% (Matthews and Fung, 1987). During the last 10-15 years, considerable attention has been focused on methane emission in northern wetlands (e.g., Vourlitis and Oechel, 1997). These studies indicate the complex relationships between methane emission and the relevant biotic and abiotic controls. Investigators have considered variables such as substrate productivity, nutrient availability, and vegetative characteristics which control potential production of methane. Environmental factors such as water table and peat temperature have been linked to methane emission in several studies. Such dependence has been explored on a spatial and temporal basis in multiple studies (inter-comparisons among wetlands with different characteristics or temporal methane emission from multiple microsites within a wetland during a season). Estimates of the methane budget indicate a significant source still is unaccounted for (Vourlitis and Oechel, 1997).

Adding to the uncertainty in the methane budget is the large variability associated with most of the available measurements, which have employed small chambers. Better large-scale estimates of methane emission are needed to provide accurate information on the methane budget. Vourlitis and Oechel (1997) suggest that the availability of fast response gas analyzers and the use of the eddy covariance approach (from towers and aircraft) enhance the ability to measure methane emission on a landscape (hectares) and regional (square kilometers) scale. The eddy covariance technique provides a measure of the vertical flux of a transported entity at a point in the atmosphere by correlating the fluctuations in the concentration of that entity with the fluctuations in the vertical windspeed (e.g., Kaimal, 1975; Kanemasu *et al.*, 1979; Businger, 1986; Baldocchi *et al.*, 1988; Wesley *et al.*, 1989; Verma, 1990). This is an *in situ* technique which causes minimal disturbance