



ENVIRONMENTAL RESEARCH BRIEF

Impacts of Fire and Solar Ultraviolet Radiation on Trace Gas Exchange in the Boreal Forest Biome: A Review

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Abstract

Projections of future climate change suggest that the largest increases in temperature and other climate variables will occur in the high-latitude forests and wetlands of the boreal forest biome. This region also is being exposed to enhanced solar UV-B radiation caused by recent depletion of stratospheric ozone. The climate change is expected to have major effects on the extent and frequency of fires in the boreal forest. The research described here was part of the Boreal Ecosystem-Atmosphere Study (BOREAS) that took place during 1994-1996 in northern Manitoba, Canada. Field studies were conducted to measure soil-atmosphere fluxes of carbon dioxide, methane, and carbon monoxide, and related ancillary data, for both upland black spruce (located on poorly drained clay-textured soils) and jack pine sites (well-drained, sandy soils) that were in early stages of succession following stand replacement fires that occurred within 7 years of BOREAS. Results of these studies indicate that locally dependent changes in boreal fire return intervals linked to global climate change represent a potential biospheric/physical feedback that is likely to alter the biosphere-atmosphere exchange of carbon gases. All of the sites were net sinks of atmospheric methane with median fluxes ranging from -0.3 to -1.4 mg CH₄-C m⁻² d⁻¹. Median fluxes of carbon dioxide from the forest floor to the atmosphere ranged between 1 and 2 g C m⁻² d⁻¹. We estimate that soil CO₂ emissions from recently burned boreal forest soils in the northern hemisphere could be on the order of 0.35 Pg C yr⁻¹; this release of carbon may offset up to 50%-60% of the carbon taken up by the unburned boreal forest. The soil-atmosphere fluxes of CO, a gas that plays an important role in controlling

the oxidizing capacity of the troposphere, were generally positive at the warmer, sunlit burn sites, but negative (sink activity) in the shaded, cooler control sites. These results indicate that interactions between CO released from burned areas and chemical processes in the troposphere likely have important regional effects on atmospheric composition over the boreal forest.

Other studies focused on trace gas biogeochemical processes that affect organic matter cycling in the oxic zones of wetlands in the boreal forest biome. Measurements of CO concentrations and fluxes and of ammonium concentrations in selected beaver impoundments, indicated that solar radiation stimulates CO and ammonium production in these ecosystems. Laboratory studies indicated that UV-induced photodegradation of dissolved organic matter (DOM) is the primary pathway for the light-induced production of inorganic carbon and nitrogen. Carbon dioxide is the main identifiable photo product and it forms over an order of magnitude more rapidly than CO. Bioassays indicate that photodegradation of the DOM enhances its biological availability through production of inorganic nitrogen and readily assimilable low-molecular-weight organic compounds.

Introduction

Projections of future climate change suggest that the most dramatic increases in temperature and other climate variables will occur in the high-latitude forests and wetlands of the boreal forest biome. Moreover, the increases in solar UV-B radiation that have occurred over this region in response to the thinning of the stratospheric ozone layer are projected to persist well into the next century.

The boreal forest is a fire-dependent ecosystem that is located primarily in Canada, the United States (Alaska), and Russia. It

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is capable of sustaining very large, high intensity wildfires. Changes in climatic parameters (e.g., lightning frequency, drought, temperature) and/or human activities strongly influence fire frequency and intensity, and future global warming would likely increase the occurrence of boreal forest fires. The changes in fire return frequency and resulting impacts on biosphere/physical climate feedbacks are likely to exhibit a strong local dependence.

About 700 Pg (1 Pg = 10^{15} g) of carbon are stored in the boreal forest biome [Apps et al., 1993], which accounts for roughly 30% of the carbon stored in the terrestrial biosphere. Thus, there is concern that the enhanced warming and shifts in soil moisture, combined with changes in fire regimes and solar UV radiation, could cause significant changes in nutrient cycling and releases of carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), and other radiatively and chemically important carbon gases from the boreal forests and wetlands.

Here we report the results of a project that was part of the Boreal Ecosystem Atmosphere Study (BOREAS), a multidisciplinary investigation of the boreal forest biome that involved research teams from Canadian and U.S. institutions. BOREAS was a cooperative field and analysis study involving elements of terrestrial ecology, trace gas biogeochemistry, modeling, and land surface climatology. The goal of BOREAS was to understand the interactions between the boreal forest biome and the atmosphere in order to clarify their roles in global change. An overview of BOREAS and the results of BOREAS studies can be viewed at the BOREAS Worldwide Web site (URL is <http://boreas.gsfc.nasa.gov>).

The research described here focused on the exchange (net uptake or emission) of carbon gases (CO_2 , CH_4 , and CO) between the soils and atmosphere or water and atmosphere at selected sites located in or near the BOREAS Northern Study Area (NSA) [Sellers et al. 1995]. The NSA was located close to Thompson, Manitoba, within a few hundred kilometers of the northern boundary of the boreal forest. These experiments were conducted in soils of upland black spruce and jack pine stands that have recently experienced stand-replacement, crown fires and in nearby controls that had not been burned for at least 80 years. Other studies of trace gas exchange and nutrient cycling were conducted in beaver impoundments located in the NSA. Results of these studies indicate that the locally dependent changes in boreal fire return intervals that are linked to global climate change represent an important biospheric/physical feedback that is likely to alter the biosphere-atmosphere exchange of CO and CO_2 . The results further indicate that solar UV radiation has significant effects on the emissions of CO and production of ammonium in wetlands of the boreal biome.

Experimental

Forest Site Description

As shown on Figure 1, studies of the trace gas exchange were conducted at both upland black spruce (*Picea mariana*) and jack pine (*Pinus banksiana*) sites that had experienced intense, stand-replacement fires within 7 years of the 1994 BOREAS field campaigns (BOREAS '94). Four black spruce sites were selected near the road to Gillam, Manitoba, about 100 km from Thompson, Manitoba. Three of the sites had distinctly different recent burn histories. The fourth site served as a control and had not burned for at least 80 years. Sites are denoted as CBS (control black spruce) and 94BS, 92BS, and 87BS (stands

burned in 1994, 1992, and 1987, respectively). All four black spruce sites were within 5 km of each other and were exposed to very similar climatic conditions. The jack pine site (89JP) was located in a large burned forest (115,643 ha; summer, 1989) that is west of the NSA. A nearby jack pine stand (CJP), unburned for at least 80 years, served as the control for the 89JP site.

The black spruce stands were located on an orthic grey luvisol soil with high water holding capacity. Biomass densities of the black spruce stands ranged from 40,000 to 180,000 kg/ha with most sites at the lower end of this range. The forest floor of the CBS site was predominantly covered by a thick layer of feathermosses. The combined organic layers at this unburned black spruce stand ranged to between 20 and 25 cm with much thinner layers representing the areas covered by lichens only. The burned sites had all experienced fires with intense torching and crowning that resulted in 100% overstory and ground cover mortality. Most of the surface was covered with charred moss, other debris, and a variety of plants that are characteristic of boreal forest regeneration. Young black spruce seedlings were just starting to emerge at the 1992 and 1987 burn sites; the largest were generally less than 15 cm tall.

The forest floor of the control jack pine site was covered mainly by a thin layer of reindeer lichen (*Cladina spp.*) with very little understory. The burned jack pine site was about 5 km away from the control site. As in the case of the black spruce sites, all trees at the 89JP site had been killed by fire and most were still standing during BOREAS '94 with only a thin layer of charred organic matter found on the forest floor.

Wetland Sites

Most measurements and experiments conducted for this study were made at a beaver impoundment (NSA Tower Pond) that was selected for intense studies (tower flux measurements and characterization of physical, chemical, and biological properties) during the BOREAS '94 field campaigns. It was located 13 km west of Thompson and approximately 300 m south of Manitoba Hwy. 391 (55°55'N, 98°01'W). CH_4 and CO_2 water-to-atmosphere fluxes were measured and process studies concerning the dynamics of these gases around the open water, vegetated zones and periphery of the pond are reported elsewhere [Roulet et al., 1997].

Soil-Atmosphere Flux Methods

We used a static chamber technique [e.g., Whalen and Reeburgh, 1988] to estimate soil/atmosphere exchange. The chamber consisted of a permanently deployed circular aluminum collar, with a water seal and skirt (~10, 25, or 30 cm deep in areas with significant moss, lichen, or burned vegetation cover, ~5 cm deep in areas in which the vegetation had burned to the mineral layer), and cover. For the CO_2 and CH_4 studies, the cover was constructed of aluminum and was equipped with a septum for syringe sampling and a small hole to equalize pressure. A transparent, borosilicate cover was used for the CO flux studies, so that the effects of solar radiation on CO exchange could be investigated.

Gas flux samples (5 to 7 samples per flux measurement) were collected at 5-7 minute time intervals over the course of 20-30 minutes in polypropylene (for CO_2 and CH_4 samples) or glass (for CO samples) syringes and the gas samples in the syringes were analyzed by gas chromatography after return from the field sites to the laboratory.

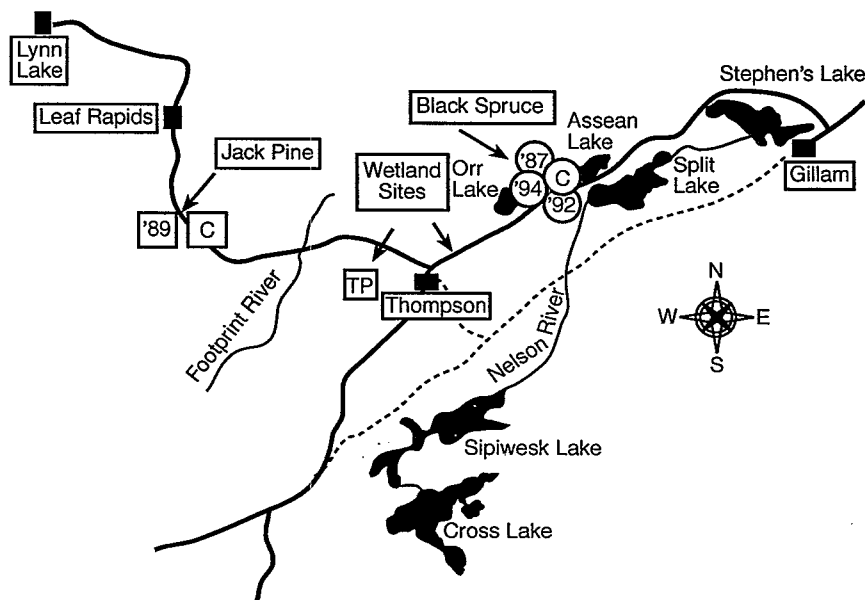


Figure 1. Map of northern Manitoba showing locations of sites included in the studies reviewed in this report. The jack pine and black spruce sites were located in upland stands that had experienced intense stand-replacement fires during the decade prior to the Boreal Ecosystem-Atmosphere Study (BOREAS). The wetland sites were located at active beaver impoundments, one of which, tower pond (TP), was a BOREAS tower site.

Wetland Studies

The flux of CO across the water-air interface was estimated using the static floating chamber method. An inverted cylindrical quartz chamber (cross sectional area = 491 cm²) was mounted in a floating aluminum base (cross sectional area = 363 cm²) and sealed with distilled water. Gas flux samples were collected in glass syringes for later analysis. Water samples were collected at various depths for measurements of CO and ammonium concentrations and for subsequent photochemical experiments in the laboratory. The latter were filtered through 0.22 µm membrane filters and stored at 4°C.

Triplicate aliquots of the filtered water samples were sealed without headspace in 30 mL quartz tubes, mounted and exposed to natural light in an open water section of the NSA tower pond at various depths. Following exposure, a known volume of headspace (5-11 mL) was added to each tube by removing water with a syringe and replacing it contemporaneously with CO-free air at atmospheric pressure. The tubes were shaken for one minute and placed in a water bath. After equilibration the headspace in each tube was sampled and analyzed for CO by gas chromatography. The aqueous phase also was analyzed for ammonium.

Water samples were irradiated using a solar simulator (DSET Heraeus), in most cases with exposure to the full spectrum. For some samples, spectral distribution of the radiation was modified by using Schott glass filters to selectively block out various wavelengths of UV radiation. Hydrophobic resins were used to isolate and fractionate the humic substances in the wetland waters. To evaluate the effects of exposure to solar radiation on the bioavailability of the organic nitrogen compounds in the wetland water, various bioassay treatments were

conducted in which the growth of a natural bacterioplankton inoculum was followed over the next 92 hr in an aqueous solution of humic substances that had been irradiated in the solar simulator for various time periods. Twelve bioassay treatments were established by additions of inorganic nutrients (N only, P only, or N+P) and/or a labile carbon source (glucose) to irradiated or non-irradiated fulvic acid solutions. Bacterial growth was measured by the uptake of tritiated leucine. Other studies, conducted in the laboratory, determined the increase in concentrations of CO and dissolved inorganic carbon (DIC) in the water on exposure to simulated sunlight.

Analytical Procedures

A Carle AGC gas chromatograph (GC) equipped with a thermal conductivity detector (TCD) and a flame ionization detector (FID) was used to analyze for CO₂ and CH₄ and a Trace Analytical RGA-3 Reduction Gas Analyzer equipped with mercuric oxide detector was used to measure CO concentrations. The chromatographic responses were carefully calibrated versus standards provided by the Atmospheric Environment Service of Canada (CO₂ and CH₄) or the National Institute of Standards and Technology, Gaithersburg, MD (CO). Dissolved organic carbon (DOC) and DIC in the wetland water samples were determined using a Dohrmann Model DC85A carbon analyzer, and ammonium concentrations were determined by ion exchange chromatography with conductometric detection and an absorptiometric phenol-hypochlorite method. Total nitrogen in the freshwater samples was determined by acid digestion and chemical oxidation of the organic nitrogen in the water samples to inorganic nitrogen as described in detail under Method 351.2 in the FWPCA Methods of Chemical Analysis of Water and Wastewater (FWPCA Methods, 1979).

UV and visible absorption spectra were obtained using a Shimadzu Model UV-160-U scanning spectrophotometer.

Results and Discussion

Soil-Atmosphere Exchange of Trace Gases During Early Post-Fire Succession

Important processes affecting the net ecosystem exchange of carbon gases are shown in Figure 2. Plants and soils act as both sources and sinks for carbon gases. Living plants are the major sink for CO₂ in the terrestrial biosphere and also are a direct source of CO to the atmosphere that likely is altered by the changes in vegetation species and biomass densities during post-fire succession. Past investigations of factors influencing soil production and consumption of CO₂, CH₄, and CO, coupled with known impacts of fires on the boreal forest biome, suggested to us that soil gas fluxes might well be strongly altered by boreal fires. Boreal stand replacement fires alter the thermal regime and moisture content of soil layers owing to enhanced solar radiation reaching the soil surface. Increased light exposure should stimulate CO production by surface photodegradation and the warmer temperatures should enhance organic matter decomposition to CO₂ and CO. Soil warming, changes in soil moisture in burned forests, and post-fire alteration in soil nutrient bioavailability also can alter microbial transformations in the soil matrix [Conrad, 1995], but the net effect is not obvious. For example, soil warming in burned soils tends to stimulate microbial activity, but increased concentrations of inorganic nitrogen released by decomposition of soil organic nitrogen may decrease microbial oxidation of CH₄ and CO by nitrifying bacteria. Finally, stand-replacement boreal fires convert the boreal forest floor from what is generally a thick living cover of mosses or lichens to a charred, blackened layer of nonliving carbonaceous substances that are likely to have quite different biogeochemical properties.

During the spring, summer, and fall of 1994-1996, we measured soil-atmosphere exchanges of CO₂, CH₄, and CO and related ancillary data near the BOREAS NSA at upland black spruce (located on poorly drained clay-textured soils) and jack pine sites (well-drained sandy soils) that were in early stages of succession following stand replacement fires that occurred within 7 years of the 1994 BOREAS field campaigns (Figure 1). Nearby control stands that had not burned in the past 80 yrs were studied for comparison. The CO₂ and CH₄ fluxes were measured using a static chamber technique with an opaque cover.

Based on our measurements made during 1994 we conclude that soil/atmosphere exchange of CH₄ and CO₂ are significantly altered by fire [Burke et al., 1997]. All of the sites were net sinks of atmospheric CH₄ with median fluxes ranging from -0.3 to -1.4 mg CH₄-C m⁻² d⁻¹. We observed that sites that have been recovering from fire for a few years (5 to 7) consume significantly more methane than sites either very recently disturbed (<1 yr) or sites that have fully recovered from previous fires. Moreover, our median values indicate that the jack pine soils tend to consume methane at a slightly greater rate than the black spruce soils.

We used our soil respiration data, along with the assumption that initial plant regrowth takes up a negligible amount of carbon [e.g., Auclair and Carter, 1993] and some information from the literature, to calculate a rough estimate of the magnitude of soil CO₂ emissions from recently burned (< decade) boreal forest [Burke et al., 1997]. For this calculation, we

assumed that 10¹² m² of the boreal forest burns in a decade [Kasischke et al., 1995], that this area is similar to the burn sites that we studied with respect to soil respiration rate, and that the forest burned had a pre-burn net ecosystem carbon uptake of 50 g C m⁻² y⁻¹ as estimated for the BOREAS NSA OBS site [Frolking et al., 1996]. We further assumed that the rate of soil respiration observed at our burn sites (~1.5 g C m⁻² d⁻¹) occurs for the ~5 months of the year when the soil is not snow-covered and that the rate of soil respiration during the rest of the year is equivalent to the 85 g C m⁻² observed for the BOREAS NSA OBS site during the snow covered period [Frolking et al., 1996]. These assumptions yield an estimate of 0.35 Pg C yr⁻¹ released as post-fire CO₂ emissions in the boreal region. Using similar assumptions regarding area burned, but basing their CO₂ emissions estimates on assumed breakdown rates of dead residual wood and SOM rather than direct measurements, Auclair and Carter [1993] estimated that similar amounts of carbon (~0.3 Pg C yr⁻¹) would be emitted post-fire from boreal and temperate forests. By comparison, the remaining 11 x 10¹² m² of unburned boreal forest would be a sink for about 0.55 Pg C yr⁻¹ if it has the net ecosystem carbon uptake of 50 g C m⁻² y⁻¹ that was estimated for a tower site located in a mature black spruce stand in the BOREAS NSA [Frolking et al., 1996]. This estimate of the unburned boreal forest carbon sink is similar to the 0.7 Pg C yr⁻¹ derived by Apps et al. [1993] from estimated annual changes in biospheric carbon pools. The magnitude of these estimates of post-burn soil CO₂ emissions, compared to the boreal biome carbon sink estimates and within the context of the global carbon cycle [e.g., Ciais et al., 1995], suggests that further study of post-fire soil CO₂ emissions is needed.

This study provided new evidence that boreal forest fires perturb soil-atmosphere exchange of CO fluxes [Zepp et al., 1997]. During BOREAS '94 (June to September 1994) CO was consumed by the forest floors of mature black spruce and jack pine stands in northern Manitoba that had not burned for close to a century. In contrast, CO was generally emitted from soils of forests that had experienced stand-replacement fires within 7 years prior to BOREAS '94.

The consumption of CO in mature black spruce and jack pine stands on a given day and location was proportional to atmospheric CO concentration. The median deposition velocities (ratio of CO soil/atmosphere flux to CO atmospheric concentration) in these unburned forests was 0.008 to 0.015 cm s⁻¹, at the lower end of the range that has been observed in other biomes, possibly reflecting the lower temperatures in boreal forest soils.

Daytime CO fluxes at the burn sites were generally positive (10¹¹ to 10¹² molec cm⁻²s⁻¹) and were lowered when solar irradiance was excluded by covering the transparent chambers or reduced during periods of cloudiness or smoke. Net fluxes at the burn sites were controlled by competition between abiotic production, mainly at the surface, and microbial oxidation in the soil. Abiotic production, which was attributable to photodecomposition and thermal decomposition of the surface organic layer and charcoal, strongly correlated with incident solar irradiance, with the greatest fluxes during midday. Burned moss patches were the strongest sources of CO at the sites. Although the soils of the most extensively burned sites were significantly warmer than the nearby controls, these studies indicate that photodecomposition of the surface organic matter was the predominant process that produced CO. Thus, prior field studies of CO fluxes in open areas using dark chambers

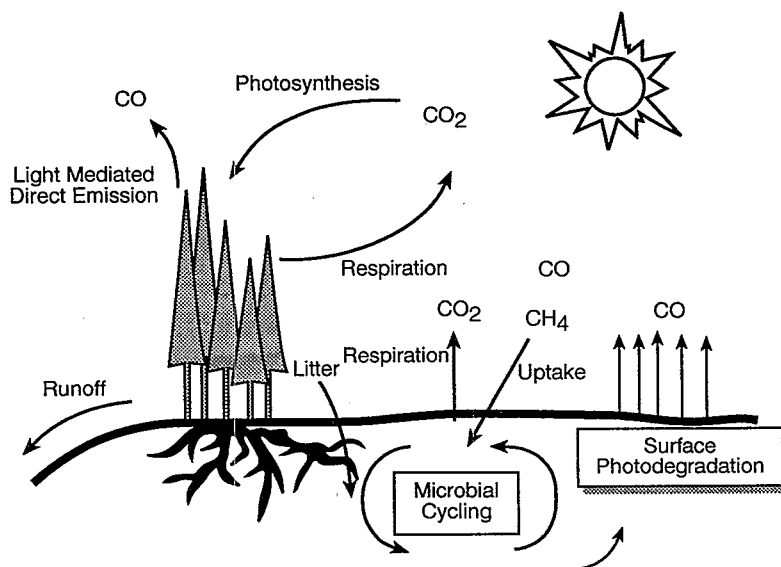


Figure 2. Processes affecting the net ecosystem exchange of trace carbon gases and carbon cycling in the boreal forest.

may have greatly underestimated daytime emissions. Evidence is presented that changes in the competition between soil uptake and production with smoky air masses present serve to buffer atmospheric CO concentrations and soil-atmosphere fluxes. Changes in the soil fluxes of CO caused by fires in the boreal biome may be a significant local source of atmospheric CO during summer days (up to 10^{12} molec cm^{-2} s^{-1}).

Solar UV Radiation, CO Emissions and Nutrient Cycles in Selected Boreal Wetlands

Many boreal wetlands contain high concentrations of chromophoric dissolved organic matter (CDOM) and thus are highly colored. This CDOM, which is derived mainly from decomposition of terrestrial plant matter from trees and mosses, consists mainly of high-molecular-weight humic substances that are not readily assimilated by microorganisms [Bourbonniere et al., 1995]. Earlier studies have indicated that CDOM from freshwater and marine environments in other biomes can be photodegraded by solar UV radiation to various low-molecular-weight compounds, including carbon monoxide [e.g., Valentine and Zepp, 1993]. These studies mainly involved laboratory studies of the effects of changing reaction conditions on rates of CO photoproduction. Few field studies documenting the role of sunlight in the production of CO in high-latitude biomes are available.

Our *in situ* experiments and measurements of ambient concentrations in selected beaver impoundments (TP and another site shown in Figure 1) confirm that CO production in such ponds depends on sunlight [Bourbonniere et al., 1997]. The diurnal changes observed in the flux of CO measured across the air-water interface also indicate that photoproduction is important and that the resulting supersaturation of surface water leads to a net flux out to the atmosphere. The supersaturation factors noted for this boreal beaver pond are the highest reported from any aquatic system, five times higher than those for any other freshwater system studied. The high concentration of CDOM in

this pond, and possibly its terrestrial origin, may be the primary cause of high supersaturation and deserves further study. The photoproduction rates of CO observed in quartz containers positioned at various depths in tower pond were found to agree closely with rates estimated using a computer model (Figure 3). The model used simulated solar spectral irradiance in the UV region and the action spectrum for CO photoproduction to compute the rates at various depths averaged over the full day.

Based on previous studies and the results presented here, the exchange of CO reflects a dynamic balance between the photochemical, biological, and physical processes at work here. Floating quartz chambers seem to reflect near surface (~1 cm) CO photoproduction rates and these "instantaneous" gas flux data track changes in solar intensity fairly closely. Flux calculations based on CO supersaturation may more accurately represent gas fluxes in the absence of strong sunlight and incorporate some aspects of mixing. From a mass transfer point of view, however, total water column CO photoproduction will reflect the significance of solar irradiance and changes in UV-B on CO exchange from these dark waters. For this, more complete data on losses from biological consumption and on daily and seasonal variations in the photochemical and optical properties of these waters are needed to constrain CO flux estimates over time scales relevant to regional carbon balances.

To better understand the impacts of solar UV radiation on processes occurring in boreal wetlands, we conducted a variety of laboratory studies using filtered water samples obtained at our field sites [Bushaw et al., 1996; Zepp et al., 1995]. The CDOM also was fractionated using hydrophobic resins to help determine the response of various components to UV exposure [Bourbonniere et al., 1995; Bushaw et al., 1996]. Laboratory studies of the water samples and the fractions were conducted to determine the kinetics of photochemical changes in optical properties and the photoproduction rates and quantum yields of carbon dioxide, carbon monoxide, and various photooxidants [Zepp et al., 1995]. The UV absorbance of the

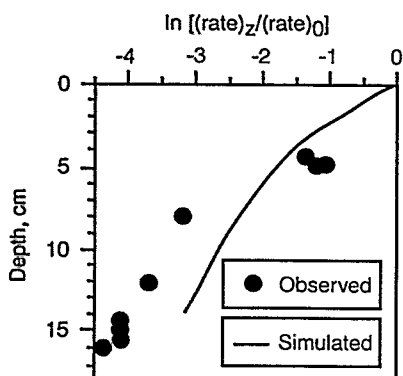


Figure 3. Depth dependence for carbon monoxide production at a beaver impoundment (TP, see Figure 1) located in the Northern Study Area (NSA) of BOREAS. The terms, $(rate)_0$, and $(rate)_z$, refer to the production rates near the surface and at depth z . Observed rates were determined for filtered samples of TP water contained in quartz tubes to permit full exposure to UV-B radiation (Bourbonniere et al., 1997). The simulated rates were computed using the GCSOLAR computer program (Valentine and Zepp, 1993).

CDOM decreased on exposure to solar UV radiation and this "fading" was accompanied by photoproduction of dissolved inorganic carbon (DIC) as well as carbon monoxide. As observed with water samples obtained from water bodies in the southeastern United States [Miller and Zepp, 1995], the DIC photoproduction was 15 - 20 times more rapid than CO photoproduction. The hydrophilic acid fraction was significantly more photoreactive than the hydrophobic acids. Quantum yields at 313 nm for the hydrophobic acid fraction collected during July were found to be 0.0014 for DIC photoproduction and 4.9×10^{-5} for CO photoproduction. The latter value is close to the quantum yields determined for other wetlands in more temperate regions [Valentine and Zepp, 1993].

Other studies were conducted to elucidate the possible role of CDOM photodegradation in carbon and nitrogen cycling in boreal wetlands. Exposure of filtered pond water, humic substances and hydrophilic acids isolated from the water indicate that the CDOM can be degraded by sunlight into a variety of photoproducts that stimulate the growth and activity of microorganisms in aquatic environments. All biologically labile photoproducts identified to date fall into one of four categories: i) low molecular weight (LMW) organic compounds (carbonyl compounds with MW < 200); ii) carbon gases (primarily CO); iii) unidentified bleached organic matter; and iv) nitrogen- and phosphorus-rich compounds (including NH_4^+ and PO_4^{3-}). A number of laboratory studies using bacterial bioassay approaches have shown that the photochemical breakdown of DOM can stimulate biomass production or activity by 1.5- to 6-fold [Moran and Zepp, 1997]. Microbial activity also has been shown to be enhanced by the photochemical formation of readily assimilable nitrogen compounds. For example, the dissolved organic nitrogen in water samples and humic substances from the BOREAS tower pond site were photodegraded to form ammonium and low-molecular-weight organic amines [Bushaw et al., 1996]. Solar UV radiation was responsible for inducing this photo-ammonification process (Figure 4). Under N-limiting con-

ditions, the release of nitrogenous photoproducts from aquatic humic substances was found to significantly increase rates of bacterial growth [Bushaw et al. 1996]. Nitrogen-rich photoproducts are likely to be of greatest biological interest in aquatic ecosystems where plants and plankton are nitrogen limited and concentrations of light-absorbing DOM are high [Bushaw et al. 1996], e.g., in coastal wetlands and estuaries.

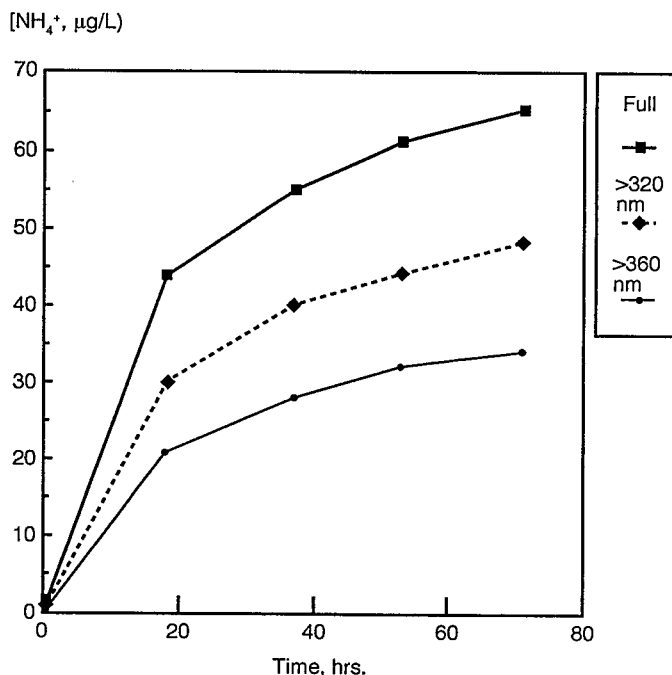


Figure 4. Photoproduction of ammonium on exposure of water samples from the BOREAS tower pond to simulated solar radiation. The full irradiance impinging on the samples was close to that observed at mid-afternoon on a clear July day in the BOREAS Northern Study Area. The rates were significantly reduced when the radiation was filtered through Schott glass filters that removed portions of the UV component. The results indicate that photoreactions of the dissolved organic nitrogen induced by solar UV radiation were mainly responsible for the ammonium production.

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