Ozone and Modeled Stomatal Conductance at a High Elevation Subalpine Site in Southeastern Wyoming[1]

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Abstract

Ozone concentrations have been monitored at the Glacier Lakes Ecosystem Experiment Site (GLEES) in the Snowy Range of the Medicine Bow Mountains 55 km west of Laramie, Wyoming, USA. The site is located at 3,186 m elevation in a large subalpine meadow of a mature subalpine forest near timberline. Continuous ozone and meteorological monitoring are a part of the GLEES research to determine the effects of atmospheric deposition on alpine and subalpine ecosystems. Ozone monitoring has shown specific summer and winter diel ozone distribution patterns, typical of remote, rural, high elevation sites. The data show relatively high background ozone concentrations with little diel variation in winter. Stratospheric intrusions contribute to the ground-level ozone concentrations in the spring. Summer ozone patterns show diurnal photochemical peaks and significant night time concentrations suggesting lack of scavenging. The relationship of modeled leaf stomatal conductances, boundary layer conductances, canopy conductances and photosynthesis rates to ambient ozone concentrations and measured ozone flux was examined by using regression analysis. Ozone concentrations were also compared with wind, radiation, temperature, and humidity conditions at the site by using regression analysis. The data provide information on ozone concentration and environmental conditions at a remote, high elevation site typical of many wilderness areas of the western United States.

Introduction

The Glacier Lakes Ecosystem Experiment Site (GLEES) is a 600-ha research site in southeastern Wyoming, where atmospheric deposition and its effects on terrestrial and aquatic ecosystem processes are being studied (Musselman 1994). The site is located at 3,100 to 3,400 m asl elevation in the Snowy Range of southeastern Wyoming, about 40 km west of Laramie. The research site is in the Medicine Bow National Forest at the alpine/subalpine ecotone. Much of the atmospheric monitoring is conducted at the Brooklyn Lake site, a forest stand dominated by Engelmann spruce (*Picea engelmannii* (Parry) Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). The Brooklyn site is occupied by patchy forest with large subalpine meadow openings.

This paper discusses the results of studies to determine the characteristics of ozone deposition in alpine and subalpine ecosystems in southeastern Wyoming.

Methods

The Brooklyn meteorological and air quality monitoring site at the GLEES is located in a small subalpine forest opening (30-m diameter). Electric power is available at the site. Standard meteorological measurements are monitored continuously at 10 m and 29 m above the ground and recorded on a data logger. Parameters measured at the site include wind speed and wind direction, soil and air temperature, radiation, wetness, and relative humidity. Precipitation is monitored at 2 m above the ground with an Alter shielded Belfort rain gauge.[3] Air quality measurements include ambient ozone and dry and wet deposition.

Dry deposition is monitored as part of two national networks, the National Dry Deposition Network (NDDN) Centennial site, and the Interagency Monitoring of Protected Visual Environments (IMPROVE) Brooklyn Lake site. The NDDN site is part of a United States Environmental Protection Agency-sponsored national network of dry deposition monitoring stations. Protocols for both dry deposition monitoring networks use a filter pack for collection of dry particles and gases, but

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[3] Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

they each conduct different analyses. The NDDN site is located in a larger opening about 120 m southwest of the Brooklyn meteorological monitoring. The IMPROVE monitor is located at the Brooklyn monitoring site meteorological tower.

Wet deposition is monitored as a part of the U.S. National Atmospheric Deposition Program (NADP) national network, site Brooklyn Lake, WY95, which monitors wet chemistry of precipitation. The NADP wet deposition station is also located at the Brooklyn Lake Monitoring site, about 80 m north of the NDDN site.

Ozone has been monitored at 3,180 m asl at the GLEES Brooklyn Lake NDDN monitoring site since 1989. Monitoring and calibrations follow standard NDDN protocols. The station monitors ozone continuously at 3-m height above the ground. Ozone flux measurements were also made at the site by using an eddy correlation system (Zeller and Hehn 1996).

The FORFLUX model (Nikolov 1995) was used to estimate canopy photosynthesis and stomatal CO_2 conductance by using meteorological (March to June 1990) data from the site. FORFLUX estimates canopy fluxes by numerical integration of LEAFC3 model (Nikolov and others 1995) over stand leaf area index. Leaf area index of 3.5 was used for this study. The modeled photosynthesis and CO_2 conductances were compared with values of ambient ozone using regression analyses. The relationship was examined between the modeled canopy conductance and (1) ambient ozone concentration or (2) ozone flux measurements. The ambient ozone concentration data were also compared to measured meteorological data by using regression analysis.

Results and Discussion

Typical ozone distribution patterns at the GLEES are characteristic of high elevation remote sites. These patterns show low diel variation in ozone concentration, a result of minimal daytime increase from photochemical production and minimal night time decrease due to scavenging. The site also shows evidence of stratospheric intrusion of ozone (Wooldridge and others 1996). Characteristics of the ozone deposition at the GLEES have been described elsewhere (Wooldridge and others 1996, Zeller and Hehn 1995). There are three main characteristics of the ozone distribution for this remote site. First, concentrations of ozone are relatively high at the site (*table 1*). Concentrations above 60 ppb occur frequently during the spring and summer (Wooldridge and others 1996). Concentrations above 50 ppb are common.

***Table 1** — 1990-1994 average monthly ozone concentration at the GLEES Brooklyn monitoring site (Wooldridge and others 1996).*

Month	*Mean ozone concentration, ppb*
January	44.6
February	47.5
March	50.5
April	53.9
May	54.6
June	49.8

A second characteristic is the diel variation of ozone concentration shows very little amplitude. Diel concentrations vary as little as 1 to 3 ppb in January and February (44 to 47 ppb). Diurnal variation and peak daily ozone concentration increase monthly from March (minimum 48 ppb, maximum 51 ppb) to May (minimum 51 ppb, maximum 58 ppb), with typical afternoon photochemical peaks. The diel pattern in May and June is more pronounced, typical of increased photochemical generation of ozone during the day and greater amount of ozone scavenging by nitrogen oxides and surfaces at night. This difference indicates the importance of the lack of night time nitrogen oxide scavenging at this site during the winter. In addition, there is very little daily photochemical generation of ozone in winter. The lack of a diurnal peak is likely because of the limited amount of precursors, and the very low temperatures that are not conducive for chemical reactions. Temperatures at the site in January average less than -10 °C. The lack of night time scavenging is likely due to the snow cover. Snow has been shown to be a poor sink for ozone (Stocker and others 1995, Zeller and Hehn 1995).

The third unique characteristic is relatively high ozone concentration occurring at this site even during midwinter, considering its remoteness, and the change in average ozone concentration as the season progresses (Wooldridge and others 1996) (*table 1*). Monthly average ozone concentration increases from January to May, then decreases in June. There is evidence that stratospheric intrusion causes the April/May ozone peak (Wooldridge and others 1996). Examination of the data indicates high concentration ozone episodes with levels above 60 ppb that can last for several days. These episodes are associated with very low (less than 25 percent) relative humidity, suggesting downward intrusion of air from the stratosphere or upper troposphere. The episodes occur frequently during April and May coincident with passage through the area of cutoff low pressure centers. Ozone concentration levels, during times of the month when these episodes occur, show almost no evidence of diurnal photochemical ozone generation.

The June pattern has the highest diel variation (41 ppb to 52 ppb), yet the average ozone concentration is reduced as the weather patterns for intrusions are greatly reduced. Diurnal photochemical generation of ozone is more likely to occur during June, and lack of a snow cover increases night time scavenging. Yet, average low concentrations in June do not fall below 41 ppb, indicating considerably less scavenging than in urban areas.

Output from the FORFLUX simulation model and ozone concentration was examined, and no significant relationships were found between ambient ozone concentration and modeled canopy photosynthesis or CO_2 conductance (*fig 1*). Variability in the modeled parameters was high. There was no significant relationship between solar radiation, temperature, wind speed, and relative humidity and ambient ozone concentration. We have previously shown a relationship between low humidity and high ozone concentrations (Wooldridge and others 1996), and ambient ozone has been shown to be related to temperature (Flaum and others 1996). There did appear to be a slight trend for increasing ozone concentration with increasing solar radiation and temperature. These relationships would reflect meteorological conditions favorable to ozone production at the site, and would be expected to be stronger with summer data than with the spring data presented here.

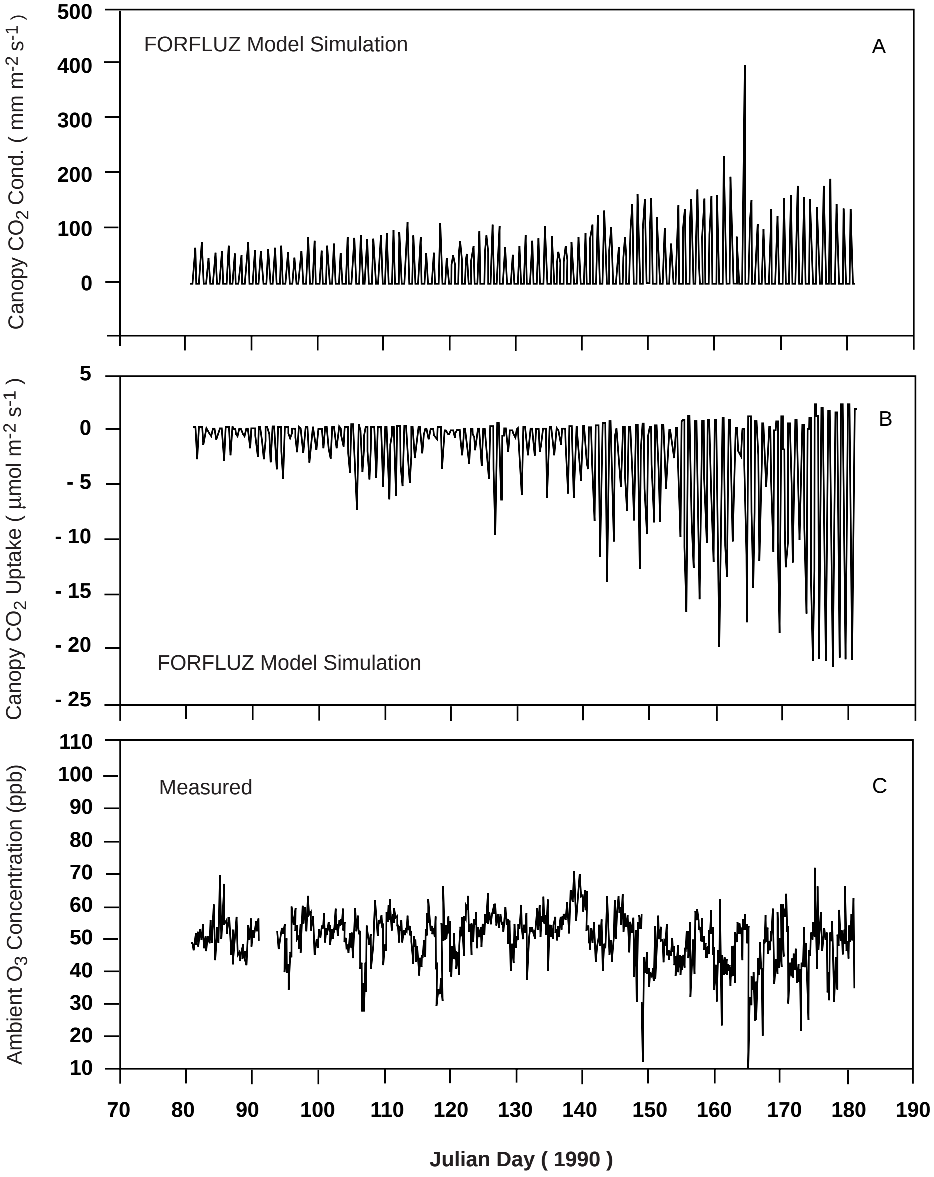
Plants often have a closer relationship to ozone flux than to ambient ozone concentration (Musselman and others 1994). Modeled canopy CO_2 conductance showed some relationship to measured ozone flux at GLEES site (*fig. 2*), in contrast to the lack of relationship between conductance and ambient ozone concentration.

There are several reasons for the lack of a relationship between modeled physiological parameters and ambient ozone. First, the model was not specifically designed to simulate physiological response to ozone. Our objective was simply to examine any possible relationship. Second, ozone concentrations are near the lower threshold where plant response should occur; thus, the impact of ozone on plant physiological response was limited. Third, these data represent early season meteorological data. Greater effects should be expected later in the growing season when plants are physiologically more active. CO_2 uptake and conductance increase as the growing season progresses (*fig. 1*). Although the ambient changes in ozone concentration are real, the magnitude of the change as the season progresses is comparatively small and cannot account for the changes in canopy photosynthesis and conductance.

A relationship was found between canopy conductance and measured ozone flux, although the r^2 value was low indicating high variability in the data. We expected that a greater relationship would be found between ozone flux and conductance than between ambient ozone and conductance.

The lack of a significant relationship between ambient ozone and meteorological factors is not surprising. The interaction of diurnal photochemical production of ozone with the longer duration episodes of stratospheric input of ozone and subsequent mixing complicate the dynamics of ambient ozone concentration at any given time, particularly when examined for only 1 year. Multi-year data were necessary to determine the relationships previously reported (Wooldridge and others 1996). Lack of significant soil and canopy surface sinks and atmospheric chemical sinks at the site also tend to stabilize ozone concentration during changing meteorological conditions. The relationship between ozone concentration and meteorological parameters would be expected to be greater in the summer when soil and canopy sinks are more pronounced and conditions for photochemical production and atmospheric chemical scavenging are greater.

Figure 1 — FORFLUX model simulation for GLEES, canopy CO_2 conductance from mid-March through June, 1990 (A); FORFLUX model simulation for GLEES, canopy CO_2 uptake from mid-March through June 1990 (B); and ambient ozone concentration from mid-March through June 1990 (C).



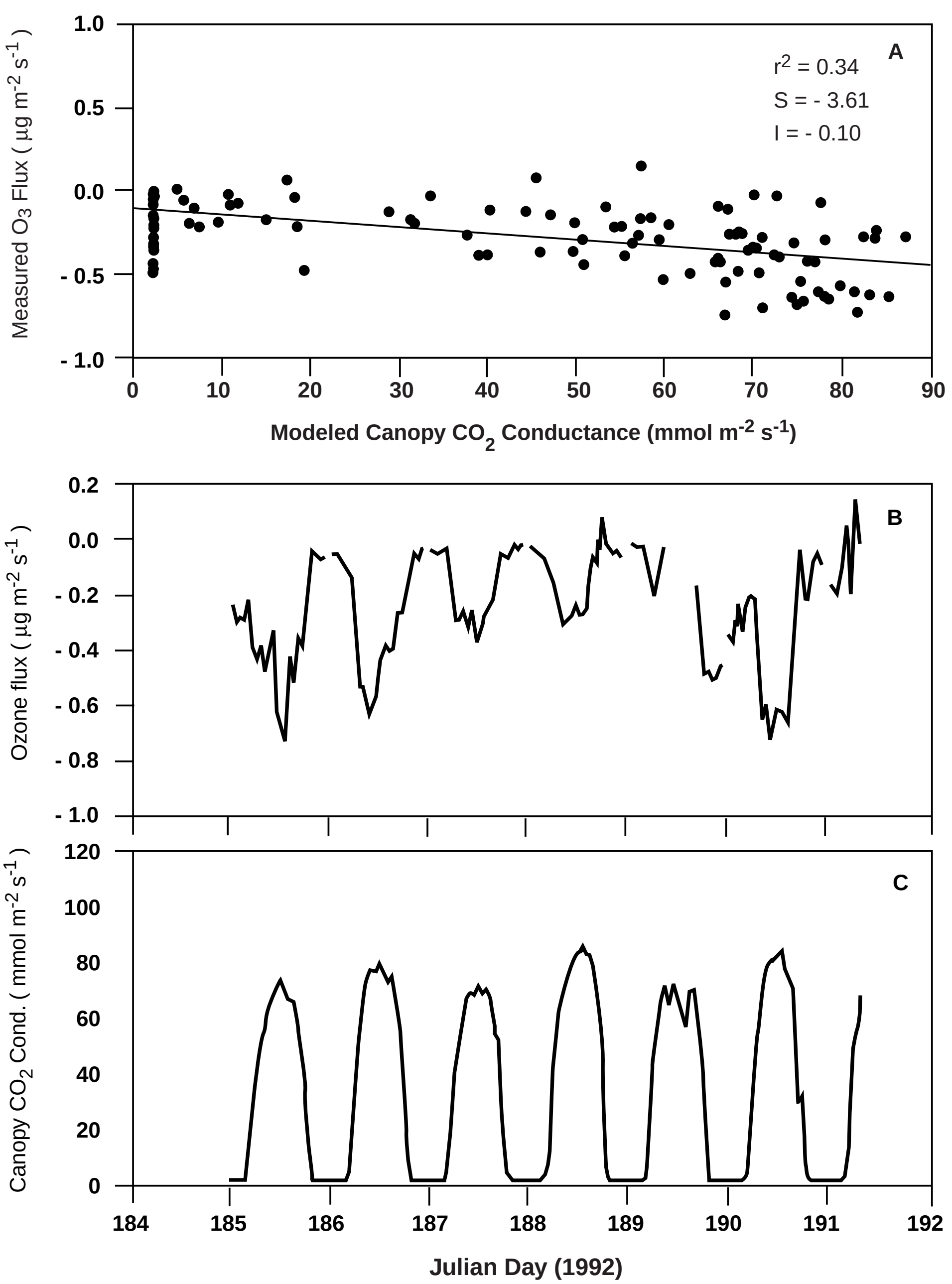


Figure 2 — Regression analysis (A) between measured O_3 flux (B) and modeled canopy CO_2 conductance (C).
r^2 = correlation coefficient;
S = slope, and
I = intercept.

Conclusions

Ozone monitoring at a relatively remote high-elevation Rocky Mountain site showed high concentrations of ambient ozone. Diel variation was slight during winter months indicating little diurnal photochemical generation of ozone; but, diel variation increased as the spring season progressed. Little night time scavenging of ozone was evident when snow cover was present. There was strong evidence of stratospheric intrusion of ozone during spring months, particularly during April and May, associated with the passage of upper level low pressure troughs. Modeled canopy physiological responses were not related to ozone concentration, but modeled canopy CO_2 conductance was related to ozone flux. There was no significant relationship between meteorological parameters and ambient ozone concentration for the 1990 data.

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