MEASUREMENT OF ENVIRONMENTAL AND POLLUTANT GRADIENTS IN THE FOREST CANOPY

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ABSTRACT

From January to December 1993 meteorology data including temperature, relative humidity, wind speed and direction, and surface wetness were collected at five elevations (0.5, 7.5, 12, 16, and 24 m above the ground) and total solar irradiance, photosynthetically active radiation, and ultraviolet-B radiation were collected at 22 m only on the VMC research tower at the Proctor Maple Research Center (PMRC) in Underhill, VT . Ozone (O_3) concentrations were also monitored and recorded at each of these same five elevations. Examination of the O_3 data for 1993 revealed a similar pattern to that observed in 1992. Ozone concentrations generally increase with height, but the largest differences occurred between 0.5 m (just above the soil) and all other elevations with O_3 levels being lowest at 0.5 m. On average over the entire sampling season (late May-mid November), O_3 concentrations were 21% lower at 0.5 than at 24 m. This reduction in O_3 concentration just above the forest floor may result from inadequate mixing of air due to a boundry layer effect and lower air velocities at this level or the physical or chemical destruction of O_3. When number of hours of O_3 exposure at certain threshhold concentrations during June, July, and August were tabulated, it was found that the entire canopy (7.5, 12, and 16 m) was exposed to more than 300 hrs. at 60 ppb, a concentration that may cause injury to sensitive plants, and to at least 17 hrs. at 100 ppb or greater. Ozone concentration data for 1993 collected at the VT State air quality site (an open site typical of many official O_3 monitoring stations) at PMRC correlated well with data recorded at all five elevations on the VMC research tower, but compared most closely to the 7.5 m level.

INTRODUCTION

Collection of meteorological and ozone (O_3) data from five elevations on the VMC research tower located at the Proctor Maple Research Center (PMRC) in Underhill, VT continued throughout 1993. In addition to the temperature, relative humidity, wind speed and direction, surface wetness, total solar irradance, photosynthetically active radiation (PAR), and O_3 data collections begun in 1992, a broad-band ultraviolet-B (UV-B) pyranometer (Yankee Environmental Systems) was purchased and installed at 22 meters on the research tower in July 1993. The UV-B project will be discussed in a separate report.

Objectives

The goal of this research is to improve our knowledge of variation in canopy-atmosphere interactions within the forest canopy using the 22 m research tower, located in a mature hardwood stand, at the PMRC. At heights of 0.5, 7.5, 12, 16, and 24 m above the ground (from ground-level to above the canopy) we are:

1. monitoring ambient environmental conditions (meteorology and O_3) beneath, within, and above a northern hardwood forest canopy. Meteorological variables continuously measured and recorded as 15 minute means at all 5 heights include: temperature, relative humidity, wind speed and direction, and surface wetness. Variables continuously measured (recorded as 15 min. means) above the canopy (22 m) include: total solar irradiance (400-1100 nm), PAR (400-700 nm), and UV-B (290-320 nm).

2. quantifying canopy structure and canopy-light relationships by measuring leaf area distribution (leaf area index, LAI) and PAR.

3. testing the hypothesis that within-canopy O_3 concentration is a function of meteorology and canopy structure.

4. determining the relationship between O_3 concentrations measured in a typical open air quality site and those observed at different elevations in a forest canopy.

METHODS

Throughout 1993 meteorological variables including ambient temperature, relative humidity, windspeed and direction, and leaf surface wetness were continuously collected at five elevations alone a vertical gradient on the VMC research tower. Elevations sampled include: 0.5 meters (just above the soil surface), 7.5 meters (below the main canopy), 12 meters (within the canopy), 16 meters (top of the canopy), and 24 meters (ambient). Ozone concentrations in parts per billion (ppb) at each of these five elevations were also recorded from 25 May to 17 November. Total solar irradiance, PAR, and UV-B (starting on 25 July) data were collected only at the 22 meter level. All data were stored as 15 min averages by a Campbell Scientific 21X datalogger or directly to a computer. For further details about instrumentation, please see the 1992 VMC Annual Report.

An initial attempt was made examine the relationship between O_3 concentrations measured in open areas (most official ozone montoring sites are located in open sites) and those to which different portions of an adjacient forest canopy are exposed. To do this 1993 O_3 data from the VT State air quality site located at the PMRC were obtained from the AIRS network through the efforts of Rich Poirot. The VT State air quality site O_3 data were then correlated with those from the five heights on the research tower and also examined graphically.

In addition to O_3 and meteorological data collected on the research tower, LAI measurements using the LI-2000 (LICOR, Lincoln, NE) were continued in 1993. On 17 August measurements were taken at 0.5, 7.5, 12, and 16 m heights at an approx. 45^o angle from each corner of the tower and 0.5 m outside the structure of the tower. Despite some evidence of damage by pear thrips, LAI values in 1993 were very similar to those in 1992. Little progress was made in 1993 toward analysis of hemispherical photographs, Sunfleck Ceptometer (Decagon Devices, Pullman, WA) PAR attenuation data, or sight-obstruction data collected in 1992. We will continue to pursue the use of these variables in quantifying canopy structure.

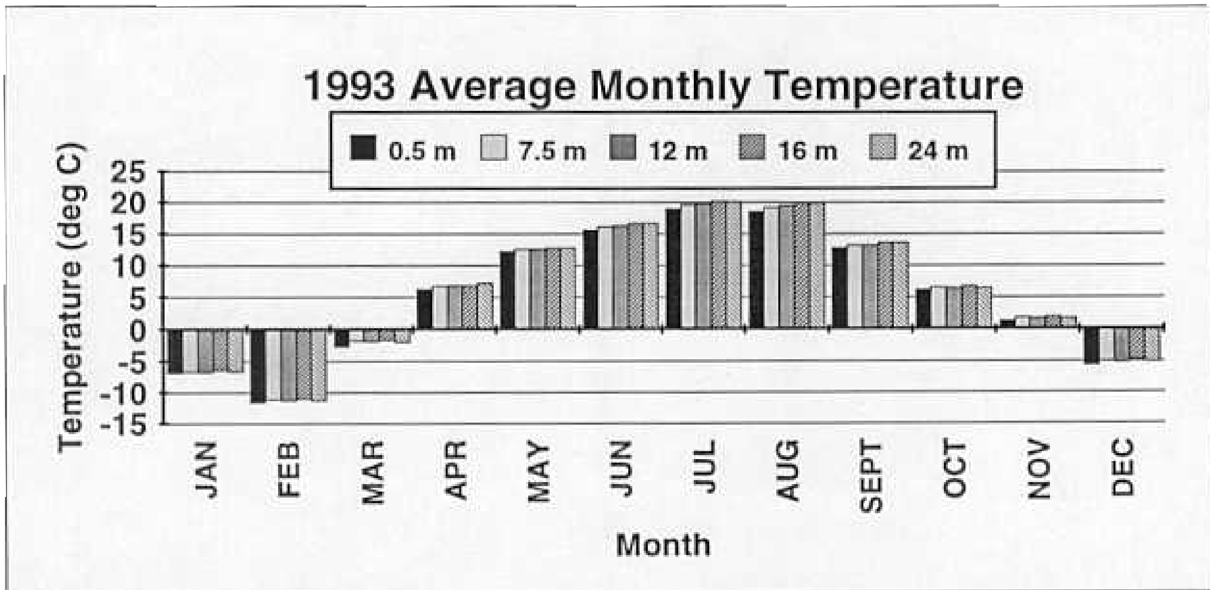
RESULTS

Meteorology. Meteorological data were collected from January to December 1993 at all five elevations on the research tower. The data are summarized in monthly files as 15 min., hourly, and daily averages and are available to VMC cooperators or other researchers in Microsoft Excel, Lotus 123, or ASCII formats. Figure 1 shows examples of some of the data summarized on a monthly basis to look at overall annual trends.

Ozone. Examination of O_3 concentrations during 1993 at all five elevations on the research tower revealed a similar pattern to 1992. Ozone concentrations generally increased with height and concentrations near the forest floor (0.5 m) were significantly lower than those at any other height during much of the sampling season (late May-mid November; Fig. 2). Concentrations of O_3 measured at the top of the reseach tower were significantly higher than those recorded at 12, 7.5, or 0.5 m, but not differerent from those at 16 m. No significant differences in O_3 concentration were found among the 7.5, 12, and 16 m levels. The largest differences in O_3 concentration that occurred between the 0.5 and 24 m heights exceeded 30 ppb. When averaged over the entire season, O_3 concentrations measured near the forest floor (0.5 m) were 21% lower than those recorded at the top of the tower.

We also looked at the total number of hours during June, July, and August that O_3 concentrations exceeded different thresholds (Fig. 3). For example, at 60 ppb, a concentration which may cause injury to certain sensitive plants, we found that while the forest floor was exposed for only 77 hours, all portions of the forest canopy (7.5, 12, and 16 m) received in excess of 300 hours, and the top of the tower saw over 400 hours of

Figure 1. Average and minimum monthly temperature, monthly surface wetness, and average monthly wind speed at five elevations (0.5, 7.5, 12, 16, and 24 m above the ground) along a vertical gradient and maximum monthly photosynthetically active radiation (PAR; 22 m only) on the VMC Research Tower at the Proctor Maple Research Center in Underhill, VT.



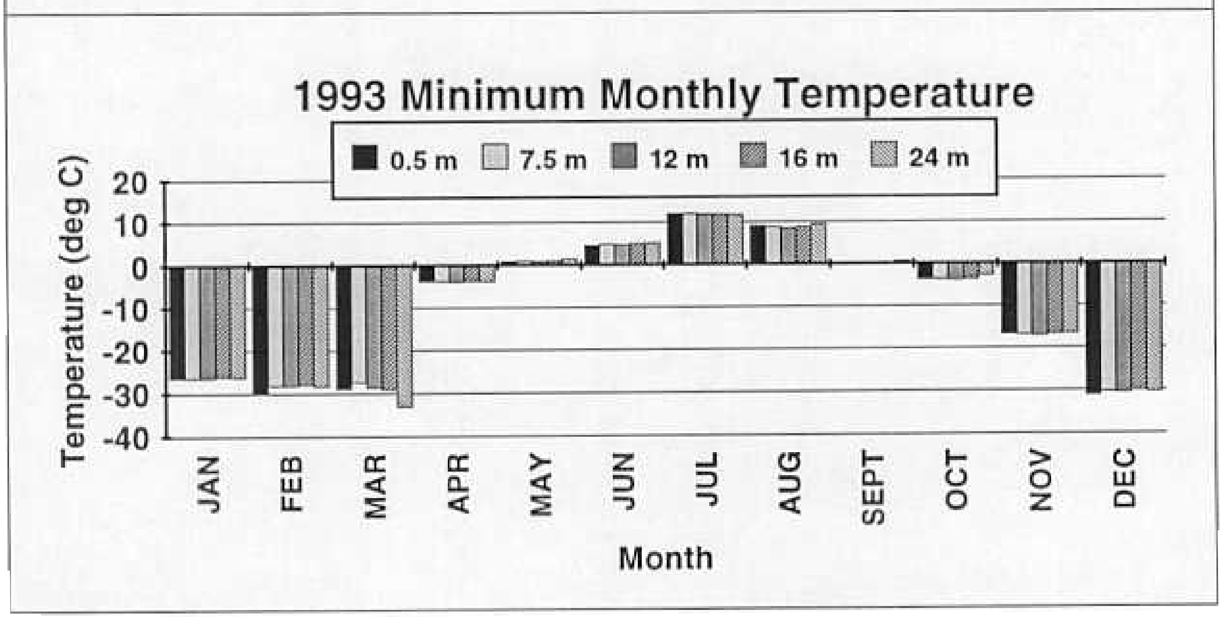
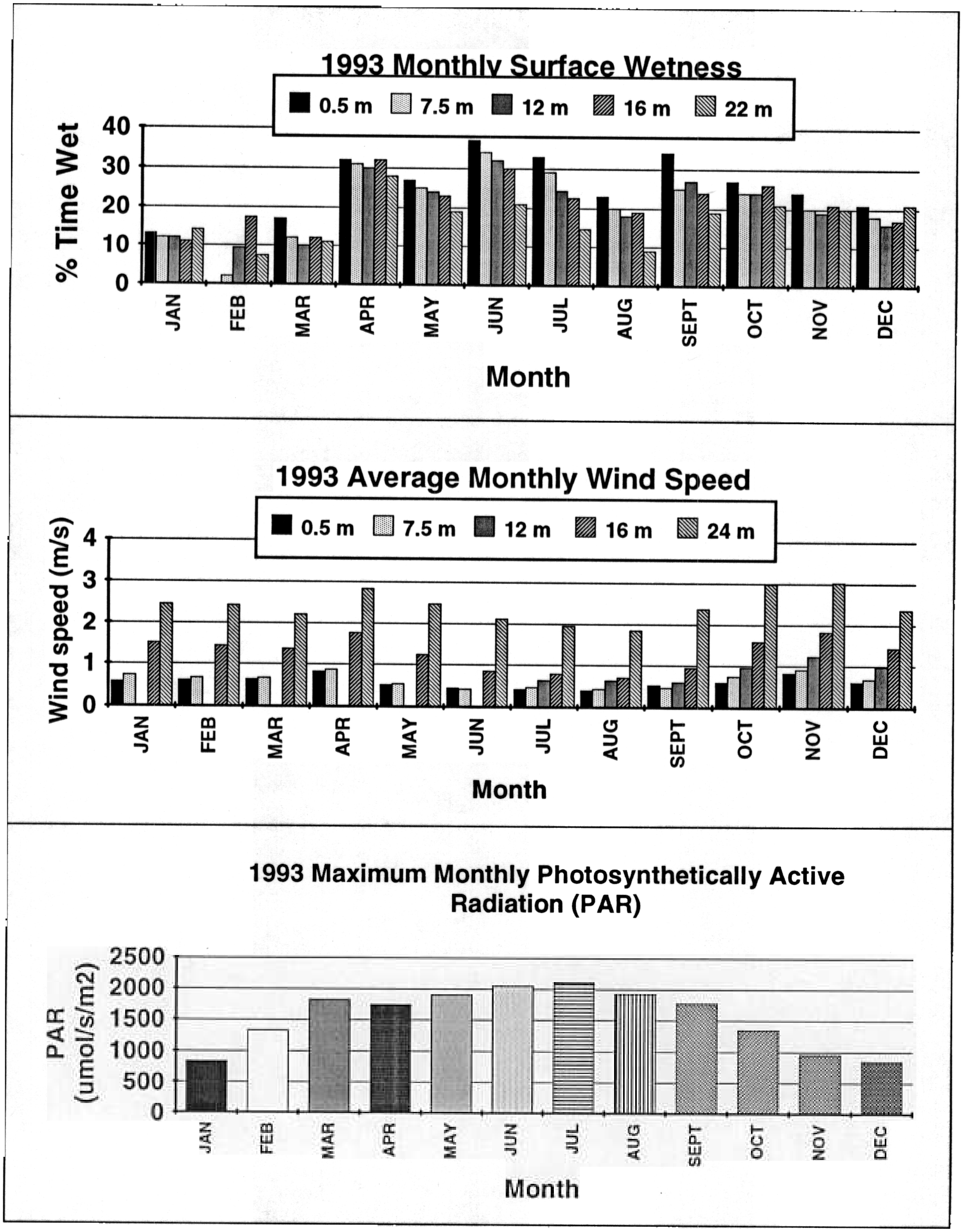
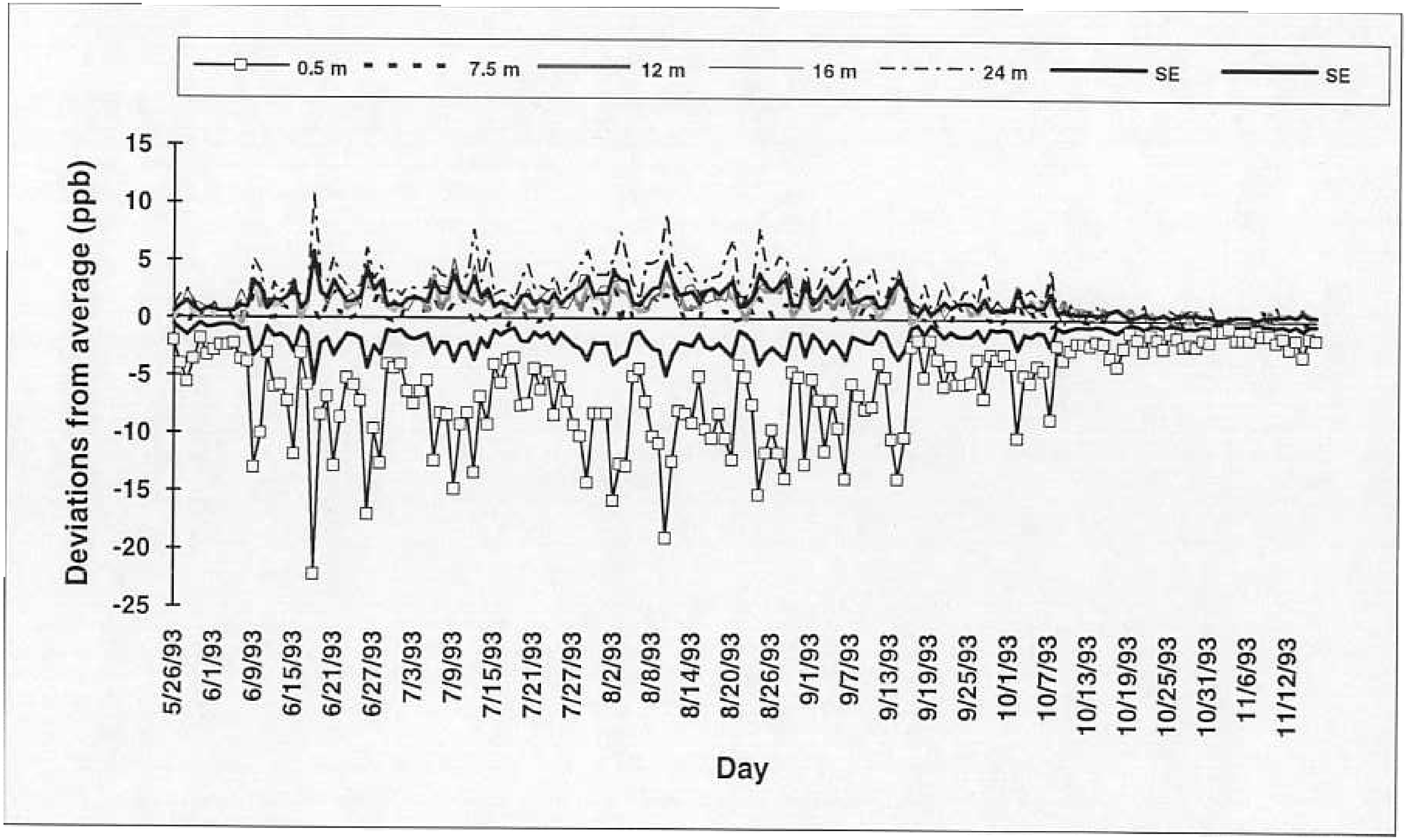


Figure 1. continued



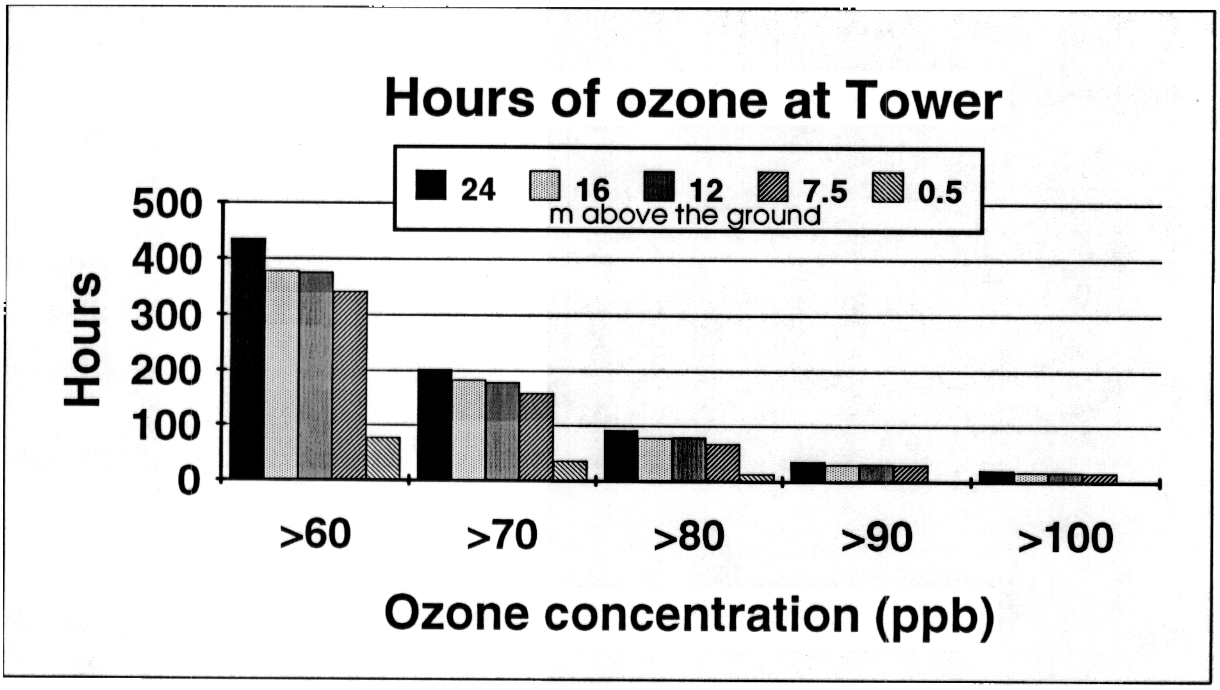
Note: No wind speed data were collected at 12 m from January through June.

Figure 2. Variation in 7-hour-average (9am-4pm) ozone concentration with height for 1993 measured at five elevations (0.5, 7.5, 12, 16, and 24 m above the ground) along a vertical gradient on the VMC Research Tower at the Proctor Maple Research Center in Underhill, VT and expressed as deviations from average ozone concentration for all five levels.



Note: A field site audit in September 1993 revealed that ozone concentrations recorded at the research tower were 7% higher on average than actual values. SE=standard error. The area inside the SE lines represents 2 SE's (+1 and -1 SE).

Figure 3. Number of hours during June, July, and August 1993 that maximum hourly ozone concentrations exceeded certain threshholds at five elevations (0.5, 7.5, 12, 16, and 24 m above the ground) along a vertical gradient on the VMC Research Tower at the Proctor Maple Research Center in Underhill, VT.



exposure at this concentration during the afore mentioned period. At 24 m, concentrations of O_3 of 100 ppb or greater were observed for 21 hours during these same three months and all portions of the canopy were exposed to this relatively high concentration for at least 17 hours.

A comparison of O_3 data from the VT State air quality site and the five heights on the research tower, from late May to the end of October, revealed that the VT State air quality data correlated well with all elevations on the tower, but corresponded most favorably ($r = 0.95$, 3492 df.) with data from the 7.5 m level. The 7.5 m height also coincides most closely to the relative height above the ground of the O_3 intake at the VT State air quality site. In mid-July and mid-October short periods (about 8 hrs. or less) of extremely low O_3 concentrations (<10 ppb) were noted at both the VT State air quality site and the VMC research tower. During these low O_3 episodes, measurements recorded at 0.5 m on the tower were identical in timing and very similar in magnitude to those noted at the VT State air quality site.

DISCUSSION

The patterns of significantly lower O_3 concentrations just above the forest floor (0.5 m) and generally increasing O_3 concentration with elevation on the tower, observed in 1992 and 93, are interesting. Ozone concentrations have been shown to increase with elevation, but this phenomenon has usually been observed along elevational gradients on mountains where monitoring stations are separated by several hundred or even thousands of meters in elevation (Lefohn, 1992). In many cases apparent increases in O_3 concentration associated with increasing elevation disappeared following corrections for differences in barometric pressure.

There are at least three plausible explanations for these lower O_3 concentrations near the soil surface. The first is lack of adequate air mixing near the forest floor due to a boundary layer effect and lower wind speeds. Both maximum and average wind speeds near the forest floor are substantially lower than at other heights on the tower. It is certainly possible that thorough mixing of air near the forest floor does not occur during the growing season. A second way that lower concentrations of O_3 might occur near the ground could be through either a physical or chemical break-down of O_3. The physical breakdown can occur simply through O_3 coming in direct contact with objects such as leaf surfaces, bark, or soil. Chemical break-down of O_3 in urban areas occurs in the presence of nitrogen oxides (NO_x) and is usually noted during evening hours. In rural areas, which may have lower levels of NO_x, a net loss of O_3 may result when ozone reacts with olefinic hydrocarbons such as propylene and isoprene (Chameides & Lodge, 1992). Low concentrations of NO_x, which allow O_3 to react with these olefinic hydrocarbons, can be important mechanisms for controlling O_3 photochemistry in low-NO_x environments (Chameides & Lodge, 1992). Finally, soil micro-organisms such as anaerobic bacteria may produce NO_x which reacts with O_3 resulting in chemical breakdown also known as "ozone scavenging". At the present time, we do not have equipment to measure concentrations of NO_x or olefinic hydrocarbons so their relative concentrations near the soil surface and possible role in reducing O_3 concentration at this level cannot be evaluated.

FUTURE PLANS

As in the past, this data will continue to be available upon request to VMC cooperators and other researchers. Collection of meteorology and O_3 data at the VMC research tower will continue through December 1994. At some point in the future, as funding permits, we hope to obtain wind instruments to measure wind speed and direction in three dimentions and calculate O_3 deposition at several heights using eddy correlation techniques.

FUNDING SOURCES

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