MEASUREMENT OF ENVIRONMENTAL AND POLLUTANT GRADIENTS IN THE FOREST CANOPY

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ABSTRACT

During spring and summer 1992 we installed instrumentation at five elevations (0.5, 7.5, 12.0, 16.0, and 24.0 m above the ground) on the VMC tower at the Proctor Maple Research Center in Underhill, VT (PMRC) to collect continuous meteorological and ozone (O_3) data. Meteorological variables continuously monitored at all five levels include: temperature, relative humidity, wind speed and direction, and surface wetness. Variables monitored at the top of the tower only (22.0 m) include total solar radiation and photosynthetically active radiation (PAR). All data are logged to a Campbell 21X datalogger or a PC as 15 min. means. Examination of monthly average temperature and relative humidity showed no significant differences in these variables among the five elevations. Absolute values for surface wetness (% of time wet) varied from month to month, but within any one month, surface wetness generally decreased with increasing height on the tower. In late summer (August) wind speeds at the lower two heights (0.5 and 7.5 m) were about 20-25% of those at the top of the tower (24.0 m) and 50% of those recorded at the top of the canopy (16.0 m). When wind speed during months with leaves present (August) and without leaves (November) were compared in vertical wind profiles, a non-linear relationship between wind speed and height was found when leaves were present. After leaf-fall, the non-linear relationship was observed only between the two lower (0.5 and 7.5 m) elevations while wind speed increased at a constant rate with height between 7.5 and 24.0 m. Ozone concentrations near the ground (0.5 m) were found to be significantly lower than the average O_3 concentrations for all heights by as much as 17 ppb. Possible explanations for reduced O_3 concentrations near the soil surface include O_3 "scavenging", believed to occur when nitrogen oxides (NO_x) react with O_3, or lack of adequate mixing of air near the ground due to a boundary layer effect. Leaf area index (LAI) estimates were made at four elevations (0.5, 7.5, 12.0, and 16.0 m) on the VMC tower using both the LI-2000 leaf area index meter and Ceptometer PAR attenuation wand. LAI estimates decreased with increasing height and estimates made with the LI-2000 were generally lower and less variable than those made with the Ceptometer wand.

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 Proctor Maple Research Center (PMRC). At heights of 0.5, 7.5, 12.0, 16.0, and 24.0 m above the ground (from ground-level to above the canopy) we are:

1. monitoring ambient environmental conditions (meteorology and ozone {O_3}) underneath, 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 radiation (400-1100 nm) and photosynthetically active radiation (PAR; 400-700 nm).

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

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

4. planning in the future to measure wind speed and direction in three dimensions and calculate ozone deposition at several heights using eddy correlation techniques.

Methods:

In April 1992, we began receiving and installing the meteorological equipment on the research tower at PMRC. Total solar radiation and PAR sensors (LICOR models 200SA and 190SA, respectively), along with the CSI 21X datalogger, were the first instruments to arrive and were installed and collecting data by mid-May. Monitoring of O_3 concentration (TECO O_3 monitor) began on 8 July at 7.5 m only, with data recorded as 15 minute means to a PC. On 23 July, the scanivalve (Scanivalve Corp., San Diego, CA), which automatically switches channels to allow consecutive sampling at different heights, was made operational and O_3 concentrations at all 5 levels on the tower were recorded as 15 minute means to a PC. In the future O_3 monitoring will begin by 1 April and continue until the end of October. Temperature and relative humidity (CSI model 207), wind speed and direction (R.M. Young AQ wind monitors), and surface wetness (CSI model 237) sensors were installed at all 5 heights, calibrated, and data collection to the 21x datalogger began on 13 August.

An attempt to quantify the phenology of leaf-out and foliage distribution around the tower was made using hemispherical photographs (fisheye lens), PAR attenuation measurements using a Sunfleck Ceptometer wand (Decagon Devices, Pullman, WA), LAI measurements using the LI-2000 (LICOR, Lincoln, NE), and a photographic sight-obstruction technique. Measurements of the first three variables began 1 May and were repeated at weekly or biweekly intervals with the most intensive sampling being conducted during the most active period of leaf-out (15 May-15 June). Measurements were taken at 0.5, 7.5, 12.0, and 16.0 m heights at an approx. 45° angle from each corner of the tower and 0.5 m outside the structure of the tower. Both image analysis hardware and software were used to analyze the hemispherical photographs. The LI-2000 has its own algorithm for calculating LAI while the Beer-Lambert equation ($-\mathrm{Ln}\{Q_1/Q_2\}/K$) where Q_1=PAR at the point of measurement, Q_2=ambient PAR without canopy interference (top of tower), and K=the coefficient of extinction estimated to be 0.65 from the research literature was used to calculate LAI from Ceptometer data. These estimated LAI values were compared to LAI measurements made on similar dates using the LI-2000. The photographic sight-obstruction measurements were made only a single time (in August) during the season.

Significant Findings:

General Trends. Monthly average temperature, relative humidity, surface wetness, and wind speed and direction at all five heights along the tower were plotted for August through December (1992). Examination of these variables showed no significant differences in temperature or relative humidity among the five heights (Fig. 1). A general seasonal decrease in average temperature at all heights was observed throughout this period. Although there was a tendency for relative humidity to decrease with increasing height, no distinct seasonal decrease pattern was observed. Absolute values for surface wetness (% of time wet) varied from month to month, but within any one month, there was a general decrease in surface wetness with increasing height, although it is not known at this time if any of the differences are significant (Fig. 1). Monthly average wind speeds in late summer at the two lower heights (0.5 and 7.5 m) were roughly 20-25% those recorded at the top of the tower (24.0 m) and 50% of those measured at the top of the canopy (16.0 m) (Fig. 2, August). By November there was a slight seasonal increase in average wind speed at all heights, but relative wind speeds at the top of the canopy (16.0 m), when compared to those at 24.0 m, had increased substantially (Fig. 2, November). In August, wind was predominantly out of the south at the three upper heights and out of the southeast at the two lower heights. Winds in November were generally out of the south at all heights.

Ozone. Examination of O_3 concentrations at all five heights on the tower revealed that although O_3 levels generally became greater with increasing height, concentrations just above the ground (0.5 m) were significantly lower by as much as 17 ppb than the average concentrations of all levels (Fig. 3). When daily maximum O_3 concentrations, based on hourly averages, were plotted against height on the tower we again found a significant increase in O_3 concentrations between the 0.5 and 7.5 m levels, but maximum concentrations did not increase with height from 7.5 to 24 m (Fig. 4). This would suggest that with the exception of the near-ground level, all other heights, including the entire canopy, were exposed to similar "threshold" O_3 concentrations. An examination of seven-hour (9 am - 4 pm) average daily ozone concentrations vs. height also showed the significant increase in O_3 between 0.5 and 7.5 m above the ground with concentrations increasing slightly, but probably not significantly, with height above 7.5 m (Fig. 4). This indicates a slight increase in "dose" levels of O_3 with increasing height above 7.5 m and suggests that mixing of the air at the upper four heights is not completely uniform. One possible explanation for the apparent reduction in O_3 concentration near the ground may be O_3 "scavenging" or break-down believed to occur when nitrogen oxides (NO_x), produced by anaerobic bacteria in the soil, react with O_3. Ozone "scavenging" is usually associated with urban sites, although, there is no reason to think it could not occur in rural areas. These lower O_3 concentrations observed near the ground could also be caused by a lack of adequate mixing of air near the ground caused by a boundary layer effect. Periods of time when differences in O_3 concentrations between 0.5 m and other heights were greatest were usually accompanied by lower wind speeds.

Vertical Wind Speed Profile: When average monthly wind speeds (m/s) were plotted against height on the tower and compared during months with and without leaves on the trees, a non-linear relationship was found to exist when leaves were present (August) (Fig. 5). Without leaves (December), a non-linear relationship held true only between the two lowest levels (0.5 and 7.5 m) while at heights above 7.5 m, wind speed increased at a constant rate with height (Fig. 5). It would appear that the presence of leaves substantially dampens wind speed within and even below the canopy. Because this relationship was examined for only a limited time frame, it must be more thoroughly examined to see if it holds true for most periods with and without leaves.

Leaf Area Index: Leaf area index (LAI) was estimated at four heights (0.5, 7.5, 12.0, 16.0 m) on the VMC research tower using both the LI-2000 and Sunfleck Ceptometer. As expected, LAI values using both instruments decreased with increasing height on the tower. LAI values from

Figure 1. Average monthly temperature, relative humidity, and surface wetness at five elevations (0.5, 7.5, 12.0, 16.0, and 24.0 m above the ground) along a vertical gradient on the VMC Research Tower at the Proctor Maple Research Center in Underhill, VT.

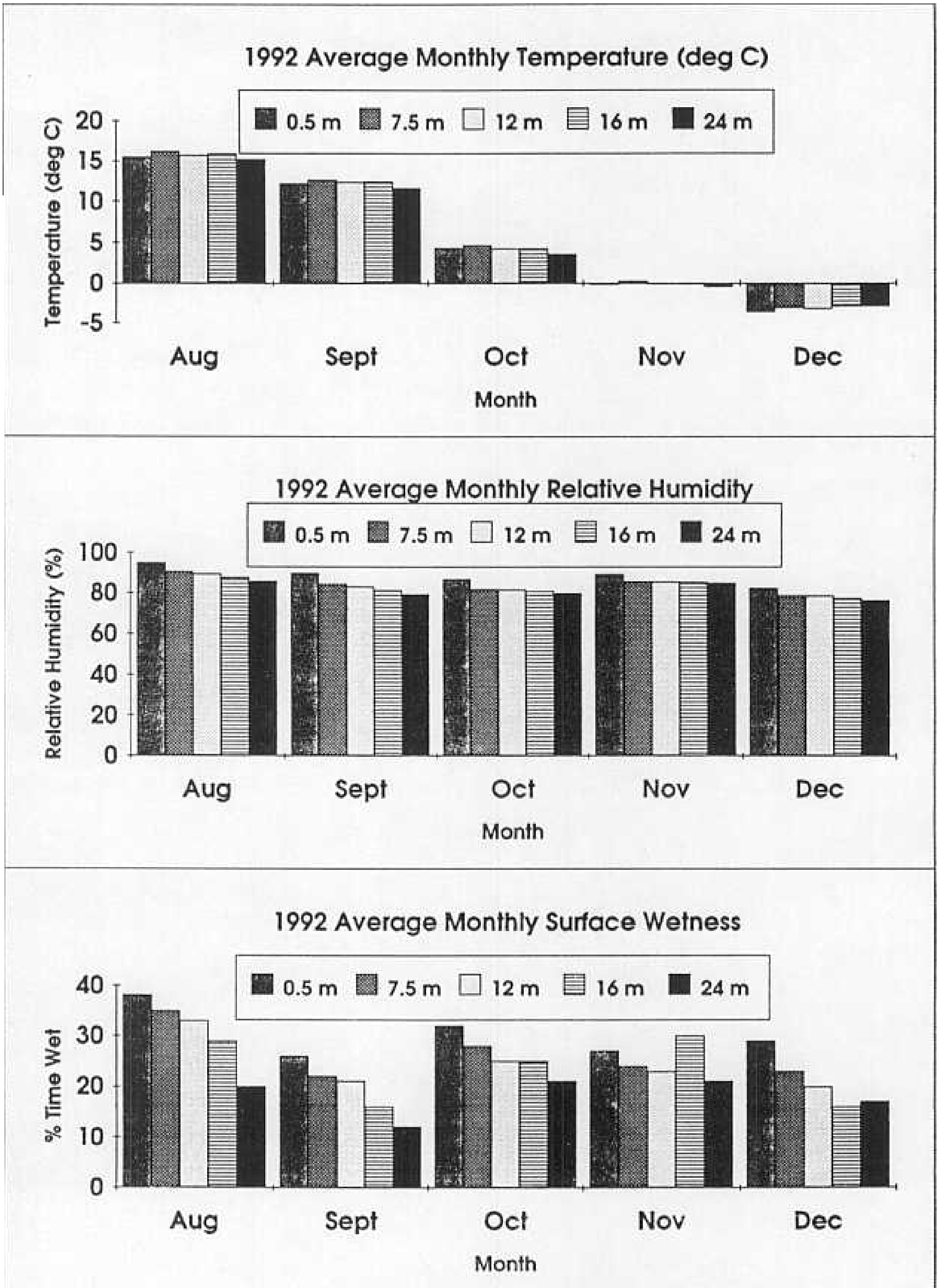
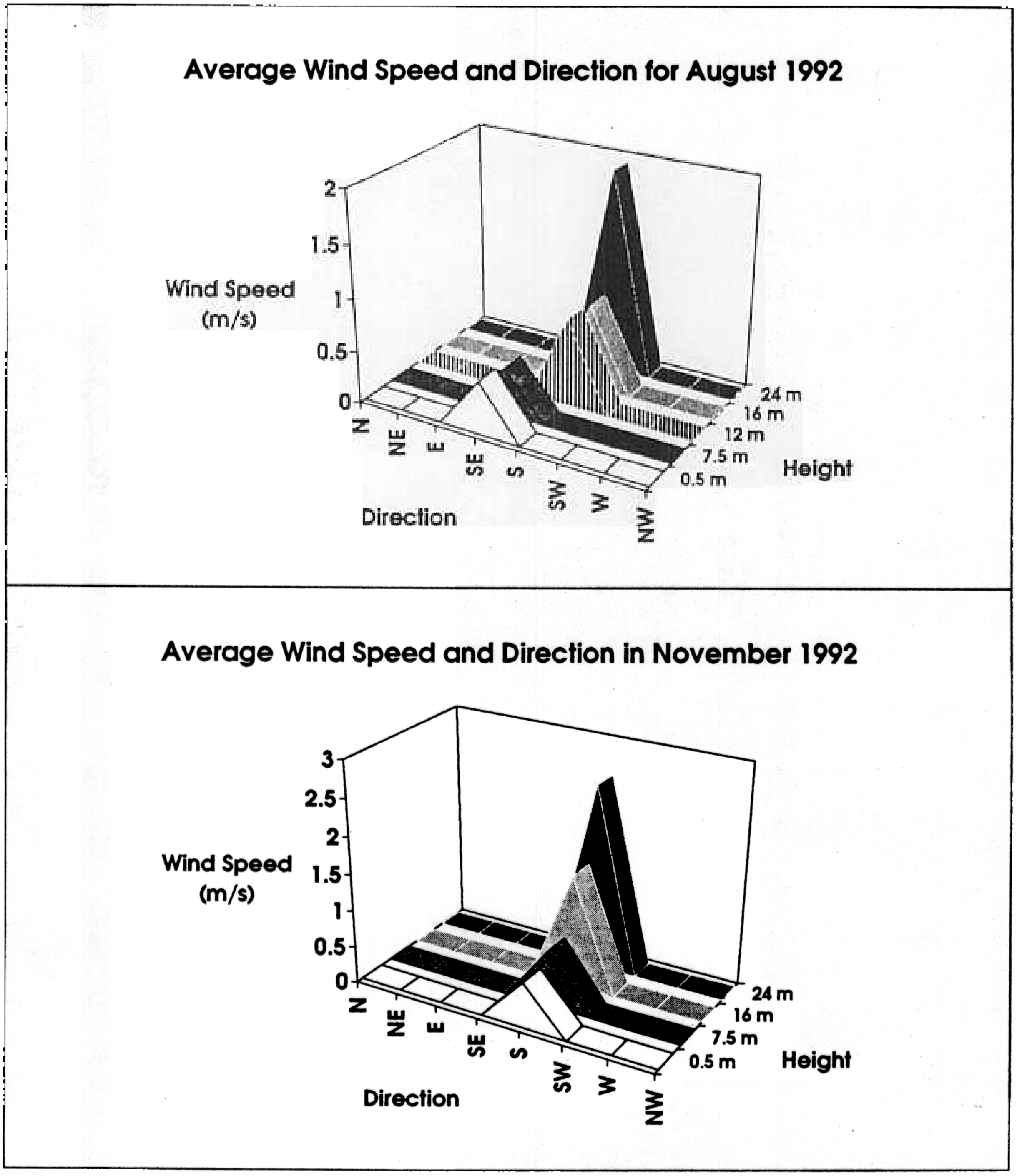


Figure 2. Average wind speed and direction in August and November 1992, recorded at five elevations (0.5, 7.5, 12.0, 16.0, and 24.0 m above the ground) along a vertical gradient on the VMC Research Tower at the Proctor Maple Research Center in Underhill, VT.



Note: No wind speed or direction data was collected at 12 m in November 1992.

Figure 3. Variation in ozone concentration with height measured at five elevations (0.5, 7.5, 12.0, 16.0, and 24.0 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 the average ozone concentration for all five elevations.

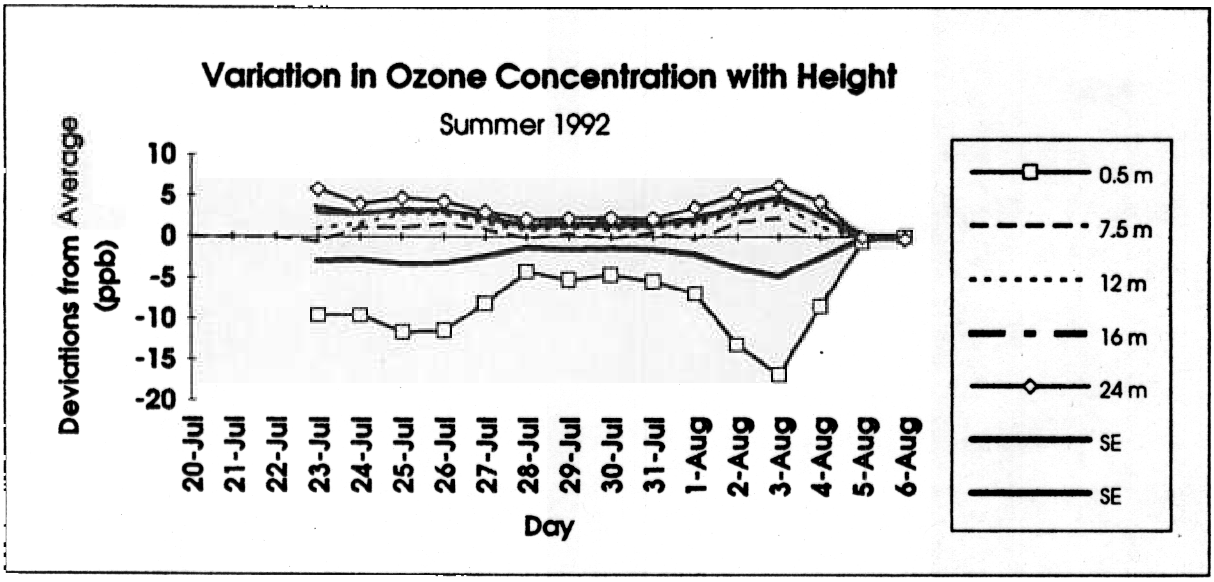


Figure 4. Vertical profiles on four representative dates during summer 1992 for one hour maximum and seven hour average (9 am-4 pm) ozone concentrations measured at five elevations (0.5, 7.5, 12.0, 16.0, and 24.0 m above the ground) along a vertical gradient on the VMC Research Tower at the Proctor Maple Research Center in Underhill, VT.

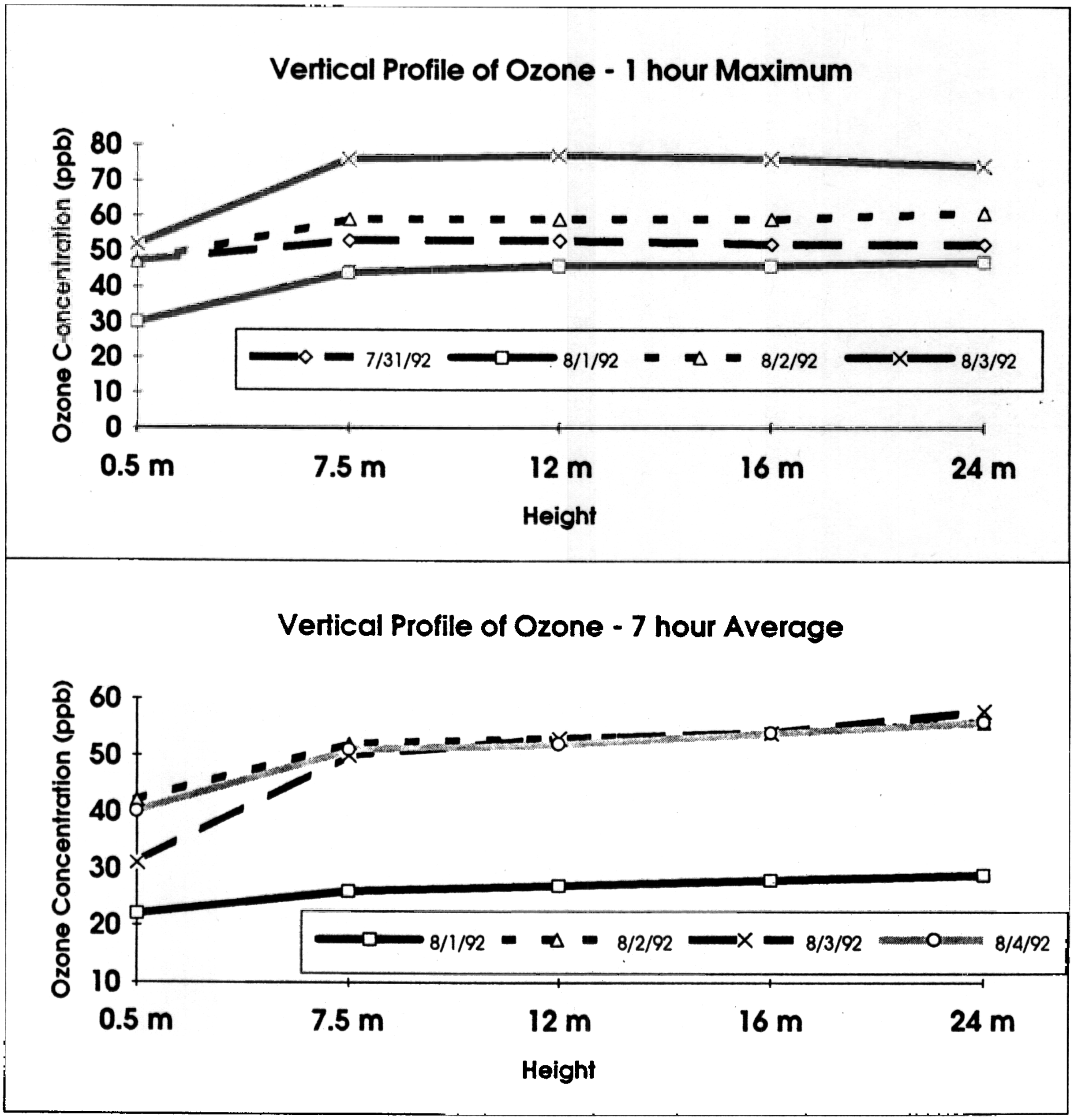
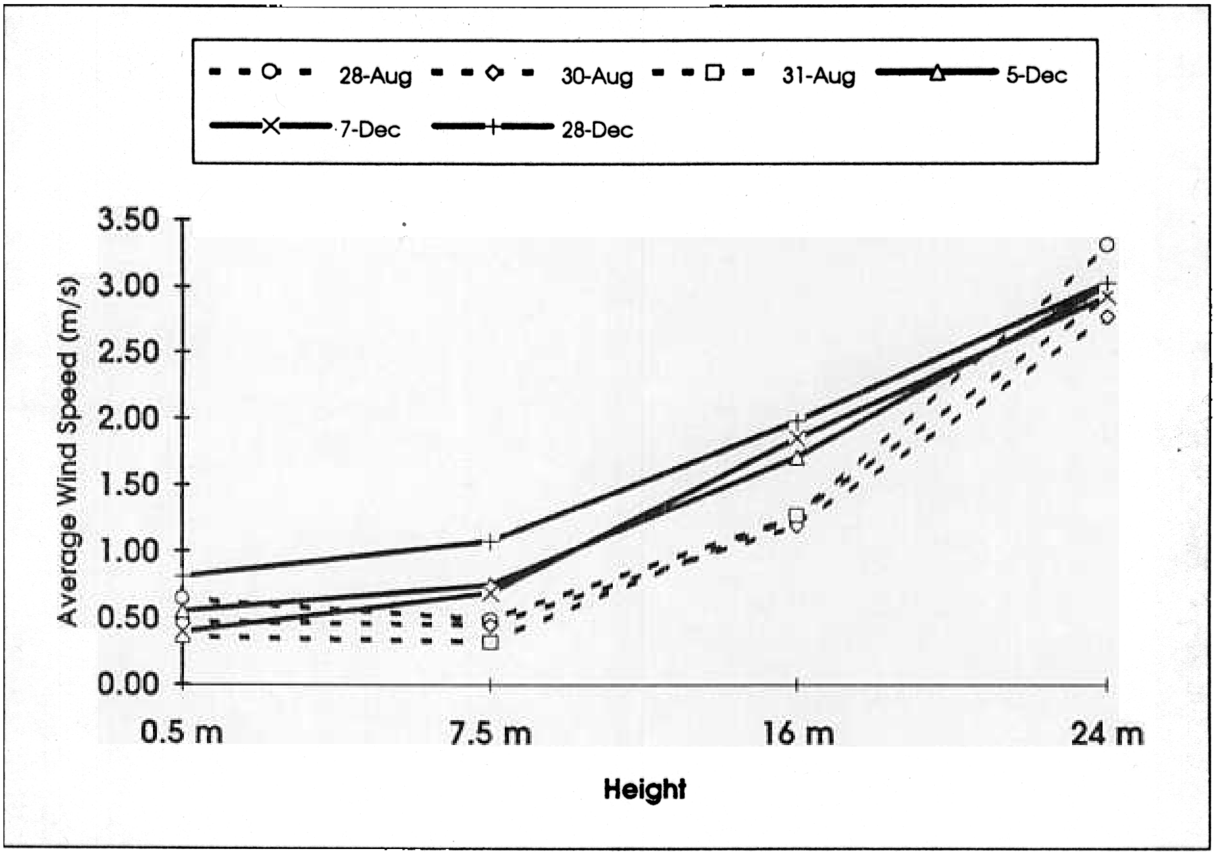


Figure 5. Vertical profiles on representative dates in August (with leaves) and December (without leaves) 1992 for average wind speeds recorded at four elevations (0.5, 7.5, 16.0, and 24.0 m above the ground) along a vertical gradient on the VMC Research Tower at the Proctor Maple Research Center in Underhill, VT.



Note: The 12 m elevation was not included because no wind speed data was collected at that location in December 1992.

Ceptometer data were generally higher and much more variable than those calculated by the LI-2000 (Table 1). Although measurements were made on different days for each instrument, measurements were done after leaves were fully expanded and both instruments use ambient PAR (above the canopy) as a base line. This limited data suggests that LAI estimates from the LI-2000 are less variable and more repeatable than those from the Ceptometer wand.

We have not yet had an opportunity to fully examine hemispherical photography or sight obstruction data collected from the VMC tower during 1992. We expect to report on these data in 1993.

Future Plans:

We plan to continue collecting data from all instrumentation on or around the tower for one to two more seasons. It was late July before all of the meteorological equipment was fully operational so we missed much of the 1992 growing season. Data from multiple years will be necessary to get even a cursory look at year to year variability. We still hope to examine O_3 deposition and flux throughout the canopy using eddy correlation techniques if funding becomes available. Early in 1993 we plan to install thermocouples in two sets of paired m^2 soil temperature plots located in the vicinity of the VMC tower. Each plot will have thermocouples installed at three depths within the soil (5, 15, 30 cm below the soil surface) and 2 cm above the soil surface. The overall objective will be to monitor soil temperature at different depths within the rooting zone of a hardwood forest. Also in 1993 we plan to purchase an ultraviolet radiation (UV-B; 290-320 nm) biometer which will be installed on the VMC tower.

Table 1. A comparison of leaf area index values determined at four elevations (0.5, 7.5, 12.0, and 16.0 m above the ground) along a vertical gradient on the VMC Research Tower at the Proctor Maple Research Center in Underhill, VT using the LICOR-2000 Leaf Area Index Meter and the Decagon Sunfleck Ceptometer PAR attenuation wand.

	LI-2000		Ceptometer	
Height	Average	Range	Average	Range
0.5 m	4.09	3.71 - 4.60	5.52	2.43 - 6.92
7.5 m	3.68	3.16 - 4.24	4.23	2.86 - 6.01
12.0 m	1.96	0.79 - 2.80	1.52	0.73 - 2.69
16.0 m	0.08	0.00 - 0.21	0.61	0.00 - 1.12

Note: Although LI-2000 measurements were made on 9 July and Ceptometer measurements on 2 July, leaf elongation was complete prior to 2 July, 1992 and measurements are comparable.