Temporal and Spatial Patterns of Stomatal Conductance, Ozone Concentration, and Ozone Uptake in a Sugar Maple Canopy (Thesis Excerpts)

Jessica P. Orrego
University of Vermont

Abstract

Tropospheric ozone is considered to be a contributory factor in widespread forest decline due to its phototoxicity and oxidizing capacity. Data from monitoring sites in the northeastern United States indicate that high ozone episodes are frequent in rural forested areas distant from ozone precursor sources. To develop a better description of potential ozone interactions in forest canopies, temporal and spatial patterns of stomatal conductance (g_s), ozone concentration (O_3), and other environmental variables were studied at five heights on a tower in an Acer saccharum Marsh canopy in Underhill, Vennont for 11 days. Both g_s and O_3 decreased with increasing depth in the canopy, with an average difference of 25% and 22% between the upper and lower canopy, respectively. Significant differences across time were found for both g_s and O_3. Both show a similar diurnal pattern reaching maxima in the early afternoon and decreasing in the evening. Regression analyses suggest that quantum flux density is the principal driving force for temporal and spatial patterns of g_s. Temperature was also found to influence both O_3 and g_s. Vertical differences in O_3 uptake per unit leaf area were a function of differences in g_s, while vertical variation in cumulative O_3 uptake was found to be a result of differences in leaf area density between heights. Uptake per unit leaf area ranged from 0.2 mmol $m^{-2} h^{-1}$ to 34 mmol $m^{-2} h^{-1}$, and cumulative uptake ranged from 0.05 mmol $ha^{-1} h^{-1}$ to 1000 mmol $ha^{-1} h^{-1}$. in the upper canopy. A large proportion (85%) of the total canopy 0_3 uptake was observed in the upper crown (>10m) where the bulk (86%) of the total carbon gain in a sugar maple canopy occurs. Thus, the combined effect of higher O_3 and g_s in the upper canopy may result in decreases in carbon gain as O_3 and its precursors (NOx and VOC's) increase in the United States, as they are predicted to do. From this detailed evaluation of canopy processes it can be shown that scaling up from values of g_s and O_3 at one height and time underestimated total canopy ozone uptake by 50%.

Data Analysis

Data were analyzed using the general linear models procedure and regression techniques of Statistical Analysis Systems (SAS, Inc., 1996, Cary, North Carolina, USA). To test for differences across heights and time for stomatal conductance, ozone concentration, ozone uptake, and meteorological data, a 3-way repeated measures ANOV A was used. It was assumed that compound symmetry was not a problem since the covariance for each observation would not have been constant due to efforts made to avoid re-sampling of leaves. The Student-Neuman-Kuels test was used to assess pair-wise differences when main or interactive effects were significant. When interaction between height and time was observed the error term for height x time x date was used. When data did not meet the assumption of normality they were ranked and a non-parametric test was usued to test for differences, and normality plots were examined for all variables. The level of significance is $p \sim 0.05$ for all reported statistical differences.

Table 1. Sums of Squares and probabilities associated with g_s, O_3, and uptake (per unit leaf area and cumulative) across heights and times (N=315).

Variable	Type III SS	F-Value	Pr > F
a. Stomatal Conductance (g_s)			
Height	299579	298.34	0.0001
Time	236508	121.50	0.0001
Height x Time	32987	10.5	0.0001
b. Ozone Concentration (O_3)			
Height	62356.3	58.65	0.0002
Time	16417.82	6.7	0.0001
Height x Time	79591.7	19.81	0.0001
c. Uptake per unit leaf area			
Height	303.2	35.54	0.0001
Time	172.2	30.99	0.0001
Height x Time	44.22	9.02	0.0001
d. Cumulative Uptake			
Height	4296.5	32.8	0.0001
Time	473.56	29.64	0.0001
Height x Time	655.58	655.6	0.0001

Table 2. Relationships between stomatal conductance (g_s) (mmol m^{-2} s^{-1}), ozone (O_3) (ppb), and ozone uptake (per unit leaf area [μmol m^{-2} h^{-1}]) and meteorological variables in a sugar maple canopy.

Independent Variable	(a) g_s	(b) Ozone	(c) Ozone Uptake
PPFD (Photosynthetic Photon Flux Density)	r^2=0.482, p=0.0001	r^2=0.0033, p=0.001	r^2=0.384, p=0.0001
Air Temperature	not significant	r^2=0.412, p=0.0001	r^2=0.416, p=0.0001
Wind Speed	r^2=0.1, p=0.0001	r^2=0.101;p=0.0001	r^2=0.087, p=0.0001

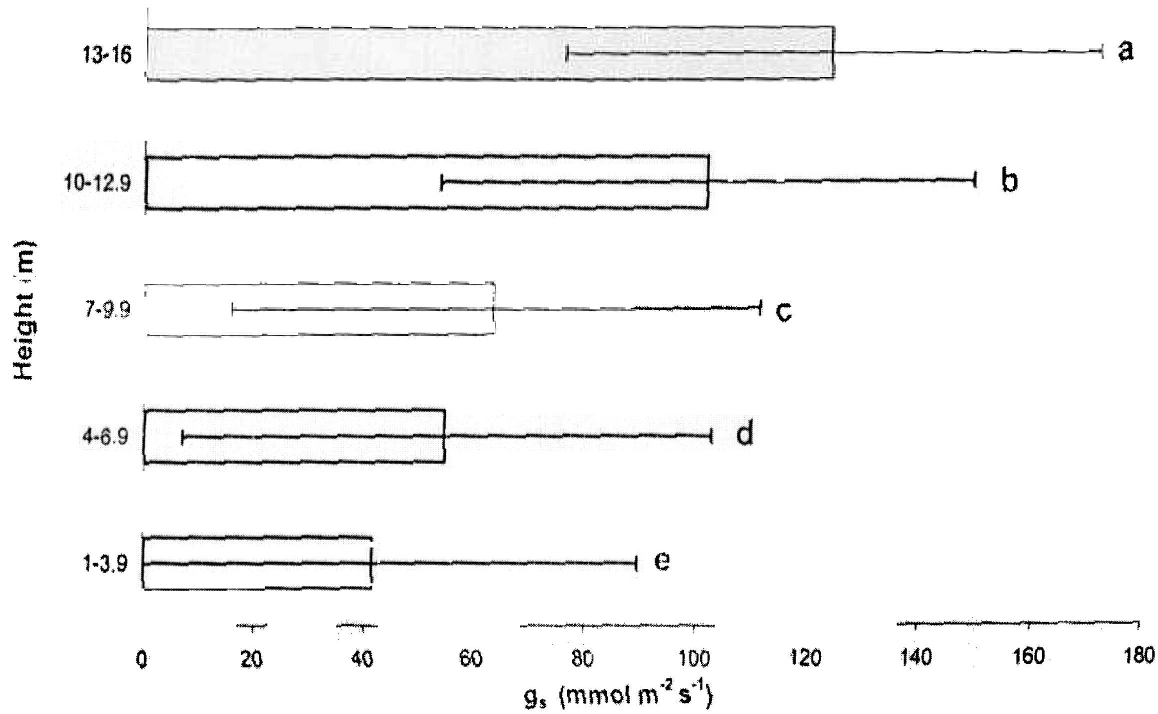

Figure 1. Average g_s (mmol $m^{-2}s^{-1}$) for 11 days at 5 heights in a sugar maple canopy (N=~65 for each height), July-August 1998. Error bars represent one standard deviation, distinct letters identify significant differences in g_s between canopy layers.

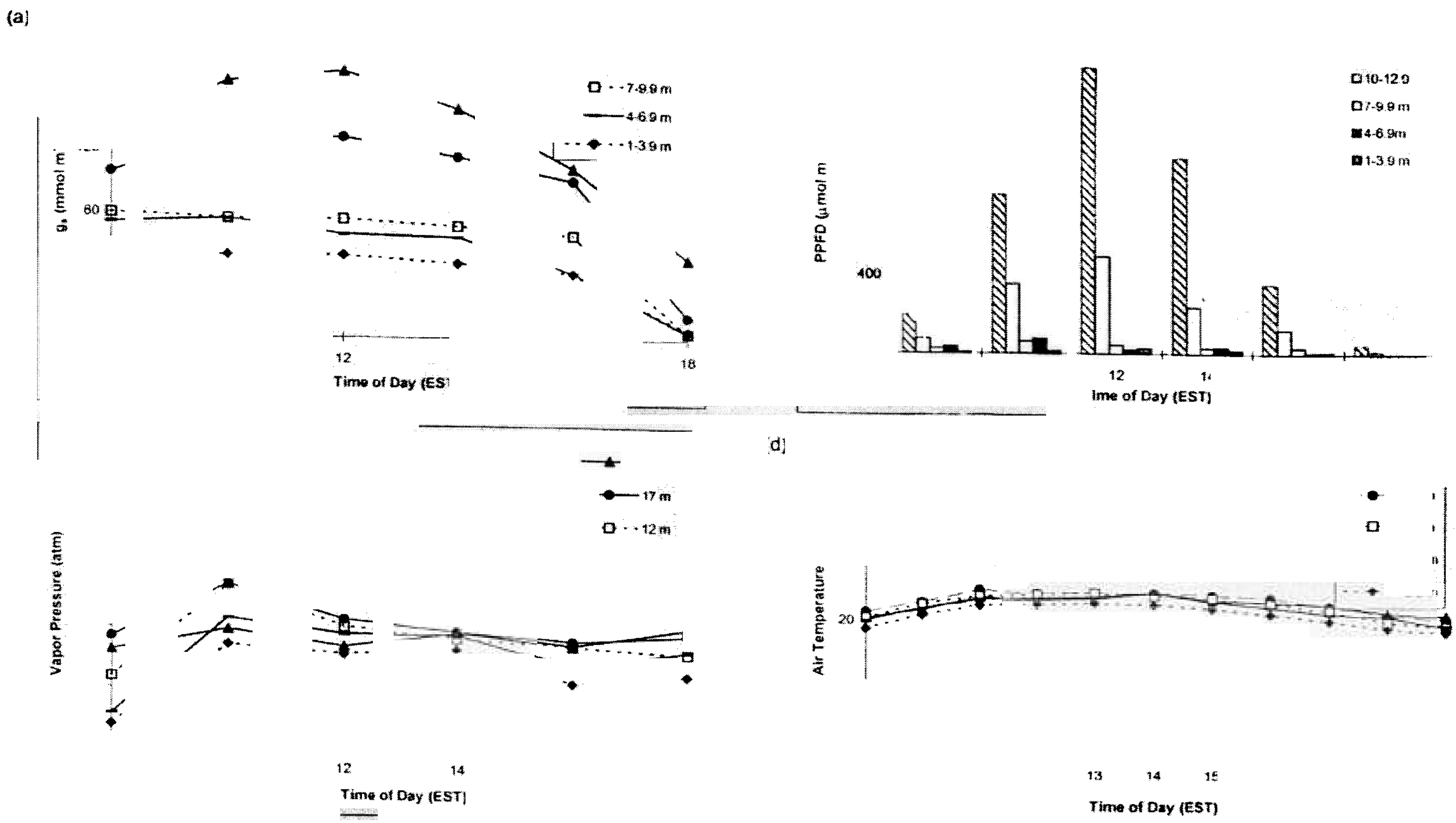

Figure 2. Average diurnal patterns for 11 days at 5 heights in a sugar maple canopy of (a) g_s (mmol m s^{-1} PPFD (mmol m^{-2} s^{-1}), (c) partial pressure of water vapor (atm), and (d) air temperature (°C).

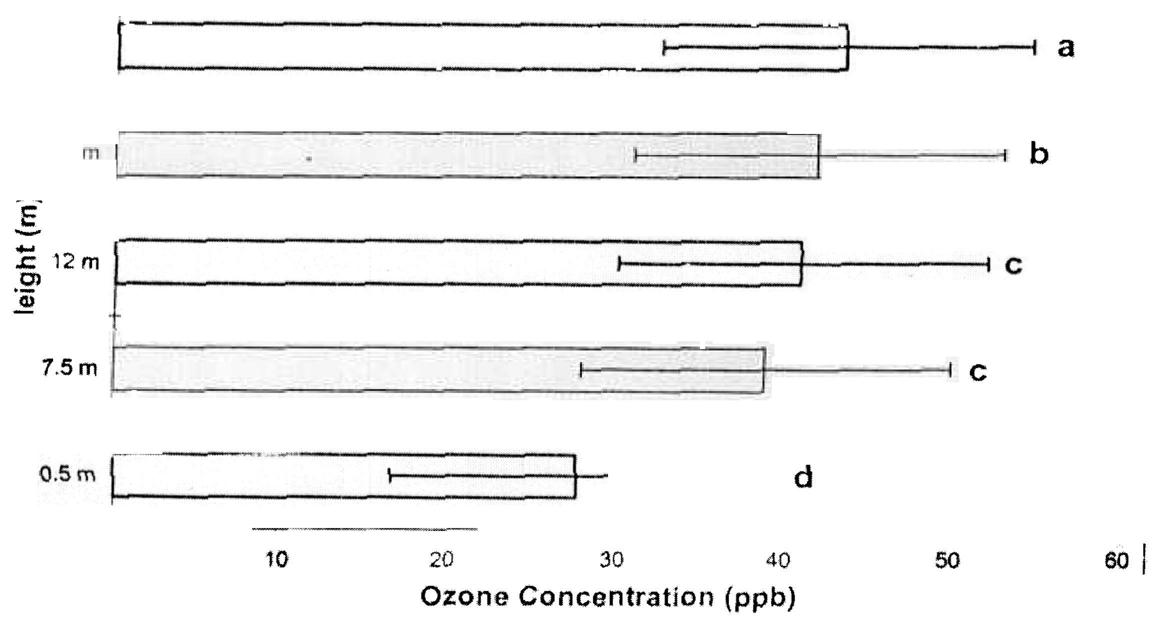

Figure 3. Average ozone concentration (ppb) at 5 heights in a sugar maple canopy for June-August 1998. Error bars represent one standard deviation, letters identify significant differences in O_3 among heights over the 11 days of study.

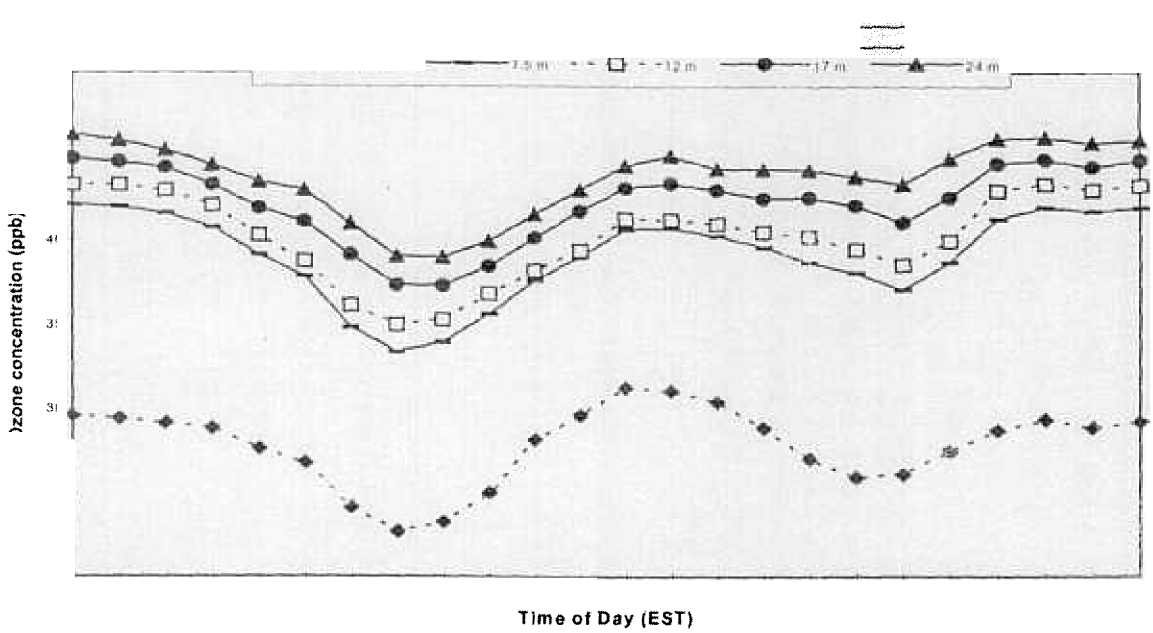

Figure 4. Di nal pattern of average ozone concentration a heights in a sugar maple canopy, June-July 1998.

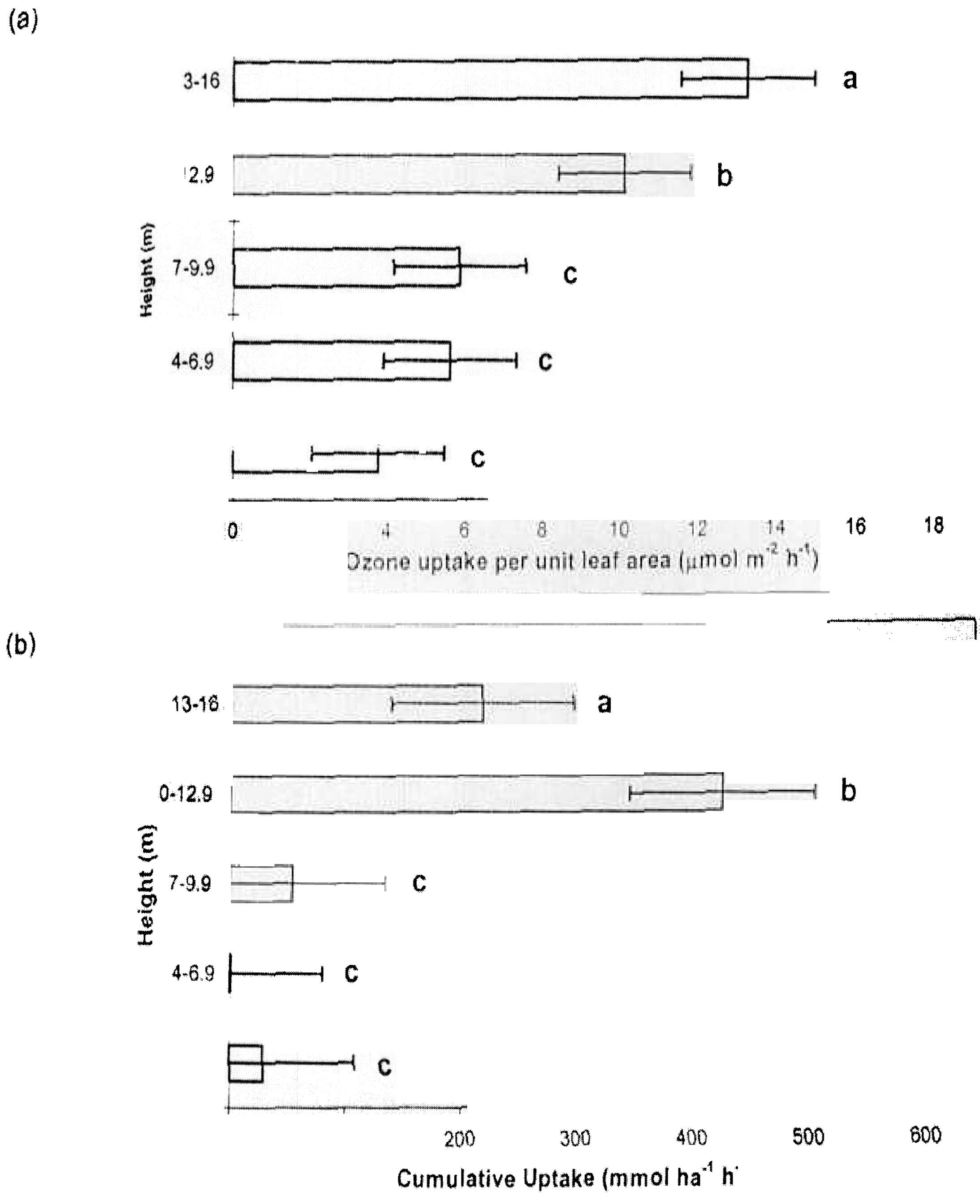

Figure 5. (a) Average uptake per unit leaf area (μmol m^{-2} h^{-1}) and (b) cumulative uptake (mmol ha^{-1} h^{-1}) of 11 days at 5 heights in a sugar maple canopy, July-August 1998 (N=~65 at each height). Error bars represent one standard deviation, distinct letters identify significant differences in uptake between heights.

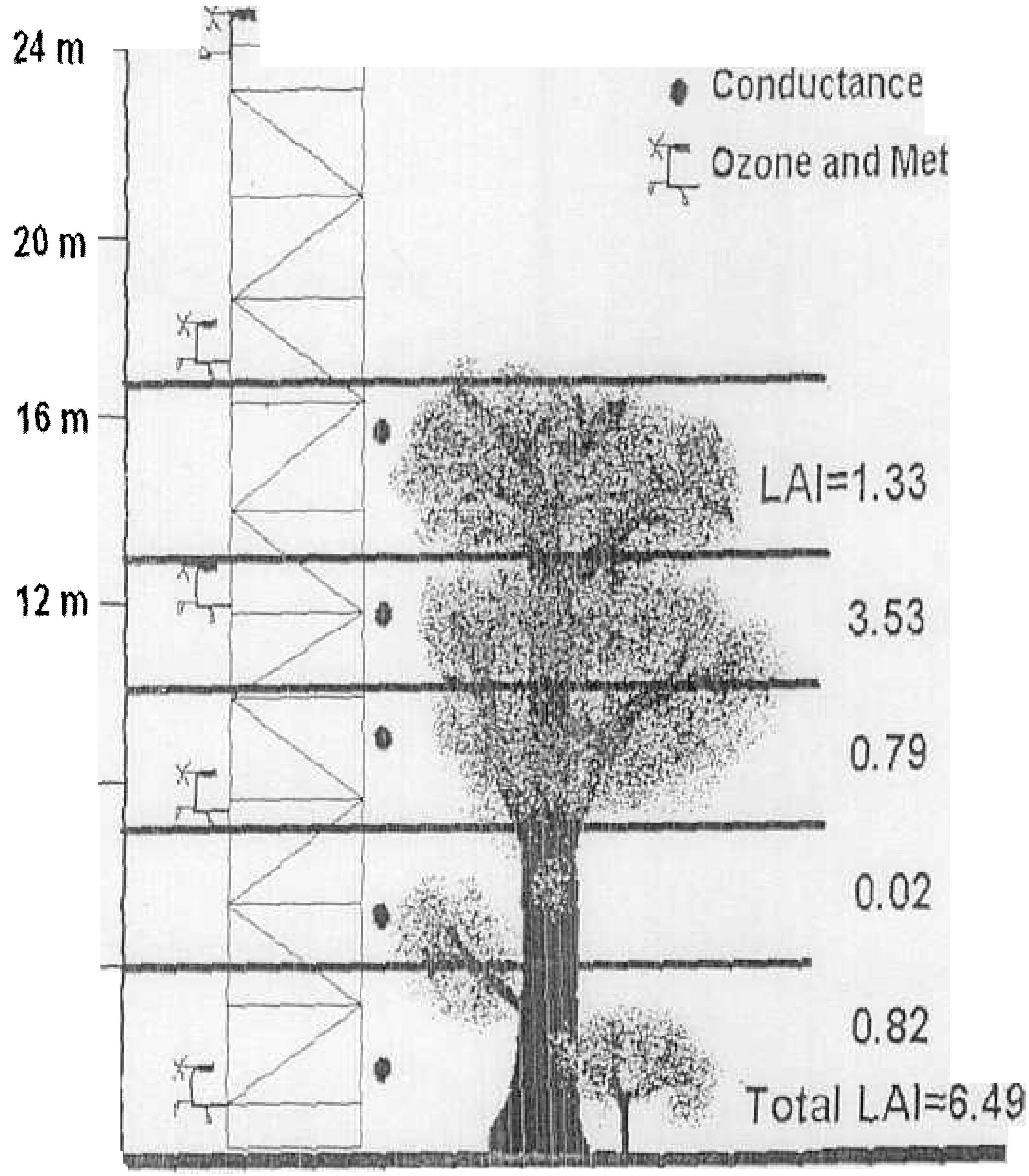

Figure 6. Schematic diagram of tower and corresponding heights where stomatal conductance, ozone, and meteorological data were measured, and LAI was calculated.

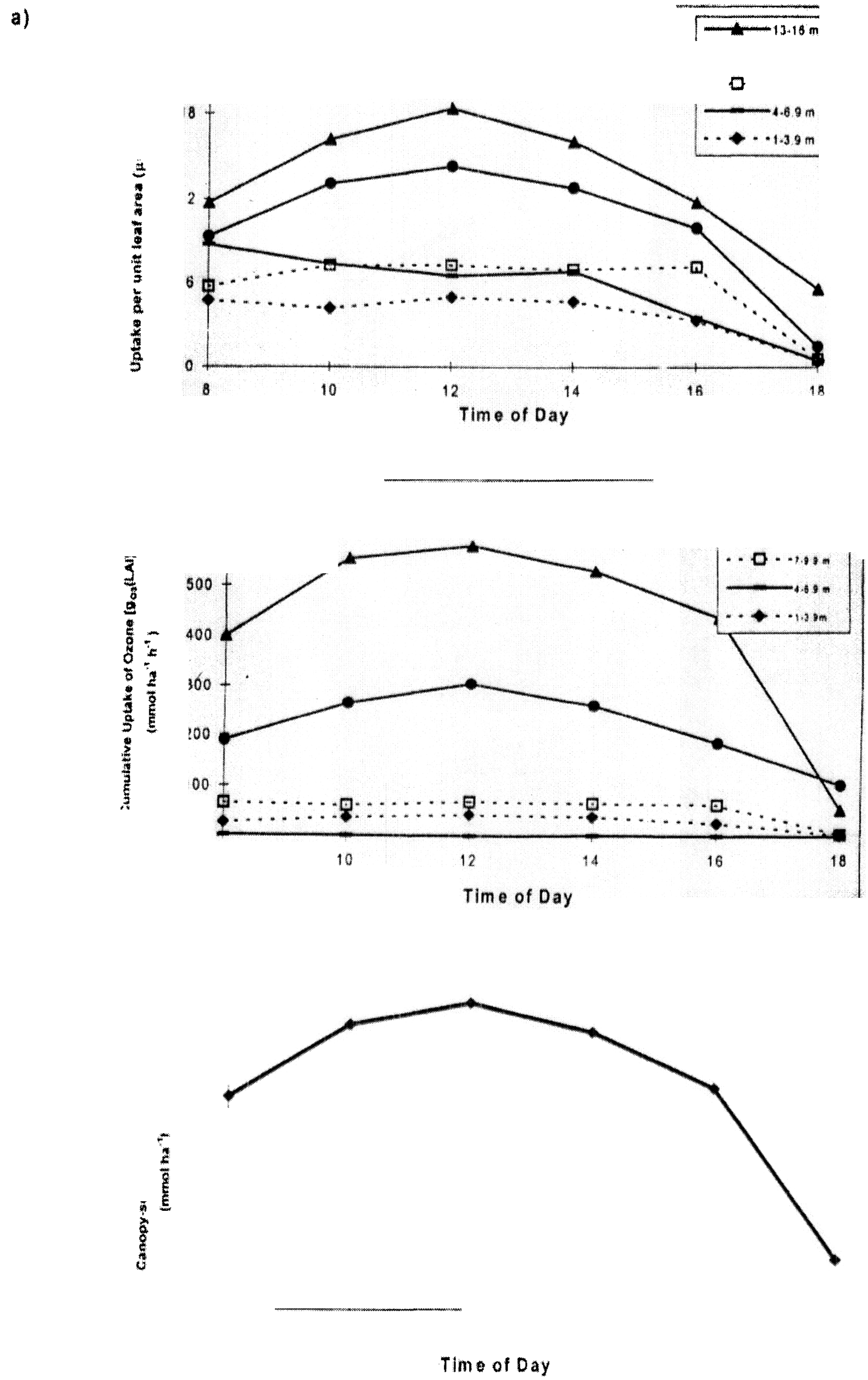

Figure 7. Average diurnal pattern of (a) uptake per unit leaf area (μmol m ⁻¹), (b) cumulative uptake (mmol ha^{-1} h^{-1}), and (c) canopy uptake (mmol ha^{-1} h^{-1}) for 11 days at 5 heights, July-August 1998.