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Seasonal Ozone Uptake of Mature Evergreen Conifers at Different Altitudes

By

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Summary

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Seasonal patterns of ozone (O_3) uptake in mature Norway spruce and cembran pine trees were estimated at six rural sites between 580 m and 1950 m a.s.l. Seasonal variations in O_3 uptake reflect variation in both ambient O_3 concentration and stomatal conductance. At all the study sites the annual course in the O_3 regime exhibited seasonal cycles with maxima between April and July and minima in winter. Seasonal variations in stomatal conductance and O_3 uptake were mainly attributed to the course of the prevailing temperature. Average O_3 uptake rates decreased with increasing tree age. However, in trees similar in age O_3 uptake increased with increasing altitude.

Introduction

During the past two decades, there has been increasing attention to the impact of ozone (O_3) on coniferous forests, which are a major sink for O_3 in the lower troposphere (MATYSSEK & al. 1995, SANDERMANN & al. 1997). Within the

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canopy the needles are the primary sites of O_3 deposition, with the stomata representing the interface for the O_3 uptake from the atmosphere into the tree. O_3 uptake however, depends both on ambient air O_3 concentration and on stomatal conductance. In alpine regions mean O_3 concentrations (STOCKWELL & al. 1977) as well as soil water reserves, relative humidity of the air and irradiance tend to increase with increasing altitude (FLIRI 1975). Consequently, trees at high altitudes are rarely forced to restrict their water loss (TRANQUILLINI 1979) so that O_3 uptake may be high under the high-altitudinal O_3 regimes. Furthermore, stomatal conductance and hence also O_3 uptake has been reported to be affected by tree age (for a review see: KOLB & al. 1997). Thus our objectives were to characterise O_3 uptake of forest trees of different age at various sites, in order to determine the impact of altitude and tree age on O_3 uptake.

Material and Methods

The study was carried out at six rural forest sites between 580 and 1950 m a.s.l. (Table 1).

Table 1. Study sites, altitude, tree species, tree age and period of investigation.

Station (country)	Altitude [m]	*Species*	Age [yrs]	Period	Reference
Klimahaus (A)	1950	*P. cembra*	65	1996	HAVRANEK & WIESER unpubl.
Davos (CH)	1660	*P. abies*	216	1987-1988	HÄSLER & al. 1991
Zillertal (A)	1000	*P. abies*	60-65	1989-1990	WIESER & HAVRANEK 1993
Lägeren (CH)	685	*P. abies*	127	1987-1988	HÄSLER & al. 1991
Aschenbrenner-marter (GER)	600	*P. abies*	65	1987-1989	KOCH & LAUTENSCHLAGER 1988, KOCH 1993
Grafrath (GER)	580	*P. abies*	17	1992-1993	GÖTZ 1996

During the period 1987 through 1996 seasonal courses of gas exchange were measured, tracking ambient conditions with fully climatized chambers (Walz, Effeltrich, Germany) in the upper sun crown of Norway spruce *(Picea abies* (L.) Karst.) and cembran pine (*Pinus cembra* L.) trees. Cembran pine has been chosen because data from spruce were not available at the highest altitude for this comparison. Furthermore, between these two conifer species there were no significant differences in maximum stomatal conductance as well as in the stomatal behaviour to changes in environmental conditions (WIESER 1999). Additionally, ambient O_3 concentration and climatic parameters were measured in order to calculate O_3 uptake according to:

$$FO_3 = [O_3] * gO_3$$

where FO_3 is the uptake rate of O_3 into the needles, $[O_3]$ is the O_3 concentration in the ambient air, and gO_3 is the stomatal conductance for O_3. The latter was calculated by multiplying the conductance for water vapour by 0.613, the ratio of diffusivities of water vapour and O_3. O_3 concentration inside the needles was assumed to be zero, because O_3 concentrations in the leaf mesophyll are undetectable low (cf. TINGEY & TAILOR 1982, LAISK & al. 1989). Data were condensed to daily means. Cumulative O_3 uptake (CU) was calculated as the uptake rate (FO_3) integrated over time.

Results and Discussion

Seasonal trends

Variations in O_3 uptake reflect variation in both ambient O_3 concentration and stomatal conductance. Typical seasonal variations of ambient O_3 concentration, stomatal conductance and O_3 uptake are shown for 685, 1660 and 1950 m a.s.l. (Fig. 1). O_3 concentration generally exhibited a seasonal cycling with maxima between April and July and minima during the winter (Fig. 1). The high summer values can be attributed to an accumulation of O_3 precursors during sunny, hot and dry periods, such conditions favouring the photochemical production of O_3 (STOCKWELL & al. 1997) O_3 uptake was highest during the growing season and

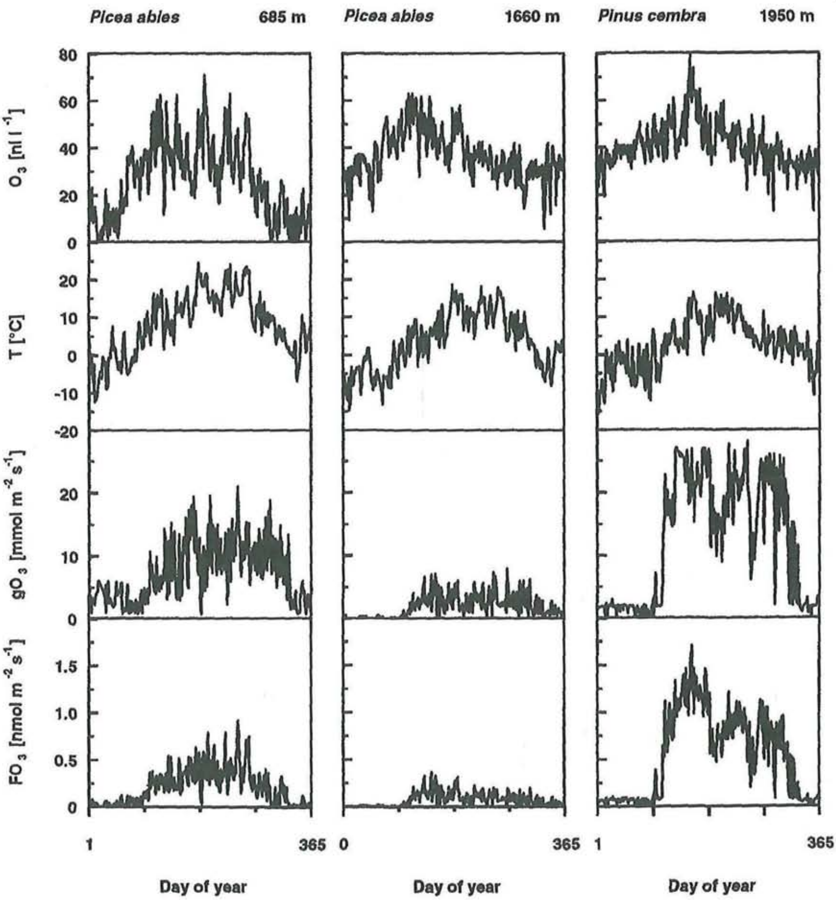

Fig. 1. Annual courses of daily mean ambient O_3 concentration (O_3), air temperature (T), stomatal conductance for O_3 (gO_3) and O_3 uptake (FO_3) in the sun crown of Norway spruce (*Picea abies*, Switzerland) and cembran pine (*Pinus cembra*, Austria).

reached minimum values in winter, when the stomata were closed. The fall decline and spring increase in stomatal conductance and O_3 uptake was coincident with seasonal temperature trends (Fig. 1).

The average and maximum daily mean O_3 uptake rates and ambient O_3 concentrations estimated from May throughout October for all the years are summarised in Table 2. The magnitude of O_3 flux into the needles varied considerably and no clear trend with respect to altitude and ambient O_3 concentration could be observed (Table 2). However, the trees under study differed significantly with respect to tree age (Table 2). Tree age is known to affect stomatal conductance (for a review see KOLB & al. 1997). and hence also the potential for O_3 uptake. Therefore, we analysed the impact of tree age and altitude as single factors on its capacity influencing O_3 uptake.

Table 2. Average and maximum daily means of O_3 uptake rates (FO_3, nmol $m^{-2}s^{-1}$) and O_3 concentrations (nl l^{-1}) from May throughout October during the years of investigation.

Altitude [m]	Year	*Species*	Tree age [yrs]	Average FO_3	Maximum FO_3	Average O_3	Maximum O_3
1950	1996	*P. cembra*	65	0.90	1.71	45	80
1660	1987	*P. abies*	216	0.11	0.37	38	62
	1988			0.14	0.40	39	60
1000	1989	*P. abies*	60-65	0.84	1.91	37	43
	1990			0.35	0.68	29	27
685	1987	*P. abies*	127	0.33	0.92	34	71
	1988			0.30	0.83	38	72
600	1987	*P. abies*	65	0.62	1.41	30	66
	1988			0.48	0.99	40	77
	1989			0.46	1.10	41	77
	1990			0.58	1.35	42	80
580	1992	*P. abies*	17	0.71	1.66	40	75
	1993			0:50	1.08	25	51

Tree age related differences

Fig. 2 shows that O_3 uptake significantly decreased with increasing tree age.

As O_3 concentrations did not differ significantly between the environments for any tree size class, observed differences in O_3 uptake can for the most part be attributed to a decline in stomatal conductance with increasing tree age and tree size (data not shown) as also found by others (SCHOETTLE 1994, YODER & al. 1994, KOLB & al. 1997). FREDERICKSEN & al. 1996 also observed higher rates of O_3 uptake in mature canopy trees as compared to seedlings and saplings of *Prunus serotina*. The opposite however, has been reported for *Quercus rubra* by HANSON & al. 1994.

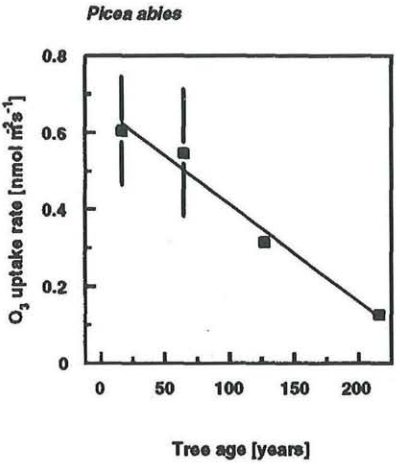

Fig. 2. Correlation of tree age and ozone uptake rate during the growing season (May throughout October) in the sun crown of Norway spruce trees (*Picea abies*) growing between 580 and 1660 m altitude). Measurements were made during the period 1987 through 1992 at a mean ambient O_3 concentration of 36 ± 5 nl l^{-1}. n = 1 to 4 ± SD.(see Table 2) The points were fitted by linear regression: $y = -0.0025*x + 0.665$, $r^2 = 0.98$.

Altitude retated differences

In trees similar in age however, average O_3 uptake rate during the growing season tended to increase with increasing altitude (Fig. 3). This could be attributed to an increase in both ambient O_3 concentration and stomatal conductance with increasing altitude (Fig. 3). The higher conductance values at elevations above 1000 m might be attributed to more favourable water relations at high than at low altitudes as also found for European larch growing at a high and a low elevation site (WIESER & HAVRANEK 1995).

These data also allow an assessment of potential cumulative O_3 uptake throughout one vegetation period. However, one has to bear in mind that the vegetation period (i.e. the snow-free period, HAVRANEK & TRANQUILLINI 1995) decreases from approximately 250 days in the valley floor to about 180 days at the alpine timberline (HAVRANEK & TRANQUILLINI 1995, TRANQUILLINI 1979). Cumulative O_3 uptake rates into needles of evergreen conifers obtained by this calculation were 11.4 ± 1.7 in the valley floor (600 m above sea level), and 14 mol m^{-2} of total needle surface area at the alpine timberline (1950 m). Apparently the difference in cumulative O_3 uptake rate between the alpine timberline and the valley floor was about 20% for the whole vegetation period. On the other hand however, the detoxification capacity for O_3 also increases with increasing altitude (POLLE & al. 1995, RENNENBERG & al. 1997). This might explain, why typical altitude-dependent effects on biochemical and physiological parameters could not be attributed to O_3 itself (RENNENBERG & al. 1997).

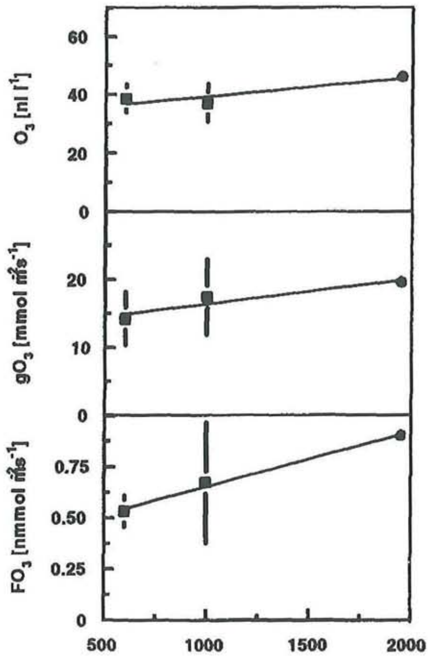

Fig. 3. Mean ambient ozone concentration (O_3, top), average stomatal conductance for ozone (gO_3, middle) and average ozone uptake rate (FO_3) during the growing season (May throughout October) in 60- to 65-year-old *Picea abies* (■) and *Pinus cembra* (●) trees in relation to increasing altitude in the central European Alps. Measurements were made during the period 1987 through 1996. n = 1 to 4 ± SD. The points were fitted by linear regression: stomatal conductance for ozone (gO_3): $y = 0.0037*x + 12.69$, $r^2 = 0.89$; ozone uptake rate (FO_3): $y = 0.00027*x + 0.38$, $r^2 = 0.99$.

Conclusions

In conclusion, in evergreen conifers O_3 uptake during the growing season (May throughout October) is mainly influenced by tree age and altitude. Stomatal conductance and O_3 flux into needles of evergreen conifers most strongly declined with increasing tree age. In comparison to tree age the altitudinal effect was small, but evident in trees similar in age. However, reassurance is needed that conductance values, usually measured on individual twigs, are representative for the canopy as a whole.

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