Seasonal Ozone Uptake of Mature Evergreen Conifers at Different Altitudes

By

G. WIESER¹, R. HÄSLER², B. GÖTZ³, W. KOCH³,⁵ & W.M HAVRANEK¹

Key words: Picea abies, Pinus cembra, ozone, stomatal conductance, tree age, altitudinal gradient.

Summary


Seasonal patterns of ozone (O₃) 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 O₃ uptake reflect variation in both ambient O₃ concentration and stomatal conductance. At all the study sites the annual course in the O₃ regime exhibited seasonal cycles with maxima between April and July and minima in winter. Seasonal variations in stomatal conductance and O₃ uptake were mainly attributed to the course of the prevailing temperature. Average O₃ uptake rates decreased with increasing tree age. However, in trees similar in age O₃ uptake increased with increasing altitude.

Introduction

During the past two decades, there has been increasing attention to the impact of ozone (O₃) on coniferous forests, which are a major sink for O₃ in the lower troposphere (MATYSSEK & al. 1995, SANDERMANN & al. 1997). Within the

¹ Federal Forest Research Centre, Div. Forest Tree Physiology, Rennweg 1, A-6020 Innsbruck, Austria. Fax : ++ 512 573933 5250; e-mail: Gerhard.Wieser@uibk.ac.at
² Swiss Federal Institute for Forest, Snow and Landscape Research, Zürcherstraße 111, CH- 8903 Birmensdorf, Switzerland.
³ Department of Forest Botany, University Munich, Hohenbachernstraße 22, D-85354 Freising, Germany.
⁴ Present address: Forest Botanical Garden, University of Applied Sciences Eberswalde, A. Möllerstraße 1, D-16225 Eberswalde, Germany.
⁵ Present address: Kerschdorf 37, A-9560 Feldkirchen, Austria.
canopy the needles are the primary sites of O\textsubscript{3} deposition, with the stomata representing the interface for the O\textsubscript{3} uptake from the atmosphere into the tree. O\textsubscript{3} uptake however, depends both on ambient air O\textsubscript{3} concentration and on stomatal conductance. In alpine regions mean O\textsubscript{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\textsubscript{3} uptake may be high under the high-altitudinal O\textsubscript{3} regimes. Furthermore, stomatal conductance and hence also O\textsubscript{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\textsubscript{3} uptake of forest trees of different age at various sites, in order to determine the impact of altitude and tree age on O\textsubscript{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>
<thead>
<tr>
<th>Station (country)</th>
<th>Altitude [m]</th>
<th>Species</th>
<th>Age [yrs]</th>
<th>Period</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klimahaus (A)</td>
<td>1950</td>
<td><em>P. cembra</em></td>
<td>65</td>
<td>1996</td>
<td>HAVRANEK &amp; WIESER unpubl.</td>
</tr>
<tr>
<td>Zillertal (A)</td>
<td>1000</td>
<td><em>P. abies</em></td>
<td>60-65</td>
<td>1989-1990</td>
<td>WIESER &amp; HAVRANEK 1993*</td>
</tr>
</tbody>
</table>

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\textsubscript{3} concentration and climatic parameters were measured in order to calculate O\textsubscript{3} uptake according to:

$$\text{FO}_3 = [\text{O}_3] \times g\text{O}_3$$

where FO\textsubscript{3} is the uptake rate of O\textsubscript{3} into the needles, [O\textsubscript{3}] is the O\textsubscript{3} concentration in the ambient air, and gO\textsubscript{3} is the stomatal conductance for O\textsubscript{3}. The latter was calculated by multiplying the conductance for water vapour by 0.613, the ratio of diffusivities of water vapour and O\textsubscript{3}. O\textsubscript{3} concentration inside the needles was assumed to be zero, because O\textsubscript{3} concentrations in the leaf mesophyll are undetectable low (cf. TINGEY & TAILOR 1982, LAISK & al. 1989). Data were condensed to daily means. Cumulative O\textsubscript{3} uptake (CU) was calculated as the uptake rate (FO\textsubscript{3}) integrated over time.
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 O₃ uptake was coincident with seasonal temperature trends (Fig. 1).

The average and maximum daily mean O₃ uptake rates and ambient O₃ concentrations estimated from May throughout October for all the years are summarised in Table 2. The magnitude of O₃ flux into the needles varied considerably and no clear trend with respect to altitude and ambient O₃ 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 O₃ uptake. Therefore, we analysed the impact of tree age and altitude as single factors on its capacity influencing O₃ uptake.

**Table 2.** Average and maximum daily means of O₃ uptake rates (FO₃, nmol m⁻² s⁻¹) and O₃ concentrations (nl l⁻¹) from May throughout October during the years of investigation.

<table>
<thead>
<tr>
<th>Altitude [m]</th>
<th>Year</th>
<th>Species</th>
<th>Tree age [yrs]</th>
<th>Average FO₃</th>
<th>Maximum FO₃</th>
<th>Average O₃</th>
<th>Maximum O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>1996</td>
<td>P. cembra</td>
<td>65</td>
<td>0.90</td>
<td>1.71</td>
<td>45</td>
<td>80</td>
</tr>
<tr>
<td>1660</td>
<td>1987</td>
<td>P. abies</td>
<td>216</td>
<td>0.11</td>
<td>0.37</td>
<td>38</td>
<td>62</td>
</tr>
<tr>
<td>1988</td>
<td></td>
<td></td>
<td></td>
<td>0.14</td>
<td>0.40</td>
<td>39</td>
<td>60</td>
</tr>
<tr>
<td>1000</td>
<td>1989</td>
<td>P. abies</td>
<td>60-65</td>
<td>0.84</td>
<td>1.91</td>
<td>37</td>
<td>43</td>
</tr>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td>0.35</td>
<td>0.68</td>
<td>29</td>
<td>27</td>
</tr>
<tr>
<td>685</td>
<td>1987</td>
<td>P. abies</td>
<td>127</td>
<td>0.33</td>
<td>0.92</td>
<td>34</td>
<td>71</td>
</tr>
<tr>
<td>1988</td>
<td></td>
<td></td>
<td></td>
<td>0.30</td>
<td>0.83</td>
<td>38</td>
<td>72</td>
</tr>
<tr>
<td>600</td>
<td>1987</td>
<td>P. abies</td>
<td>65</td>
<td>0.62</td>
<td>1.41</td>
<td>30</td>
<td>66</td>
</tr>
<tr>
<td>1988</td>
<td></td>
<td></td>
<td></td>
<td>0.48</td>
<td>0.99</td>
<td>40</td>
<td>77</td>
</tr>
<tr>
<td>1989</td>
<td></td>
<td></td>
<td></td>
<td>0.46</td>
<td>1.10</td>
<td>41</td>
<td>77</td>
</tr>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td>0.58</td>
<td>1.35</td>
<td>42</td>
<td>80</td>
</tr>
<tr>
<td>580</td>
<td>1992</td>
<td>P. abies</td>
<td>17</td>
<td>0.71</td>
<td>1.66</td>
<td>40</td>
<td>75</td>
</tr>
<tr>
<td>1993</td>
<td></td>
<td></td>
<td></td>
<td>0.50</td>
<td>1.08</td>
<td>25</td>
<td>51</td>
</tr>
</tbody>
</table>

**Tree age related differences**

Fig. 2 shows that O₃ uptake significantly decreased with increasing tree age.

As O₃ concentrations did not differ significantly between the environments for any tree size class, observed differences in O₃ 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 (SCHOTTLE 1994, YODER & al. 1994, KOLB & al. 1997). FREDERICKSEN & al. 1996 also observed higher rates of O₃ 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\textsubscript{3} concentration of 36 ± 5 nl l\textsuperscript{-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 related differences

In trees similar in age however, average O\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{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\textsuperscript{-2} of total needle surface area at the alpine timberline (1950 m). Apparently the difference in cumulative O\textsubscript{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\textsubscript{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\textsubscript{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 = 0.0037x + 12.69, r$^2$ = 0.89; ozone uptake rate (FO$_3$): y = 0.00027x + 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.
References


