

Significance of sampling height of airborne particles for aerobiological information

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Pollen and spore counts from Burkard traps for routine pollen and spore sampling placed at 15 m above ground and at ground level were compared. Daily counts of most pollen types were higher on the ground than at roof level, but the counts were significantly correlated. The ratios of pollen frequencies at high and low levels varied between 1.0 and 11.5. The most prominent differences were recorded for herbaceous pollen (e.g. *Artemisia* counts 11.5 and Poaceae counts 4.4 times higher at ground level) and in *Botrytis* and Ustilaginales spores. Tree pollen grains and basidiomycetous spores were more equally distributed. Wind speed did not affect the variation of pollen frequencies at either height. Large spores are not so unevenly distributed as previously supposed. *Artemisia* and grass pollen was detected 1 to 2 weeks earlier at ground level than on the roof. It is therefore concluded that especially the beginning of flowering should be monitored at a low level.

Key words: aerobiology; pollen; spores.

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CLINICAL ASPECTS

In this study we have shown that a sampler at roof level does not always give the relevant information useful in the guidance of pollen/mould-sensitive patients. For example, pollination of *Artemisia* (mugwort) and grasses was observed in the ground level samples 1 to 2 weeks earlier than at roof level. It is suggested that threshold values for the most important pollen and spores provoking allergic symptoms differ between ground and roof level sampling.

Most aerobiological sampling sites are situated 10-30 m above ground level. This is considered high enough to avoid being affected by disturbing local factors. Other logical sites would be on the ground or the level of human respiration (approximately 1.5 m above the ground). The proper placing of air samplers has been subject to discussion ever since the introduction of routine aerobiological sampling (6, 7, 8, 18, 19). Strict standardisation of sampling height has proved unrealistic, but in many cases sampling height is not even mentioned in comparisons of results from various countries or sampling locations.

Raynor et al. (17) tested variations in ragweed pollen concentrations at five levels, from

1.5 to 108 m, using roto-slide and slide-edge cylinder samplers. The vertical pollen profiles showed great day to day variation, but averaging over pollen seasons or longer periods showed little systematic variation due to height. It may be assumed that this is true only when there are no local pollen sources in the immediate vicinity (within a radius of 100 m), and when the sampling results are not affected by wind speed. Burkard sampling is reported as not always independent of wind speed (10), and, generally, local sources exist close to any acceptable sampling site.

Few attempts have been made to determine the threshold values of airborne pollen concentrations that provoke allergic reactions in sensi-

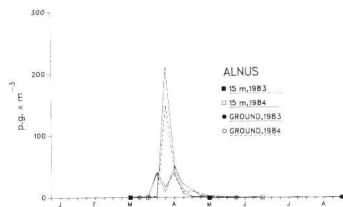


Fig. 1. Daily mean counts of airborne *Alnus* pollen at roof and ground level in 1983 and 1984.

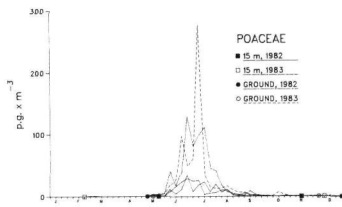


Fig. 3. Daily mean counts of airborne Poaceae pollen at roof and ground level in 1982 and 1983.

tized subjects (5, 21). The aim of this study was to find whether any useful information could be obtained by sampling at ground level and high level, simultaneously. We have compared both pollen and spore periods and airborne particle concentrations at the two most extreme sampling heights. Different estimated threshold values for pollen reports are needed depending on the sampling height. The effect of wind speed was studied at a general level.

MATERIAL AND METHODS

The study made use of two Burkard samplers (Burkard Manufacturing Co). One was situated 15 m above ground level, on the roof of a building of Turku University, at the boundary between the southwest archipelago and the Finnish mainland. The other sampler was situated 200 m distant, on a garden lawn at

ground level. The samples were taken daily over a period of 2 years, from the beginning of May 1982 till the end of May 1984. The slides, mounted in Gelvatol, were microscopically analysed using the random count method (14). The results obtained were used directly for the calculation of diel variations. Pollen were classified by genus rank. Only certain groups of fungal spores (*Cladosporium*, *Botrytis*, *Alternaria*, *Epicoccum*, *Helminthosporium*, Ustilaginales, Uredinales, Russulaceae, *Suillus* and other bolets) were counted. The normality of the material was tested with the SAS Univariate program (19). The counts from the two sites were compared with a correlation test (BMDP1R; 1). Variance due to wind speed variation was tested

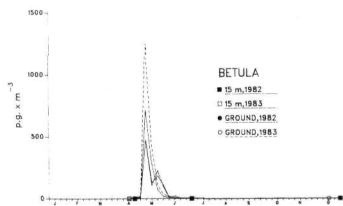


Fig. 2. Daily mean counts of airborne *Betula* pollen at roof and ground level in 1982 and 1983.

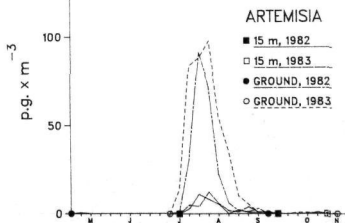


Fig. 4. Daily mean counts of airborne *Artemisia* pollen at roof and ground level in 1982 and 1983.

Table 1.

Pollen ratios and correlations between roof and ground level

Pollen	Ratio ground: roof	Correlation ground/roof
<i>Alnus</i>	1.02	0.949***
<i>Artemisia</i>	11.48	0.651***
<i>Betula</i>	1.64	0.919***
<i>Juniperus</i>	2.01	0.434***
<i>Poaceae</i>	4.42	0.666***
<i>Picea</i>	2.25	0.884***
<i>Pinus</i>	1.44	0.525***
<i>Populus</i>	1.71	0.333***
<i>Quercus</i>	1.32	0.299***
<i>Rumex</i>	3.19	0.236***
<i>Salix</i>	1.94	0.367***
<i>Ulmus</i>	1.48	0.852***
<i>Urtica</i>	7.66	0.401***

with the SAS t-test and correlations with average wind speed with the SAS GLM correlation test. The wind speed figures were from Turku airport, 6 km away. Threshold values for pollen levels provoking allergic symptoms have been published by few authors (5, 20, 21).

RESULTS

Pollen

Variations in all pollen types at the two levels were significantly correlated (Table 1). The pollen curves have the same form, but the counts are clearly lower at roof level than on the ground. The differences between the two levels

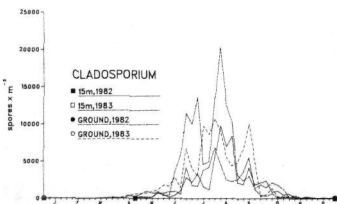


Fig. 5. Daily mean counts of airborne *Cladosporium* spores at roof and ground level in 1982 and 1983.

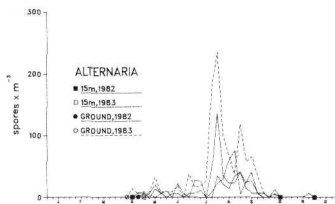


Fig. 6. Daily mean counts of airborne *Alternaria* spores at roof and ground level in 1982 and 1983.

tested were smaller for tree pollen frequencies (*Alnus*, *Betula*) than for herbaceous plants (Figs. 1-4).

The ratios between roof and ground for different pollen types are listed in Table 1. The most marked difference between the two levels was found in *Artemisia* concentrations, these being approximately 11 times higher at ground level. Likewise, *Urtica* counts were almost 8 times higher at ground level. The ground:roof ratio for almost all tree pollen was between 1 and 2.

The pollen period was defined by excluding the aggregates (single days or several days) contributing < 1% of the total, and at a distance of more than 1 week from the nearest acceptable record. The pollen periods of *Artemisia* and *Poaceae* began 1-2 weeks earlier at ground level, and in some cases also lasted longer than at 15 m; the pollen period of *Poaceae*,

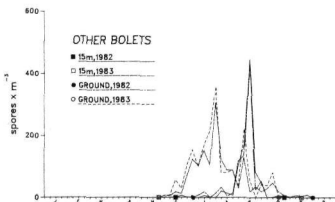


Fig. 7. Daily mean counts of airborne other bolet spores at roof and ground level in 1982 and 1983.

Table 2.
Beginnings and ends of pollen periods at ground and roof level. Differences in lengths of periods

	1982					1983					1984				
	start roof	diff. comp. with ground	end roof	diff. comp. with ground	diff. whole season	start roof	diff. comp. with ground	end roof	diff. comp. with ground	diff. whole season	start roof	diff. comp. with ground	end roof	diff. comp. with ground	diff. whole season
Alnus						3.4	14	28.4	7	21	30.3	4	18.5	0	4
Artemisia	25.7	5	16.8	27	32	25.7	9	1.9	4	13					
Betula	28.4	-5	30.6	21	16	20.4	0	8.7	-7	-7	4.4	-1	17.4	1	0
Corylus						3.4	-2	7.5	-10	-12					
Juniperus						17.5	-4	28.6	-1	-5					
Picea						17.5	-1	13.6	-1	-2					
Pinus	28.5	1	17.7	56	57	17.5	10	9.7	12	22					
Poaceae	27.5	14	29.8	22	36	1.6	14	1.1	28	42	10.4	-1	2.5	18	17
Populus						20.4	21	26.5	3	18					
Quercus	27.5	3	11.6	7	10	20.5	3	15.6	-6	-3					
Rumex	28.5	-4	16.7	19	15	13.6	14	14.7	19	33					
Salix	19.4	-15	9.6	10	-5	14.4	1	28.5	10	11					
Ulmus	5.5	-3	15.5	1	-2	21.4	3	10.5	13	16	29.4	-1	5.5	0	-1
Urtica	28.6	7	2.9	15	22	12.6	1	24.9	-19	-18					

Table 3.

Correlations with daily average wind speed. T-test results between roof and ground pollen counts, with days divided according to daily mean wind speed (< 2.2, 2.5–5 and > 5 m/s)

Pollen	Corr. with daily wind speed (roof) <i>n</i> = 443	Corr. with daily wind speed (ground) <i>n</i> = 443	Wind speed		
			2.5 m/s <i>n</i> = 133	2.5–55 m/s <i>n</i> = 255	> 5 m/s <i>n</i> = 55
<i>Alnus</i>	-0.060 NS	-0.042 NS	2.20 ***	1.19 NS	2.54 **
<i>Artemisia</i>	-0.001 NS	-0.057 NS	177.50 ***	74.01 ***	63.04 ***
<i>Betula</i>	-0.054 NS	-0.080 o	4.26 ***	2.11 ***	1.28 NS
<i>Juniperus</i>	-0.037 NS	0.087 o	2.95 ***	1.82 ***	18.26 ***
<i>Quercus</i>	-0.084 o	0.072 NS	2.26 ***	1.27 o	271.68 ***
<i>Picea</i>	0.033 NS	0.026 NS	2.32 ***	4.06 ***	no
<i>Pinus</i>	0.009 NS	0.119 *	2.49 ***	1.04 NS	5.14 ***
<i>Poaceae</i>	-0.031 NS	0.009 NS	24.30 ***	26.77 ***	40.15 ***
<i>Populus</i>	-0.033 NS	-0.121 *	7.85 ***	1.91 ***	5.89 ***
<i>Rumex</i>	0.082 o	0.034 NS	10.46 ***	6.30 ***	6.42 ***
<i>Salix</i>	-0.025 NS	0.067 NS	3.54 ***	5.16 ***	3.41 ***
<i>Ulmus</i>	-0.096 *	-0.082 o	2.34 ***	3.81 ***	1.96 o
<i>Urtica</i>	-0.056 NS	-0.038 NS	21.77 ***	25.18 ***	96.01 ***

for instance, was more than a month longer at ground level than roof level (Table 2). Classifying research days according to daily average wind speed (< 2.5, 2.5–5 and > 5 m/s) showed no clear tendency. On the other hand, almost all pollen, both at ground and roof level, varied significantly, although *Betula* did not, when wind speed was > 5 m/s (Table 3).

Pollen frequencies were generally not affected by the average daily wind speed, *Pinus* and *Populus* at ground level and *Ulmus* at roof level being the only exceptions. Of these, *Populus* and *Ulmus* were negatively correlated with wind speed (Table 3).

Knowing the airborne threshold values of birch pollen-provoking symptoms in birch allergic subjects (21), the pollen volume has been used as a "standard", and new threshold values for the most important allergenic pollen and spores have been calculated separately for roof and ground level sampling (Table 4).

Spores

All roof and ground spore counts (except *Epicoccum*, which occurred only occasionally) were significantly intercorrelated (Table 5). The ratios between high and low level counts varied

between 1.0 and 4.6 (Table 5). Spores typically more abundant at ground level were those of *Cladosporium*, *Epicoccum*, *Alternaria*, *Helminthosporium*, *Botrytis* and *Ustilaginales*. Only *Boletaceae* (*Suillus* and other bolets), *Russulaceae* and *Uredinales* spores were equally distributed (Figs. 5–7).

The spore period has been defined as starting when the frequencies exceed 10% of the daily mean concentration on at least 3 successive days, and as ending when there are at least 3 successive days with concentrations lower than 10% of the mean.

Epicoccum and *Helminthosporium* had no clear period, but occurred more sporadically. The period of *Botrytis* was actually 100 days longer on the ground than at roof level. *Alternaria* also had a clearly longer spore period close to the ground. For *Cladosporium* the spore period in 1 study year ended earlier at ground level. The periods for *Uredinales* and *Ustilaginales*, which were some 50 days longer, were based on the results of only 1 year (1983; cf. Table 6).

Uredinales was the only spore type that was significantly more abundant on the roof than on the ground when there was a strong wind (Table 7). The t-test results for the differences in spore concentrations at the two sites at different wind speeds are shown in Table 7. In

Table 4.

Threshold values in use and new threshold values suggested on the basis of birch as a standard pollen, for both roof and ground level, when sampling with Burkard trap. Only pollen and spores reported are included

Pollen/spore	Threshold values at roof level			Vol. pollen/ spore μm^3	Ratio to birch pollen vol.	Threshold values suggested roof level/ground level		
	low	moderate	abundant			low	moderate	abundant
<i>Betula</i> (used as a "standard")	< 10	10-100	> 100	5600		< 10/< 20	10-100/ 20-150	> 100/ > 150
<i>Alnus</i>	< 10	10-100	> 100	6400	ca. 1	< 5/< 5	5-50/5-50	> 50/> 50
<i>Artemisia</i>	< 10	10-30	> 30	4200	0.75	< 5/< 50	5-10/ 50-100	> 10/> 100
Poaceae	< 10	10-30	> 30	17000 (<i>Phleum pratense</i>)	3.0	< 5/< 5	5-10/5-50	> 50/> 50
<i>Alternaria</i>	< 20	20-100	> 100	2300 ¹	0.40	< 20/< 50	20-250/ 40-500	> 250/ > 500
<i>Cladosporium</i>	< 2000	2000-4000	> 4000	160 ²	0.03	< 500/ < 1000	500-3500/ 1000-7000	> 3500/ > 7000

¹Hyde (11); ²Koivikko (12)

general, wind speed categories did not differ, but *Alternaria* and Ustilaginales counts were more equal at the two levels when wind velocity was high.

DISCUSSION

Releasing-height explains the obvious difference in pollen types: tree pollen grains were uniformly distributed, and the pollen of herbaceous (soft-stemmed) plants occurred more abundantly at ground level.

A large source (wasteland) close to the sampling sites could partly explain the difference. Also birch and willows grew in the vicinity (within a radius of 100 m) of the samplers, but the ratios of these tree pollen at two heights were < 2. Increasing distance makes a more even distribution at low and high levels. Different aerodynamical properties may cause similar terminal velocities in pollen of different sizes, such as *Pinus* and *Betula* pollens (16). Grass

pollen was more evenly distributed at the two levels than *Artemisia* pollen. This may be due to the difference in diurnal rhythm: *Artemisia* pollen is released in the morning hours, when the wind has not yet risen, while grass pollen generally has two daily peaks (due to several species having different release periods), and in the afternoon the wind usually increases (13).

The pollen periods particularly of Poaceae and *Artemisia* were so much longer at ground level that these pollens are not recommended for monitoring at roof level, but close to the ground. A more reliable recording of the beginning of flowering is particularly important in order to start medication in time. The pollen period might be prolonged due to turbulent wind causing a secondary release of pollen rising from various surfaces. In close to the ground trapping this secondary release can be important. One might assume that long distance transport would be observed more efficiently at high level than at low level. In our

Table 5.

Ratios of spores calculated at roof and ground level.
Correlations between sampling sites

Spore	Ratio ground:roof	Correlation ground/roof
<i>Alternaria</i>	2.2	0.473 ***
<i>Botrytis</i>	5.9	0.123 ***
<i>Cladosporium</i>	2.1	0.840 ***
<i>Epicoecum</i>	2.7	0.000 NS
<i>Helminthosporium</i>	4.1	0.214 ***
<i>Russulaceae</i>	1.1	0.647 ***
<i>Suillus</i>	1.0	0.915 ***
Other bolets	1.2	0.764 ***
<i>Uredinales</i>	1.4	0.666 ***
<i>Ustilaginales</i>	4.6	0.421 ***

results no major differences were recorded at the two levels at the beginning of the tree pollen period. Thus for tree pollen analyses both levels should be tested. Wind speed did not account for any differences in the pollen results at the two levels.

Hyde (11) estimated that 10% of hay fever patients are likely to have symptoms when the grass pollen count exceeds $10/\text{m}^3$ of air. Frankland & Davies (unpublished; referred to by 5) found that when the mean daily concentration of grass pollen grains in the air over Central London was $50/\text{m}^3$ or more, symptoms were experienced by all grass pollen-sensitive patients in the area. Viander & Koivikko (21) have shown that a birch pollen concentration of 80

grains/ m^3 of air is high enough to provoke allergic reactions in most birch allergy subjects. The appearance of symptoms at pollen counts under $30/\text{m}^3$ in the early season was significantly associated with a high nasal sensitivity.

Estimated threshold values for the provoking of allergic symptoms have been determined on the basis of the volume of a "standard" pollen, birch, which is the most important allergenic pollen in Finland. Calculations based on volume yield the values shown in Table 4. After correction with a roof/ground correction coefficient, the new threshold value for *Artemisia* is assessed as only 10 at roof level. Threshold values are complicated because the experimental testing of different pollen concentrations requires much higher doses for hay fever patients in a pollen-free period (4).

Spores could be divided into two groups according to their dispersal a) equally distributed (*Uredinales*, *Russulaceae*, bolets) and b) those distributed close to the ground (e.g. *Botrytis*, *Ustilaginales*). The main explanation may be the distance from the source. A sampling location close to an urban area is far from forests, where basidiomycetes grow abundantly. Eversmeyer & Kramer (8) have shown that 50 m from the source area, a wheat field, the spore mass was already uniform in a vertical (1–3 m) direction. They even used uniformity as a criterion in determining whether the spores had originated in the field or in more remote areas. The terminal velocities of basidiospores are gen-

Table 6.

Beginnings and ends of spore periods at ground and roof level. Differences in lengths of periods

	1982					1983				
	start roof	diff. comp. with ground	end roof	diff. comp. with ground	diff. whole season	start roof	diff. comp. with ground	end roof	diff. comp. with ground	diff. whole season
<i>Alternaria</i>	10.8	33	2.8	16	49	2.8	78	20.9	13	91
<i>Botrytis</i>	25.5	22	2.9	79	101	4.5	15	12.7	85	100
<i>Cladosporium</i>	8.5	3	7.12	-24	-21	20.4	1	11.11	1	2
<i>Russulaceae</i>	2.9	1	31.10	-1	0	6.7	7	18.10	0	7
<i>Suillus</i>	29.8	4	11.10	20	24	30.6	-13	28.10	3	-10
Other bolets	11.8	22	1.10	49	71	5.6	-5	27.10	-9	-14
<i>Uredinales</i>						8.7	51	29.7	0	51
<i>Ustilaginales</i>						29.6	50	10.9	6	56

Table 7.

T-test results between roof and ground spore counts with days divided according to daily mean wind speed.
Correlations with the daily mean wind speed

Spore	Corr. with daily wind speed (roof) $n = 443$	Corr. with daily wind speed (ground) $n = 443$	Wind speed		
			< 2.5 m/s $n = 133$	2.5-5 m/s $n = 255$	> 5 m/s $n = 55$
<i>Alternaria</i>	-0.065 NS	-0.055 NS	97.24 ***	64.98 ***	2.14 NS
<i>Botrytis</i>	-0.068 o	0.015 NS	0.37 NS	28.97 ***	38.35 ***
<i>Cladosporium</i>	-0.072 o	-0.054 NS	396.84 ***	1183.76 ***	455.53 ***
<i>Epicoccum</i>	0.027 NS	0.052 NS	0.02 NS	0.17 NS	0.00 NS
<i>Helminthosporium</i>	0.020 NS	-0.049 NS	3.23 o	35.00 ***	27.36 ***
<i>Russulaceae</i>	-0.075 o	-0.058 NS	118.41 ***	378.70 ***	47.99 ***
<i>Suillus</i>	-0.014 NS	0.000 NS	739.25 ***	3177.90 ***	737.55 ***
Other bolets	-0.048 NS	-0.065 NS	261.11 ***	548.78 ***	243.63 ***
<i>Uredinales</i>	0.040 NS	0.102 **	74.44 ***	215.73 ***	414.98 ***
<i>Ustilaginales</i>	0.005 NS	0.029 NS	26.78 ***	83.24 ***	3.32 o

erally lower (2) than those of mould spores (e.g. 3, Gregory & Henden unpublished; referred to by 9). For example, a mould with large spores, *Alternaria* only had a ratio of 1 to 2.2, which was similar to that of *Cladosporium* and *Epicoccum*. It has been supposed that these spores become underestimated when spore traps are at roof level. *Alternaria* is second in importance, after *Cladosporium*, in provoking fungus spore allergies in children in south Finland (12).

The difference in spore periods between ground and roof was even more marked in spores than in pollen.

As wind speed did not correlate with any other spore than *Botrytis* and *Uredinales*, it can be concluded that wind speed is probably not a very important factor in the differences between the two dispersal models.

New estimated threshold values for the two most important fungal allergens (*Cladosporium*, *Alternaria*) have been suggested on the basis of standard pollen volume. For *Alternaria* this means higher threshold values than used previously.

On the basis of our findings, at least one short daytime sample (e.g. by rotorod sampler (15)) should be taken daily at ground level, for better monitoring of the beginning of the flowering periods of important herbal allergenic plants and fungal spores. Except for tree pollen,

threshold values for samples taken at ground and roof level are not the same.

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