

Pollen survival and spore dispersal on altitudinal clines: the case of the Popocatepetl volcano, Mexico

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Abstract

Pollen grains are abundant micro-organisms in the summer or dry season outdoor atmosphere. Moreover, they are fragile organisms, living for only a few days and their constant chemical interactions with their surrounding environment makes them prime candidates as biological indicators of ambient conditions. Volumetric samples were taken at different altitudes (3900–4400 m) on the Popocatepetl volcano (5452 m), 70 km south-east of Mexico City (2240 m). Results from September–October 1992 show that: (1) Local airborne pollen emission is negligible, most plant species found along the altitudinal transect being entomophilous. Indeed, maximum *in vivo* pollen viability was found at 4100 m a.s.l., where very few total airborne pollens were collected. (2) Regional pollen transport is found under 4000 m a.s.l., where pollen viability is discontinuous, being either below 50% or over 75%. (3) There is a long distance transport layer of pollen and spore dispersal below Mean Cloud Base, but over maximum wind speed, at a height of 4200–4300 m a.s.l., where pollen were found highly viable (>80%). (4) Pollen concentration or viability were not correlated with wind speed, relative humidity or temperature. However, the same factors were all significant regarding spore concentrations.

Keywords: Pollen; Spore; Dispersal; Viability; Altitude; Mountain

'J'aurais pu m'élever en aérostat, mais, pour des études d'essai, préliminaires en quelque sorte, j'ai pensé qu'il serait plus commode, et peut-être plus utile, d'opérer comparativement dans la plaine et sur les montagnes.'

Louis Pasteur (1860)

1. Introduction

Even if the biogeography of the atmospheric biological content has inspired much descriptive and timely research (Gregory, 1973), it is well known that workers have studied only a tiny fraction of the atmosphere, namely the area directly influenced by human activity; and that they have not considered what is actually taking place in the 'natural' atmosphere. Indeed, it is also well known that the 'upper' atmosphere presents a biological content and an aerobiological structure totally different from that found at ground level (Meier et al., 1933).

Mountains are not only a simple and cheap way to become 'airborne' in order to study the atmospheric layering of the biological content, they are also of interest in themselves. Their intrusion into the atmospheric structure and their physical effects on air movements lead to a particular biometeorology characteristic of the mountain environment (Geiger, 1965).

However, when these areas were used in fundamental microbiological research mostly at the turn of the past century (Pasteur, 1860; Pouchet et al., 1863; Miquel, 1884; Bonner et al., 1911), they were rarely studied in a systematic way, since most past observations were '*extremely fragmentary and had the flavor of holiday tasks on fine days in summer*' (Gregory, 1973).

Moreover, it was previously shown (Comtois and Schemenauer, 1991) that airborne particles collected on mountain clines could be used as a biological indicator of the ambient conditions found at sampling sites, and notably the total pollution load coming from distant sources.

In order to begin to understand what could be the aerobiological structure of mountain clines and the

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major parameters that could explain it, volumetric samples of airborne dust were collected on the Popocatepetl volcano, Mexico.

2. Material and methods

The Popocatepetl volcano (5452 m) is located 70 km south east of Mexico City (19°35'N; 99°40'W) (2240 m) (Fig. 1). It is therefore a sub-arctic habitat that is surrounded by a subtropical environment. Indeed, the climatic parameters of Mexico City are: a mean temperature of 15°C and an average annual precipitation ranging from 600 to 1200 mm, depending on the geographical situation of the different zones of the city. There are two seasons: a dry season from November to April, and a wet season from May to October.

Samples were taken in September–October 1992, at the end of the wet season, at a time when mainly Gramineae, Compositae and Chenopodiaceae-*Amaranthus* pollen were found in the air of Mexico City (Bronillet Tarrago, 1992). Fifty-four samples were taken from 9–11 September, and from 30 September–2 October.

The air spora were collected with the help of a Lanzoni VPPS 1000 pollen and spore sampler. This sampler is battery (nickel-cadmium) operated, with a 6-h autonomy. However, because of the difficult conditions

in which it was operated, and the absence of recharging capacity, it was operated with an external Powerstar dry 12-volt battery. This sampler draws 10 l of air a minute, and the airborne particles are impacted on a 25 × 75 mm microscopic slide, previously coated with glycerine-gelatine. The sampler has a clock allowing a 2 mm × 14 mm sample every hour. The sampler was operated for at least 30 min at each site (for a minimum total sampled volume of 0.3 m³). Slides were changed at each site.

In addition, a few drops of a 1% TTC (2,3,5-triphenyl tetrazolium chloride) solution (10% TTC in 60% saccharose) were added to the sample before being covered with a cover slip. The TTC is a biological stain that is used to detect respiration (i.e. viability) of cells. Therefore, a viable pollen takes a red staining, while a dead pollen remains yellow.

Samples were taken at 3900 m, 4000 m, 4100 m, 4200 m, 4300 m and 4400 m, that is from the tree line (Tlamacas) to the snow cover (Ventorillo). However, it was not always possible to do a complete transect on every half day, the meteorological conditions (rain or fog) either washing the air content or making it impossible to work on the transect. Pollen samples were also taken directly from open flowers found along the transect, in order to estimate, with the same stain, the in vivo pollen viability.

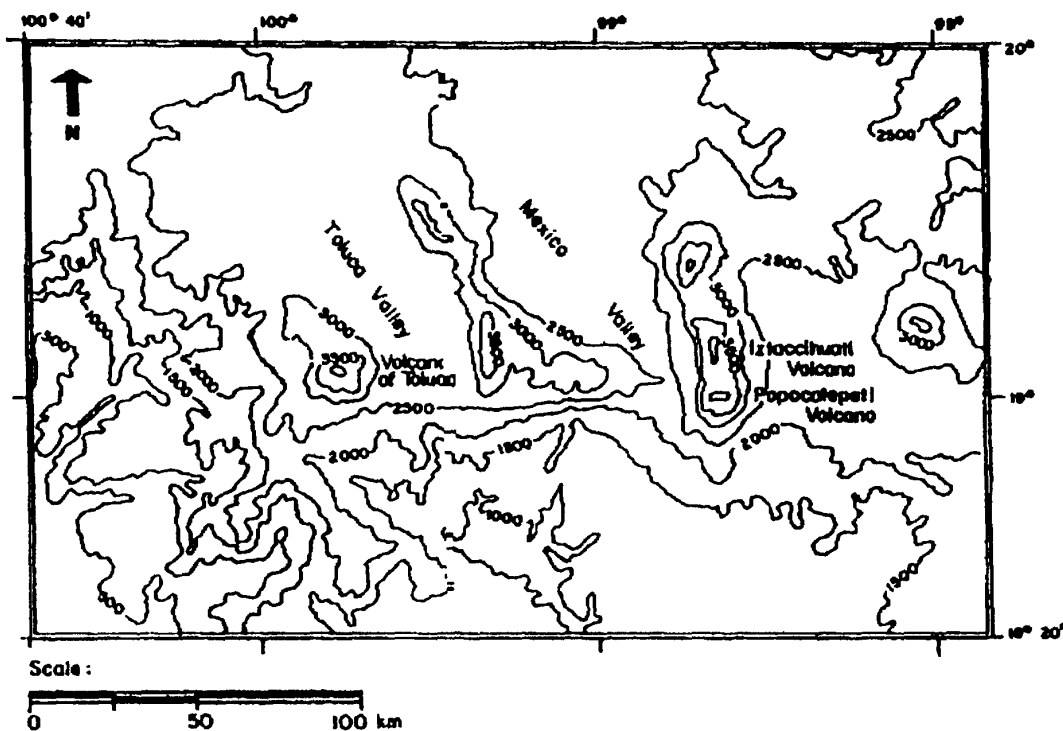


Fig. 1. Localization of the Popocatepetl volcano, in the Valley of Mexico.

Finally, in conjunction with each aerobiological samples, air temperature (Micron 6944, $\pm 1^\circ\text{C}$), relative humidity (SPER 800016, $\pm 5\%$), and wind speed (Salmoiraghi, ± 1 m/s) were also recorded.

3. Results

The results will be presented in two parts, first the average situation found along the transect, with all samples taken into consideration, then the situation found on two complete days.

3.1. Average situation

On average, there were 55 pollen grains/ m^3 (with a mean viability of 43%) and 538 fungal spores/ m^3 at the time of sampling on Popocatepetl. The average situation for Mexico City for the same period was 27 pollen grains/ m^3 (without any viability) and 403 fungal spores/ m^3 , respectively. The average ambient conditions were 12.4°C , 55% relative humidity, and 2.2 m/s wind speed.

Fig. 2 shows the average aerobiological content of the Popocatepetl atmosphere. Fungal spores show an almost regular distribution for all heights, except at 4300 m, where concentrations reach $1520/\text{m}^3$, as compared to a mean of $340/\text{m}^3$ for the other sites. Pollen grains concentrations were less variable, but still show an under-representation below 4100 m, and an over-representation over 4300 m. Viability was generally low ($<30\%$) except over 4300 m where concentrations were also above average.

It therefore looks as if there were three different aeropalynological layers of transport: at 3900–4000 m, pollen is less abundant than the average, but similar to

what is produced in Mexico City, and could represent the regional transport layer.

At 4100–4200 m, there is an average pollen concentration, but minimum airborne viability, corresponding to the local transport layer, as can be seen from the in vivo pollen viability distribution (Fig. 3), which culminates at the same height. Indeed, all in vivo pollen found along the transect were from entomophilous plants (Cruciferae, Scrophulariaceae, Compositae, Leguminosae) that did not contribute to the aerobiological pollen content.

At 4300–4400 m, there were both high concentrations and high viability, and this layer could represent the long distance transport layer being different both from the regional situation (i.e. Mexico City) and the local situation (i.e. flowering on Popocatepetl). This also corresponds to the 'aerobiological-convection layer' sensu Gregory (1973), usually found around 2000 m above ground level (which would mean 4240 m above sea level in Mexico City valley).

Fig. 4 shows the average ambient conditions along the transect. Long distance transport is found at maximum air temperatures, but at minimum relative humidity, just over maximum wind speed and maximum relative humidity. On the other hand, regional transport is found at minimum wind speed.

3.2. 10 September 1992

The first complete data set was collected on 10 September 1992. Fig. 5 shows that, compared to the average situation, maximum viability and maximum spore concentrations are again found at the highest altitude. However, maximum pollen concentration was more characteristic of the local layer (4100 m). Regional

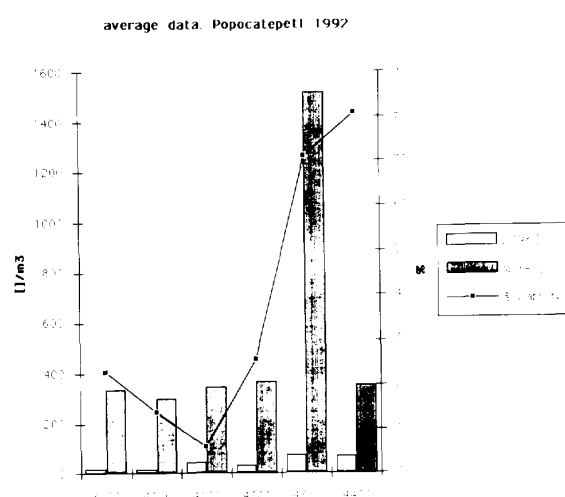


Fig. 2. Average aerobiological data in fall 1992 on Popocatepetl.

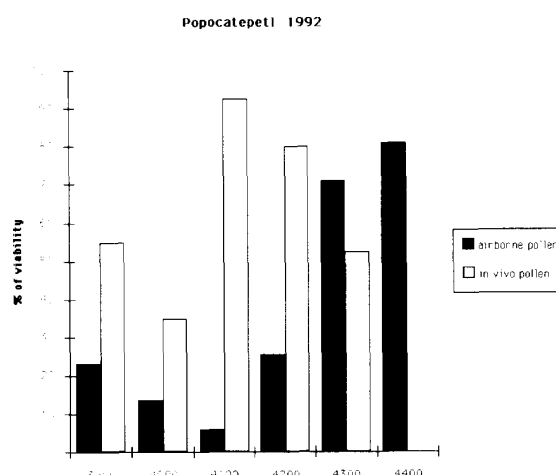


Fig. 3. In vivo and airborne pollen viability in fall 1992 on Popocatepetl.

average ambient conditions. Popocatepetl 1992

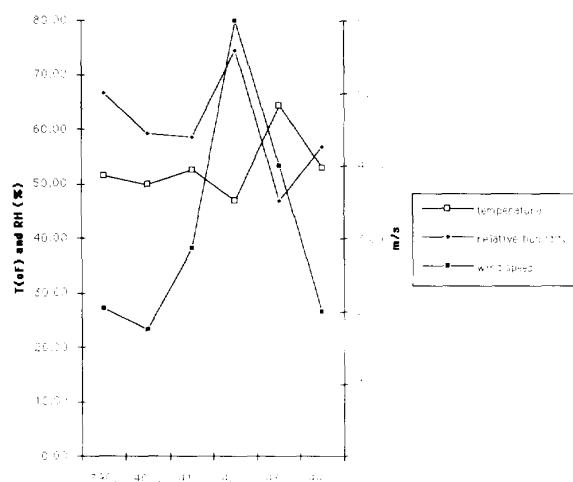


Fig. 4. Average ambient conditions in fall 1992 on Popocatepetl.

transport was almost absent, and pollen viability of those pollen found in this layer was at its lowest (1%).

The conditions found at the same time (Fig. 6) again show a long distance transport at the same height as maximum temperature and minimum relative humidity. This time however, it was also concomitant with maximum wind speed, which could explain why spore concentrations did not decrease as much after 4300 m, and why pollen concentrations were still important up to 4400 m.

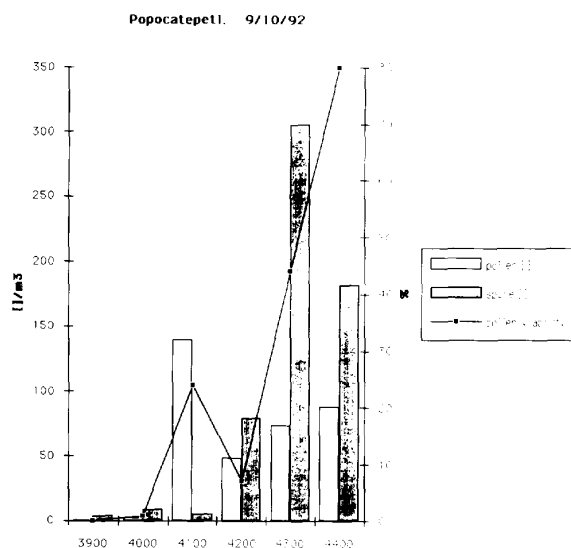


Fig. 5. Aerobiological data on 10 September 1992 on Popocatepetl.

Popocatepetl 9/10/92

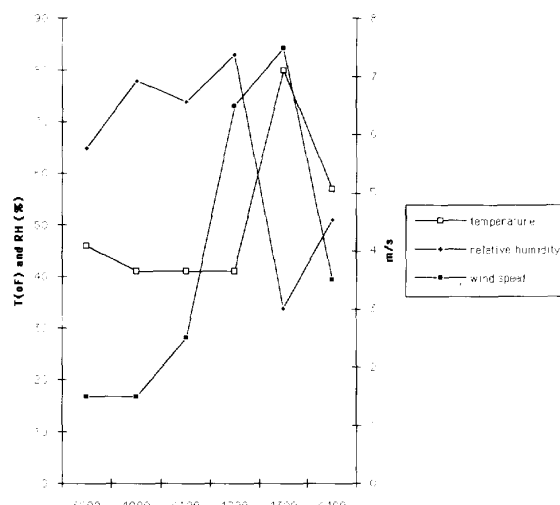


Fig. 6. Ambient conditions on 10 September 1992 on Popocatepetl.

3.3. 1 October 1992

The second complete data set was collected on 1 October 1992. Again, as can be seen in Fig. 7, long distance transport is characterized by a maximum spore concentration and maximum viability. However, this time maximum pollen was typical of the regional transport system (3900 m), and its viability was significantly above average (87%). Local transport was absent, as far as pollen is concerned, and spores had concentrations above 1000/m³.

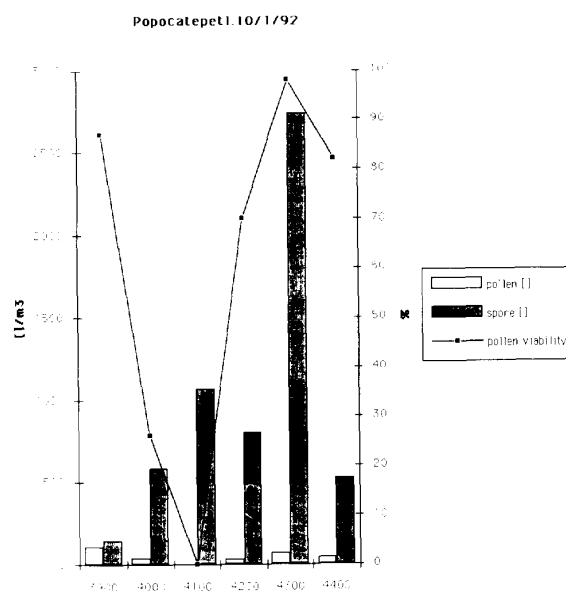


Fig. 7. Aerobiological data on 1 October 1992 on Popocatepetl.

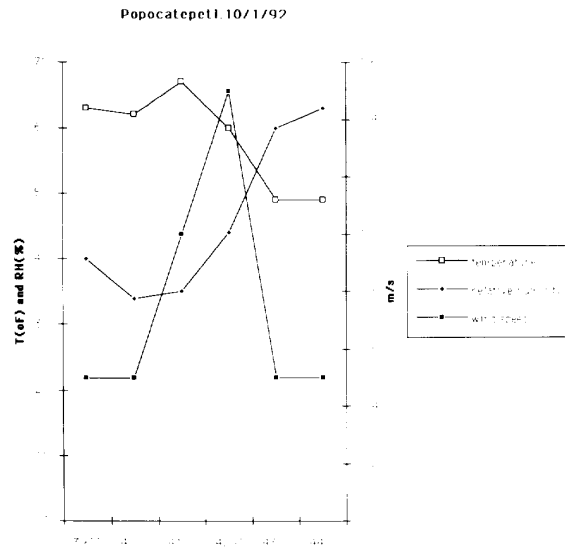


Fig. 8. Ambient conditions on 1 October 1992 on Popocatepetl.

On the same day, long distance transport was again just above maximum wind speed, but this time, correlated with maximum relative humidity and minimum temperature (Fig. 8). It was the regional pollen transport system which was related to maximum temperature and minimum relative humidity. This could explain why above average pollen concentrations and viabilities were found.

4. Discussion

As stated in the Introduction, mountains are of interest because of both the local conditions they create, and their capture of the synoptic air masses, which allow the regional and long distance transport to co-exist. We will therefore analyse our results from these two points of view.

4.1. Ambient conditions

Some regular features were mentioned as the results were presented: long distance transport, mostly characterized by high atmospheric spore content, and usually with maximum temperature and minimum relative humidity. A correlation analysis also shows the same relevant features. The non-parametric Spearman correlation coefficient (Rho, ρ) was used, because of the non-normal distribution of the aerobiological data. Indeed, spore concentrations were significantly correlated not only with temperature, but also (though negatively) with wind speed and relative humidity (Table 1). These were the only significant correlations found. Both pollen concentration and viability were not directly governed by the local ambient conditions, (although relative humidity was almost and negatively correlated, with a P -value of 0.061).

The spores population is known to be much more cosmopolitan than airborne pollen, and often constitutes the major part of what is found in the upper air. On Popocatepetl, it is mainly represented by *Basidiomycetes* and *Cladosporium* spores. They probably constitute the epitype of the long distance traveller: they

Table 1
Correlation analysis between factors, using Spearman's rank coefficient (Rho, ρ)

Independent variable	Dependent variable	Rho-value	Probability of association	Significance level
Temperature	Pollen	0.253	0.206	NS
Relative humidity	Pollen	-0.375	0.061	NS
Wind speed	Pollen	-0.140	0.482	NS
Temperature	Spore	0.506	0.011	*
Relative humidity	Spore	-0.458	0.022	*
Wind speed	Spore	-0.469	0.019	*
Temperature	Pollen viability	0.365	0.121	NS
Relative humidity	Pollen viability	-0.338	0.151	NS
Wind speed	Pollen viability	-0.047	0.962	NS
Pollen	Viability	0.353	0.134	NS
Spore	Viability	0.186	0.430	NS
Spore	Pollen	0.352	0.078	NS
Temperature	Relative humidity	-0.866	0.0001	***
Temperature	Wind speed	0.212	0.288	NS
Relative humidity	Wind speed	0.299	0.134	NS

NS, not significant.

*, significant at $P = 0.05$.

**, significant at $P = 0.01$.

***, significant at $P = 0.001$.

Table 2

Wind direction and condensation and freezing levels for the sampling dates

Parameter	Level (Mb)	10 September 1992		11 September 1992		30 September 1992		1 October 1992	
		06:00 h	18:00 h	06:00 h	18:00 h	06:00 h	18:00 h	06:00 h	18:00 h
Wind direction (°)	500	049	058	117	335	045	—	241	—
	600	052	—	146	345	058	—	021	—
	700	324	108	180	328	017	—	004	—
Condensation level (m)		2400	3300		3400	2700			
Freezing level (m)		4600	5000		4400	4600			

passively follow an 'ideal' aerobiological layer — higher temperatures and minimum relative humidity. They are 'supported' by a high wind speed layer, wind speed having a diluting effect on the spore density (Table 1).

Airborne pollen is much more complex (at least for the system studied). It is not well correlated with any ambient conditions, and has often a dichotomous behavior not seen in the average situation. It could be more a reflection of different pollen transport systems, governed by different laws.

On 10 September 1992, there was an absence of any regional transport, and Gramineae pollen was largely dominant, even if it was absent from local grass flowers along the transect. We believe that this pollen comes from long distance transport, and also travels with higher temperature and low relative humidity, and therefore shows high viability.

On 1 October 1992, Gramineae pollen is dominant only in the upper heights, with *Chenopodiaceae-Amaranthus* while *Fraxinus* and *Ephedra* pollen are found below 4200 m. We have therefore a hybrid situation, where viable and regional tree pollen is found below 4000 m, and viable but extra-regional weed pollen is found above 4200 m.

Pollen behavior seems therefore to be more a reflection of air mass movements, and source phenology, than just ambient conditions at the sampling site. It is also possible that the low level of pollen concentrations found (1/10 of the spore concentrations) is not sufficient for determining any significant correlation with ambient conditions.

4.2. Synoptic conditions

At the time of sampling, Popocatepetl was under the influence of tropical maritime air masses, tropical spells and convergence zones. Table 2 lists the dominant wind direction at different heights (Mb) on the sampling days, along with the condensation and freezing levels.

On 10 September 1992, cloudy sky and the presence of fog explain the high humidity level and low temperatures recorded (Fig. 6). Pollen transport in the regional layer is low probably because these conditions decrease both emission from Mexico Valley and

floatability of airborne pollen. In contrast, on 1 October 1992, clear sky allowed an increase in temperature and a decrease in relative humidity in this layer. Pollen viability seems to follow the same pattern, which therefore supports both its possible relationship with ambient conditions and the hypothesis of low correlation coefficients exclusively caused by low numbers.

On both days, local transport was present, by definition not influenced by regional conditions, a fact that is strengthened by the entomophily of most of the local flora. The high pollen viability in this layer on 10 September 1992 where ambient conditions are unfavorable, and its low viability on 1 October 1992, when they were favorable, could only be due to the proximity of the sampling site to the source.

Finally, the constant high viability and numbers of the long distance layer spora reflect the stability of this layer and its isolation from day to day processes.

5. Conclusions

By sequential and systematic sampling on an altitudinal cline, it was shown that three layers can be distinguished by the behavior of their airborne spora: a long distance transport layer, of stable and favorable characteristics; a local transport layer, not related to ambient conditions; and a regional transport layer, highly influenced by the environment.

Only fungal spores seem to be statistically correlated with specific ambient parameters, but this could be a reflection of their higher relative concentrations, on average 10 times those of pollen.

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