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Airborne pollen patterns in Mar del Plata atmosphere (Argentina) and its relationship with meteorological conditions

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Abstract This work is part of a series of aerobiological researches conducted in the city of Mar del Plata, Argentina. The annual, seasonal and daily features of the pollen cloud were analyzed over 2 years, together with the effects of the meteorological variables. Cupressaceae amounted to 75 and 54% of the annual total in each year, and it was analyzed separately due to its proven overrepresentation. Eighty-five pollen types were registered during the 2 years, bearing a similar annual pattern (more than 50% from August to November, December also being an important month). Arboreal pollen predominated between late winter and spring (61 and 49% of the annual total), while non-arboreal pollen did so from late spring to summer. The observed seasonality was significantly correlated with the monthly mean temperatures and associated with its effect on phenology. No significant differences along the day were detected between years and 50% of the daily total was recorded between 1000 and 1600 hours. The maximum concentration was registered at 1000 hours in spring and summer, but later in autumn and winter. Regarding the hourly scale, the significant correlation of total pollen with temperature and wind speed was positive, albeit negative with relative humidity. These effects are linked to airborne pollen release and transport. The role rainfall plays on airborne pollen is discussed. To interpret the results, it is important to consider the time scale at which the aerobiological phenomenon is analyzed.

Keywords Airborne pollen · Meteorology · Pollen pattern variability · Temporal scales

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1 Introduction

The aerobiological pathway mainly comprises three sequential stages from the releasing source to the impact: production, dispersal and deposition (Edmonds 1979). Each of them is linked to different biological phenomena (e.g., microsporegenesis, flowering, anthesis, pollination, and fertilization) that are governed by different meteorological conditions such as solar radiation, temperature, rainfall and wind speed, among others (Comtois and Sherknies 1987; Gioulekas et al. 2004).

Notwithstanding the foregoing, atmospheric factors can play different roles depending on the level at which the analysis is conducted. This is due to the fact that biological systems are fundamentally hierarchical in nature, and the patterns and ecological processes operate at different variation scales (Meyer et al. 1979; O'Neil et al. 1986). For instance, strong winds increase pollen release though they dilute pollen concentration in the air (Rodríguez-Rajo et al. 2003), and low temperatures result in high pollen production in early flowering trees (Latorre 1999c; Jato et al. 2002), yet they favor neither anthesis nor the maintenance of airborne pollen (Latorre et al. 2001). Once flowering is determined, on the basis of factors characterizing the taxon and previous seasonal climatic conditions, the amount of pollen produced is mature enough to be released into the atmosphere and dispersed by air masses. Anthesis and pollen release are influenced by the circadian patterns associated with air temperature, relative humidity and wind speed (Kasprzyk 2006). Pollen transport or dispersal is mainly affected by meteorological factors, among which temperature, rainfall and winds are the major concentration moderators. Yet the aerodynamic features of pollen grains, the characteristics of the source vegetation and their territorial distribution in relation to their proximity to the sampling stations, and the conditions characterizing the location, such as the presence of filters, whether natural or not, also play a part (Tauber 1967; Silva Palacios et al. 2007).

Therefore, restricting the study of the atmospheric pollen to just one interaction level would be inappropriate. This particular situation leads to the need to analyze the production and dispersion processes separately. To approach them, it is necessary (1) to analyze the number of total pollen grains produced as well as the climatic conditions corresponding to the period prior to flowering (production) (Latorre 1999a) and (2) to examine the number of atmospheric pollen grains and the prevailing meteorological conditions that could influence dispersion. This last aspect is the one covered in this work. Both analyses are relevant for the predictive models of future pollen release periods (Bianchi et al. 1992), in which it is also necessary to count on detailed information on (1) the activity of the pollen sources and (2) the distribution of such sources (Puppi Branzi and Zanotti 1989). For the location surveyed in this work, the first aspect specified above was covered by Latorre (1997), (1999a, b) and Latorre and Bianchi (1998), while the second was explored by Latorre and Bianchi (1997) and Latorre et al. (2001), in which vegetation representativeness in the atmospheric pollen spectrum was also established. The effect of atmospheric conditions on pollen capture in relation to the amount and types of pollen grains collected by different methods (impact, suction and deposition) had already been analyzed by Latorre et al. (2008) for this site.

This article sought to analyze the aspects related to pollen grains after being released into the air from their source of origin as well as to determine the main pollen types with which vegetation contributes to aerobiological registration. With this purpose in mind, the pollen-atmosphere system was approached and the concentration changes experienced at different temporal scales analyzed along two reproductive cycles. Moreover, the influence exerted by the meteorological factors in each of them was established.

2 Materials and methods

2.1 Environmental features

Mar del Plata city is located in the southeastern part of Buenos Aires province, Argentina, on the Argentine Sea shore corresponding to the Atlantic Ocean (latitude: 38°03′S, longitude: 57°33′W). The region climax vegetation (Pampean phytogeographic province, *sensu* Cabrera 1994) comprises a grass steppe bearing certain xerophyl features and corresponding, to a great extent, to the *Stipa* genus. Grass intermingles with terophyte and geophyte species, which flower at the start of spring, and reach their maximum development by the end of said season, concurrently with the dominant grass flowering period. At the start of summer, the grass begins to dry out and when autumn rains arrive, most bushes and dwarf shrubs (sub-shrubs) flower. The loose soils of the littoral shell ridges and slime dunes give place to the development of xerophyl forests of *Celtis tala* (Espinal phytogeographical province, Tala district; Cabrera 1994), which are located at more than 50 km away from the east of Mar del Plata city. Their herbaceous layer is sciophilous and *Bromus unioloides* predominate.

In the city as much as in the rural/natural environments, weed and adventitious species coexist. In the streets and public parks, *Prunus ceracifera* var. *athropurpurea* and *Lagerstroemia indica* dominate the site among entomophilous species; and *Fraxinus,* *Ulmus, Populus, Platanus, Acer, Callistemon, Betula, Cupressus, Salix and Cedrus* do so among anemophilous genera. Poaceae, Asteraceae, Chenopodiaceae, Apiaceae (mainly the invasive *Conium maculatum* weed during the whole year), Brassicaceae and Polygonaceae are the most frequently found herbaceous plants. A complete flowering calendar of the flora and potential pollen sources is available (Latorre 1999c).

2.2 Sampling features

The atmospheric pollen of Mar del Plata city was analyzed for 2 years between December 1992 and November 1993 and between March 1994 and February 1995; only summers were not consecutive. Pollen monitoring was interrupted for short periods of time: in 1993, from 27 to 31 July and from 27 to 30 November; and in 1994, from 1 to 5 August.

A Burkard (Hirst-type) aerobiological pollen sampler was used. It was placed 15 m high on one of the terraces of the University Complex premises at the Universidad Nacional de Mar del Plata, situated in the geographic city center.

2.3 Samples and counts

For the microscopic analysis, adhesive tapes and sample mounting were implemented in agreement with O'Rourke (1986) and Bianchi (1992).

The Papilionoideae (Fam. Fabaceae) taxon was considered herbaceous, taking into account that its presence in the vegetation surrounding the sampler is more abundant as weed or spontaneous vegetation than as ornamental trees in the city (Latorre and Bianchi 1997; Latorre et al. 2008). Nevertheless, *Stiphnolobium japonica* and *Gleditsia triacanthos* species may be found as well. *Corylus* and *Casuarina* were taken as a single taxon owing to the difficulty encountered when it came to differentiating between the pollen types. However, their flowering period does not overlap (Latorre 1999c), rendering it possible to ascribe to each of them the pollen registered.

Hourly counts were performed with transects perpendicular to the turning direction of the drum. The length of each transect equaled the width of the sampling tape and its width was 0.9 mm under the final magnification of 200×; then the effective sampling per transect accounted for 27 min. Twelve transects were analyzed on a daily basis (one every two even hours). This sampling intensity enables an unbiased estimate of the daily mean and a general pattern of the daily variation (Käpylä and Penttinen 1981).

The results of the pollen analysis are expressed as a function of the air volume suctioned by the sampler (pollen grains/m^3). The number of pollen grains registered per unit of time and air volume were calculated following the model proposed by O'Rourke (1986). Pollen concentrations were estimated for different intervals (hourly, daily, monthly or seasonal and annual). Pollen types were grouped in agreement with the lifestyle of the species comprising them; thus, total pollen (TP) was divided into arboreal pollen (AP) and non-arboreal or herbaceous pollen (NAP). TP includes all pollen types except Cupressaceae (explained later).

Pollen concentration data (p) do not yield a normal distribution. In general, a few days (or hours) yield high concentrations, while many days (or hours) yield low (or null) concentrations, thereby resembling much more a logarithmic distribution (Norris-Hill and Emberling 1990). Data normalization is a requisite to apply statistical tools, which presuppose linear associations between variables (Recio et al. 1996). To normalize data, the following transformation was employed in this work: ln $(p + 1)$.

2.4 Climatic features and meteorological data

The climatic classification corresponding to this region is humid/sub-humid and mesothermal with scarce or null water deficiency (Burgos and Vidal 1951). The data recorded during the last 50 years reveal that the mean annual temperature in this area is 13.7°C, the wind speed is 13 km/h, the relative humidity is 78%, and the rainfall is 784 mm per annum. With regard to wind direction, no significant prevalence of any of the cardinal points has been observed.

The meteorological data were gathered from a meteorological station situated next to the aerobiological sampler. The hourly record of temperature (°*T*), relative humidity (RH) and wind speed and direction (WS and WD, respectively) were obtained. The rainfall (Rf) records, instead, were provided by the station located in Mar del Plata airport, 8 km away from the pollen sampling point, which belongs to the National Meteorological Service and which also furnished the statistical data corresponding to the 1960–1980 period.

2.5 Data analysis

In order to examine pollen distribution during the day, the intradiurnal distribution index (IDI) was used as proposed by Trigo et al. (1997). IDI is calculated as follows:

$$\mathrm{IDI} = (M - m)/T$$

where M is the maximum value obtained at a certain interval (in this case hourly), m is the minimum and T is the total. Along these lines, high values (>0.20) indicate highly pronounced peaks of maximum concentration; values ranging from 0.10 to 0.20 designate pollen with less pronounced peaks, and values below 0.10, very flat curves.

Rainfall days were also included in the calculations to account for the variability inherent to this kind of data.

Non-parametric correlation coefficients (r_s) from hourly, daily and monthly data were calculated (Spearman), and the Student's *t*-test was employed to evaluate differences between sample means (Sokal and Rholf 1979).

To detect whether the differences in the atmospheric parameters correlated with the variations in pollen concentration in the atmosphere during the period of the year when it dominates and to evaluate the way in which said parameters influenced pollen transport, comparison of means and variances test, analysis of linear correlation (r), stepwise multiple linear regression (Sokal and Rholf 1979) and cluster analysis (Ward's method and the squared Euclidean distances) were jointly applied to daily/hourly pollen and meteorological data.

3 Results

3.1 Annual pattern

During a 2-year period of atmospheric sampling in Mar del Plata city, 85 pollen types were registered (53 corresponding to trees and 32 to herbs), out of which 61 were detected in both years (Table 1). In 1992/1993, nine exclusive types of pollen were identified, while in 1994/1995, fifteen were identified. Save for *Ginkgo* (amounting to 12 p/m^3 registered in 16 days), all the other 1-year exclusive pollen types were found at very low concentrations and frequency. In the special case of *Ginkgo*, the first pollination of young trees in the close proximity of the sampling stations occurred in 1994.

Cupressaceae amounted to 75 and 54% in each year. Given the fact that the high concentration detected obscures the description of the general pollen pattern (Latorre 1993), this taxon was excluded from the subsequent analyses and considered separately. In accordance with said adjustments, pollen index of TP accounted for 6,927 and 6,149 in 1992/1993 and 1994/1995, respectively.

Annual pattern of TP was similar over the 2 years, there existing a significant correlation between the monthly totals ($r_s = 0.80$, $P = 0.0016$). The smallest concentrations were recorded between May and July (less than 5% of annual total), although the percentage of registered pollen did not exceed 6% in any month between January and April. The maximum concentrations were recorded between August and November (with more than 50% of annual pollen) in both years. December could also be considered of relative relevance. In 1993, such concentration was recorded in September, while in 1994 in November (with 25% of annual TP in each of these 2 months) (Fig. 1).

Some differences in concentration were detected between both years during the August to November time period. Nonetheless, the most important difference (out of the confidence interval of 95%) was registered in November, the concentration recorded in 1994 being fourfold greater than the concentration corresponding to the same month in 1993. Additionally, it should be highlighted that the difference in November follows the opposite direction if compared to that between years corresponding to August, September and October, in which the concentration in 1993 was greater than in 1994 (Fig. 1).

3.2 Seasonal pattern

The 61% annual TP recorded in 1992/1993 and the 49% in 1994/1995 were in accordance with AP. The percentages of each pollen group indicate that the annual spectrum is shared by AP and NAP in relatively similar proportions over the 2 years. Even though 1,200 more of AP were registered during

Table 1 Atmospheric pollen types in Mar del Plata city during the analyzed periods: 12/1992–11/1993 and 3/1994–2/1995

Acer	Monocotyledoneae inaperturate[e]	
Aesculus	Moraceae[f]	
Alnus	*Myoporum*	**1992/1993**
Ambrosia	*Myriophyllum*	*Ailanthus*
Apiaceae	Myrtaceae	*Bougainvillea*
Artemisia	*Nothofagus*	*Chorisia*
Asteraceae Asteroideae[a]	*Olea*	*Dichondra*
Asteraceae Cichioriodeae	*Pinaceae*[g]	Eleagnaceae
Betula	*Plantago*	*Lomatia*
Brassicaceae	*Platanus*	*Oxalis*
Caryophyllaceae	Poaceae	*Sambucus*
Castanea	Políada de Mimosoidea	*Trapaeolum*
Casuarina	Poligonaceae	
Celtis[b]	*Populus*	
Chenopodiineae	*Prosopis*	**1994/1995**
Citrus	*Prunus*	*A. campestris*
Corylus	*Ricinus*	*Araucaria*
Cupressaceae	Rosaceae[h]	*Carya*
Cyperaceae	*Rumex*	Cucurbitaceae
Echium	*Quercus robur*	*Datura*
Ephedra	*Quercus ilex*	*Dodonea*
Euphorbiaceae	*Viburnum*	Geraniaceae
Fabaceae Papilionoidea[d]	*Salix*	*Ginkgo*
Fagus	*Schinus*	*Ligustrum*
Fraxinus[c]	Solanaceae	*Phytolacca dioica*
Grevilea	*Tilia*	Ranunculaceae
Juglans	*Typha*	Rutaceae[i]
Labiatae	*Ulmus*	*Sapium*
Lauraceae	Urticaceae	Scrophulariaceae
Liquidambar	Verbenaceae	Mimosoideae tetrad
Monocotyledoneae monocolpada		

The last column lists exclusive pollen types registered only in one period

[a] Includes *Leuceria* type, *Xantium* type, *Mutisia* type

[b] Includes *C. australis*, *C. tala*

[c] Includes *F. excelsior*, *F. americana*, *F. ornus*

[d] Includes *Adesmia* type, *Gleditsia* type, *Trifolium* type, *Vicia* type, *Stiphnolobium* type

[e] Includes Juncaceae, *Triglochin* type

[f] Includes *Maclura*

[g] Includes *Cedrus*, *Pinus*

[h] Includes *Rosa* type, *Franseria* type

[i] Includes *Fagara* type

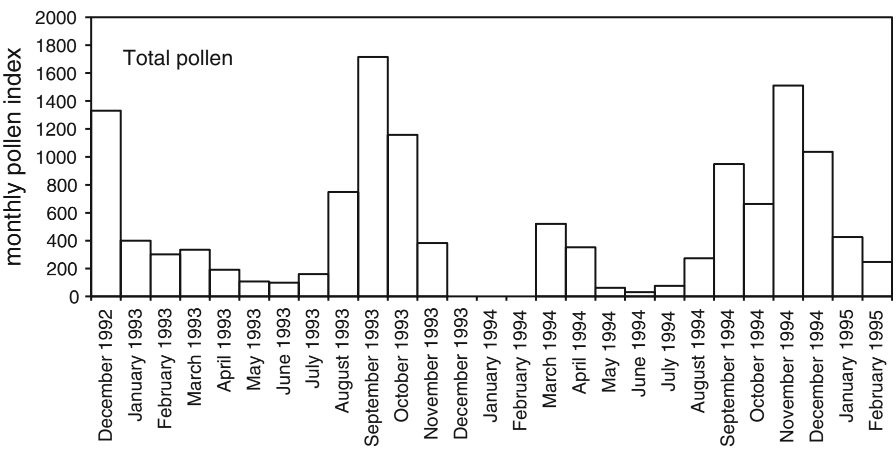

Fig. 1 Monthly sums of total pollen (excluding Cupressaceae) for every period analyzed (December 1992 to November 1993 and March 1994 to February 1995)

1992/1993 in relation to 1994/1995, NAP difference between years, though smaller, was the opposite, with 412 more in 1994/1995. In general, AP dominates the atmosphere in spring and NAP does so in summer (Table 2).

While TP concentration reached its maximum value between August and December, the composition of pollen types in this period displays a successive dominance pattern between AP and NAP. During the 2 years, nearly 80% of the annual AP was registered from August to November, while December was dominated by NAP. During the months of low AP contribution (December to July), a small increase was detected only in April (Fig. 2).

The greatest differences registered in November are attributed as much to AP as to NAP. Concentrations during this month were higher in 1994 (500 p/m^3 more AP and 600 p/m^3 more NAP). The differences of opposite sense (higher concentrations in 1993) recorded between August and October are only ascribed to AP, of which, in September only, 736 p/m^3 more were registered in the first year under analysis (Fig. 2).

3.3 Daily pattern

The maximum concentration of Cupressaceae was registered at H12, with a very pronounced peak (IDI > 0.2). The difference between this hour and the other ones becomes more notorious if included within TP, which would mask the daily TP trend.

Except for Cupressaceae, the daily TP pattern was similar each year with a highly positive and significant correlation between the registered concentrations over the years in each 2-hour interval ($r_s = 0.94$, $P = 0.000007$). The maximum value was registered at H10 and accounted for 13 and 14% of the daily total of each annual period, i.e., 1992–1993 and 1993–1994. The largest amount of atmospheric pollen concentrated between H10 and H16 (50% of the daily total along the year). The average IDI was 0.122 (between

Table 2 Seasonal distribution of atmospheric pollen discriminated according to life-forms and expressed as a percentage of the annual total

		Summer	Autumn	Winter	Spring	Annual total
Arboreal pollen	1992/1993	3	4	14	40	4,201
	1994/1995	4	5	6	34	3,010
Herbaceous pollen	1992/1993	26	5	1	7	2,726
	1994/1995	24	9	1	17	3,139

The last column lists the total concentration corresponding to each period

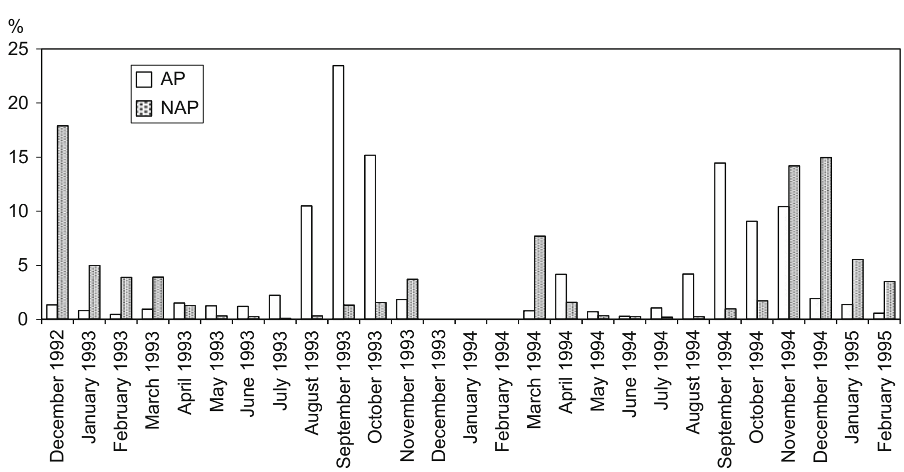

Fig. 2 Monthly percentage of arboreal pollen (AP; excluding Cupressacea) and non-arboreal pollen (NAP) with respect to the annual total of the periods analyzed (1992/1993 and 1994/1995)

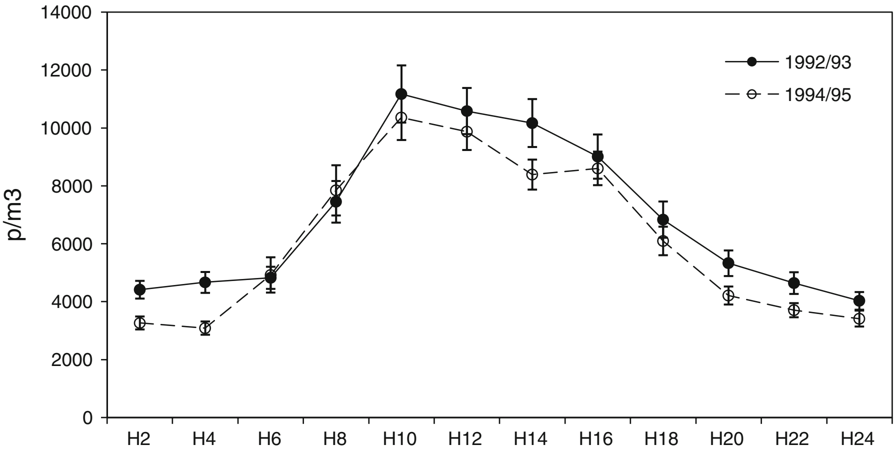

Fig. 3 Hourly concentration of total pollen for every period analyzed

0.098 and 0.146), thereby demonstrating that the maximum concentration is not very pronounced during the day. The minimum TP concentrations were registered between H20 of 1 day and H6 of the following day. At H8 and H18, the daily TP trend (turning point) changed. This accounted for the hours of intermediate concentrations.

The atmospheric status also seems to vary over the year. The analysis of hourly concentrations in the different months enabled to determine that maximum concentrations were registered at different hours. For both years, the highest concentrations in spring and summer were observed at H10, the H8–H16 interval bearing relative importance; February, in turn, yielded the highest IDI. On the other hand, in autumn the maximum value was recorded at H12 and in winter at H14, though these maximum values were not as pronounced as those in spring and summer, since between H10 and H16, TP concentrations were relatively high. In spite of the foregoing, in every month, the intradiurnal distribution index remained within the 0.1–0.2 interval, thus indicating that there is not a certain hour at which almost all the released pollen concentrates.

3.4 Relationship between pollen concentration and meteorological variables

The annual mean values of T°C and RH mirrored those of the last 10-year statistical mean data. T°C yields an annual cycle of minimum values always recorded in July (between 7 and 8°C on average), and with the warmest values recorded in January (20–21°C). No significant differences were observed in the daily values of this variable between both years ($t = 1.213$; $P = 0.226$). The RH varies in a narrow range of high values. Despite the fact that the mean values were significantly different between years ($t = 5.174$, $P = 0.0000003$), the daily data did not differ significantly in relation to the corresponding mean ($F = 1.080$, $P = 0.477$).

Conversely, WS analyzed was much smaller during these 2 years if compared to the statistics. Nonetheless, it should be borne in mind that the location of the meteorological stations differed. The statistical data correspond to the sub-urban area, while the one used in this work does to the urban area. Moreover, this variable varies greatly even on consecutive days ($t = -16.59$, $P < 0.0000001$), and so the annual mean value seems not to be indicative enough. Days with very high speeds, especially during the second year analyzed, could be related to atmospheric phenomena of great scale (Fig. 4). Northern and northwestern winds frequencies in the first and second year superseded the National Meteorological Service statistics for the last 10 years, thereby yielding a rather isomorphic wind rose for Mar del Plata area (Fig. 5).

Total Rf values were similar during the years with 829 and 852 mm, respectively, and slightly lower with respect to the statistics: 81–90 (921 mm). Generally speaking, Rf follows the general pattern described for this region, with minimum values recorded in winter. No significant differences were observed regarding the

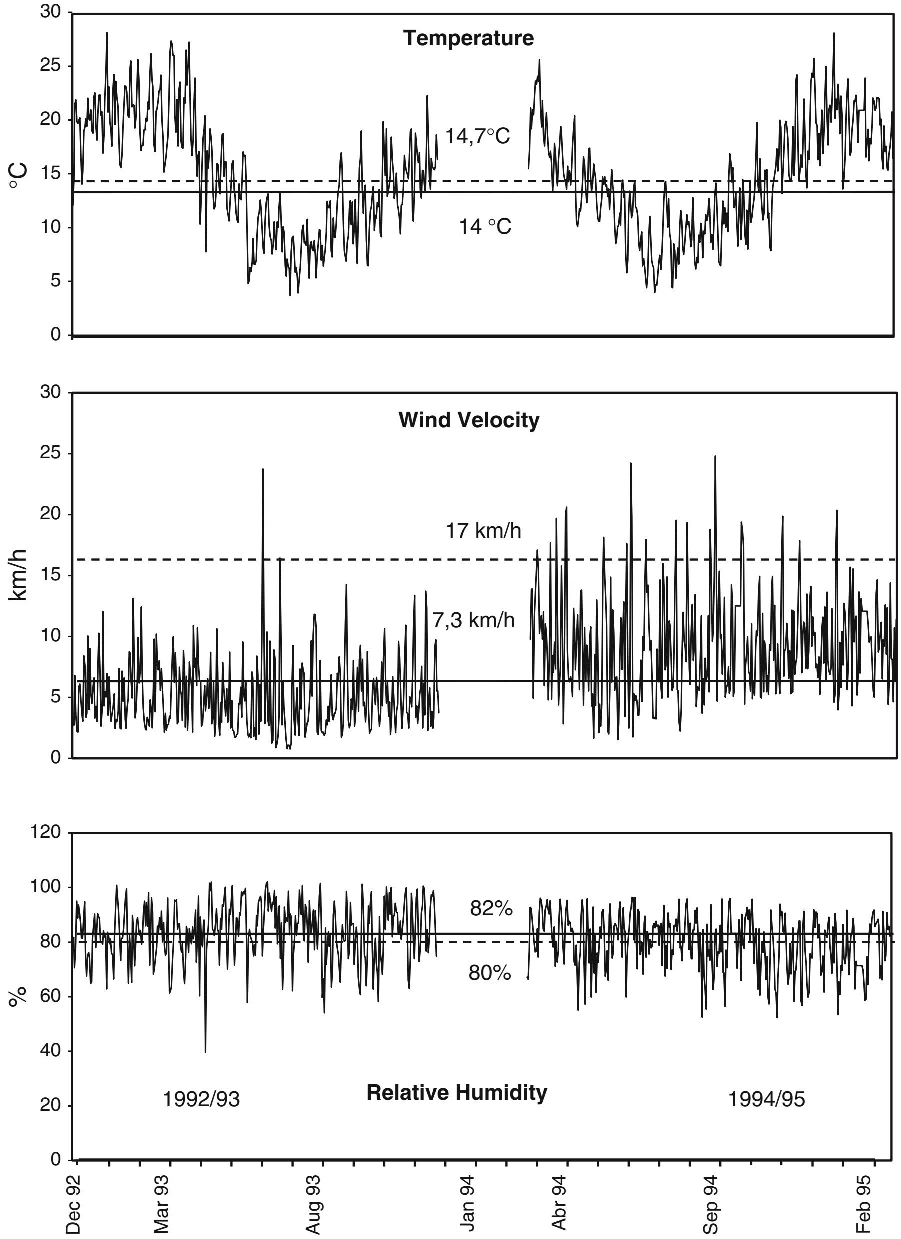

Fig. 4 Daily data of meteorological variables: temperature, wind speed and relative humidity, taken at the same site of pollen sampling. The *horizontal lines* indicate the mean values of the 2 years surveyed and the *dotted line* indicates the 81–90 average of the National Meteorological Service

daily data of this variable between years ($t = 0.192$; $P = 0.848$).

Rainfall values were always positively correlated with RH ($r_{1993} = 0.189$, $P < 0.0001$; $r_{1994} = 0.168$, $P = 0.002$); Rf days yielded greater RH values. Only in the first year, the daily T°C proved to be associated with the average daily WS ($r = 0.165$, $P = 0.002$).

Figure 6 portrays high values of Rf between March and June 1993, which is consistent with the scarce number of atmospheric TP grains. Conversely, in the second half of this year, the scarce rainfall is in accordance with the high pollen concentrations in the air, except in November. The correlations between daily data are indicative of the negative effect rains

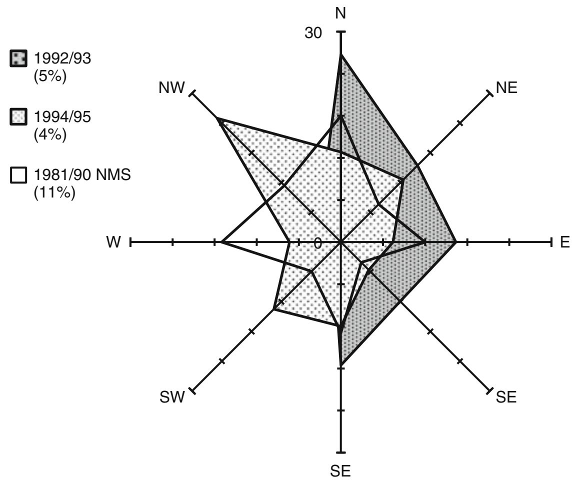

Fig. 5 Frequency (in percentage) of winds in each direction. Between parentheses, the relative proportion of hours without wind corresponding to each interval

have on arboreal pollen ($r = -0.137$, $P = 0.10$), although if November is analyzed in particular, this association is not significant ($r = 0.082$, $P = 0.709$).

In the second annual period, the smaller atmospheric concentration of AP in September could be ascribed, in principle, to high values of Rf. Besides abundant Rf recorded in October seems to have led to a decrease in AP. On the other hand, the high concentration in November 1994 was associated with a near absence of Rf. However, the correlation between AP and Rf was not significant ($r = -0.211$, $P = 0.696$), and in particular, it was only marginally significant and negative for September ($r = -0.412$, $P = 0.051$) and non-significant for October (Fig. 6).

The correlations between daily Rf and NAP were not significant for any of the 2 years. Nevertheless, there was a strong positive correlation between NAP and T°C ($r_{1992/1993} = 0.745$, $r_{1994/1995} = 0.762$; $P < 0.001$) and, to a lesser extent, a negative correlation with RH ($r_{1992/1993} = -0.224$, $r_{1994/1995} = -0.207$; $P < 0.0001$). With these two atmospheric variables, nearly 60% of the information could be reconstructed. The resulting regression equation is as follows: $\mathrm{NAP}_{1992/1993} = 0.778 + 0.148\mathrm{T°C} - 0.019\mathrm{RH}$, $r = 0.767$, $R^2 = 59\%$ and $\mathrm{NAP}_{1994/1995} = 0.512 + 0.184\mathrm{T°C} - 0.022\mathrm{RH}$, $r = 0.782$, $R^2 = 61\%$, $P < 0.0000001$ for both cases. Even though NAP was also positively correlated with WS ($r = 0.152$, $P = 0.004$) in 1993, the association between this meteorological variable and T°C ($r = 0.165$, $P = 0.002$), and the highest correlation value of T°C with NAP regarding WS, leaves WS out of the stepwise regression equation as an explanatory variable.

On the other hand, and contrarily to NAP, AP concentration was negatively correlated with temperature, though only significantly in 1993 ($r = -0.260$, $P < 0.0001$). With regard to RH, the correlation was negative ($r_{1992/1993} = -0.218$ and $r_{1994/1995} = -0.207$, $P < 0.0001$) and, in this case, just as the association with NAP. Nonetheless, the resulting regression equation would not suffice to explain the increase in AP atmospheric concentration based on these atmospheric variables at a daily scale, since R^2 reaches 8.5% on the average.

The TP pattern along the day was similar over the years (Fig. 3), and in accordance with the hourly variations of T°C, RH and WS. The pattern of these meteorological variables was also similar between years, recording maximum T°C and WS values and minimum RH values at H14. On average, the differences between years did not exceed 0.6°C and 4% of RH. Despite the fact that WS was greater in the whole second period, hourly variations were similar. The values between H10 and H18 were always greater than the daily mean for the 2 years. Pollen concentration was greater than the daily mean from H8 to H18. The greatest differences were appreciated between H8 and H10 and between H16 and H18, when changes in the daily trend of all the variables (meteorological and pollen) took place (Fig. 7). In this way, when analyzing the pollen and meteorological variables applying the cluster technique along the day, it ended up divided into two periods: day and night (Fig. 8).

The three meteorological variables were correlated with TP. When all the hours comprising the 2 years were considered, the correlation coefficients were the following: $r_{T°\mathrm{C}} = 0.347$, $r_{\mathrm{RH}} = -0.313$, $r_{\mathrm{WS}} = 0.137$; $P < 0.001$.

4 Discussion

4.1 Annual pattern

The pollen spectrum of Mar del Plata city is substantially diverse: 70 and 76 different taxa were analyzed each year, respectively, corresponding to 50

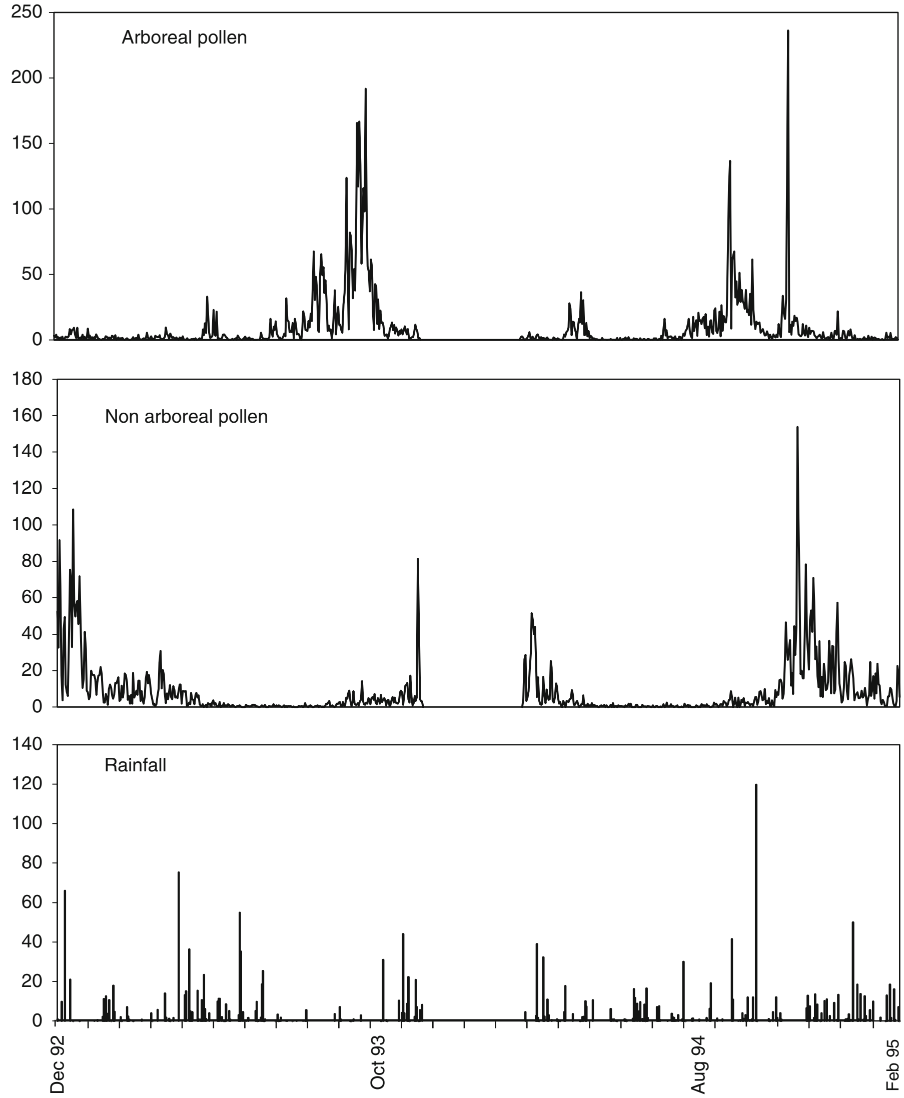

Fig. 6 Daily concentration of arboreal pollen (excluding Cupressaceae) and herbaceous pollen and daily rainfall during the periods analyzed

families. The large number of pollen types reflects the complexity of the urban vegetation, which features a great variability of species, as already demonstrated by Bianchi (1992) and Latorre and Pérez (1997) for this location. Similar results were obtained in other cities in Argentina: La Plata (Nitiu 2006) with 79 pollen types, Diamante (Latorre and Caccavari 2007) with 69, Buenos Aires (Nitiu et al. 2003) with 54, and Bariloche (Bianchi and Olabuenaga 2006) with 66. Even though these cities have a temperate climate, they are placed between 52 and 1,800 km apart, and the native vegetation of their influence areas differ notoriously, corresponding to different phytogeographic provinces (Cabrera 1994). In spite of this, the historical trend of the urban trees in these Argentine cities is similar, as well as the preference for ornamental plants of European origin. Only Bahía Blanca (Murray et al. 2002) seems to have a remarkably smaller diversity (43 taxa). In this particular case, mean annual rainfall is lower (614 mm) if compared to the cities above named, and this could exert an effect on its flora composition. In neighboring countries, diversity is dependant on the cities, and differences probably arise from multiple factors. In Brazil (Caxias do Sul; Vergamini et al. 2006) 29 pollen types were recognized, in Uruguay (Montevideo; Tejera and Beri 2005) 76, and in Chile (Santiago; Rojas Villegas and Roure Nolla

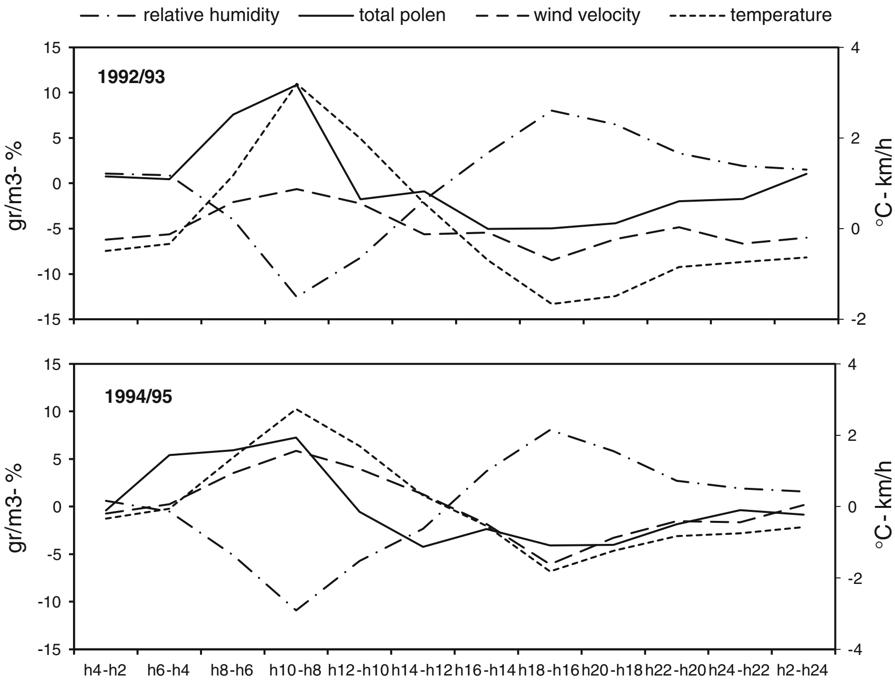

Fig. 7 Differences between consecutive hours of total pollen and meteorological variables for every period

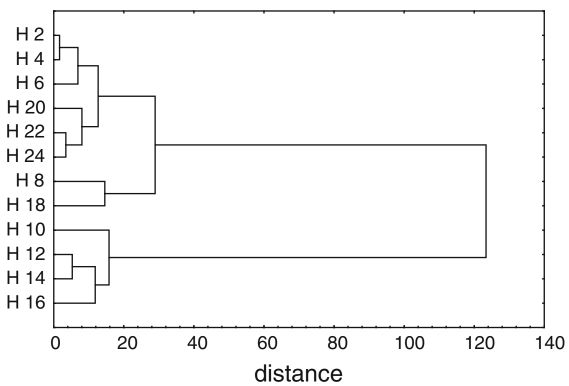

Fig. 8 Cluster analysis of hours according to pollen (total pollen) and meteorological (temperature, relative humidity and wind speed) variables of the two periods

2001) 103. In Brazil and Chile, tree pollen predominates, whereas in Uruguay herb pollen abounds, such a fact being basically connected with the environment and the natural vegetation of the different phytogeographic regions.

Cupressaceae pollen (more than 50% of the total registered grains) mainly corresponds to the *Cupressus* genus, the most abundant at this site and which represents as much as 92%. The proximity of several sources (15 m) to the sampler in conjunction with the copious productivity and favorable aerodynamic features for airborne grains would explain the high atmospheric concentration values detected (Meiffren 1988). In Italy, Cupressaceae pollen also represents more than 50% of the annual total (Zerboni et al. 1991). In Italy as much as in Spain, it constitutes the most important winter taxon (Galán et al. 1998). However, in those cases, source proximity would not be involved, since the contribution derives from adjacent forests. According to previous studies conducted at the same site in Mar del Plata, very high concentrations were observed in winter (Bianchi 1994). All the above mentioned points toward an overrepresentation of *Cupressus*, which renders it necessary to analyze it separately, as including *Cupressus* in the analysis tends to bias the spectrum data.

The great interannual difference as regards *Cupressus* concentration (much greater in 1993 that in 1994) is consistent with that of Spain, recorded during the same years. The winter months of 1993, prior to pollination, were colder and relatively drier and associated with the difference in productivity (Galán et al. 1998). The relevance of its study in the Old World lies in its allergenicity, responsible for the largest incidence of winter pollinosis. In Mar del Plata, pollinosis incidence is unknown.

4.2 Seasonal pattern

A pollen pattern has been regularly noticed over the analyzed years. Concentration increases by the end of the winter and reaches its peak in spring (early or late spring depending on the year). In summer, the concentration begins to diminish since the anemophilous trees in bloom are scarce, although the pollination of herbaceous species remains significant until March. The minimum concentration occurs in autumn and early winter when there are practically no trees in bloom and herbaceous species remain in vegetative state (in many cases like rhizomes), or as seeds (Latorre 1999c).

Pollen concentrations correspondence with herbaceous and arboreal species flowering reflects the structure of the pollen spectrum related to the reproductive phases of these life-forms, which are referred to as arboreal and non-arboreal pollen, respectively. Along these lines, the structure of Mar del Plata spectrum can be characterized by the presence of two seasons: (1) a season with AP prevalence (late winter–spring), which reaches its peak in September, and (2) a season with NAP prevalence (late spring–summer), whose highest concentration occurs in December when grasses, sedges and plantains, among others, are in bloom (Latorre 1999c). Each of them correlates with the monthly mean temperature, i.e., AP with the low temperatures of late winter and early spring, and NAP with the highest temperatures of the year. This variable is indicative of the climatic seasonality of the region and seems to arise in an indirect way from the synchronization of vegetables physiologic answer to the atmospheric time conditions that favor flowering, and not from a direct effect on the airborne grains during their transport by air masses.

Arboreal pollen types, in general, were more productive in 1992/1993. On the contrary, herbaceous pollen types were so in 1994/1995, although the differences in pollen of the most abundant taxon (Poaceae) were below 20 p/m3 (Latorre 1999c). This would partially explain the difference of relative importance of the months between years with respect to pollen concentration (August, September and October were important in 1993 and November in 1994). Arboreal species mainly flower in late winter–early spring, whereas herbaceous species do so in late spring–summer (Latorre 1999c). The exceptional increase in tree pollen in April, especially in 1994, is explained by the blooming of Cedrus and Casuarina. The reproductive requirements of autumn flowering species are different from that of the trees flowering in winter–spring (Latorre 1999c).

The monthly differences between years were observed between September (greatest concentration in 1993) and November (greatest concentration in 1994). This could partly result from the different representations of the two *Quercus* species: *Q. robur* (greatest concentration in 1993 and its main pollination during September) and *Q. ilex* (much higher concentration in 1994 and during November) (Latorre 1999b).

4.3 Daily pattern

With regard to Cupressaceae, a highly pronounced maximum value was observed at H12 when the largest proportion of daily pollen concentrated. The concentration peak was delayed with respect to the rest of the taxa because these plants flower in August, the second coldest month of the year; and the temperature needed for anther aperture and pollen release is reached long after the sun comes out. This narrow and pronounced peak would indicate that there existed several pollen sources placed at a very short distance from the sampler. Moreover, it implies that the pollen of this family belongs to the *Cupressus* genus, as it comprises the most abundant source and is placed nearest the sampler. This all comes to confirm the hypothesis that *Cupressus* overrepresentation in this spectrum is due to its close proximity to the sampler.

As for the remaining taxa, the daily concentration trend follows the same pattern every year yielding higher concentrations between the last hours of the morning and the first hours of the afternoon, just as at other sites (Galán et al. 1991). The maximum values were registered at H10 and they were not pronounced, being coherent with the multi-taxa origin of total pollen (Trigo et al. 1997). Low concentrations were observed at dark hours (Berggren et al. 1995). During such hours, unfavorable meteorological conditions for dispersal were registered, such as high relative humidity and low wind speed, apart from low temperature. The atmospheric status differed during the day, thereby favoring a greater proportion of airborne grains during the daylight hours.

In the seasons in which the highest temperatures are registered (spring and summer), the highest concentrations occur early in the morning, yet when temperature goes down (autumn and winter), the highest concentrations are registered after midday. This seems to be strongly related to the circadian pattern of temperature (warm during daylight hours) as well as to the associated variables like wind speed and RH (greater speeds and lower humidity during daylight hours). The values of these variables also change on a seasonal basis along the year. A study undertaken by Pérez et al. (2003) at the same site but in different years and contemplating just NAP showed a daily trend of high concentration during daylight hours, when instability and convective movements prevailed, and low concentrations at night, when meteorological conditions favored the development of a stable stratified layer. The daily pattern variation over the year can also be ascribed to the fact that pollen types contributing to most part of the spectrum vary over the year depending on their flowering period. According to Trigo et al. (1997), the pattern of daily variation depends, on the one hand, on the distance between the pollen source and the sampler, and on the other hand, on the number of species contributing to such pollen type. Therefore, not only should the way the atmosphere state varies along the day be analyzed, but also the composition of the pollen cloud over the year, keeping in mind the abundance and location of the species that contribute the most (Latorre et al. 2001).

4.4 Relationship between pollen concentration and meteorological variables

The fact that rainfall reduces the number of pollen grains in the air is very well known (Norris-Hill and Emberling 1993; Jato et al. 2002). However, if we compare different reproductive cycles, it should be considered that lower concentrations of pollen could result so much from the rainfall washing out of the atmosphere as from the lack of relevant flowering, which would lead to relative low pollen productivity. Also, if the number of rainy days during the highest concentration were scarce, the negative influence would not be evidenced in the atmospheric pollen (Recio et al. 1997).

The negative correlation detected in 1993 between Rf and AP would not be confirmative of the atmospheric "washout" effect. Trees begin to flower in the second half of the year coinciding with a relatively free period of Rf. Only in November, when high concentrations of atmospheric AP are expected to exist, Rf values were considerable albeit their effect was not significant. This supports the hypothesis of smaller productivity in 1993 regarding trees that pollinate in November (*Q. ilex* and *C. tala*). This could result from the fact that the species of late flowering in spring demand different prior climatic-seasonal reproductive requirements, or a reproductive cyclic rhythm (biannual) independent of the climatic conditions (Emberlin et al. 1993). These patterns were observed in both taxa, i.e., in *Quercus* (Jäger et al. 1991; Emberlin et al. 1990, 1993; and specifically in relation to *Q. ilex*: Jato et al. 2007) and in *Celtis* (Cadman et al. 1994).

Even though, in principle, it seems that Rf values could have affected concentration in 1994 during the most important AP month, i.e., September, and so favored the high concentration registered in November with its absence, the results derived do not allow us to confirm such a hypothesis. The differential productivity of the tree species between years (greater in 1993) constitutes the strongest hypothesis (Latorre 1999a, b) about low pollen values during the second year, although it does not refute that rainfall could have played a role. To find further explanations, it would be appropriate determining its influence on the different species and its distribution along the day. Rainfall is a complex phenomenon acting at different scales. Its influence is attributed not only to intensity, duration or drop/pollen size but also to the time of the day when it occurs. Hence, if rain falls at the end of the day, it would probably not affect the concentration of pollen emitted in the morning or midday but could influence the transport from distant sources.

With regard to NAP, concentration seems not to be influenced by the rainfall depressor effect at the scale analyzed (non-significant correlations). NAP presence seems to be mainly determined by the high T°C and low RH. According to Trigo et al. (1996), this is best explained by the physiologic effects of T°C summation on herbaceous plants growth and reproduction, rather than by the instantaneous effects of the atmospheric variables on airborne grains.

AP had a negative correlation with *T*°C, significant in 1993 and non-significant in 1994. This may suggest that temperature effect is on the floral phenology, since trees begin to flower at the end of the winter with low temperatures. Evidently, the analysis scale is extremely important when it comes to interpreting the results. At a seasonal scale, the associations between pollen concentration and atmospheric variables are not related to the direct effect on airborne particles, but rather they result from the cumulative effects over time on plants phenology. Conversely, during the day, as atmospheric conditions change, both the anthesis and the permanency of the already released grains in the atmosphere are directly affected by meteorological variables that affect the air movements and the atmospheric features. Bianchi (1994) considers that the non-significant association of pollen concentration, especially with RH and WS does not denote a lack of relationship between these variables, but rather that the weekly scale considered does not reach any explanatory value; it only manifests at a smaller temporal scale (hourly). As stated by Moreno-Grau et al. (1998), hourly data should be used, as daily averages can distort the real effects.

The total pollen concentration yields a daily variation pattern of high concentration during the day and low concentration at night. Temperature rise and relative humidity fall favor not only anthesis and anthers dehiscence (Recio et al. 1997) but also pollen permanency in the air (O'Rourke 1986). The increase in wind speed results in atmospheric turbulence (unstable conditions) and in pollen release into the atmosphere and transport (Käpylä 1984). The proportion of the pollen concentration variability explained by the atmospheric variables is always low as its effects are very complex (Hart et al. 1994).

At H8 and H18, changes took place in the daily trend of both TP (with intermediate concentrations) and the meteorological variables. The variations evinced in the predominant wind direction during the day explain the sea breeze system (Bianchi 1992). This effect has been verified only for spring and early autumn and particularly examined for Poaceae, there existing a pollen re-entrainment brought about by air recirculation starting from H_2O (Gassmann et al. 2002).

5 Conclusions

The pollen-meteorological variables relationship analyzed at an intradiurnal hourly scale is strongly related to the dynamics of the pollen cloud modifying the atmospheric concentration. On the other hand, at a larger scale (seasonal–annual), and as it was previously found, the main effects are evinced on the phenology of the source species, and therefore their influence is indirect.

Other particular conclusions worth mentioning are:

- The total concentration of atmospheric pollen in Mar del Plata was similar during the years analyzed and its composition was diverse.
- *Cupressus* is overrepresented in this atmospheric spectrum.
- The highest pollen concentration takes place between late winter and spring. In summer, it is low and the minimum concentration is registered in autumn and early winter, as there are practically no plants in bloom contributing with pollen.
- AP is mainly registered during spring and NAP during summer.
- Highest daily concentrations of pollen are recorded during daylight hours (between H10 and H16) in coincidence with results found in other years for the same area, whereas smaller concentrations are registered during the night. This can be ascribed to the circadian pattern of air temperature as well as to the associated variables such as relative humidity and wind speed (the former being lower and the latter higher when the high temperatures of the day are recorded).
- The effect of rainfall on pollen concentration is not clear. Further analysis would be needed for individual pollen taxa and at the hourly time scale.

Indeed, this is worthy of further study over time and in the same location so as to reach a more refined generalization of the conclusions drawn.

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