Int J Biometeorol (2001) 45:124–132

ORIGINAL ARTICLE

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Predicting days of high allergenic risk during *Betula* pollination using weather types

Received: 12 December 2000 / Revised: 24 April 2001 / Accepted: 9 May 2001

Abstract The aim of this study was to build up a picture of the influence of meteorological conditions on pollen and pollinosis, taking account of weather types, pollen concentrations in the air and pollinosis symptoms, with the aim of preventing allergic responses. The study took place in Burgundy from 1996 to 1998, during the pollination of the birch (*Betula*), which is the most important arborean allergen in this region. We used daily pollen data from four Hirst volumetric traps, identified weather types by Bénichou's classification, and obtained data on the occurrence of rhinitis, conjunctivitis, asthma and coughing from a sample of 100 patients. These data were analysed by multiple-component analysis. The results show that pollen dispersal is favoured by windy conditions, low relative humidity, precipitation below 2 mm and temperatures above 6°C. Such weather also favours pollinosis, but other particular meteorological situations, even if they do not assist pollen dispersal, can act directly on the development of symptoms: a decrease of temperature (3°C) led to the development of rhinitis and conjunctivitis, while strong winds were associated with many cases of conjunctivitis and asthma, owing to the irritant effect of cold or wind; asthma was favoured by temperature inversions with fog, probably because such weather corresponds to high levels of pollution, which act on bronchial hyperreactivity. Because the weather types favouring pollination and pollinosis are predicted by the meteorological office, this can constitute a tool for reducing the effect of high-risk allergenic days.

Keywords Allergenic risk · Weather types · *Betula* pollen · Pollinosis

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Introduction

The influence of weather on pollinosis has long been suspected (Dingle 1955) and meteorological conditions are known to act at two levels: indirectly, influencing the development of allergens (Pehkonen and Rantio-Lehtimäki 1994), and directly on the bronchial contraction in asthma or by irritating the nasal and ocular mucous. Indeed, allergic people have very reactive respiratory mucous, on which non-allergic factors, such as meteorological conditions or pollution, can act in the same way as allergic factors (Frankland 1989). Thus a sudden fall in temperature accompanied by strong winds (Laaidi and Besancenot 2000) or thunderstorms (Newson et al. 1998) favour asthma crisis, while sudden changes of atmospheric pressure and temperature induce reactional, circulatory and secretory modifications on the mucous membranes, and then the periodical triggering of rhinitis (Guerrier and Sultana 1974).

A meteorological factor rarely intervenes alone but acts mostly in synergy with others. Thus some authors (Peyre et al. 1979) have shown that it is difficult to identify correlations between asthma crisis and an isolated meteorological factor, but that the path of fronts is much more conclusive, suggesting that the study of asthma morbidity should be made with reference to the larger meteorological scale and by integrating diverse parameters.

In order to build-up a comprehensive view of the influences of meteorological conditions on pollen and pollinosis, we took account of weather types, which were correlated, by multiple-component analysis, to the pollen concentrations in the air and to pollinosis symptoms, with the aim of preventing allergic responses.

Materials and methods

This study took place in Burgundy (France) from 1996 to 1998, during birch (*Betula*) pollination, as the birch is an allergenic taxa responsible for 40% of positive prick tests among our patients.

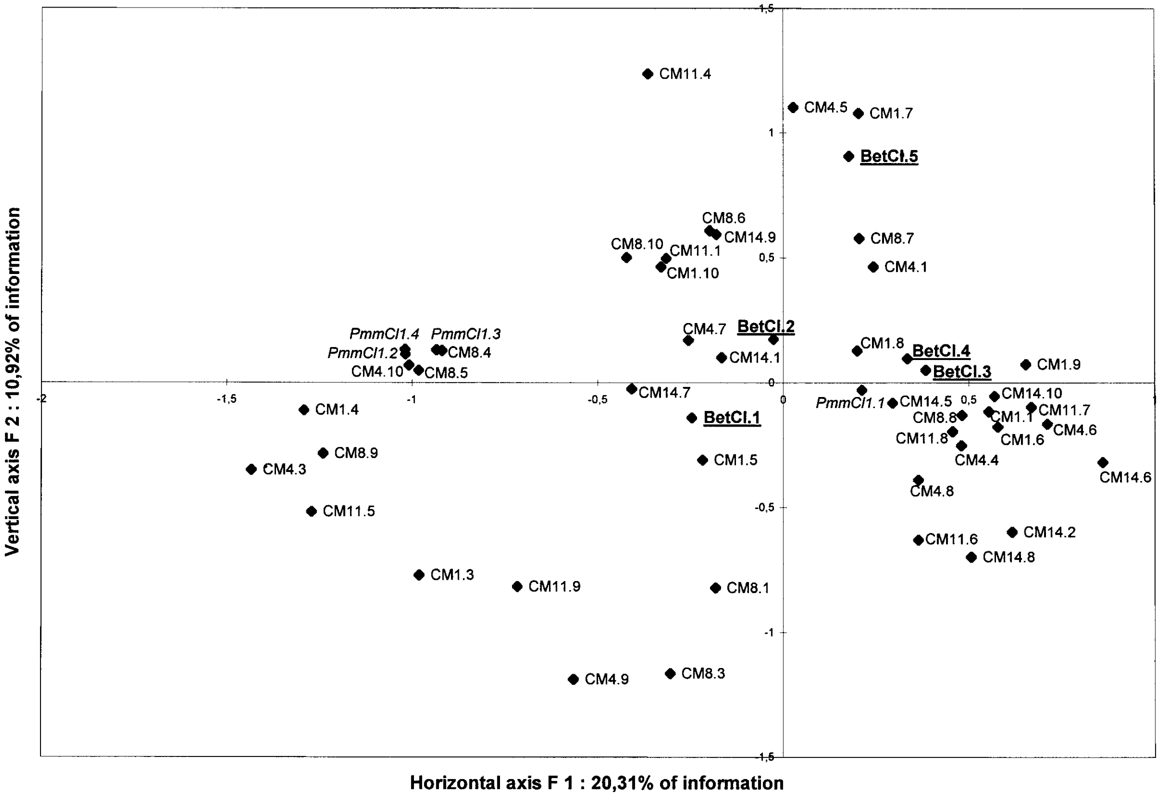

Fig. 1 Multiple-component analysis (MCA) on birch pollen concentrations and weather types. See Materials and methods for the identification of the classes used and their abbreviations

The pollen data (daily birch pollen concentrations in the air, expressed in grains per cubic meter of air) came from four 7-day volumetric Hirst traps (Hirst 1952) placed on the flat roof of buildings in the cities of Mâcon, Chalon-sur-Saône, Dijon and Montbard. The periods used for the analysis were centred on the time of birch pollination and represent a total of 370 days.

The meteorological data were rainfall, an essential factor for washing-out the pollen in the air, and the weather types classified by Bénichou (Bénichou 1995), who identifies 15 meteorological fields and 10 weather types for each of them. Five fields were used here: the geopotential at 1,000 hPa and 500 hPa, the relative humidity at 900 hPa, the pseudoadiabatic temperature of the wet-bulb thermometer at 850 hPa and the vertical gradient of temperature between 850 and 700 hPa (fields CM1, CM4, CM8, CM11 and CM14).

The data on pollinosis symptoms came from a sample of about 100 people (106 in 1996, 101 in 1997 and 74 in 1998). These patients received slips from their allergist on which they noted each evening their symptoms of rhinitis, conjunctivitis, asthma or coughing.

In order to perform the different multiple-component analysis (MCA), the different variables were distributed into classes. For this, we ranked the 370 measurements of pollen concentration in increasing order. From the different methods of creating a discrete from a continuous variable (Rican 1998), we have chosen the method of "natural thresholds", in which the main discontinuities of the distribution are located and are then used to define the class limits. In the case of the pollen concentrations, the classes are also in line with the clinical thresholds estimated in a previous study (Laaidi 2001); these have been estimated as 35 grains/m^3 for the most sensitive patients whatever their symptom and, for the others, 68–81 grains/m^3 for those suffering from asthma, 68–108 grains/m^3 for coughing, 81–252 grains/m^3 for conjunctivitis and 75–205 grains/m^3 for rhinitis. The threshold even reached 834 grains/m^3 in the year 1998 for coughing symptoms. However, we must not forget that the threshold only corresponds to the minimum value necessary for symptoms to begin, and above the threshold an increase in pollen concentration can also lead to an increase of the symptoms.

The five classes of pollen concentration are:
- BetCl.1: 0–49 grains/m^3
- BetCl.2: 50–99 grains/m^3
- BetCl.3: 100–299 grains/m^3
- BetCl.4: 300–599 grains/m^3
- BetCl.5: ≥600 grains/m^3

The four classes of precipitation are:
- PmmCl1.1: 0–2 mm
- PmmCl1.2: 2.1–5 mm
- PmmCl1.3: 5.1–8 mm
- PmmCl1.4: ≥8 mm

Depending on the different reports and the different pollens (Davies and Smith 1973; Laaidi 1997), the rainfall threshold below which there is absolutely no washing-out of the pollens is 2 mm or 5 mm. These two thresholds define the two first classes.

For the allergy symptoms, four classes have been established for rhinitis, conjunctivitis and asthma:
- Class 1: no symptom
- Class 2: 0.1%–5% patients suffering
- Class 3: 5.1%–10% of patients suffering
- Class 4: above 10% of patients suffering

Because of the low percentage of patients suffering, only three classes were established for coughing:
- Class 1: no symptom
- Class 2: 0.1%–5% of patients suffering
- Class 3: above 5% of patients suffering

All the variables previously described have been integrated by MCA, which reveals the interdependence of two variables by their graphic proximity or projection on the axis (Escoffier and Pagès 1990).

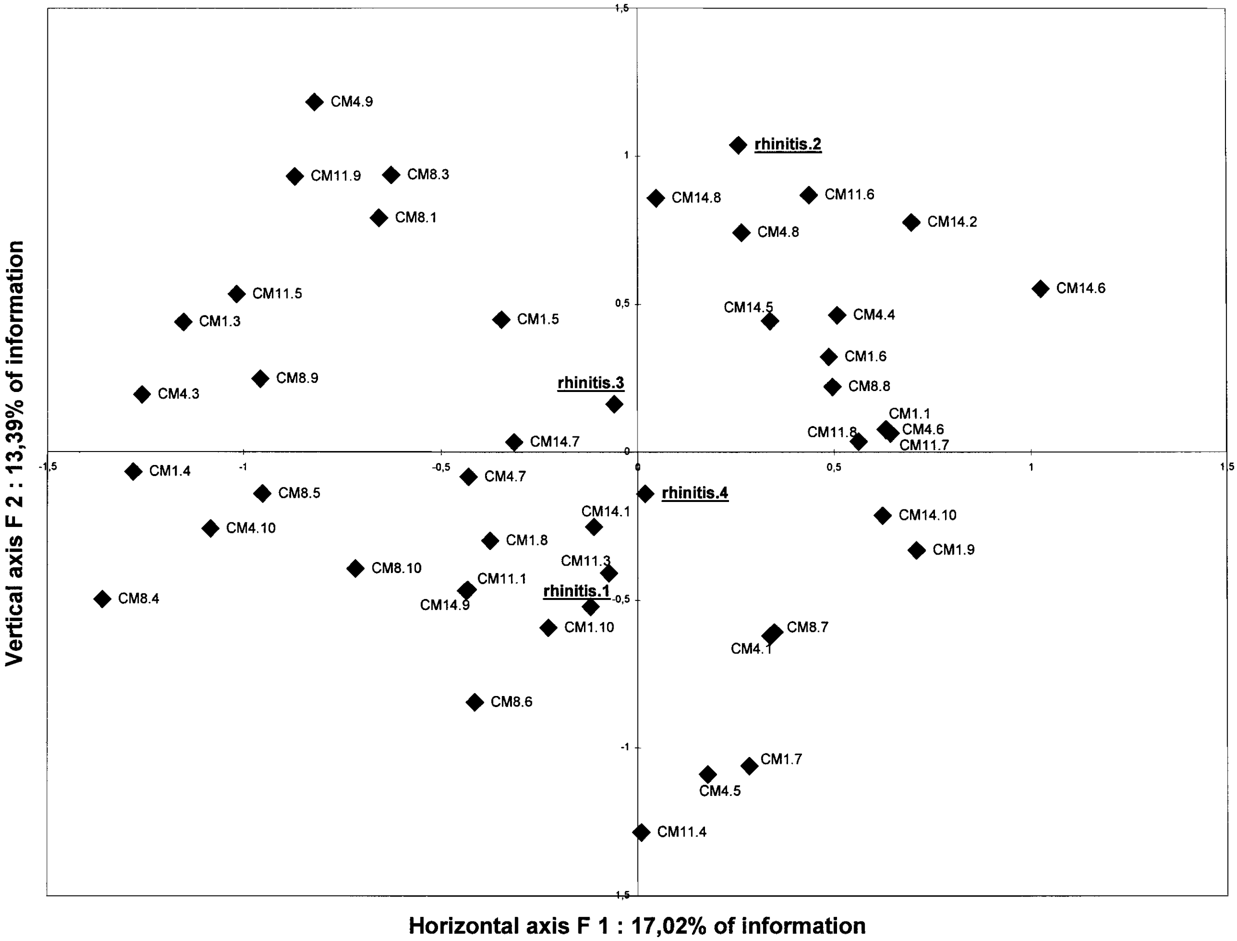

Fig. 2 MCA on rhinitis and weather types

Results

MCA on pollen concentrations, weather types and rainfall

As shown in Fig. 1, BetCl.1 is close to CM1.5 (unstable weather dominated by a light north wind bringing a weak cooling) and CM4.7 (disturbed situation). CM14.7 and CM14.1 are also related to an unstable situation, it being potentially rainy if the air mass is wet, which is actually the case as indicated by CM8.1 (high relative humidity, above 80%). With regard to temperatures, CM11.9 and CM11.1 represent cold situations (7°C or 9°C isotherm over Burgundy). BetCl.1 is located on the first axis on the same side as PmmCl1.4, PmmCl1.3 and PmmCl1.2, so the rainfall is above 2 mm.

BetCl.2 is close to CM14.1 (unstable situation), CM4.7 (disturbed situation) and also CM1.10 (low-pressure area, south-west flooding, medium winds, sometimes thunderstorms), CM8.6 and CM8.10 (low humidity under 70%), CM11.1 (cold but undisturbed type, Burgundy being located between the 8°C and 9°C isotherms), CM14.9 (unstable situation).

BetCl.3 and BetCl.4 are very close to each other and not far away from CM1.8 (north-westerly disturbance, strong winds, abundant rainfall), which is on the same side of the F2 axis. When projected on to the F1 axis, they are close to CM14.5 (stable atmospheric situation), CM8.8 (low relative humidity, 65%–70%), CM11.8 (cold and disturbed situation, 6°C isotherm over Burgundy), and even to PmmCl1.1 (rainfall between 0 and 2 mm) and CM4.4 (disturbed situation), but this last field is the most distant from the two pollen classes.

BetCl.5 is close to CM1.7 (well-marked anticyclonic type, sunny weather, southerly drying wind) and CM4.5 (anticyclonic situation). As regards temperatures, the point CM11.4 (warm weather type, 11°C) has coordinates on F2 close to BetCl.5. Nevertheless, it is also noticeable that the point CM11.1, which characterizes a colder situation (8–9°C) is not far away. CM8.6 and CM8.7 indicate a low relative humidity (under 70%) and CM14.9 a stable atmospheric situation.

MCA on pollinosis symptoms and weather types

MCA on rhinitis

The first class (rhinitis.1, Fig. 2) is close to CM1.10 (disturbed weather with south-west flooding, medium winds, sometimes thunderstorms) and CM11.3 (mild weather, 12°C isotherm over Burgundy).

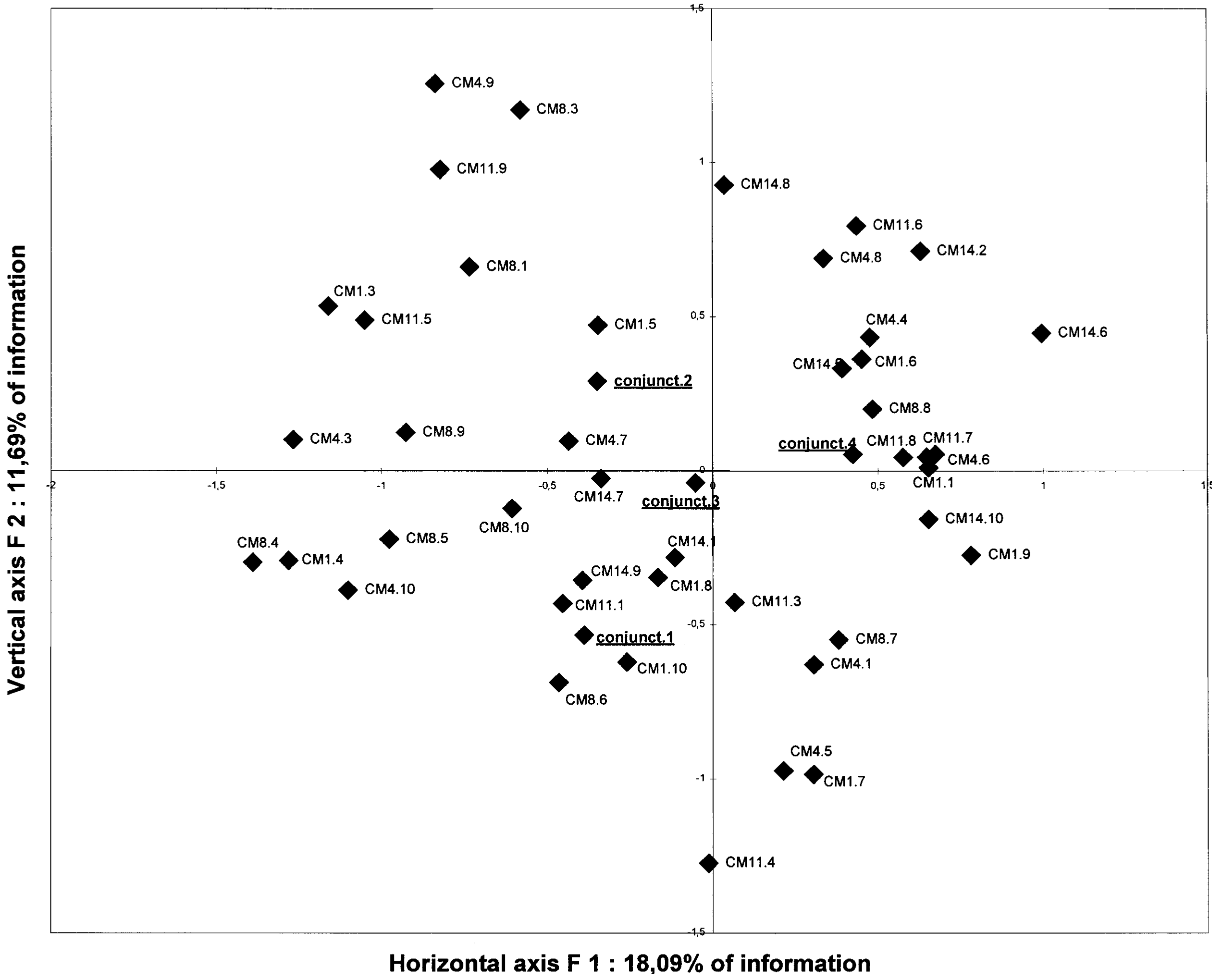

Fig. 3 MCA on conjunctivitis and weather types

The second class is close to CM14.8 (stable situation), CM4.8 (disturbed situation) and CM11.6 (disturbed and cold weather, isotherm 3°C over Burgundy). Knowing the humidity of the air mass would have allowed us to determine whether these disturbed situations can generate rainfall; no point of the eighth meteorological field is close to this class of rhinitis, but the point CM8.3 has a close coordinate on the F2 axis (+0.94), which mostly influences rhinitis.2; it represents low relative humidity (70%), so there is an *a priori* assumption of little rain.

The third class is not very distant from CM14.7 (unstable situation) and CM1.5. CM1.5 is characteristic of unstable weather with a greatly disturbed northerly air stream bringing a slight cooling; however, as we pointed out before, this type includes various continental or Mediterranean influences, generating rainy or sunny weather. In fact, rhinitis.3 is quite close to the intersection of the two axes, but if one supposes that it is slightly more influenced by the F2 axis, two points have close coordinates: CM8.8 (relative humidity, 65%–70%) and CM4.3 (disturbed situation).

The fourth class is close to CM14.1 (unstable situation) and has the same coordinate on the F2 axis (–0.14) as CM8.5, which corresponds to low humidity (65%–70%) so the weather changeability cannot generate cloud formation and rainfall.

MCA on conjunctivitis

The first class (conjunct.1, Fig. 3) can be related to five meteorological fields in terms of proximity or projection: CM11.1 (cool meteorological situation, Burgundy being located between the 8°C and 9°C isotherms), CM1.10 (warm and disturbed weather, south-westerly air streams, medium winds, sometimes thunderstorms), CM8.6 and CM8.7 (low relative humidity, under 70%) and CM4.1 (anticyclonic situation).

The second class has the same coordinates on the F1 axis as the meteorological field CM14.7 (unstable situation). The point CM1.5 is also close, but it corresponds to various meteorological situations, rainy as well as sunny ones. This conjunctivitis class is quite distant from the other points but relates mostly to the the axis F1 so it is possible to examine the points that have close coordinates on this axis: CM4.7 (disturbed situation); CM14.9 (unstable situation with a high rainfall potential); CM8.6 (low relative humidity of 70%, insufficient to lead to air condensation and cloud formation); CM11.1 (cool situation, as for the previous class, 8–9°C).

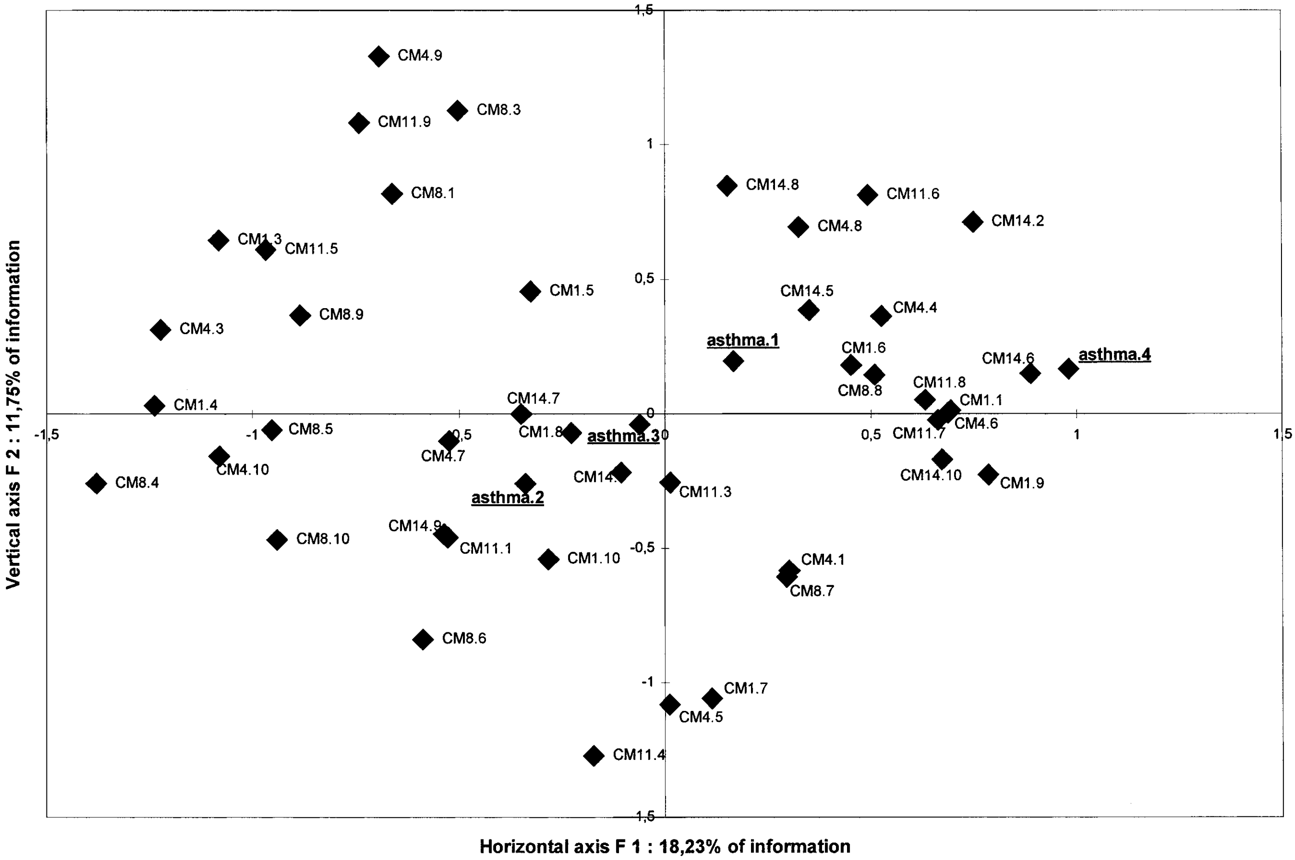

Fig. 4 MCA on asthma and weather types

The third class is mostly close to CM14.1 (unstable situation), and also CM1.8 (disturbed and rainy weather).

The fourth class relates strongly to the F1 axis. All the points close to this class or having close coordinates on the F1 axis show the influence of anticyclonic situations (CM4.6, CM1.1, CM1.6, CM1.9), quite cold (6°C for the meteorological field CM11.8, 8–9°C for the field CM11.7), stable (CM14.10, CM14.5, CM14.2) and a little damp (CM8.8) but not rainy.

MCA on asthma

The first class (asthma.1, Fig. 4) is quite isolated from all the meteorological fields, but it is not very far from the fields CM1.6 (anticyclonic weather), CM8.8 (low relative humidity, 65%–70%) and CM14.5 (stable atmosphere relatively unfavourable to pollen dispersal).

The location of the second class is the reverse of that of the first relative to the two axes. It is close to the fields CM14.1, CM14.7 and CM14.9 (unstable situations), CM1.8 (disturbed weather, strong precipitation, strong winds), CM4.7 (disturbed situation), CM11.1 (8–9°C isotherms on Burgundy) and, as regards relative humidity, the nearest point is CM8.6 (70%).

The third class is close to CM14.1 (unstable atmospheric situation), CM1.8 (north-westerly disturbance with strong winds and abundant rainfall, mostly on west-facing slopes) and CM11.3 (warm temperatures, 12–13°C).

The fourth class is particularly marked by the axis F1, having the coordinate 0.98. The closest meteorological field is CM14.6 (unstable situation infrequent during the cold half-year). The nearer point of the eighth field is CM8.8, indicating a low relative humidity (65%–70%) meaning an insignificant risk of rain. This is confirmed by the point CM1.1 (anticyclonic situation with a light west-north-west wind), and by the point CM4.6 (anticyclonic weather). The 6°C isotherm (CM11.8) is then centred on Burgundy. The point CM1.9 has coordinates close to those of the fourth class of asthma on axis F1 and corresponds to a cold anticyclonic situation, with frequent temperature inversions and fog.

MCA on cough

The first class (cough.1, Fig. 5) is paradoxically very close to the third class. The second class is represented by a point far away from all the others that relates little to either axis. The low percentage of patients involved may explain the failure of the MCA for this symptom.

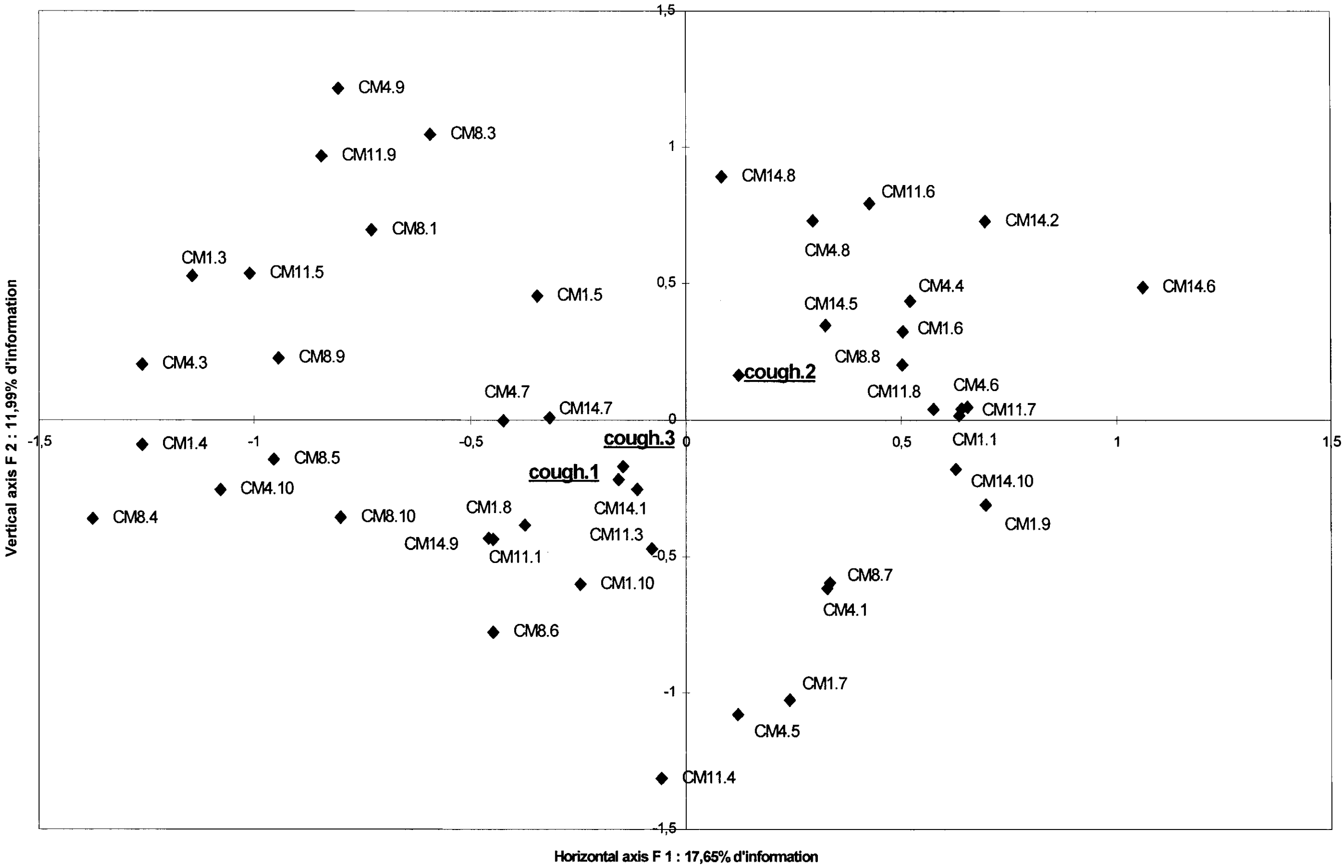

Fig. 5 MCA on coughing and weather types

Discussion

MCA on pollen concentrations

The results show that the lowest birch pollen concentrations were favoured by disturbed and unstable situations with a wet air mass, rain and cold (7–9°C). The increase in concentrations to 99 grains/m^3 also corresponded to low pressure and unstable situations, but temperatures were somewhat higher (above 8°C), with a lower relative humidity. Concentrations of 100–599 grains/m^3 corresponded to stable situations with little rain where the relative humidity was low, or to very disturbed weather types, but in all the cases temperature was low. Higher concentrations were favoured by dry anticyclonic situations with medium winds and an air mass temperature of 11°C. Only precipitation of 2 mm or less was compatible with good pollination. This MCA brought out the fact that the air-borne birch pollen was reduced by low pressure and unstable and rainy situations with a wet air mass. By contrast it was favoured by dry anticyclonic situations. The role of temperature is less evident and it is possible to find quite high concentrations when the air is cold, with temperature sometimes as low as 6°C. Colder weather types (CM11.5 and mostly CM11.6) have been recorded but have never been associated with high pollen concentrations. Galàn et al. (1998) showed on another winter-blossoming taxa, the Cupressaceæ, where temperature has different effects depending on the harshness of the winter, pollen counts being more influenced by minimal temperatures during cold winters and by maximal temperatures during other years.

MCA on pollinosis symptoms

As regards rhinitis, the results of the analysis show that rainy and warm weather favoured an absence of symptoms. By contrast, a low percentage of rhinitis (up to 5%) corresponded to the presence of a non-saturated air mass, thus tending to favour pollination, the atmospheric situation being disturbed or stable. In addition, temperatures were low (+3°C), which is, by contrast, not favourable at all to ripening of the pollen grains insofar as we did not find such cold situations when birch pollen was present in the previous MCA. Such low temperatures act on the nasal mucous membranes of the patients, making them more sensitive and leading to some rhinitis when pollen concentrations remain very low in the atmosphere.

It can be expected that the weather types favouring an absence of symptoms would be the same as those unfavourable to pollination. But this MCA has shown that the reality is not so clear-cut. In fact, the absence of rhinitis was favoured by rainy weather, which leads to pollen being washed-out from the atmosphere, even if the weather is warm; however during this season, which is still almost winter, rhinitis, even the allergic type, is influenced by both pollen and the meteorological factors themselves. The cold irritates the nasal mucous membranes and can lead to rhinorrhea, while milder temperatures, when they are associated with rainfall (and so with the quasi-disappearance of pollens) tend to decrease the prevalence of rhinitis. In addition, classes 2, 3 and 4 are rather close to situations of low relative humidity, favouring pollination and so the development of rhinitis.

As regards conjunctivitis, its absence was favoured by cool to mild weather, either disturbed or anticyclonic, but with a clear tendency to drought. The development of some symptoms (up to 5%) corresponded to a similar thermal (8–9°C) and hygrometric (70%) situation, but in this case the weather was clearly disturbed. The increase of conjunctivitis to 10% was linked to disturbed weather; it was surprising to notice that the point CM1.8 was close to this class of symptoms insofar as it represents disturbed weather characterized by abundant precipitation leading to a virtual absence of pollination. In fact, the strong winds accompanying this weather type can cause ocular irritations that are mistaken for conjunctivitis by the patients. It is also important to notice that rainfall tends to be concentrated on the west-facing slopes and is less frequent in the plain where the majority of our patients live. It is therefore possible that pollination became abundant enough to lead to some conjunctivitis, associated with the irritant effect of the wind. Overall, the higher percentages of conjunctivitis corresponded to weather types that also favour birch pollination. As for rhinitis, low temperatures, as are usual in this season, prevent neither pollen production nor the multiplication of conjunctivitis. Besides it is possible that a colder temperature (up to 3°C) increases the ocular irritation caused by pollen allergy, or causes symptoms that are easily confused with it.

If ones looks at asthma symptoms, their absence was favoured by anticyclonic, dry and stable weather without any wind able to disperse the pollen grains. By contrast, the appearance of symptoms, at whatever level, always corresponded to an unstable atmospheric situation or to a windy anticyclonic one. In all cases the relative humidity remained low, below or equal to 70%. As for rhinitis and conjunctivitis, low temperatures did not prevent the development of symptoms since the highest percentages corresponded to temperatures of 6°C. As for the third asthma class (5.1%–10%), this was related to a north-westerly disturbance, strong winds and abundant rainfall on west-facing slopes (CM1.8); this situation is *a priori* incompatible with a high pollen density, abundant rainfall washing out the pollen grains and preventing the presence of smaller allergenic particles that are mostly favoured by light rainfall (Schappi et al. 1997). This situation therefore represents a single factor favouring asthma, the strong wind acting in a mechanical way to exacerbate the bronchial hyper-reactivity of patients whose bronchi are already sensitized by the pollen previously present in the air, even if there are fewer pollen grains in such a meteorological situation. In addition, mild temperatures (12–13°C) were propitious to high pollen production and so to an increase of asthma. Some authors have shown stormy days to influence asthma crisis, even if the effect was not always very pronounced (Antó and Sunyer 1997; Newson et al. 1997; Higham et al. 1997) and even if it only involved a few patients, not all the asthmatic subjects being sensitive to this phenomenon (Celenza et al. 1996). We did not notice such a phenomenon during birch pollination, but it was verified for grasses (Laaidi 2000). A quite particular weather type was found at times of higher asthma prevalence: the field CM1.9 corresponded to an anticyclonic and cold situation, without any wind, with frequent temperature inversions and fog. If this weather type is not very compatible with a good dispersal of pollen, it can single-handedly lead to an increase in bronchial hyper-reactivity and so to the appearance or to a worsening of asthma symptoms during a period when the allergic person is already under the influence of the pollen or of its allergens. It is important to notice that fog alone is usually not a trigger for asthma; the best proof of this is that the Mont-Dore (France), where fog is very frequent, every year receives 16,000 patients for a thermal or climatic course of treatment, most of them having a respiratory illness (Peyre et al. 1979). However the patients are submitted to a special environment bringing together medium altitude, the absence of pollution, the modification of their usual allergens, a certain level of relaxation and rest and the pharmacological aspects of the cure. By contrast, when fog is heavy with dust, fumes, an irritative gas such as sulfur dioxide and various micro-organisms, it forms a real aerosol able to penetrate deeply into the respiratory system: the action of this polluted fog (frequent during the weather type CM1.9) on bronchi already exposed to the action of pollen during previous days contributes to a worsening of allergic asthma because its harmful effects (those of pollutants) are added to those of pollens (Bylin et al. 1987; Rossi et al. 1993; Charpin 1996; Strand et al. 1997, 1998; Ito et al. 1996; Aubier 1998). The pollen grain can be a vector for such polluting substances (dust, etc.), which can themselves be allergens or irritant factors leading to allergenic or non-allergenic symptoms accompanying the exposure to pollen (Obtulowicz 1993; Knox et al. 1997). But pollutants can also modify the mineral composition of the pollen (Cerceau-Larrial and Derouet 1988; Nilsson and Berggren 1991) and increase its concentration in proteins and allergens (Masuch et al. 1997; Bieberdorf et al. 1961; Ruffin et al. 1983; Jilek et al. 1993), conferring an increased allergenic power (Ruffin et al. 1986).

The results of the different MCA can be summed up in Table 1. A table of this sort constitutes an interesting tool for the prevention of high-risk allergenic exposure, because the weather types can be predicted by the meteorological office (Météo-France). It would be interesting in the future if the forecast could be broadcast to allergists and to the general public, in particular by the Internet or television, giving appropriate advice to those concerned: take measures that limit contact with the pollen allergens (avoid going out if possible, do not undertake

Table 1 Weather types influencing the birch pollination and the pollinosis symptoms. *Pmm* precipitations, *CM* meteorological field (*CM1* geopotential at 1000 hPa, *CM4* geopotential at 500 hPa, *CM8* relative humidity at 900 hPa, *CM11* pseudoadiabatic temperature of wet thermometer at 850 hPa, *CM14* vertical gradient of temperature between 850 and 700 hPa). For each meteorological field the classification distinguishes between to corresponding weather types (for exemple the geopotential at 1,000 hpa: CM1.1 to CM1.10). See Results for details on each weather type

Pollen and symptoms		Weather type						
		Pmm	CM1	CM4	CM8	CM11	CM14	High-risk weather types
Betula	0–49	>2	5	7	1	1, 9	1, 7	
(grains/m^3)	50–99		10	7	6, 10	1	1	
	100–299	0–2	8	4	8	8	5	Anticyclonic situation, relative humidity <70%, temperature 6–11°C
	300–599	0–2	8	4	8	8	5	
	≥600		7	5	6, 7	4	9	
Rhinitis	0		10			3		
(%)	0, 1–5			8	3	6	8	
	5, 1–10		5	3	8		7	
	>10				5		1	Unstable and dry weather, (relative humidity <70%), cold (3–9°C)
Conjunctivitis (%)	0		10	1	6, 7	1		
	0, 1–5			7	6	1	7, 9	
	5, 1–10		8				1	
	>10		1, 6, 9	6	8	7, 8	2, 5, 10	Temperature 3–9°C, isotherm 6°C over Burgundy = highest prevalences of symptoms, strong winds, relative humidity <70%
Asthma	0		6		8		5	
(%)	0, 1–5		8	7	6	1	1, 7, 9	
	5, 1–10		8			3	1	
	>10		1, 9	6	8	8	6	Disturbed situation + strong winds or anticyclonic situation with light winds, relative humidity <70%, temperatures inversions with fog

any outdoor physical activity and close the windows of your home or car); take any preventive medecine prescribed by the physician that has a rapid effect (a few minutes or 1 or 2 days) on rhinitis and conjunctivitis (Durham 1998) so that its use on the day before a high-risk day can lead to effective prevention (Naclerio and Solomon 1997). This preventive action has a slower response in asthma, where it manifests itself only after several days or weeks because of the extent of the bronchus and the bronchioles and because of bronchial non-specific hyper-reactivity. The advice to avoid allergens is then very important as part of a preventive treatment before the start of the pollen season.

In conclusion

To sum up, the analyses have shown that the weather types favouring pollination can also be related to the presence of many symptoms: anticyclonic and windy situations, low relative humidity, unstable, cool and damp situations. By contrast, rainy situations are usually favourable for the allergic patients, whatever their symptoms, as the rain washes-out the pollen and decreases concentration in the air. However, there are some exceptional effects, some weather types being able by themselves to increase the number of clinical manifestations: temperatures of 3°C, even if not favouring pollination, led to a slight increase of rhinitis and conjunctivitis; in the same way an anticyclonic situation with fog and temperature inversion, not favourable to pollination, corresponded to the highest percentage of asthma; very strong winds corresponded to a high prevalence of conjunctivitis and asthma as a result of their irritant effect. It is therefore important, when forecasting high-risk situations, to consider not only the effects of the weather on pollen dispersal of but also any direct effect on the allergic symptoms. The impact of a weather type on a particular symptom of pollinosis shows the importance, emphasized by Besancenot (1992), of considering some precise and well-defined nosological entities when carrying out meteoro-pathological research.

Acknowledgements This research was partly supported by the Burgundy Region, France. I would like to thank G. Chassepot from the Laboratoire de Chrono-Écologie of Besançon, who analysed the pollen strips from Dijon, Montbard and Mâcon, M. Thibaudon from the Réseau National de Surveillance Aérobiologique, who gave me the pollen counts of Chalon-sur-Saône, and S. Taboulot from Météo-France who supplied me with the meteorological data. I would like to express my gratitude to Drs D. Schwender, P. Hardel, C. Rauld, S. Joly-Tisserand and P. Scherer who supplied the patients for the survey. The experiments comply with the current laws of the country in which they were performed (France).

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