



## Airborne fungal spores and the thunderstorm of 24 June 1994

Ursula Allitt

20 Acrefield Drive, Cambridge, CB4 1JP, UK (fax: +44 1223333392)

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### Abstract

On the evening of 24 June 1994 there were thunderstorms which passed from the south to the north over large areas of England, followed by an extensive and initially alarming episode of 'thunderstorm asthma'. It was eventually concluded that the probable cause of this episode was the release of allergenic particles from wetted grass pollen.

As part of the investigation of this episode changes in the fungal air spora were investigated at several sites. The fungal spores present varied from site to site. At London, Addlestone and Leicester there were very marked transient peaks of smut ustilospores, (and to a much smaller extent at Cambridge), particularly those of *Ustilago segetum* (Bull.) Roussel. At many sites there were transient peaks of *Cladosporium* conidia. The possible causes of the transient peaks are discussed.

At most of the other sites except London there were high concentrations of ascospores after the rain. Typically, *Didymella* ascospores occur after rain, but on this occasion they occurred at low concentrations at all sites, because of dry weather in the previous month. Instead, there were high concentrations of ascospores which normally occur in far lower numbers, viz. ascospores of *Phaeosphaeria nigrans* and Diatrypaceous ascospores. The reasons for this were related to increased rainfall in the previous thirteen months. There were site to site differences in the ascospore composition of the air spora, and this was related to habitat differences, where this was known.

### Introduction

On 24 June 1994 there were thunderstorms covering large parts of England. After the storm there were many cases of people experiencing asthma for the first time, although typically they already suffered from allergy to grass pollen, Venables et al. (1997). A Thunderstorm Asthma Study Group composed of appropriate specialists was convened. The eventual consensus of this group, reported in Venables et al. (1997) was that the cause of the asthma epidemic had been the release of sub- or paucimicronic particles from wetted grass pollen, a topic summarized by Knox (1993), with perhaps some contribution from the high numbers of particles of pollutants less than 10  $\mu\text{m}$  in diameter. The present author investigated changes in concentrations of airborne fungal spores before, during and after the storm for several air monitoring sites.

The course of aerobiological events surrounding a thunderstorm was first described by Hirst, (1953). Before the storm there was a dry air spora, and then a transient increase in *Ustilago* and a transient rise in *Cladosporium* spores as the rain began. All the dry air spores were then washed out by the rain, and later ascospores were released under the prevailing damp conditions. In Hirst's illustrations the ascospores appear to be those of *Leptosphaeria* species and *Leptospora rubella*.

In contrast a storm in Leicester in 1989 showed no transient increase in *Cladosporium* spores, but those already there were washed out during the rain. High concentrations of ascospores followed the rain, and in this case they were those of *Didymella*, Allitt and Stern (1997). Both sequences of events are common in England during and after rain.

## Materials and methods

Burkard Recording Volumetric Spore Traps were in operation at several sites, and the spore trap traces were examined from nine selected sites where the storms had occurred, viz. Isle of Wight, Oxford, two sites in Leicester, Derby, Addlestone, (near Weybridge, Surrey), North London, Cambridge and Norwich. Traces were also examined from traps in Maidstone and Hull, where no storms had occurred. All traps were at roof-top height, ranging from 7 m at Addlestone, 10 m at the Isle of Wight and Derby, 12 m at the Department of Geography, University of Leicester, 14 m at Oxford, 16 m at Cambridge, 18 m at the University of North London and 30 m at Leicester Royal Infirmary. No information is available for roof heights at Maidstone, Hull and Norwich. In addition a Burkard Continuous Recording Automatic Sampler was in operation in a house in West Chesterton, Cambridge. This sampler was ca 3.5 m from a large window which was open from ca 18.00–22.45 h GMT.

A preliminary microscopic examination was made of all the traces by means of selected 6-hourly longitudinal traverses for all sites except Maidstone and Hull. Counts were also made using transverse traverses of the slides at hourly intervals for the Isle of Wight, the Department of Geography, Leicester, site, North London and the two Cambridge sites. Subsequent counts at 15 min intervals were made for the Cambridge roof-top site.

Identification and counting was performed at a magnification of 750 under an oil-immersion objective, except for the additional counts for the Cambridge roof-top site, which were made at a magnification of 400. The visual identification of fungal spores was made by comparison with spore reference slides made from reliably identified collections of fungi. The validity of visual identification for airborne *Didymella* ascospores was established by cultural methods, Allitt (1986).

Informal notes on the time and nature of the rain-fall were made in Cambridge, while hourly weather records and detailed wind records were available for London, but no detailed weather records were available for the other sites.

## Results

All the slides except those from Maidstone and Hull exhibited to the naked eye the difference between the

first part of the trace, which clearly contained many coloured particles, and the second part of the trace, presumed to be after the rain, when no particles were visible. In addition the trace for London had a band a little over 2 mm wide, and the trace for Addlestone had a band, 2.3 mm wide, of an even darker deposit at the end of the first part of the slide. The spores on the trace from the Department of Geography roof in Leicester had been stained, and there was a 2 mm wide band of a more darkly stained deposit at the end of the first part of the trace. (The width of the bands was established by noting the limits of the bands under the microscope, and measuring the distance between the limits using the stage micrometer. This should be looked on as a reasonable estimate of width, but not an accurate measurement.)

Microscopic examination using a longitudinal traverse, starting in the first part of the trace, showed that there was a dry air spora composed of particles such as pollen grains, *Cladosporium* spores, *Ustilago* spores, and, especially in London and Addlestone, particles of pollutants. The second part of the trace was composed mostly of ascospores. The ascospores of many species were present, but there were scarcely any of *Didymella*. At several sites there were unusually high concentrations of ascospores of *Phaeosphaeria nigrans* and ascospores, occurring mostly in octads, of members of the fungal family Diatrypaceae. Spore concentrations of these two groups differed from site to site. The ascospores of many other fungi were also present, but the only other ones occurring in high numbers, (at Norwich only) was an ascospore which resembled the ascospores of *Gnomonia vulgaris* Cesati and de Notaris. Several of the sites had a small number of spores which matched illustrations of the spores of the asexual state of *P. nigrans*, Webster (1955). The narrow bands on the traces from North London and Addlestone were composed of dry air spores such as *Cladosporium*, ustilospores of the smut *Ustilago segetum* (Bull.) Roussel, see Mordue and Ainsworth (1984), other smut spores, myxomycete spores and pollen, including an unusual clump of ca 40 grains of *Tilia* pollen in the North London band. The 2 mm wide band on the Leicester trace was composed almost entirely of *Cladosporium* spores, but there were other spores present, including *U. segetum*.

Hourly counts for North London, Figure 1, Leicester, Department of Geography roof, Figures 2–3 and Cambridge, Figure 4 clearly showed features such as transient peaks of *Cladosporium* at all sites and transient peaks of *U. segetum* at North London

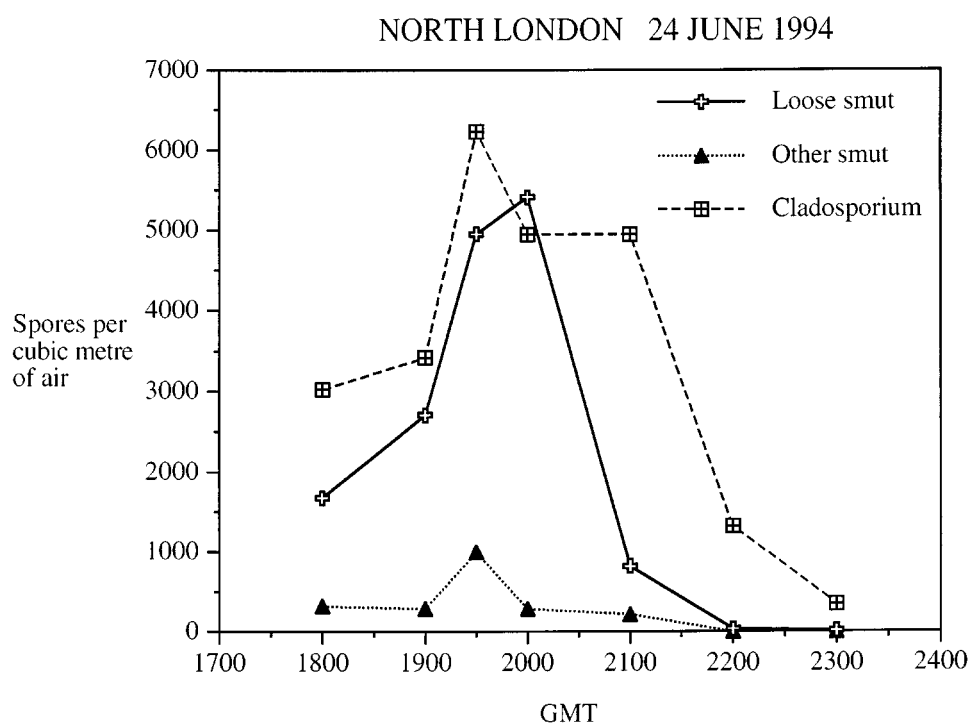


Figure 1. Airborne concentrations of spores of loose smut (*Ustilago segetum*), other smut species and *Cladosporium* on 24 June 1994 at the University of North London.

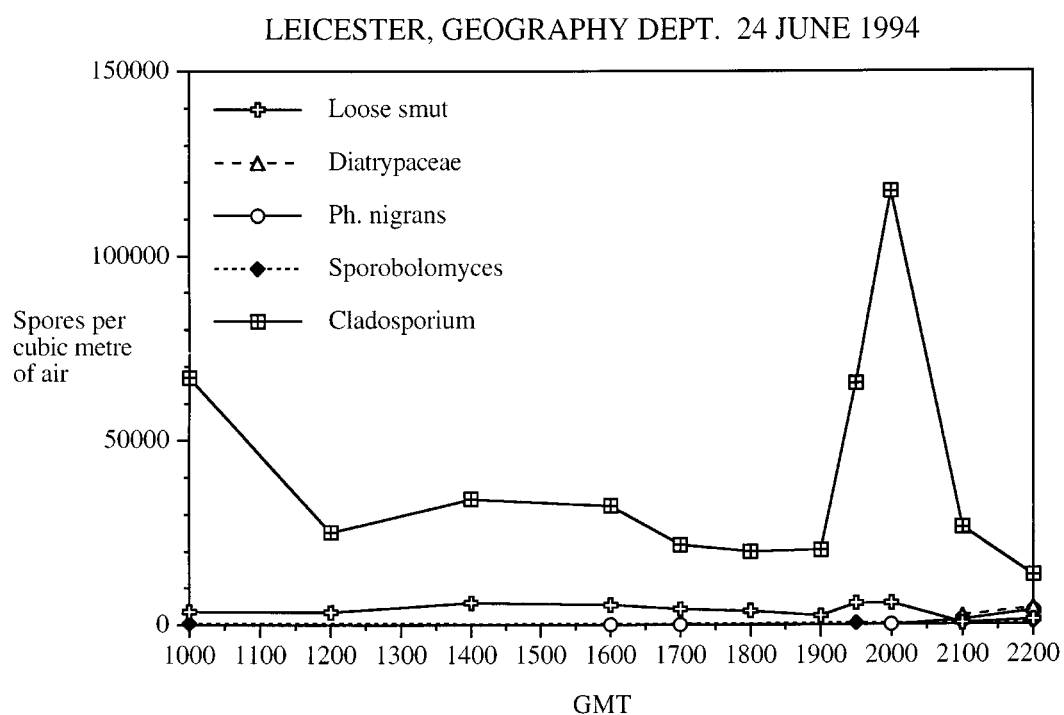


Figure 2. Airborne concentrations of spores of loose smut (*Ustilago segetum*), Diatrypaceae, *Phaeosphaeria nigrans*, *Sporobolomyces* and *Cladosporium* on 24 June 1994 at the Department of Geography, University of Leicester.

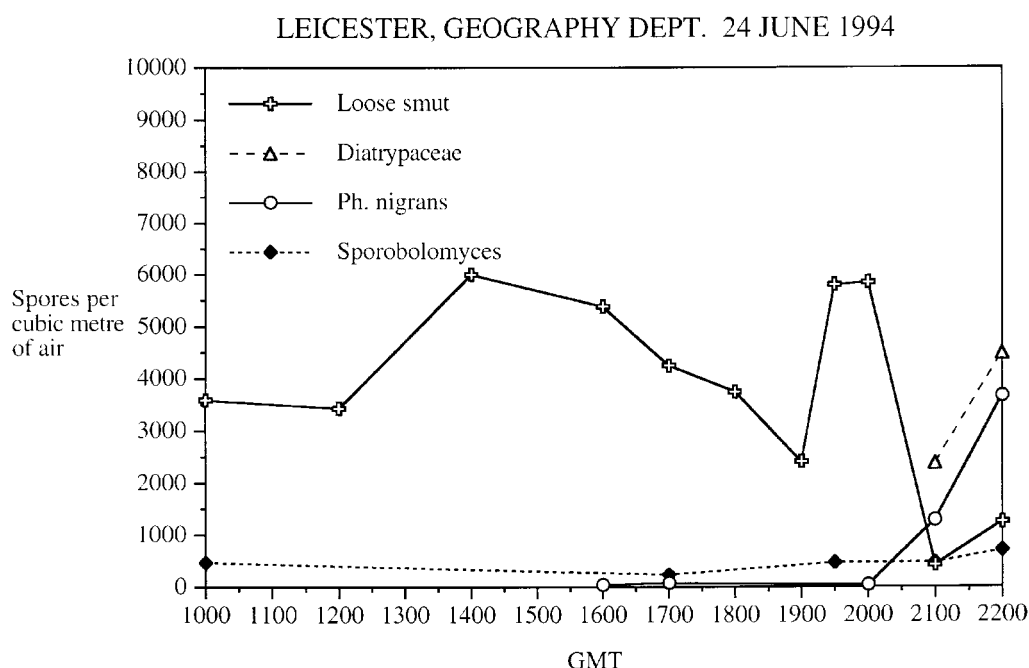


Figure 3. Airborne concentrations of spores of loose smut (*Ustilago segetum*), Diatrypaceae and *Phaeosphaeria nigrans* on 24 June 1994, at the Department of Geography, University of Leicester.

and Leicester, but only a slight increase at Cambridge. There were scarcely any ascospores at North London until some time after the rain, whereas at Cambridge and Leicester ascospores were trapped immediately after the rain had stopped.

## Discussion

The above results raised several questions, viz. what caused the transient peaks of *Ustilago* and *Cladosporium* spores, why were there transient peaks of *Ustilago* at some sites but apparently not at others, why were there so few *Didymella* ascospores, and why were concentrations of ascospores of *P. nigrans* and Diatrypaceae so much higher than usual? The answers lie in the life cycles and ecology of the fungi involved, which explains which fungi were available for release when the storm started, and in how spore release mechanisms might have been affected by the storm.

### Transient peaks of *Ustilago* spores

The *Ustilago* species whose spores were present in high concentrations was *U. segetum*, varieties of which

cause loose smut in barley, wheat, oats and oat grass, *Arrhenatherum elatius*. The spores occur in the ovaries of the host, and their production coincides with pollen production in the host. The spores are very dry and powdery, with no morphological connection to one another, although there is a tendency for them to stick together.

The release of spores of *U. segetum* was investigated in plots of infected barley by Sreeramulu (1962), and oats by Mills (1967). Sreeramulu (1962), concluded that the prevailing wind velocity, and especially wind gustiness, was the main agent in removing spores from the exposed spore mass into the air. Similarly Mills (1967), thought that wind turbulence was the main disseminating agent when wind velocities were low. However, charts given by both authors did show that occasionally there was release of spores at the beginning of rain, even when the wind was low. Hirst and Stedman, (1963), seeking to explain transient rises in concentrations of *Ustilago* spores at the beginning of rain, had shown that falling water drops could move spores of *U. segetum* var. *tritici* into the air under experimental conditions.

The *U. segetum* spores at the beginning of the storm could then have been released by either wind or rain. (There may even be a third possibility for

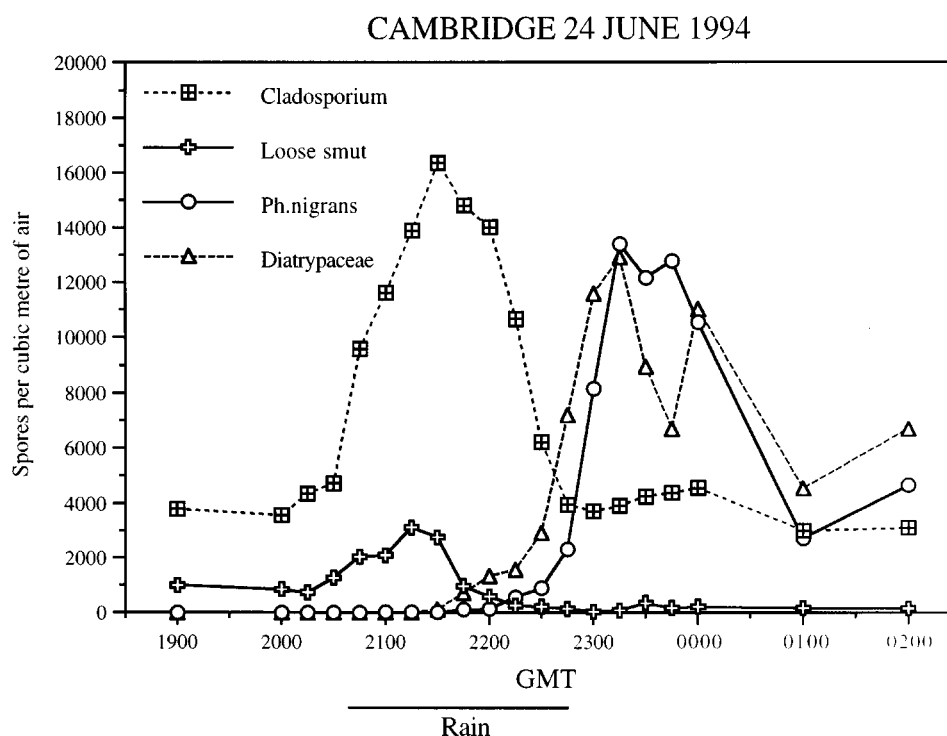


Figure 4. Airborne concentrations of spores of *Cladosporium*, loose smut (*Ustilago segetum*), *Phaeosphaeria nigrans* and Diatrypaceae on 24–25 June 1994, at the Department of Plant Sciences, University of Cambridge.

release: Leach (1976), in his description of his electrostatic theory of spore release, see next section, states on page 78 that dust particles on the surface of the *Drechslera turcica* lesions on the experimental leaves may have become electrically charged and repelled from the lesion in the same way as the conidia of *D. turcica*.) Ustilospores of loose smut are similar to the dust particles, in that they are not attached, and could perhaps also achieve 'take-off' by electrostatic means.)

The best evidence that wind was the most important factor in this storm was supplied by wind speed data for Gravesend, 30 km from North London, Figure 5. At 19.20 h GMT wind speed dropped to  $0.5 \text{ m s}^{-1}$ , but gusted to  $15 \text{ m s}^{-1}$  at 19.28 h GMT, then gusted to  $26 \text{ m s}^{-1}$  at 19.30 h GMT, followed by another gust to  $15 \text{ m s}^{-1}$  a minute or so later. Wind speed then gradually dropped in a series of decreasing gusts. For about 6 minutes wind speed was both gusty and greater than  $13 \text{ m s}^{-1}$ . This coincides in time with the band including many dry powdery particles of just over 2 mm wide at 19.30 h GMT at North London, and suggests the period during which the

dry powdery particles were lifted by gusting lasted from about one to six minutes. However, concentrations of *U. segetum* spores were even higher at 20.00 h GMT at North London. Addlestone, a little to the west of London, and presumably affected by the same winds, had a similar band estimated at 2.3 mm wide, suggesting that the gusts capable of lifting particles so effectively lasted for about 9 minutes. A transient peak of *U. segetum* spores at Leicester, Department of Geography, Figure 3, was in a band of 2 mm width. (Because the intake slit of the trap is 2 mm wide the minimum width of deposit is 2 mm. Because the trapping surface is moving underneath the slit at  $2 \text{ mm h}^{-1}$ , or  $0.1 \text{ mm}$  in 3 minutes, then it is possible to make an estimate of the length of time taken to deposit a band of particles, as every 0.1 mm over 2 mm should represent 3 minutes.)

Only a slight transient peak of *U. segetum* spores was registered at Cambridge, and its existence only became apparent when counts at 15 min intervals were made. It occurred after the rain had started. Detailed wind records were not available for Cambridge, but the wind run recorded there did not suggest any evid-

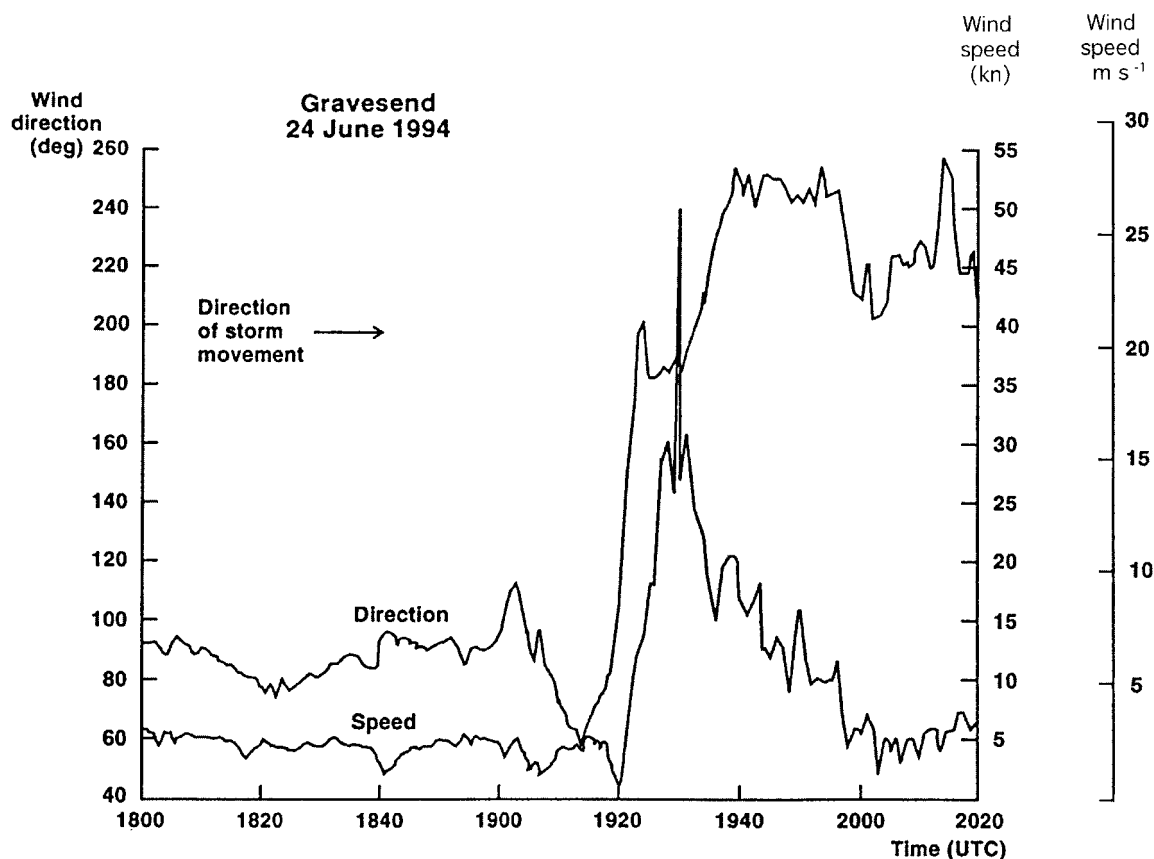


Figure 5. Surface observations of wind speed and direction from the Gravesend station from 18.00 to 20.20 h UTC (= GMT), on 24 June 1994.

ence of such exceptional speeds, and only very strong winds were noticed, pers. obs.

#### *Transient peaks of Cladosporium spores*

These peaks occurred at all the sites where hourly counts were made, Figures 1, 2 and 4, peak concentration varying from site to site, but the highest was a peak of 117,000 spores  $\text{m}^{-3}$  air at Leicester, Figure 2. Concentrations of *Cladosporium* spores had been high there throughout the day, and conditions were evidently favourable for the production of *Cladosporium* spores at this site.

Hirst (1953) described a transient rise in airborne *Cladosporium* spores at the beginning of rain, and Hirst and Stedman (1963) demonstrated that under experimental conditions falling water drops could disperse spores in two ways, by mechanical shock, a process they called 'tap', and another process 'puff', which they suggested was caused by the fast air currents produced when the water drops spread. There

is another theory of spore release for spores such as *Cladosporium*, which are attached either to stalks or other spores. This is the electrostatic theory of spore release, described by Leach (1976), and refined in a long series of subsequent papers, e.g. Leach (1980). Briefly, this suggests that as surfaces can be electrically charged, then spore and stalk, (or other spore) to which it is attached are similarly charged, and when the connection between spore and stalk weakens or breaks then they repel one another electrically. Since the stalk is fixed the spore is propelled away from it. This process can be affected by vibration, for example by raindrop impact or the buffeting of vegetation, and also by changes in RH, and the quality of light. Changes of all these factors occurred at the beginning of the storm, and there are of course electrical changes involved in thunderstorms as well. It seems possible that 'mechanical shock' and 'vibrational release' are the same phenomenon, and similarly that 'puff' could be electrostatic repulsion.

It seems that any of these factors, singly or in combination, could have been acting on *Cladosporium* spore release in this storm.

Informal records of the timing and intensity of the rain had been made for Cambridge, so it was possible to investigate the course of changes in *Cladosporium* concentrations in some detail. Initially hourly counts were made for the roof-top site in Cambridge, and these showed that concentrations of *Cladosporium* spores were  $3,557 \text{ m}^{-3}$  at 20.00 h, before the storm,  $11,606 \text{ m}^{-3}$  at 21.00 h GMT, after the storm had started, and at a peak of  $13,997 \text{ m}^{-3}$  air at 22.00 h GMT. This peak occurred 83 minutes after the first raindrops fell at 20.37 h GMT. A more immediate response to rain might have been expected, as Hirst and Stedman (1963), had shown experimentally that release of *Cladosporium* spores by falling water drops was immediate, and also that larger drops released more spores. Additional counts were therefore made at 15 min intervals, Figure 4, and these showed that the peak concentration was  $16,416 \text{ m}^{-3}$  air, and was actually reached 30 min earlier, at 21.30 h GMT. This was still 53 minutes after the first raindrops fell, not an immediate response.

It had been observed that in the traverses at 15 min intervals for 20.00 to 20.45 h GMT that many of the *Cladosporium* conidia were mature, being golden, rough, and in the size range of  $8.5 - 14.0 \times 3.0 - 5.5 \mu\text{m}$  for airborne *Cladosporium* conidia produced under usual conditions (unpublished data).

In contrast, for traverses from 21.00 to 00.00 h GMT a high proportion of *Cladosporium* spores were very small, pale or colourless, and relatively unornamented, indicating that they were immature. In order to quantify these observations counts of mature vs immature *Cladosporium* conidia, arbitrarily defined as  $7.0 \mu\text{m}$  or greater, vs less than  $7 \mu\text{m}$  in length, were made for three traverses. These traverses were before the rain, at 20.30 h GMT, after the rain had started, at 21.00 h GMT, and at the peak concentration of *Cladosporium* spores, at 21.30 h GMT. The percentage of immature spores was 35%, 35% and 50% respectively, supporting the observation that before and immediately after the start of rain the proportion of immature conidia was identical and lower, but at the peak concentration the proportion of immature conidia was higher.

This change in the degree of maturity of the conidia suggests a more complex situation than the usual one in which conidia are released in response to the start of the rain, but then rapidly removed by rain-scrubbing. It

is suggested that during this storm in Cambridge there were three phases in the rise and fall of *Cladosporium* spore concentrations, not the usual two. The first phase was the release of those conidia, mostly mature, which had formed, but had not been released, before the rain. These would have been released by the first raindrops at 20.37 h GMT, and by some heavy raindrops at 20.49 h GMT, and first detected in the traverse centred at 20.45 h GMT. (These conidia would have been deposited over a band just over 2 mm wide.) The proposed second phase, one which does not usually occur, was during a period when rain was for the most part very light, until 21.48 h GMT. During this period concentrations of immature spores were high. It is suggested that conditions were simultaneously favourable for the formation of *Cladosporium* spores, and also for their release at an unusually early stage in their development. Certainly under normal conditions *Cladosporium* concentrations increase after rain, Hjelmroos (1993), and pers. obs. Presumably rain was not heavy enough for spores to be removed quickly by rain-scrubbing.

The proposed third phase is after the start of heavy rain, after 21.48 h GMT. It is suggested that after this time the predominant mechanism in operation was rain-scrubbing, removing spores from the air quickly. By 22.45 h GMT the thunder and rain were over, and *Cladosporium* concentrations rose again to the levels of concentration found before the storm.

The proposed sequence of three phases for *Cladosporium* concentrations for this storm can only be tentative, given the qualitative nature of the rainfall record.

For London hourly rainfall records were available, Figure 6, and these show a small amount of rain starting at some time between 19.00 and 20.00 h GMT, when *Cladosporium* concentrations rose to a peak at 19.30 h GMT, a similar amount of rain during the next hour, when *Cladosporium* concentrations levelled off, and heavier rain between 21.00 and 22.00 h GMT when *Cladosporium* spore concentrations declined, returning to pre-storm levels after 23.00 h GMT, after the rain had stopped. The sequence of events for *Cladosporium* spore concentrations in North London shared some features with that in Cambridge, but interpretation is complicated by the strong gusting at 19.30 h GMT in London, Figure 5.

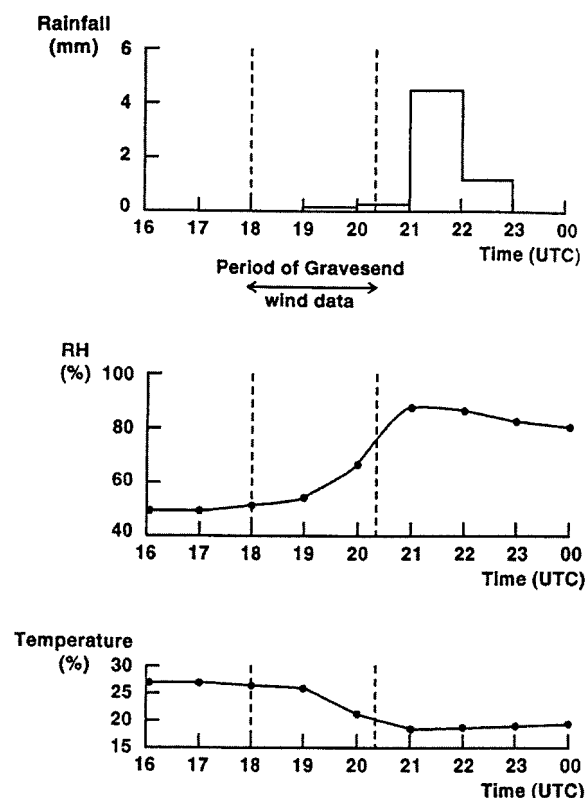


Figure 6. Surface observations of rainfall, RH, and temperature from the London Weather Centre on 24 June 1994.

### Ascospore release

The first unusual feature was the paucity of *Didymella* ascospores, as it is very common for high numbers of these spores to be released after rain. The relevant species of *Didymella* occur on grasses, Allitt (1986). They produce their fruiting bodies on living grass leaves, and the ascospores are ready for release as the leaves become older. In culture this process takes about 3 weeks, Obst (1983). The ascospores are released after rain (or dew), and the asexual spores are spread by rain splash, so only after a period of wet weather will infection levels build up. In fact the weather was very dry in England for the 3 or 4 weeks before 24 June, for example in Cambridge there were only 11.3 mm of rain in the previous 28 days.

The second unusual feature was the high concentrations of ascospores of *P. nigrans*. This fungus fruits on dead grass culms, but it has an annual life-cycle, not one of a few weeks. Webster (1957), concluded that *P. nigrans* 'has a moderately high moisture requirement'. The summer and autumn of 1993, and winter

and spring of 1994 had been very wet. In Cambridge the rainfall for 11 of the 13 months from April 1993 to April 1994 had been well above the 30 year mean. It had been wet for over one cycle, so numbers of fruiting bodies of *P. nigrans* would be expected to be much higher than usual. As mentioned above June itself was particularly dry, so there would have been many ripe ascospores awaiting release by 24 June.

The third unusual feature of the ascospore air spora was the high numbers of Diatrypaceous ascospores present at several sites. Members of the Diatrypaceae occur on wood, either living, moribund or dead. Research has been done on some of the pathogenic species in the Diatrypaceae, for example a study of *Eutypella parasitica* by Johnson and Kuntz (1979). The stromata of *E. parasitica* last for several years, and new fruiting bodies form in the old tissue. It is not reported whether this process is favoured by wet conditions, but it seems possible. This could be a reason why so many Diatrypaceous ascospores were available for dispersal on 24 June. As in *P. nigrans*, perithecial development of Diatrypaceous species could have been favoured by a long period of wet weather, except for the preceding month, during which time many ripe ascospores could accumulate undischarged.

Levels of concentrations of ascospores of *P. nigrans* and Diatrypaceae varied from site to site, presumably because at some sites there were many grass culms, and at others more trees. The importance of differences in the proportions of ascospores belonging to different species from site to site, even over quite small distances, is demonstrated by the differences between the two Cambridge sites. The high concentrations of *P. nigrans* and Diatrypaceous ascospores occurred at the Department of Plant Sciences site, close to college gardens with grass mown only once a year, in July, and many old trees, but in lower concentrations close to a garden in West Chesterton, where the immediate surroundings included fewer trees and grass which was mown more often. At that site there were more ascospores of *Leptosphaeria rubicunda*, quite common on the previous year's dead flowering stems of herbaceous plants and ascospores of *Diaporthe* species, on similar substrates. In the calmer conditions after the rain, when most ascospores were released, spores would not be carried away so quickly, and any local effects could be detected.

Another surprising feature was that at three of the sites spores were caught which matched published

illustrations of the conidia of the coelomycete stage of *P. nigrans*, Webster (1955). It is extremely unusual to find the asexual spores of species of *Leptosphaeria* in the air, pers. obs. It is known that they are normally dispersed by rain-splash, or more rarely by wind-blown water drops, Brennan et al. (1985). The occurrence of these conidia indicates that some splash droplets containing the spores had been blown by wind, and the water had later evaporated, leaving the spores airborne. This prompts the speculation that the small allergenic particles produced from grass pollen grains by osmotic shock could have become airborne from wind-blown water droplets.

The differences between this storm and the storms at Rothamsted, Hirst (1953) and Leicester in 1989, Allitt and Stern (1997), can be reconciled by the general observation that a dry air spora before a storm is succeeded after the rain by a damp air spora of ascospores (and later *Sporobolomyces* ballistospores etc.). In some storms there may be an intervening stage at the beginning of the storm when there may be a transient increase in dry loose powdery spores or pollen, and there may be a transient increase in spores such as those of *Cladosporium*. This is further illustrated by the events of two subsequent storms in Cambridge. In a storm on 24 July 1994 there was a small transient rise of spores of several smut species (the main season for *U. segetum* was over), the loose dry powdery urediniospores of rust fungi and a dense band of translucent dust. There was also a transient rise in *Cladosporium* spores, and after the rain there were modest concentrations of ascospores of *Didymella*, *P. nigrans* and *Diatrypaceae*. A storm early in the summer, on 6 June 1996, was characterised by a transient rise in grass pollen, followed by the release of ascospores of *Lewia*.

The original reason for this study was to investigate a possible cause of the asthma epidemic involving fungal spores. The variation in spores from site to site, and the very short-lasting nature of some of the changes, and the relatively low concentrations of fungal spores in the London area, where the epidemic was worst, Venables et al. (1997), would seem to rule this out.

## Conclusions

This may be the first time that the airborne fungal spores at so many sites were examined for the same event. The availability or non-availability of spores of

particular fungi is explicable in terms of the presence or absence of particular substrates, the way in which environmental factors had affected different species, and seasonality. Ascospore release was straightforward enough, but the difficulty in disentangling the numerous factors involved in the release of conidia and ustilospores under these unusual conditions demonstrated that the usual methods of studying changes in spore concentrations are not sufficient. In order to understand spore release more fully, in both normal and extreme conditions, it may be necessary to compare changes in spore concentrations with such variables as wind turbulence and changes in electrical charges on substrate surfaces, as well as, or even rather than, the meteorological variables which are more easily obtainable, and to follow changes in spore concentrations in hours, minutes, and seconds, rather than days and hours.

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## References

- Allitt U.: 1986, Identity of airborne hyaline, one-septate ascospores and their relation to inhalant allergy. *Trans. Br. Mycol. Soc.* **87**, 147–154.
- Allitt U. and Stern M.A.: 1997, Asthma and *Didymella* ascospores following a thunderstorm in Leicester (England). In: S.N. Agashe (ed), *Aerobiology*. New Delhi, Calcutta, Oxford & IBH Publishing Co. PVT. Ltd., pp. 321–326. (Proceedings of the 5th International Conference for Aerobiology, Bangalore, 1994.)

- Brennan R.M., Fitt B.D.L., Taylor G.S. and Colhoun J.: 1985, Dispersal of *Septoria nodorum* pycnidiospores by simulated rain and wind. *Phytopath. Z.* **112**, 291–297.
- Hirst J.M.: 1953, Changes in atmospheric spore content: Diurnal periodicity and the effects of weather. *Trans. Br. Mycol. Soc.* **36**, 375–393.
- Hirst J.M. and Stedman O.J.: 1963, Dry liberation of fungus spores by raindrops. *J. Gen. Microbiol.* **33**, 335–344, 2 plates.
- Hjelmroos M.: 1993, Relationship between airborne fungal spore presence and weather variables, *Cladosporium* and *Alternaria*. *Grana* **32**, 40–47.
- Johnson D.W. and Kuntz J.E.: 1979, Eutypella canker of maple: Ascospore discharge and dissemination. *Phytopathol.* **69**, 130–135.
- Knox R.B.: 1993, Grass pollen, thunderstorms and asthma. *Clin. Exp. Allergy* **23**, 354–359.
- Leach C.M.: 1976, An electrostatic theory to explain violent spore liberation by *Drechslera turcica* and other fungi. *Mycologia* **68**, 63–86.
- Leach C.M.: 1980, Evidence for an electrostatic mechanism in spore discharge by *Drechslera turcica*. *Phytopathol.* **70**, 206–213.
- Mills J.T.: 1967, Spore dispersal and natural infection in the oat loose smut (*Ustilago avenae*). *Trans. Br. Mycol. Soc.* **50**, 403–412.
- Mordue J.E.M. and Ainsworth G.C.: 1984, Ustilaginales of the British Isles. *Mycol. Papers, CMI* **154**, 1–96.
- Obst A.: 1983, Observations and findings on a little-known *Ascochyta* leaf spot disease of cereals. *Z. Pflanzenkr. Pflanzenschutz* **90**, 113–118.
- Sreeramulu T.: 1962, Aerial dissemination of barley loose smut (*Ustilago nuda*). *Trans. Br. Mycol. Soc.* **45**, 373–384.
- Venables K.M., Allitt U., Collier C.G., Emberlin J., Greig J.B., Hardaker P.J., Higham J.H., Laing-Morton T., Maynard R.L., Murray V., Strachan D. and Tee R.D.: 1997, Thunderstorm-related asthma – the epidemic of 24/25 June 1994. *Clin. Exp. Allergy* **27**, 725–736.
- Webster J.: 1955, Graminicolous Pyrenomycetes. V. Conidial states of *Leptosphaeria michotii*, *L. microscopica*, *Pleospora vagans* and the perfect state of *Dinemasporium graminum*. *Trans. Br. Mycol. Soc.* **38**, 347–365.
- Webster J.: 1957, Succession of fungi on decaying cocksfoot culms, Part II. *J. Ecol.* **45**, 1–30.