Pageoph, Vol. 116 (1978), Birkhäuser Verlag, Basel

Distribution of Airborne Pollen and Spores and their Long Distance Transport

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Abstract – The atmosphere near the ground contains a mixed population of pollen and spores in the 1 to 90 μm diameter range. Continuous sampling at Rothamsted Experimental Station at 2 m above ground level indicated concentrations averaging 12,000 m^{-3} over 5 summer months, but 1 million m^{-3} can occur for short periods. Concentrations change rapidly with locality, season, time of day or night and weather. Normally concentration in the troposphere decreases logarithmically with height. The occurrence of long distance transport of pollen and spores by wind is demonstrated by sampling from aircraft, and supported by much circumstantial evidence. Possible effects of this air spora on the atmosphere may be sought in alterations to: opacity, ionization, condensation nuclei, and sinks for minor gases.

Key words: Pollen; Spores; Transport; Vertical distribution.

1. Introduction: the air spora

Continuous sampling of particles in the diameter range of 4–90 μm in outdoor air became possible 25 years ago with the introduction of the Hirst automatic volumetric spore trap, which impacts particles on to a slowly moving slide for microscopic examination. As a result, we now know that the atmosphere near the ground carries an 'air spora' which varies in time and place, season and weather, both in numbers of particles and their species composition.

An example illustrates the catch in fine weather in late summer in southern England. In this size range most of the airborne particles are clearly organismal, and most of them originate from surface vegetation, rather than directly from the soil.

Their great variation in size affects their terminal velocity of fall which is proportional to the square of equivalent diameter. They vary in shape, surface wettability, and colour (pigments probably have some protection against radiation). All have densities close to that of water, say 0.9–1.2 g cm^{-3}. Resulting terminal velocities cover the range: 1 mm sec^{-1} to 30 cm sec^{-1}.

According to season we find pollen grains, especially grasses, conifers and other trees; spores of mosses and ferns; and spores of fungi, especially from moulds and agarics (the cap fungi, or hut pilze) and the Sporobolomycetes (the mirror yeasts, or spiegelhefe) which abound on leaf surfaces.

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At Rothamsted Experimental Station in the south of England, sampling continuously with the Hirst trap during the 5 summer months at 2 m above ground level, showed the pollen and spore content of the air averaging 12,500 m^{-3} (GREGORY and HIRST, 1957). Pollen accounted for only 1 percent of this total. Nearly half the total consisted of spores of the common mould *Cladosporium* which predominated by day. Whereas 30 percent consisted of minute hyaline basidiospores of *Sporobolomyces* (Spiegelhefe) which predominated at night.

A neighbouring trap at 24 m a.g.l. averaged 82 per cent of the trap at 2 m.

These are long-term means: over short periods much denser concentrations have been observed, for instance night time concentrations of a million spores of *Sporobolomyces* per cubic metre. Mowing or harvesting crops gives a great local increase in concentrations.

The species composition of the air spora varies characteristically with time and weather. With a little practice it is easy to recognize on the dust trace on the microscope slide the typical pattern of a fine day in summer, followed by a dry dewy night. Rain puts a characteristic spora into the air, but prolonged rain washes it out again (HIRST, 1953).

These airborne pollens and spores are parts of the life-cycles of living organisms. Inorganic dusts may happen to be airborne because of their properties, picked up by wind or ejected from volcanoes. By contrast, the structure and behaviour of components of the air spora have been modified in evolution towards recurrent needs in the life-cycle (an example of feed-back). They use wind movement either: (1) to colonize territory not already occupied by the species; or (2) to transmit genetic novelty between populations on the ground, and test it in new environments.

Airborne pollen does *not* enable a plant to occupy new territory: it is solely an airmail service for posting genes. By contrast the spores of ferns, mosses and fungi are usually (perhaps incorrectly) considered only as colonizing fresh substrates.

Among organic adaptations, most conspicuous are the numerous intricate devices which launch the pollen grain or spore into the wind. Usually the resulting aerosol is monodisperse, though some mould spores which are formed in chains may fail to separate completely. But usually the aerosol consists of single pollen grains and single spores.

Conspicuously successful is the launching mechanism typically found in the basidiomycetes including mushrooms, toadstools and other cap fungi. Probably 98 percent of their spores are launched successfully and remain in the air as single spores – perhaps discouraged from coagulating because each basidiospore normally carries a small electrostatic charge when it leaves the parent fungus.

2. *Concentration changes in horizontal travel*

Consider an individual organism, which is launching spores or pollen into the air, as a point source. The resulting aerosol may even be a visible cloud of airborne particles. This cloud decreases in concentration as it travels with the wind, firstly because it is diluted by eddy diffusion, spreading out the cloud in the x, y and z coordinates as it travels downwind.

Concentration also decreases during wind transport by dry deposition to ground, to vegetation and to other surfaces near the ground (not to mention a small but socially important fraction inhaled into the human respiratory tract).

Dry deposition depends in various ways on terminal velocity of the particle. Different sized components of a mixed aerosol, although behaving very similarly in respect to eddy diffusion, will be sorted out in travel as the cloud is depleted of larger particles faster than it is of smaller ones.

Biologically a further loss is imposed on the effects of diffusion and dry deposition – this is loss of viability as a result of ageing, radiation, desiccation and other stresses of the aerial environment, such as the toxic 'open air factor' (see: STRANGE and COX, 1976). Viability may well have little relevance to the effect of the air spora on the atmosphere.

The foregoing account applies to travel of the aerosol in dry weather. Rain falling through the spore and pollen cloud rapidly washes out the entrained particles and so puts an end to the dispersal process.

3. *Escape fraction*

An apparent contradiction must now be examined. Experiments in which known numbers of large spores are liberated artificially from a point source show that commonly over 90 percent are deposited within 100 m of the point of liberation (SREERAMULU and RAMALINGAM, 1961). Extrapolating to say 1 km downwind suggests that little or nothing remains in suspension for long-distance dispersal – yet much circumstantial evidence shows that it indeed occurs.

The apparent contradiction may be explained by using an equation to calculate Q_x (the fraction of the source cloud, Q_0, remaining in suspension after different distances of travel) and plotting on a double logarithmic scale. Decrease in Q_x at first follows a straight line, but eventually when much of the remaining cloud has diffused far enough upwards to put it beyond the risk of dry deposition to ground, the rate of loss decreases rapidly. Commonly at this point Q_x turns out to be about 5 or 10 percent of Q_0. This I have termed the escape fraction. With larger spores such as *Lycopodium* or cereal rusts, the escape fraction becomes apparent between 100 and 1000 m distance from source.

4. *Vertical concentration gradient*

The resultant between upward forces, mechanical turbulence and convection, acting against downward sedimentation under gravity, leads on average to a vertical concentration gradient – a logarithmic decrease of concentration with height. Deviations from this idealized vertical profile can be instructive: for instance some early records of cereal rust spores trapped by aircraft over the Canadian Prairies (CRAIGIE, 1945).

Profiles A and D (Fig. 1) were obtained during a local wheat rust epidemic and approach the ideal pattern of logarithmic decrease of concentration with height.

Profile B is interpreted as exemplifying the condition when rust spores are being transported from the south early in the season when local Manitoba wheat was not infected, but when by contrast the local wheat fields were acting as a sink removing spores from the lower part of the air mass.

Profile C was recorded at the height of a local rust epidemic and presumably shows the effect of a temperature inversion.

5. *Long distance dispersal*

Facts about long distance dispersal are difficult to obtain: there are people who deny its significance. Present knowledge is derived from two main sources: sampling from aircraft, and circumstantial evidence.

FULTON (1967) sampled for viable microbes, using aircraft flying at three different altitudes on a course seaward from Houston, Texas, for distances up to 640 km into the Gulf of Mexico. The irregular distributions obtained may be explained by the work of HIRST and HURST (1967) who sampled from aircraft over the sea between England

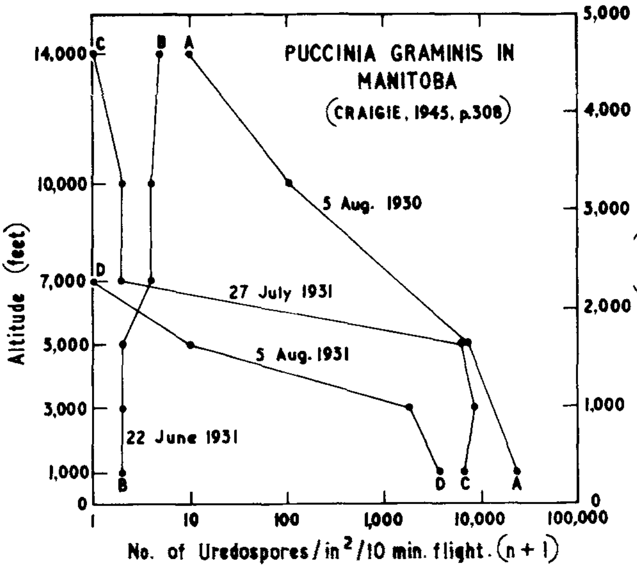

Figure 1

and Denmark: i.e., downwind of a geographically simpler source than available to Fulton.

Hirst and Hurst assessed particles by microscopic examination after trapping in isokinetic suction impactors.

One flight took samples between Yorkshire and the Skagerrak, around mid-day with the wind between south and west in July 1964. The flight first met the expected daytime *Cladosporium* and pollen cloud blown off the land; this, again as expected, decreased in concentration soon after leaving the coast. Unexpectedly concentrations increased again to a maximum at 400 to 500 km from the English coast. In between, at 100 to 200 km, and again further still from land at 500 to 600 km out, they found a maxima of types such as *Sporobolomyces* which had almost certainly been liberated into the air at night.

Evidently the aircraft started off in the current day's spore cloud, flew next into the previous night's cloud, then on into the previous day's cloud, and finally near the Danish coast, into that of the previous night.

Among circumstantial evidence, probably the long distance record is reported from Norwegian workers who found unmistakable pollen grains of the southern beech tree, *Notofagus*, and of *Ephedra*, in peat on the Island of Tristan da Cunha, 4500 km from the nearest sources in South America (Hafsten, 1960).

Notable circumstantial evidence is provided by the Rust Fungi, a group causing important diseases in many species of plants. Many examples could be cited, for instance:

The spread of the tropical maize rust is instructive. *Puccinia polysora* is probably indigenous on maize in the Americas on tolerant varieties of maize, separated by the 5600 km of the Atlantic Ocean which apparently formed an impassable barrier to wind transport to the African continent. In 1949 the fungus suddenly appeared in Sierra Leone, probably carried by aircraft with seed corn or corn on the cob (Cammack, 1958). African maize varieties were highly susceptible and the attack was devastating. Once in Africa it spread at about 1000 km a year. Another focus started in Malaysia.

Hermansen, Torp and Prahm (1976) detected living and virulent spores of barley and wheat rusts in western Denmark, carried by an air mass which back-tracking showed had crossed southern England 12 or more hours earlier.

Wilkinson and Spiers (1976) give circumstantial evidence that invasion of New Zealand by two different species of *Melampsora*, a rust genus attacking poplars, occurred by wind across the Tasman Sea from Australia during March 1973.

6. *Possible influences on the atmosphere*

Formerly the atmosphere and its circulation have been considered for effects on airborne pollen and spores (Gregory, 1973). This Symposium reverses enquiry.

Preliminary estimates suggest that between the altitudes of 2 m and 1 km above land surface the atmosphere carries between 1000 and 6000 spores and pollens over each cm^2 of surface. Over the sea, between 0.6 and 1.8 km altitude the load is about 1000 per cm^2 of surface (HIRST and HURST, 1967; GREGORY, 1973, p. 197). The following possible effects of this load might be considered.

(1) *Opacity.* Is transparency decreased by particles in the 10 μm range, averaging perhaps 25,000 m^{-3} in fine summer weather, or even 1 million m^{-3}, at peak concentration?

(2) *Electrical effects.* Little is known about charges carried by spores or pollen, but at least basidiospores when liberated commonly carry an electrostatic charge, which might be a sink for atmospheric ions.

(3) *Condensation nuclei.* Numbers of spores and pollens encountered are many orders of magnitude fewer than figures commonly quoted for Aitken nuclei. But with their diverse properties the components of this fraction of the aerosol would be worth considering for effects on precipitation.

(4) *Sinks for gases.* The spore cloud consists of carbohydrates, lipids, proteins and water bounded by walls of cellulose, chitin, waxes, sporopollenin, etc. Is it a significant sink for some of the rarer gases considered by other contributors to the Symposium?

Finally, to elucidate some chemical studies of the atmosphere, the data suggest that it is necessary to distinguish between the contributions made by solid, liquid and gas phases.

REFERENCES

CAMMACK, R. H. (1958), *Studies on* Puccinia polysora *Underw. II. A consideration of the method of introduction of* P. polysora *into Africa*, Trans. Br. mycol. Soc. *42*, 27–32.

CRAIGIE, J. H. (1945), *Epidemiology of stem rust in Western Canada*, Scient. Agric. *25*, 285–401.

FULTON, J. D. (1966), *Micro-organisms of the upper atmosphere. IV. Micro-organisms of a land air mass as it traverses an ocean*, Appl. Microbiol. *14*, 241–4.

GREGORY, P. H., *The Microbiology of the Atmosphere*. 2nd Edition. (Leonard Hill/Intertext, Aylesbury 1973), 377 pp.

GREGORY, P. H. and HIRST, J. M. (1957), *The summer air spora at Rothamsted in 1952*, J. gen. Microbiol. *17*, 135–52.

HAFSTEN, U. (1960), *Pleistocene development of vegetation and climate in Tristan da Cunha and Gough Island.* Arbok Univ. Bergen, Mat. Natur. Ser. 1960, No. 20, 48 pp.

HERMANSEN, J. E., TORP, U. and PRAHM, L. P. (1976), *Evidence of long-distance dispersal of live spores of* Puccinia hordei *and* P. recondita *f.sp.* tritici, Cereal Rusts Bulletin *4*, 31–35.

HIRST, J. M. (1953), *Changes in atmospheric spore content: diurnal periodicity and the effects of weather*, Trans. Br. mycol. Soc. *36*, 375–93.

HIRST, J. M. and HURST, G. W. (1967), *Long-distance spore transport* in *Airborne Microbes* (ed. P. H. Gregory and J. L. Monteith), Symp. Soc. gen. Microbiol. *17*, 307–44. Cambridge University Press.

SREERAMULU, T. and RAMALINGAM, A. (1961), *Experiments on the dispersion of* Lycopodium *and* Podaxis *spores in the air*, Ann. appl. Biol. *49*, 659–70.

STRANGE, R. E. and COX, C. S. (1976), *Survival of dried and airborne bacteria*, in The Survival of Vegetative Microbes (ed. T. R. G. Gray and J. R. Postgate), Symp. Soc. gen. Microbiol. *26*, 111–54. Cambridge University Press.

WILKINSON, A. G. and SPIERS, A. G. (1976), *Introduction of the poplar rusts* Melampsora larici-populina *and* M. medusae *to New Zealand and their subsequent distribution*, N.Z. J. Sci. *19*, 195–8.

(Received 28th July 1977)