Meteorological aspects of particle dispersal

Meteorologiczne aspekty dyspersji cząstek

JEAN EMBERLIN

National Pollen Research Unit, University College, Worcester WR2 6AJ UK

Abstract

The main meteorological factors that influence particle dispersal are atmospheric stability, wind direction and speed, and precipitation.

The troposphere, the lowest layer of the atmosphere, contains 75% of the total molecular or gaseous mass of the air and nearly all the water vapour and aerosols.

The airborne particle diffusion, transport and precipitation depend on the wind speed, its direction and rainfalls.

Meteorological factors, which control the patterns of particle dispersal, have an important influence on their air concentrations.

Key words: *particle dispersal, atmospheric stability, wind, precipitation.*

Streszczenie

Głównymi czynnikami wpływającymi na dyspersję cząstek są: równowaga atmosferyczna, kierunek i prędkość wiatru oraz precypitacja.

Troposfera, najniższa warstwa atmosfery, zawiera 75% całkowitej masy molekuł i gazów powietrza oraz prawie całą parę wodną i aerozole.

Rozproszenie, przemieszczanie się oraz precypitacja cząstek powietrznopochodnych zależy od prędkości wiatru, jego kierunku oraz opadów deszczu.

Czynniki meteorologiczne kontrolujące modele dyspersji cząstek wywierają znaczący wpływ na ich stężenie w powietrzu.

Słowa kluczowe: *dyspersja cząstek, równowaga atmosferyczna, wiatr, precypitacja.*

(PDiA 2003; XX, 4: 209–211)

Concentrations of airborne particles differ a lot spatially and temporally because of the location of sources, the factors that govern release to the airflow and the factors of dispersal. Meteorological factors control the broad patterns of particle dispersal and therefore they have an important influence on the concentrations in the air. It is essential to know the main ways in which the meteorological factors work in order to understand changes in particle concentrations in time and space and to be able to develop methods of forecasting.

The main meteorological factors that affect particle dispersal are atmospheric stability, wind direction and speed, and precipitation. Aspects such as temperature and relative humidity are important for the production of pollen and spores and their release, and may be auto correlated with the other variables. This lecture will cover the main meteorological aspects relevant to dispersal. It will not deal with the physics of particle diffusion or with the factors of deposition.

Atmospheric stability

Seventy-five per cent of the total molecular or gaseous mass of the air and nearly all the water vapour and aerosols are contained in the lowest layer of the atmosphere. This layer, known as the **troposphere** also has the most pronounced weather phenomena and turbulence. Generally there is a decrease in temperature with height through the troposphere at an average rate of 6.25°C per km. The top of this layer is marked by the **tropopause** that acts like a weather ceiling because it consists of either a layer of warm air or a zone where temperatures remain constant with height. In both cases it operates to limit convection so that the troposphere is like a self contained system to a large extent.

Within the troposphere there is a layer through which the surface of the earth exerts an influence. This is the **atmospheric boundary layer**, usually known simply as the boundary layer. This layer is characterised by well developed turbulence generated by frictional drag as the air moves across the rough surface, and by parcels of air rising up by convection from the heated surface. The depth of the boundary layer varies through time, depending on the strength of the surface generated mixing. During the day when the surface is heated by the sun, there is an upward transfer of energy into the cooler atmosphere. Vigorous thermal mixing /convection enables the boundary layer to extend to about 1 to 2 km.

At night when the earth's surface cools more rapidly than the atmosphere there is a downward transfer of heat. Mixing is suppressed and the boundary layer may shrink to less than 100m. This ideal cycle can be disrupted by large scale weather systems whose wind and cloud patterns are not tied to surface features or to the daily heating cycle. For example anticyclones (high pressure systems) have stable atmospheric conditions which result in little vertical mixing whereas cyclonic (low pressure) systems have instable air flows and lead to greater dilution of particle clouds released near to the ground.

In order to understand how atmospheric stability influences particle dispersal it is useful to consider a parcel of air rising through the atmosphere fast enough to prevent energy exchange with the surroundings. A parcel like this is said to be moving **adiabatically**. As it rises it will pass through progressively lower atmospheric pressure because the mass of the air above it becomes progressively less. The parcel of air will expand due to the decreased pressure around it. In doing this it will push away the surrounding air, a process that requires energy. The only source available is the thermal energy within the parcel, so as the parcel expands it becomes cooler. Calculations have shown that in dry, unsaturated air the rate of temperature change with height is the constant value of 9.8°C per km. This is called the **dry adiabatic lapse rate**, (DALR) and is usually denoted by the symbol Γd. The **environmental lapse rate** (ELR) is a measure of the actual temperature structure of the troposphere at a particular site. It varies with both space and time. The relative tendency for a parcel of air to move vertically can be evaluated in a dry atmosphere by comparing the values of the ELR against the DALR This will indicate the degree of stability.

Basically there are three possible situations:

- **strong lapse rates** (leading to instability and much vertical mixing). Strong lapse rates generally lead to dilution of particulates in the air and therefore to low concentrations of pollen and spores;
- **stable lapse rates** (leading to settled conditions that prevent much mixing). Stable lapse rates generally lead to higher concentrations of pollen and spores because there is less dilution in the air flow. In summer, stable conditions are associated with dry warm weather. However local convection currents can develop in hot weather leading to mixing;
- **neutral lapse rates** (that are between the two extremes).

Inversions exist when warm air overlies cooler air. This can be through cooling from below, warming from above (usually adiabatic) or by the advection of warmer or cooler air. Inversions are very important to dispersion of pollen, spores and aerosols so special attention needs to be devoted to their characteristics and origins.

Wind speed and direction

Horizontal temperature variations in the earth's atmosphere produce horizontal pressure differences, resulting in winds. In this way the thermal energy from solar energy is converted into the kinetic energy (energy of movement) of winds. The energy then participates in a kinetic energy cascade involving the transfer of energy to increasing smaller scales of motion by turbulence. The existing airflow will also be modified on scales larger than those of the boundary layer by the presence of large-scale weather systems.

The energy of motion in the atmosphere will also diffuse (dilute) and transport the airborne particles. When a wind is blowing, particles are diffused both in the along wind axis and by **turbulent eddy diffusion** in the across wind and vertical directions. The greater the wind speed the greater the volume of air passing over the source, and the smaller the concentration per unit volume will be. In this way, dilution can occur by forward stretching, if the release of the pollen or spores from the plant is constant.

Greater wind speeds also mean greater turbulence since wind speed governs the amount of forced convection generated in the boundary layer both due to internal shearing between layers and between the air and the surface roughness elements. Eddies generated in this way are characteristically small and their action on the pollen or spore cloud is to dilute it rapidly by mixing with a larger volume of air. Turbulence involves fluctuations in direction as well as speed and these small-scale eddy motions diffuse a pollen cloud horizontally.

Wind direction is important for determining the course of the transport from the source to the receptor. When analysing flow paths it is important to realise that wind direction often changes with height because of shearing.

Trajectories of air masses at different pressure levels need to be examined to determine the possible origins of particular pollen incidents. Even at individual heights there is typically perpetual variation in directions over the course of short periods such as an hour. These fluctuations may cover an arc of 30–45 degrees centred on the mean wind direction.

Wind speed has a large responsibility for determining the distance of transport. In strong winds the pollen cloud may be transported long distances but the concentration will decrease because of stretching and because of the increased depletion from impaction through more turbulence etc. In weak winds concentrations are high locally but are typically lower away from source areas such as in cities.

The surface configuration of the land will have a great influence on wind speed and direction. Very few places are completely flat so in most cases the influence of slopes, hills and valleys needs to be considered. Every hill, valley and obstacle creates a disturbance in the pattern of airflow so that the detailed wind climate of every landscape is unique. However it is possible to isolate some typical flow patterns associated with specific features, such as the flow round an isolated obstacle, flow over a break of slope and valley wind systems.

Coastal locations tend to have lower pollen counts than inland regions because of the flushing by „clean" air from over the seas. However on hot days if there is not a strong regional airflow a local air circulation can develop between the land and the seas. The land will heat up more than the sea warming the air above it. This sets up convection currents causing the air to rise. Other air will flow in from over the sea to replace the rising air so creating a breeze. The air that has risen will flow out over the seas at a high level, will cool and will sink to replace the air that has gone inland. The circular flow will be reversed at night when the land cools and the seas remains relatively warm. This reversal of the circulation can occur for many days consecutively resulting in a build up of the pollen concentration in the air mass so that the air coming from above the seas contains a high pollen count. This situation can occur for example, along the Adriatic coasts.

Precipitation

Even slight rainfall will usually cause a marked decrease the concentration of airborne particles but the timing of the rainfall during the day is important in determining the magnitude of the daily average pollen count. Most grasses release pollen in the mornings (and some also in the evenings) so if it is raining at this time, the pollen concentration will be low all day but conversely a dry morning followed rain later in the day may result in a high or moderate daily average count.

On certain occasions, such as with increased gustiness at the start of storms, pollen concentrations may increase temporally with the onset of rainfall. Contact with raindrops may cause pollen grains to burst through osmotic shock releasing paucimicronic granules that contain allergen. This mechanism can result in a high allergen load in the atmosphere even though the pollen count is low.

Medium and Long range transport

In certain meteorological conditions pollen can be transported greater distances than would normally be observed. For example on hot dry days convection cells may develop. These may be several kilometres across and rise several hundred metres above ground. Even relatively heavy pollen grains such as Maize may be lifted up by these, travel horizontally with the flow at the top of the cell then be returned to ground level several kilometres from the source.

The long range transport of air pollution (e.g. over distances of more than 100 km) has been studied since the 1960s but less attention has been given to long range transport of pollen. However this process is known to occur , for example with *Betula* pollen into Scandinavia from areas to the south and with Ambrosia pollen from Hungary into Austria. It is mostly likely to happen in dry conditions of limited mixing depth and a moderate to strong steady wind without high turbulence.

An example of special situation: Urban Climates

More than sixty per cent of the world's population live in towns with more than 10,000 inhabitants. Typically most pollen monitoring sites are in towns and cities so it is very important to understand the climates of urban areas and the ways in which they influence the dispersal of biological particles.

Urbanisation produces radical changes in aerodynamic features of a region. The block like configurations create the possibility of radiation trapping and air stagnation, and gives a very rough surface that alters the features of the airflow.

The air in cities is usually warmer than that in the surrounding country side partly because of heat from buildings including lighting and power plant and partly due to differences in albedo (reflectivity). This warmer air over the city is known as the urban heat island effect. This is important for aerobiology in several ways. It influences the phenology of plants within the city, often giving an earlier start to the growing season compared with the surrounding rural areas. The heat island also affects airflow patterns and local stability.

References

1. Ahrens CD: Meteorology Today: An Introduction to Weather, Climate and the Environment. Brookes/Cole London 1999.
2. Anthes RA: Meteorology. Prentice Hall 1997.
3. Barry RG, Chorley RJ: Atmosphere weather and Climate. Routledge 1992.
4. Cox CS, Wathes CM (Eds): Bioaerosols handbook. Lewis Publishers ISBN 1-87371-615-9 (An advanced but very useful text) 1995.
5. Elcombe D: Weather Climate and Ecosystems. Hodder and Stoughton 1998.
6. Moran J, Morgan M: Meteorology. The atmosphere and the science of weather. Macmillan College Publishing 1994.
7. Barry RG, Chorley RJ: Atmosphere weather and Climate. Routledge (8th edition due Septmber 2003) 1992.

The 6th European Course On Basic Aerobiology,
Poznan, Poland
J. Emberlin