Atmospheric particulate matter

Atmospheric particulate matter is a central component of the atmospheric chemical and climate system, a major air pollutant harmful to human health, and a component of biological systems and global biogeochemical cycles.

The terms particulate matter (PM) or aerosol particles describe condensed (solid or liquid) material suspended in the atmosphere. They includes crustal material, soot, combustion particles, nucleating clusters and biological material such as spores, but not by convention raindrops, hail or other hydrometeors. The term aerosol is often used in reference to PM, but technically refers to both the condensed phase particles and the gaseous medium they are suspended in. Primary PM is released to the atmosphere from sources such as incomplete combustion, dust and sea salt. Secondary PM is formed in the atmosphere from the condensation of low volatility gases such as sulfuric acid, ammonia and functionalised organic compounds. Many airborne particles comprise both anthropogenic and natural components.

Physical properties of PM

Size: Atmospheric particles have a range of shapes and morphologies. Their size is a somewhat elusive property; a number of operationally defined metrics are used, perhaps most commonly aerodynamic diameter. A particle with an aerodynamic diameter of 1 μm will exhibit the same inertial properties as a sphere with a diameter of 1 μm and a density of 1 g cm^{-3}, irrespective of the actual size, shape or density of the particle. A trimodal size distribution is commonly observed in the lower atmosphere, with a nucleation mode (< 0.1 μm diameter), an accumulation mode (~0.1 to 2 μm), and a coarse mode (> 2 μm). Secondary particles are formed in the nucleation mode (or, more commonly, material condenses onto existing particles). Particles grow in the accumulation mode through coagulation and condensation. Mechanically generated primary particles are mostly emitted in the coarse mode. The lifetime of accumulation-mode particles is largely determined by precipitation, whereas nucleation-mode particles more readily diffuse and undergo agglomeration, and the largest coarse mode particles undergo gravitational settling at appreciable rates. The greatest numbers of particles are in the nucleation mode; the greatest mass is in the coarse mode.

Composition: Typical continental urban boundary layer PM samples include natural crustal materials (carbonates, silicates), inorganic constituents such as sulfate (SO_4^{2-}), nitrate (NO_3^-), sodium, potassium, chloride and ammonium (NH_4^+), trace quantities of group I and II metals and other species such as copper, arsenic, zinc and vanadium (found in fuels and derived from crustal sources and vehicle brake and tyre wear), and organic components. The latter include products of incomplete combustion (such as soot or black carbon), larger molecules such as polycyclic aromatic hydrocarbons (PAHs) and secondary organic aerosol (SOA), formed from oxidation and subsequent condensation of volatile organic compounds (VOCs). Sea salt is an important contributor of sodium, chlorine and other ionic components; sulfate and nitrate originate in sulfuric and nitric acid, which in turn are derived from the gas-phase oxidation of SO_2 and NO_x respectively. Ammonia, derived mainly from agriculture, readily dissolves in aqueous particles and neutralises sulfate and nitrate, which are usually found as ammonium sulfate or ammonium nitrate in urban regions.

Abundance: Most current legislative limits to PM abundance, developed from an air quality perspective, relate to mass concentration below a certain size limit—commonly PM_{10} and $PM_{2.5}$, denoting the concentration of PM with aerodynamic diameters below ca. 10 and 2.5 μm respectively, which correspond roughly to adult human inhalable (thoracic) and respirable (alveolar) particle sizes respectively. Typical urban atmospheric loadings of PM range from tens to hundreds of μg m^{-3} for PM_{10}. For a city such as London, a mean mass concentration for PM_{10} of the order of 30 μg m^{-3} might be observed; considering the area of Greater London (ca. 400 km^2) and assuming a 1 km boundary layer height, this equates to around 12 tonnes of material suspended above the city.

Importance and impacts of PM

Human health impacts: Particulate matter has been a dominant factor in historical air pollution episodes, including the London Smogs of the 1950s and the Donora Valley (Pennsylvania) and Meuse Valley (Belgium) episodes. Inhalation of PM in an urban atmospheric context is associated with enhanced respiratory and cardiovascular disease (marked by an increase in hospital admissions) and increased associated mortality. The figures are not trivial: studies find a 1 to 4 % increase in cardiovascular mortality per 10 μg m^{-3} increase in PM_{10} (1). In the UK, eliminating all anthropogenic $PM_{2.5}$ (a practical impossibility) would increase life expectancy from birth by approximately six months, averaged across the whole population—roughly double the impact from elimination of all road accidents or passive smoking (2). Those with pre-existing respiratory conditions, as well as the young and elderly are at greater risk. PM mass concentrations in many nations are substantially higher than those in the UK, particularly in the developing world; burning wood, coal or biomass for domestic heating and cooking is a substantial source of personal exposure to PM in many such areas.

Impacts on climate and atmosphere: Atmospheric PM loading contributes to the reduction in visibility associated with poor air quality, and both directly and indirectly affects atmospheric radiation transmission and hence climate. These effects (mainly but not exclusively cooling in nature) are among the largest, and least well quantified, terms in climate models and could potentially substantially alter the magnitude of the calculated warming (3). Aerosol particles also play important roles in atmospheric chemistry, providing a reaction site for heterogeneous reactions that would not otherwise occur. Dust transport is an important component of the biogeochemical cycles for crustal minerals, notably iron, representing a major route for their input into marine ecosystems. Recently, the role of bioaerosols (viruses, fungal spores, plant and animal debris) has received increasing attention because of their potential role as cloud and ice nuclei and their health impacts, particularly allergenic reactions.

Legislative measures

***Table 1**: Air Quality Standards for Particulate Matter*

	WHO guidelines (4)	**EU Standards**
PM_{10}	20 μgm^{-3} (annual mean)	40 μgm^{-3} (annual mean)
	50 μgm^{-3} (24hr average)	50 μgm^{-3} (24 hr average, < 35 exceedances/yr)
$PM_{2.5}$	10 μgm^{-3} (annual mean)	25 μgm^{-3} (annual mean)
	25 μgm^{-3} (24hr average)	Target Value from 2010; Limit Value from 2015. See AEI discussion in text

Air Quality Standards for protection of health are set by bodies such as the World Health Organisation (WHO) and EU (**Table 1**). EU member states will have to meet an objective of 25 μg m^{-3} for all annual average $PM_{2.5}$ levels by 2015; this value has been an aspirational target value since 2010. Average Exposure Index (AEI) limits will also soon come in to force. The AEI is the three-year running mean of $PM_{2.5}$ levels in urban background locations; $PM_{2.5}$ exposure reduction targets, for AEIs relative to levels measured over the period 2009-2011, will come into force by 2020. The aim of the AEI concept is to reduce population-level exposure to $PM_{2.5}$, rather than focussing on the most polluted locations. The EU Thematic Strategy on Air Pollution, which drives the EU directives from which national environmental legislation is derived, is currently under review.

Compliance: In the UK, all areas meet current annual mean limit values for PM_{10} and $PM_{2.5}$, although the PM_{10} 24-hour target has been exceeded in Central London. Further policy measures are likely to be required to meet future $PM_{2.5}$ exposure reduction targets. Worldwide, the situation is very different. Unlike long-lived greenhouse gases, which are globally mixed, the health effects of PM are usually felt locally to the emission region, and so should be more amenable to national policy initiatives. Tensions exist between climate (“carbon”) policy and air quality; for example, increased use of local biofuel combustion for combined heat and power may increase local PM levels, and higher-mileage (lower-carbon) diesel vehicles are associated with higher primary and secondary PM formation. Yet globally, aerosol particles (other than black carbon) offset a substantial fraction of the warming that would otherwise result from greenhouse gases. Wider appreciation of the health impacts of PM exposure will inform development and acceptance of the optimum policy response.

Links and resources

EU Air Quality Objectives:
http://ec.europa.eu/environment/air/quality/standards.htm

UK Air Information Resource: http://uk-air.defra.gov.uk

References

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2. *The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the UK*; Committee on the Medical Effects of Air Pollutants (COMEAP), 2010.
3. S. Solomon, *et al.*, *Climate Change: The Physical Science Basis, IPCC Fourth Assessment Report*, Cambridge University Press, 2007.
4. WHO (2006), *WHO Air Quality Guidelines: Global Update 2005*, WHO/SDE/PHE/OEH/06.02 (2006); http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf

DR WILLIAM BLOSS
School of Geography, Earth and Environmental Sciences,
University of Birmingham,
w.j.bloss@bham.ac.uk