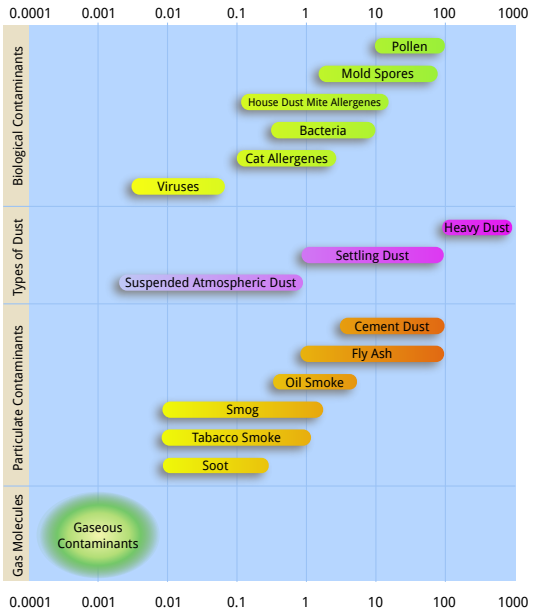
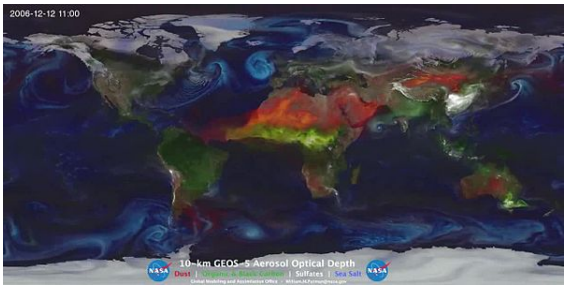
Particulates

This article is about particles suspended in air. For general discussion of particulate types, see Particle § Distribution of particles.
For other uses, see Particulates (disambiguation).

Atmospheric particulate matter – also known as

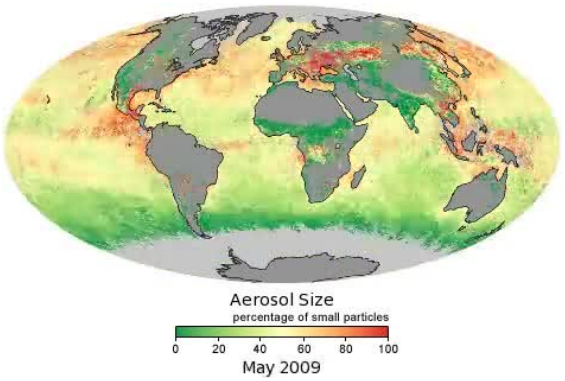


This diagram shows types, and size distribution in micrometres, of atmospheric particulate matter



This animation shows aerosol optical thickness of emitted and transported key tropospheric aerosols from 17 August 2006 to 10 April 2007, from a 10 km resolution GEOS-5 "nature run" using the GOCART model.[1][2] (click for more detail)
** green: black and organic carbon*
** red/orange: dust*
** white: sulfates*
** blue: sea salt*

particulate matter (**PM**) or **particulates** – are microscopic solid or liquid matter suspended in the Earth's atmosphere. The term aerosol commonly refers to the particulate/air mixture, as opposed to the particulate matter alone.[3] Sources of particulate matter can be man-made or natural. They have impacts on climate and precipitation that adversely affect human health.



Movie map of distribution of aerosol particles, based on data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite.
** Green areas show aerosol plumes dominated by larger particles.*
** Red areas show aerosol plumes dominated by small particles.*
** Yellow areas show where large and small aerosol particles are mixing.*
** Gray shows where the sensor did not collect data.*

Subtypes of atmospheric particulate matter include:

- Suspended particulate matter (SPM)
- Thoracic and respirable particles[4]
- Inhalable coarse particle, which are [coarse] particles with a diameter between 2.5 and 10 micrometres (μm)[5]
- Fine particles with a diameter of 2.5 μm or less[5]
- $PM_{2.5}$ [6]
- PM_{10}
- Ultrafine particles, and
- Soot

The IARC and WHO designate airborne particulates a Group 1 carcinogen. Particulates are the deadliest form of air pollution due to their ability to penetrate deep into the lungs and blood streams unfiltered, causing permanent DNA mutations, heart attacks, and premature

death.[7] In 2013, a study involving 312,944 people in nine European countries revealed that there was no safe level of particulates and that for every increase of 10 μg/m3 in PM_{10}, the lung cancer rate rose 22%. The smaller $PM_{2.5}$ were particularly deadly, with a 36% increase in lung cancer per 10 μg/m3 as it can penetrate deeper into the lungs.[8]

1 Sources of atmospheric particulate matter

Some particulates occur naturally, originating from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray. Human activities, such as the burning of fossil fuels in vehicles,[9] power plants and various industrial processes also generate significant amounts of particulates. Coal combustion in developing countries is the primary method for heating homes and supplying energy. Because salt spray over the oceans is the overwhelmingly most common form of particulate in the atmosphere, *anthropogenic* aerosols—those made by human activities—currently account for about 10 percent of the total mass of aerosols in our atmosphere.[10]

2 Composition

The composition of aerosols and particles depends on their source. Wind-blown mineral dust[11] tends to be made of mineral oxides and other material blown from the Earth's crust; this particulate is light-absorbing.[12] Sea salt[13] is considered the second-largest contributor in the global aerosol budget, and consists mainly of sodium chloride originated from sea spray; other constituents of atmospheric sea salt reflect the composition of sea water, and thus include magnesium, sulfate, calcium, potassium, etc. In addition, sea spray aerosols may contain organic compounds, which influence their chemistry.

Secondary particles derive from the oxidation of primary gases such as sulfur and nitrogen oxides into sulfuric acid (liquid) and nitric acid (gaseous). The precursors for these aerosols—i.e. the gases from which they originate—may have an anthropogenic origin (from fossil fuel or coal combustion) and a natural biogenic origin. In the presence of ammonia, secondary aerosols often take the form of ammonium salts; i.e. ammonium sulfate and ammonium nitrate (both can be dry or in aqueous solution); in the absence of ammonia, secondary compounds take an acidic form as sulfuric acid (liquid aerosol droplets) and nitric acid (atmospheric gas), all of which may contribute to the health effects of particulates.[14]

Secondary sulfate and nitrate aerosols are strong light-scatterers.[15] This is mainly because the presence of sulfate and nitrate causes the aerosols to increase to a size that scatters light effectively.

Organic matter (OM) can be either primary or secondary, the latter part deriving from the oxidation of VOCs; organic material in the atmosphere may either be biogenic or anthropogenic. Organic matter influences the atmospheric radiation field by both scattering and absorption. Another important aerosol type is elemental carbon (EC, also known as *black carbon*, BC): this aerosol type includes strongly light-absorbing material and is thought to yield large positive radiative forcing. Organic matter and elemental carbon together constitute the carbonaceous fraction of aerosols.[16] Secondary organic aerosols, tiny "tar balls" resulting from combustion products of internal combustion engines, have been identified as a danger to health.[17]

The chemical composition of the aerosol directly affects how it interacts with solar radiation. The chemical constituents within the aerosol change the overall refractive index. The refractive index will determine how much light is scattered and absorbed.

The composition of particulate matter that generally causes visual effects such as smog consists of sulfur dioxide, nitrogen oxides, carbon monoxide, mineral dust, organic matter, and elemental carbon also known as black carbon or soot. The particles are hygroscopic due to the presence of sulfur, and SO_2 is converted to sulfate when high humidity and low temperatures are present. This causes the reduced visibility and yellow color.[18]

3 Size distribution of particulates

Aerosol particles of natural origin (such as windblown dust) tend to have a larger radius than human-produced aerosols such as particle pollution. The false-color maps in the third image on this page show where there are natural aerosols, human pollution, or a mixture of both, monthly.

Among the most obvious patterns that the size distribution time series shows is that in the planet's most southerly latitudes, nearly all the aerosols are large, but in the high northern latitudes, smaller aerosols are very abundant. Most of the Southern Hemisphere is covered by ocean, where the largest source of aerosols is natural sea salt from dried sea spray. Because land is concentrated in the Northern Hemisphere, the amount of small aerosols from fires and human activities is greater there than in the Southern Hemisphere. Over land, patches of large-radius aerosols appear over deserts and arid regions, most prominently, the Sahara Desert in north Africa and the Arabian Peninsula, where dust storms are common. Places where human-triggered or natural fire activity is common (land-clearing fires in the Amazon from August–October, for example, or lightning-triggered fires in the forests of northern Canada in Northern Hemisphere summer) are dominated by smaller aerosols. Human-produced (fossil fuel) pollution is largely responsible for

the areas of small aerosols over developed areas such as the eastern United States and Europe, especially in their summer.[19]

Satellite measurements of aerosols, called aerosol optical thickness, are based on the fact that the particles change the way the atmosphere reflects and absorbs visible and infrared light. As shown in the seventh image on this page, an optical thickness of less than 0.1 (palest yellow) indicates a crystal clear sky with maximum visibility, whereas a value of 1 (reddish brown) indicates very hazy conditions.[20]

4 Deposition processes

Main article: Deposition (aerosol physics)

In general, the smaller and lighter a particle is, the longer it will stay in the air. Larger particles (greater than 10 micrometers in diameter) tend to settle to the ground by gravity in a matter of hours whereas the smallest particles (less than 1 micrometer) can stay in the atmosphere for weeks and are mostly removed by precipitation. Diesel particulate matter is highest near the source of emission.[21] Any info regarding DPM and the atmosphere, flora, height, and distance from major sources would be useful to determine health effects.

5 Control technologies

Main article: Dust collector

A complicated blend of solid and liquid particles result in particulate matter and these particulate matter emissions are highly regulated in most industrialized countries. Due to environmental concerns, most industries are required to operate some kind of dust collection system to control particulate emissions.[22] These systems include inertial collectors (cyclonic separators), fabric filter collectors (baghouses), wet scrubbers, and electrostatic precipitators.

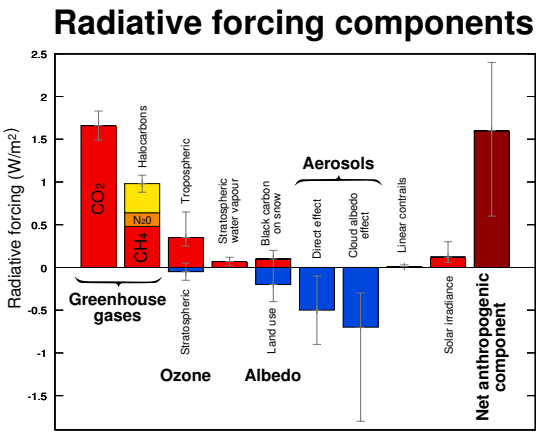
Cyclonic separators are useful for removing large, coarse particles and are often employed as a first step or "precleaner" to other more efficient collectors. Well-designed cyclonic separators can be very efficient in removing even fine particulates, and may be operated continuously without requiring frequent shutdowns for maintenance.[23]

Fabric filters or baghouses are the most commonly employed in general industry.[24] They work by forcing dust laden air through a bag shaped fabric filter leaving the particulate to collect on the outer surface of the bag and allowing the now clean air to pass through to either be exhausted into the atmosphere or in some cases recirculated into the facility. Common fabrics include polyester and fiberglass and common fabric coatings include PTFE (commonly known as Teflon). The excess dust buildup is then cleaned from the bags and removed from the collector.

Wet scrubbers pass the dirty air through a scrubbing solution (usually a mixture of water and other compounds) allowing the particulate to attach to the liquid molecules. Electrostatic precipitators electrically charge the dirty air as it passes through. The now charged air then passes by large electrostatic plates which attract the charged particle in the airstream collecting them and leaving the now clean air to be exhausted or recirculated.

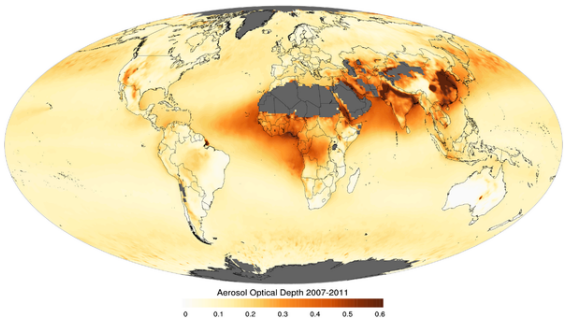
Besides removing particulates from the source of the pollution, it can also be cleaned in open air. Daan Roosegarde's Smog Free Tower for instance does this and the technique used in it (developed by Bob Ursem) is said to be able to reduce 60% of the particulates.[25]

6 Climate effects

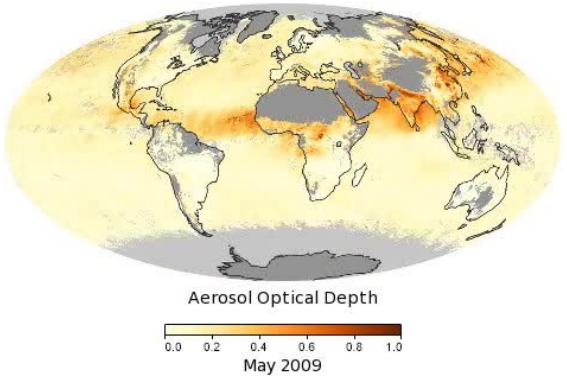


2005 radiative forcings and uncertainties as estimated by the IPCC.

Atmospheric aerosols affect the climate of the earth by changing the amount of incoming solar radiation and outgoing terrestrial long wave radiation retained in the earth's system. This occurs through several distinct mechanisms which are split into direct, indirect[26][27] and semi-direct aerosol effects. The aerosol climate effects are the biggest source of uncertainty in future climate predictions.[28] The Intergovernmental Panel on Climate Change, Third Assessment Report, says: *While the radiative forcing due to greenhouse gases may be determined to a reasonably high degree of accuracy... the uncertainties relating to aerosol radiative forcings remain large, and rely to a large extent on the estimates from global modelling studies that are difficult to verify at the present time.*[29]



Global aerosol optical thickness. The aerosol scale (yellow to dark reddish-brown) indicates the relative amount of particles that absorb sunlight.



These maps show average monthly aerosol amounts around the world based on observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite.

6.1 Aerosol radiative effects

6.1.1 Direct effect

Particulates in the air causing shades of grey and pink in Mumbai during sunset

The direct aerosol effect consists of any direct interaction of radiation with atmospheric aerosol, such as absorption or scattering. It affects both short and longwave radiation to produce a net negative radiative forcing.[30] The magnitude of the resultant radiative forcing due to the direct effect of an aerosol is dependent on the albedo of the underlying surface, as this affects the net amount of radiation absorbed or scattered to space. e.g. if a highly scattering aerosol is above a surface of low albedo it has a greater radiative forcing than if it was above a surface of high albedo. The converse is true of absorbing aerosol, with the greatest radiative forcing arising from a highly absorbing aerosol over a surface of high albedo.[26] The direct aerosol effect is a first order effect and is therefore classified as a radiative forcing by the IPCC.[28] The interaction of an aerosol with radiation is quantified by the single-scattering albedo (SSA), the ratio of scattering alone to scattering plus absorption (*extinction*) of radiation by a particle. The SSA tends to unity if scattering dominates, with relatively little absorption, and decreases as absorption increases, becoming zero for infinite absorption. For example, sea-salt aerosol has an SSA of 1, as a sea-salt particle only scatters, whereas soot has an SSA of 0.23, showing that it is a major atmospheric aerosol absorber.

6.1.2 Indirect effect

The Indirect aerosol effect consists of any change to the earth's radiative budget due to the modification of clouds by atmospheric aerosols, and consists of several distinct effects. Cloud droplets form onto pre-existing aerosol particles, known as cloud condensation nuclei (CCN).

For any given meteorological conditions, an increase in CCN leads to an increase in the number of cloud droplets. This leads to more scattering of shortwave radiation i.e. an increase in the albedo of the cloud, known as the Cloud albedo effect, First indirect effect or Twomey effect.[27] Evidence supporting the cloud albedo effect has been observed from the effects of ship exhaust plumes[31] and biomass burning[32] on cloud albedo compared to ambient clouds. The Cloud albedo aerosol effect is a first order effect and therefore classified as a radiative forcing by the IPCC.[28]

An increase in cloud droplet number due to the introduction of aerosol acts to reduce the cloud droplet size, as the same amount of water is divided between more droplets. This has the effect of suppressing precipitation, increasing the cloud lifetime, known as the cloud lifetime aerosol effect, second indirect effect or Albrecht effect.[28] This has been observed as the suppression of drizzle in ship exhaust plume compared to ambient clouds,[33] and inhibited precipitation in biomass burning plumes.[34] This cloud lifetime effect is classified as a climate feedback (rather than a radiative forcing) by the IPCC due to the interdependence between it and the hydrological cycle.[28] However, it has previously been classified as a negative radiative forcing.[35]

6.1.3 Semi-direct effect

The Semi-direct effect concerns any radiative effect caused by absorbing atmospheric aerosol such as soot, apart from direct scattering and absorption, which is classified as the direct effect. It encompasses many individual mechanisms, and in general is more poorly defined and understood than the direct and indirect aerosol effects. For instance, if absorbing aerosols are present in a layer aloft in the atmosphere, they can heat surrounding air which inhibits the condensation of water vapour, resulting in less cloud formation.[36] Additionally, heating a layer of the atmosphere relative to the surface results in a more stable atmosphere due to the inhibition of atmospheric convection. This inhibits the convective uplift of moisture,[37] which in turn reduces cloud formation. The heating of the atmosphere aloft also leads to a cooling of the surface, resulting in less evaporation of surface water. The effects described here all lead to a reduction in cloud cover i.e. an increase in planetary albedo. The semi-direct effect classified as a climate feedback) by the IPCC due to the interdependence between it and the hydrological cycle.[28] However, it has previously been classified as a negative radiative forcing.[35]

6.2 Roles of different aerosol species

6.2.1 Sulfate aerosol

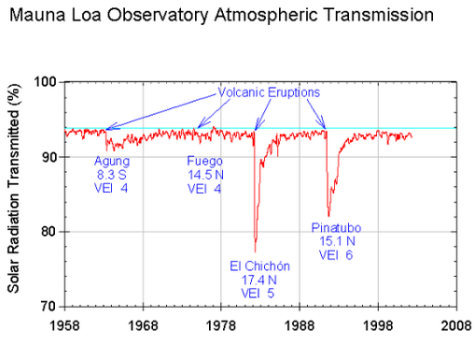
Main article: stratospheric sulfur aerosols

Sulfate aerosol has two main effects, direct and indirect. The direct effect, via albedo, is a cooling effect that slows the overall rate of global warming: the IPCC's best estimate of the radiative forcing is −0.4 watts per square meter with a range of −0.2 to −0.8 W/m^2[38] but there are substantial uncertainties. The effect varies strongly geographically, with most cooling believed to be at and downwind of major industrial centres. Modern climate models addressing the attribution of recent climate change take into account sulfate forcing, which appears to account (at least partly) for the slight drop in global temperature in the middle of the 20th century. The indirect effect (via the aerosol acting as cloud condensation nuclei, CCN, and thereby modifying the cloud properties -albedo and lifetime-) is more uncertain but is believed to be a cooling.

6.2.2 Black carbon

Black carbon (BC), or carbon black, or elemental carbon (EC), often called soot, is composed of pure carbon clusters, skeleton balls and buckyballs, and is one of the most important absorbing aerosol species in the atmosphere. It should be distinguished from organic carbon (OC): clustered or aggregated organic molecules on their own or permeating an EC buckyball. BC from fossil fuels is estimated by the IPCC in the Fourth Assessment Report of the IPCC, 4AR, to contribute a global mean radiative forcing of +0.2 W/m^2 (was +0.1 W/m^2 in the Second Assessment Report of the IPCC, SAR), with a range +0.1 to +0.4 W/m^2. Bond et al., however, states that "the best estimate for the industrial-era (1750 to 2005) direct radiative forcing of atmospheric black carbon is +0.71 W/m^2 with 90% uncertainty bounds of (+0.08, +1.27) W/m^2" with "total direct forcing by all black carbon sources, without subtracting the preindustrial background, is estimated as +0.88 (+0.17, +1.48) W/m^2"[39]

6.3 Instances of aerosol affecting climate



Solar radiation reduction due to volcanic eruptions

Volcanoes are a large natural source of aerosol and have been linked to changes in the earth's climate often with consequences for the human population. Eruptions linked to changes in climate include the 1600 eruption of Huaynaputina which was linked to the Russian famine of 1601 - 1603,[40][41][42] leading to the deaths of two million, and the 1991 eruption of Mount Pinatubo which caused a global cooling of approximately 0.5 °C lasting several years.[43][44] Research tracking the effect of light-scattering aerosols in the stratosphere during 2000 and 2010 and comparing its pattern to volcanic activity show a close correlation. Simulations of the effect of anthropogenic particles showed little influence at present levels.[45][46]

Aerosols are also thought to affect weather and climate on a regional scale. The failure of the Indian Monsoon has been linked to the suppression of evaporation of water from the Indian Ocean due to the semi-direct effect of anthropogenic aerosol.[47]

Recent studies of the Sahel drought[48] and major increases since 1967 in rainfall over the Northern Territory, Kimberley, Pilbara and around the Nullarbor Plain have led some scientists to conclude that the aerosol haze over South and East Asia has been steadily shifting tropical rainfall in both hemispheres southward.[47][49]

The latest studies of severe rainfall declines over southern Australia since 1997[50] have led climatologists there to consider the possibility that these Asian aerosols have shifted not only tropical but also midlatitude systems southward.

7 Health effects

Air pollution measurement station in Emden, Germany

See also: Environmental impact of the coal industry

7.1 Size, shape and solubility matter

The size of the particle is a main determinant of where in the respiratory tract the particle will come to rest when inhaled. Larger particles are generally filtered in the nose and throat via cilia and mucus, but particulate matter smaller than about 10 micrometers, can settle in the bronchi and lungs and cause health problems. The 10 micrometer size does not represent a strict boundary between respirable and non-respirable particles, but has been agreed upon for monitoring of airborne particulate matter by most regulatory agencies. Because of their small size, particles on the order of ~10 micrometers or less (PM_{10}) can penetrate the deepest part of the lungs such as the bronchioles or alveoli.[51]

Similarly, so called fine PM, (often referred to as *PM2.5*), tend to penetrate into the gas exchange regions of the lung (alveolus), and very small particles (< 100 nanometers) may pass through the lungs to affect other organs. Penetration of particles is not wholly dependent on their size; shape and chemical composition also play a part. To avoid this complication, simple nomenclature is used to indicate the different degrees of relative penetration of a PM particle into the cardiovascular system. **Inhalable particles** penetrate no further than the bronchi as they are filtered out by the cilia. **Thoracic particles** can penetrate right into terminal bronchioles whereas PM which can penetrate to alveoli, the gas exchange area, and hence the circulatory system are termed **respirable particles**. In analogy, the inhalable dust fraction is the fraction of dust entering nose and mouth which may be deposited anywhere in the respiratory tract. The thoracic fraction is the fraction that enters the thorax and is deposited within the lung's airways. The respirable fraction is what is deposited in the gas exchange regions (alveoli).[52]

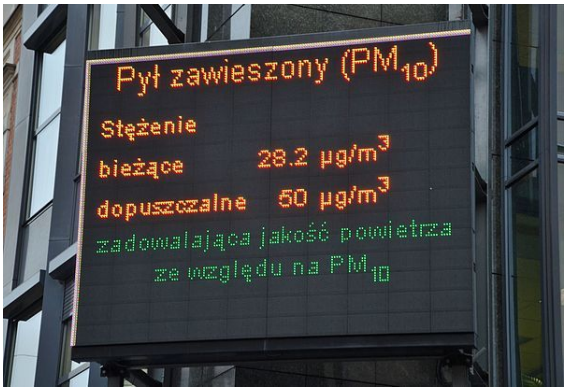
The smallest particles, less than 100 nanometers (nanoparticles), may be even more damaging to the cardiovascular system.[53] Nanoparticles can pass through cell membranes and migrate into other organs, including the brain. Particles emitted from modern diesel engines (commonly referred to as Diesel Particulate Matter, or DPM) are typically in the size range of 100 nanometers (0.1 micrometer). These soot particles also carry carcinogens like benzopyrenes adsorbed on their surface. Particulate mass is not a proper measure of the health hazard, because one particle of 10 μm diameter has approximately the same mass as 1 million particles of 100 nm diameter, but is much less hazardous, as it unlikely to enter the alveoli. Legislative limits for engine emissions based on mass are therefore not protective. Proposals for new regulations exist in some countries, with suggestions to limit the particle *surface area* or the *particle count* (numerical quantity) instead.

The site and extent of absorption of inhaled gases and vapors are determined by their solubility in water. Absorption is also dependent upon air flow rates and the partial pressure of the gases in the inspired air. The fate of a specific contaminant is dependent upon the form in which it exists (aerosol or particulate). Inhalation also depends upon the breathing rate of the subject.[54]

Another complexity not entirely documented is how the shape of PM can affect health, except for the needle-like shape of asbestos which can lodge itself in the lungs. Geometrically angular shapes have more surface area than rounder shapes, which in turn affects the binding capacity of the particle to other, possibly more dangerous sub-

stances.

7.2 Health problems



Air quality information on PM10 displayed in Katowice, Poland

The effects of inhaling particulate matter that have been widely studied in humans and animals include asthma, lung cancer, cardiovascular disease, respiratory diseases, premature delivery, birth defects, and premature death.

Increased levels of fine particles in the air as a result of *anthropogenic* particulate air pollution "is consistently and independently related to the most serious effects, including lung cancer[8] and other cardiopulmonary mortality."[55] The large number of deaths[56] and other health problems associated with particulate pollution was first demonstrated in the early 1970s[57] and has been reproduced many times since. PM pollution is estimated to cause 22,000–52,000 deaths per year in the United States (from 2000)[58] contributed to ~370,000 premature deaths in Europe during 2005.[59] and 3.22 million deaths globally in 2010 per the global burden of disease collaboration.[60]

A 2002 study indicated that $PM_{2.5}$ leads to high plaque deposits in arteries, causing vascular inflammation and atherosclerosis – a hardening of the arteries that reduces elasticity, which can lead to heart attacks and other cardiovascular problems.[61] A 2014 meta analysis reported that long term exposure to particulate matter is linked to coronary events. The study included 11 cohorts participating in the European Study of Cohorts for Air Pollution Effects (ESCAPE) with 100,166 participants, followed for an average of 11.5 years. An increase in estimated annual exposure to PM 2.5 of just 5 µg/m^3 was linked with a 13% increased risk of heart attacks.[62]

The World Health Organization (WHO) estimated in 2005 that "... fine particulate air pollution (PM(2.5)), causes about 3% of mortality from cardiopulmonary disease, about 5% of mortality from cancer of the trachea, bronchus, and lung, and about 1% of mortality from acute respiratory infections in children under 5 years, worldwide.".[63] Short-term exposure at elevated concentrations can significantly contribute to heart disease. A 2011 study concluded that traffic exhaust is the single most serious preventable cause of heart attack in the general public, the cause of 7.4% of all attacks.[64]

The largest US study on acute health effects of coarse particle pollution between 2.5 and 10 micrometers in diameter. was published 2008 and found an association with hospital admissions for cardiovascular diseases but no evidence of an association with the number of hospital admissions for respiratory diseases.[65] After taking into account fine particle levels (PM 2.5 and less), the association with coarse particles remained but was no longer statistically significant, which means the effect is due to the subsection of fine particles.

Particulate matter studies in Bangkok Thailand from 2008 indicated a 1.9% increased risk of dying from cardiovascular disease, and 1.0% risk of all disease for every 10 micrograms per cubic meter. Levels averaged 65 in 1996, 68 in 2002, and 52 in 2004. Decreasing levels may be attributed to conversions of diesel to natural gas combustion as well as improved regulations.[66]

The Mongolian government agency recorded a 45% increase in the rate of respiratory illness in the past five years (reported in September 2014). Bronchial asthma, chronic obstructive pulmonary disease and interstitial pneumonia were the most common ailments treated by area hospitals. Levels of premature death, chronic bronchitis, and cardiovascular disease are increasing at a rapid rate.[18]

8 Effects on vegetation

Particulate matter can clog stomatal openings of plants and interfere with photosynthesis functions.[67] In this manner high particulate matter concentrations in the atmosphere can lead to growth stunting or mortality in some plant species.

9 Regulation

Due to the highly toxic health effects of particulate matter, most governments have created regulations both for the emissions allowed from certain types of pollution sources (motor vehicles, industrial emissions etc.) and for the ambient concentration of particulates. The IARC and WHO designates particulates a Group 1 carcinogen. Particulates are the deadliest form of air pollution due to their ability to penetrate deep into the lungs and blood streams unfiltered, causing permanent DNA mutations, heart attacks and premature death.[7] In 2013, the ESCAPE study involving 312,944 people in nine European countries revealed that there was no safe level of particulates, and that for every increase of 10 µg/m3 in PM10, the lung cancer rate rose 22%. For PM2.5 there was a 36% increase in lung cancer per 10 µg/m3.[8] In a 2014 metaanalysis of

18 studies globally including the ESCAPE data, for every increase of 10 μg/m3 in PM2.5, the lung cancer rate rose 9%.[68]

9.1 Australia

Australia has set limits for particulates in the air:[69]

9.2 Canada

In Canada the standard for particulate matter is set nationally by the federal-provincial Canadian Council of Ministers of the Environment (CCME). Jurisdictions (provinces) may set more stringent standards. The CCME standard for particulate matter 2.5 (PM2.5) as of 2015 is 30 μg/m^3 (daily average, i.e. 24-hour period, 3-year average, 98th percentile).[70]

9.3 China

China has set limits for particulates in the air:[71]

9.4 European Union

The European Union has established the European emission standards which include limits for particulates in the air:[72]

9.5 Hong Kong

Hong Kong has set limits for particulates in the air:[73]

9.6 Japan

Japan has set limits for particulates in the air:[74][75]

9.7 Russia

Russia has set limits for particulates in the air.[77]

9.8 South Korea

South Korea has set limits for particulates in the air:[78][79]

Limit on annual average of PM2.5 will be lowered to 20 μg/m^3 in 2020.[80]

9.9 Taiwan

Taiwan has set limits for particulates in the air:[81][82]

9.10 United States

The United States Environmental Protection Agency (EPA) has set standards for PM_{10} and $PM_{2.5}$ concentrations.[83] (See National Ambient Air Quality Standards)

9.10.1 California

In October 2008, the Department of Toxic Substances Control (DTSC), within the California Environmental Protection Agency, announced its intent to request information regarding analytical test methods, fate and transport in the environment, and other relevant information from manufacturers of carbon nanotubes.[85] DTSC is exercising its authority under the California Health and Safety Code, Chapter 699, sections 57018-57020.[86] These sections were added as a result of the adoption of Assembly Bill AB 289 (2006).[86] They are intended to make information on the fate and transport, detection and analysis, and other information on chemicals more available. The law places the responsibility to provide this information to the Department on those who manufacture or import the chemicals.

On 22 January 2009, a formal information request letter[87] was sent to manufacturers who produce or import carbon nanotubes in California, or who may export carbon nanotubes into the State.[88] This letter constitutes the first formal implementation of the authorities placed into statute by AB 289 and is directed to manufacturers of carbon nanotubes, both industry and academia within the State, and to manufacturers outside California who export carbon nanotubes to California. This request for information must be met by the manufacturers within one year. DTSC is waiting for the upcoming 22 January 2010 deadline for responses to the data call-in.

The California Nano Industry Network and DTSC hosted a full-day symposium on 16 November 2009 in Sacramento, CA. This symposium provided an opportunity to hear from nanotechnology industry experts and discuss future regulatory considerations in California.[89]

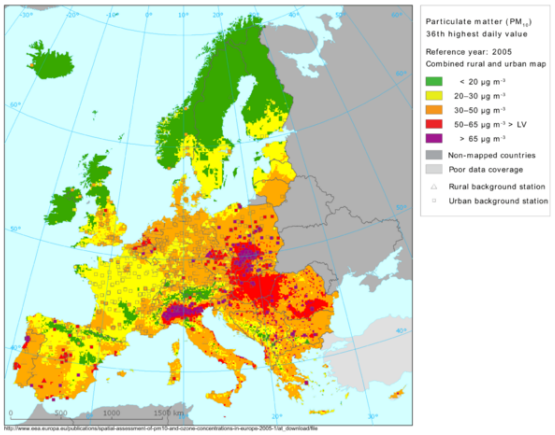
DTSC is expanding the Specific Chemical Information Call-in to members of the nanometal oxides, the latest information can be found on their website.[90]

9.10.2 Colorado

Key points in the Colorado Plan include reducing emission levels and solutions by sector. Agriculture, transportation, green electricity, and renewable energy research are the main concepts and goals in this plan. Political programs such as mandatory vehicle emissions testing and the prohibition of smoking indoors are actions taken by local government to create public awareness and participation in cleaner air. The location of Denver next to the Rocky Mountains and wide expanse of plains makes

the metro area of Colorado's capital city a likely place for smog and visible air pollution.

10 Affected areas



Concentration of PM_{10}[59] in Europe

The most concentrated particulate matter pollution resulting from the burning of fossil fuels by transportation and industrial sources tends to be in densely populated metropolitan areas in developing countries such as Delhi and Beijing.

10.1 Australia

PM10 pollution in coal mining areas in Australia such as the Latrobe Valley in Victoria and the Hunter Region in New South Wales significantly increased during 2004 to 2014. Although the increase did not significantly add to non-attainment statistics the rate of increase has risen each year during 2010 to 2014.[91]

10.2 China

Some cities in Northern China and South Asia have had concentrations above 200 µg/m^3 up to a few years ago. The PM levels in Chinese cities have been extreme in recent years, reaching an all-time high in Beijing on 12 January 2013, of 993 µg/m^3.[18]

To monitor the air quality of south China, the U.S. Consulate Guangzhou set a PM 2.5 monitor on Shamian Island in Guangzhou, and displays readings on its official website and social platforms.[92]

10.3 Ulaanbaatar

Mongolia's capital city Ulaanbaatar has an annual average mean temperature of about 0 °C, making it the world's coldest capital city. About 40% of the population lives in apartments, 80% of which are supplied with central heating systems from 3 combined heat and power plants. In 2007, the power plants consumed almost 3.4 million tons of coal. The pollution control technology is in poor condition.

The other 60% of the population reside in shantytowns (Ger districts), which have developed due to the country's new market economy and the very cold winter seasons. The poor in these districts cook and heat their wood houses with indoor stoves fueled by wood or coal. The resulting air pollution is characterized by raised sulphur dioxide and nitrogen oxide levels and very high concentrations of airborne particles and particulate matter (PM).[18] Annual seasonal average particulate matter concentrations have been recorded as high as 279 µg/m^3 (micrograms per cubic meter). The World Health Organization's recommended annual mean PM_{10} level is 20 µg/m^3,[93] which means that Ulaanbaatar's PM_{10} annual mean levels are 14 times higher than recommended, and that it has left Northern China's most polluted cities in its wake.

During the winter months in particular, the air pollution obscures the air, affecting the visibility in the city to such an extent that airplanes on some occasions are prevented from landing at the airport.

In addition to stack emissions, another source unaccounted for in the emission inventory is fly ash from ash ponds, the final disposal place for fly ash that has been collected in settling tanks. Ash ponds are continually eroded by wind during the dry season.

11 See also

12 References

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13 Further reading

- Article at earthobservatory.nasa.gov describing the possible influence of aerosols on the climate
- The Intergovernmental Panel on Climate Change (the principal international scientific body on climate change) chapter on atmospheric aerosols and their radiative effects
- InsideEPA.com, Study Links Air Toxics To Heart Disease In Mice Amid EPA Controversy
- Preining, Othmar and E. James Davis (eds.), "History of Aerosol Science," Österreichische Akademie der Wissenschaften, ISBN 3-7001-2915-7 (pbk.)
- G Invernizzi et al., *Particulate matter from tobacco versus diesel car exhaust: an educational perspective*. Tobacco Control 13, S.219–221 (2004)
- JEFF CHARLTON *Pandemic planning: a review of respirator and mask protection levels.*
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14 External links

- National Pollutant Inventory — Particulate matter fact sheet
- CDC – NIOSH Pocket Guide to Chemical Hazards
- American Association for Aerosol Research
- Particulate Air Pollution
- Watch and read 'Dirty Little Secrets', 2006 Australian science documentary on health effects of fine particle pollution from vehicle exhausts
- Little Green Data Book 2007, World Bank. Lists C02 and PM statistics by country.
- Air Pollution in World Cities (PM10 Concentrations)
- Airborne Particles and their Health Effects – A multinational research network
- Measurement of personal exposure to PM10 in the Non-Workplace Environment using Passive Sampling Techniques by RJ Aitken, LC Kenny and A Soutar. IOM Research Report TM/01/05
- Integrated Science Assessment for Particulate Matter (Report)
- Integrated Science Assessment for Particulate Matter (Annexes Only) (PDF) (1157 pages) 52 MB

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15.1 Text

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