

# Effects of Aerosols on Climate, Human Health, and Plant and Mitigation Strategies

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**Abstract.** With the increasing global air pollution, aerosols have received increased attention from researchers. Aerosols have been shown to have critical impacts on Earth's climate, human health, and plant photosynthesis. In this context, this paper briefly introduces the composition of aerosols, the effects on Earth, and mitigation strategies. Aerosols scatter sunlight, as well as trap heat in the atmosphere, affecting Earth's surface temperatures and reducing visibility. Besides, particulate matter can enter deeply into lungs, causing serious respiratory and cardiovascular diseases and spreading infective diseases. Meanwhile, by scattering sunlight, aerosols facilitate plant photosynthesis and protein expression. Because of the adverse effects of aerosols on climate and humans, several mitigation strategies, based on primary pollution sources, are proposed and discussed. To reduce vehicle aerosol emissions, implementing traffic restrictions is a potential strategy if practical and feasible for local communities. Encouraging the switch to electric vehicles is another strategy suggested and is more widely applied. For industry, a cap-and-trade system serves as another mitigation strategy to limit industrial emissions and provide incentives to reduce emissions.

**Keywords:** Aerosols, climate effects, human health effects, botanic effects, mitigation strategies.

## 1. Introduction

Aerosols are fine particles or liquid droplets suspended in the air. Aerosols can be formed either naturally or anthropogenically. Naturally formed aerosols include fog, mist, and dust, while aerosols formed under human activity include particulate matter (PM), such as PM<sub>2.5</sub>. The 2.5 indicates that the particle has a diameter less than 2.5 micrometers. Given that the human hair is approximately 70 micrometers in diameter on average, the largest PM<sub>2.5</sub> is approximately 30 times smaller than a single hair. Though not even visible to human naked eyes, aerosols have great significance and impacts on global climate, human health, as well as plants. Aerosols can scatter sunlight, while specific composition, black carbon, can trap heat in the atmosphere. The former one lowers ground temperature by blocking sunlight, while the latter raises surface temperature because of conduction from the heated atmosphere. Understanding how aerosols affect global climate overall is critical for predicting weather, researching on implication of aerosols on Earth, etc. For human health, since the size of aerosols are typically very small, aerosols can easily enter the human body, as deep as lungs, through breath, inducing severe health problems. Besides, aerosols are media for disease to spread in the breath. For plants, aerosols could facilitate photosynthesis by reducing direct solar radiation. However, aerosols contain heavy metal contents, exposing toxic substances to plants. The overall effect on plants is determined to be positive.

In recent years, aerosols have gradually come into view because of pollution. Researchers have paid a lot of attention to aerosols, particularly in identification of composition, climate impacts, and health effect. The global effects of aerosols have been reviewed, but mitigation strategies are not discussed comprehensively, and the review was done several years ago. Therefore, with new technologies that have been developed, researchers have more understandings on aerosols and have come up with more sustainable methods and policies to help reduce aerosols pollution.

This paper aims to provide a comprehensive overview of current research progress on aerosols and suggestions on pollution control. This paper focuses on current technologies to measure aerosols

identification and composition, and global climate impacts, health effects, and botanic effects of aerosols, as well as discusses strategies to mitigate aerosols pollution.

## 2. Classification

There are several ways to classify aerosols. This section introduces two ways to classify aerosols: size and formation.

### 2.1. Fine/Coarse Aerosols

Aerosols can be classified by size. As the name suggests, fine particles are small particles, typically with a diameter less than or equal to 2.5 micrometer. Coarse particles are particles ranging from 2.5 to 10 micrometers in diameter. Particles with diameter greater than 10 micrometers are called large coarse particles. Fine and coarse particles differ by composition, health effect, and sources [1]. This classification is more commonly used in research field.

### 2.2. Primary/Secondary Aerosols

Aerosols enter the atmosphere through different ways. Based on the form of aerosols entering the atmosphere, aerosols are classified as two types: primary aerosols and secondary aerosols. Particles injected into the atmosphere directly are called primary aerosols. Common sources are fires, construction sites, smokestacks, etc. Common examples include volcanic ash, mineral dust, smoke, etc. Secondary aerosols are in gas form when being emitted to the atmosphere. They then become aerosols after a series of chemical reactions in the atmosphere. Secondary aerosols are mainly formed on a regional scale and play an important role in urban haze episodes in megacities [2].

## 3. Composition of Aerosols and Technologies to Measure

Since the composition of aerosols affects how far they can travel around the world, how they interact with solar and thermal radiation, and how they affect human health, knowing the composition and concentration is critical in aerosols research and making policy. The following sections introduce 4 major components of aerosols and the current technology to determine identification and make measurements on concentration.

### 3.1. Sulfates

Sulfates in aerosols mainly come from industrial burning of fossil fuels and show little seasonality. Sulfate in aerosols is usually presented as ammonium sulfate ( $(\text{NH}_4)_2\text{SO}_4$ ), where ammonium mainly comes from anthropogenic activities, such as domesticated animals and agricultural operations like farm fertilizers. Wind brings the two components together and they combine with each other to form ammonium sulfate. Sulfate, ammonium, and nitrate are important constituents of PM.

The concentration of sulfates in aerosols is often measured using ion chromatography (IC) in the lab. When assessing air quality in fields, filters are often used. Air passes through filters, and particulate matter remains on filters. These filters are collected and dissolved using methanol and ultrasonic bath. The extracted solution is then used for IC. Ions in solution are separated depending on their affinity to the IC column [3]. IC have two types: anion- and cation-exchange. Both types are performed to determine aerosols compositions. Common anions measured by IC include fluoride, chloride, nitrite, bromide, sulfate, nitrate, and phosphate; cation measured by IC include lithium, sodium, ammonium, potassium, magnesium, and calcium. The identity of each ion is determined by retention time. When ions flow out column at certain time, a peak will form on the IC spectrum. To determine concentration, calibrated standard solutions, of which ion concentrations are known, are used. By comparing the integral area of peak from samples with that from standard solutions, one can deduce the actual concentration of samples based on calibrated curves.

### 3.2. Nitrates

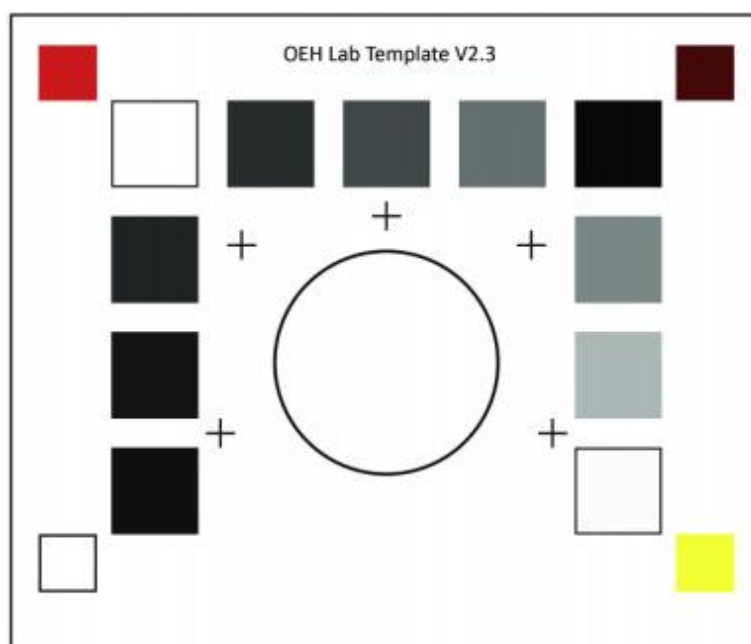
Nitrates in fine particles primarily exist as ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ). Anthropogenic nitrates emission has little seasonality. Nitrate is formed primarily by photochemically initiated reactions [4]. As mentioned in 3.1, nitrates concentration is measured using ion chromatography.

### 3.3. Black Carbon

Black carbon is composed of pure carbon in different linked forms. The primary source of black carbon is the incomplete combustion of carbon-based fuels in industry. Black carbon absorbs light and stays in the atmosphere for a relatively short period, usually from several days to one week, compared to greenhouse gases like  $\text{CO}_2$  which linger in the atmosphere for more than 100 years. Due to its ability to trap heat in the atmosphere, black carbon has warming effects on Earth.

Two of the technologies applied in the lab to measure black carbon are smoke stain reflectometer (SSR) and image-based reflectance (IBR). Black carbon is usually collected on a filter. SSR emits light on the filter, which is then reflected to a photo-sensitive element, producing an electrical current. This current is amplified to produce a meter reading. The blacker carbon present on the filter, the less light it reflects, and the less the reading is [5]. However, SSR is very sensitive and subjected to shake and crash, which makes human error a significant error source. Therefore, in lab, multiple measurements are required, and the standard deviation is restricted to be lower than 1.50.

Besides SSR, IBR is more commonly used in laboratories. In IBR, filter from field is placed on a standardized template (Fig. 1) in an evenly lit chamber. A camera is set at a fixed distance from the template and used to take photos of the filter with the template. The image is then processed using computer programs to estimate filter's reflectance by comparing to the image template. The reflectance is used to determine black carbon content [6].



**Figure 1.** Image-Based Reflectance (IBR) Template.

<https://www.sciencedirect.com/science/article/abs/pii/S135223102030042X>

### 3.4. Other Dust

Mineral dust, as one of the most abundant aerosol compositions, is emitted as wind blows over dry soil like deserts. Indeed, one of the major emission sources of mineral dust, and the most famous one, is the Sahara Desert. Wind lifts the solid particles and carries them into the atmosphere. It is mainly oxides and carbonates from the crust of Earth. Compared to other components, dust particles are much

larger, with diameter of several micrometers. Major elements in dust particles include aluminum, calcium, iron, potassium, magnesium, and silicon [7].

X-ray Fluorescence (XRF) is a method of analyzing the chemical compositions of aerosol dust samples collected on filters. An X-ray, generated from an X-ray tube, is emitted, and hits the inner shell of an electron, ejecting the electron from the atom. Electron from outer shell fills the open position, releasing energy and emitting fluorescence radiation. Since the fluorescence energy is unique for each atom, atom identity could be determined by detecting this radiation energy.

## 4. Factors of Aerosols

Aerosols range in size from nanometers to several micrometers, making them capable of influencing the energy balance of Earth, the amount of greenhouse gas and trace gas (ozone, VOCs, carbon monoxide, etc.), atmospheric circulation, and the hydrological cycle. In addition, aerosols can cause or enhance disease in biological organisms, especially in respiratory reproductive systems [8]. Understanding the influence of aerosols on Earth is critical in many aspects.

### 4.1. Climates

Aerosols affect global climates directly and indirectly. Sulfates and dust, as the major components, scatters sunlight, reflecting incoming sunlight back to space and therefore have a cooling effect on the atmosphere. This cooling effect is qualified by radiative forcing, which is an index of a factor's influence on altering incoming and outgoing energy on Earth. The current estimate of sulfates radiative forcing is  $-0.4 \text{ W/m}^2$ , while that of dust is  $-0.2 \text{ W/m}^2$  [9, 10]. The negative value suggests that the Earth loses more energy to space than it receives from space, confirming that sulfates and dust net cool the climate.

On the other hand, black carbon absorbs sunlight and trap solar energy within the atmosphere. The absorption reduces light reaching on surface but keeps heat in the atmosphere. Eventually the heated atmosphere increases the surface temperature. Since aerosols have both cooling and warming effects on surface temperature, the overall effects should be determined according to actual conditions, depending on certain sulfate, dust, and black carbon concentration.

Apart from global temperature impacts, scattering light also decreases atmospheric visibility. Studies have shown that the two substances contributing the most to visibility degradation are sulfate and black carbon [11]. As mentioned earlier, sulfate reflects sunlight, while black carbon absorbs sunlight; both are preventing light from reaching the ground, resulting in decrease in visibility.

In addition, as black carbon can absorb light and reduce solar irradiation, it may affect the hydrologic cycle, and eventually affect the size of cloud droplets and cloud brightness and persistence. The change in climate has significance on the whole ecosystem.

### 4.2. Humans

Epidemiological studies have elucidated the negative effects of aerosols on human health. Given that particulate matter in aerosols is typically smaller than 2.5 micrometer in diameter, aerosols can enter deep into lungs and cause serious respiratory problems, inflammation, and oxidative stress. Long-term exposure to PM has been shown related to increased incident of cerebrovascular and ischemic heart disease. Serious cases may result in chronic pulmonary disease, lung cancer, strokes, and heart attacks. Besides PM, dust transported for long distance from desert area may lead to cardiovascular and respiratory diseases. Long-term exposure causes hospitalization and even mortality [12]. Pathogens, which cling to the dust surface and spread in the atmosphere, have a negative effect on public health [9].

### 4.3. Plants

Aerosols have both advantageous and adverse effects on plants. Aerosols affect plants mainly through photosynthesis, which can have impacts on protein expression in plants. Diffused solar

radiation, compared to direct solar radiation, is absorbed on the plant canopy more homogeneously and is therefore more advantageous for photosynthetic processes. As discussed in 4.1, aerosols scatter sunlight, facilitating photosynthesis. In contrast, several studies report that heavy metals that are widely present in aerosols decrease the synthesis of soluble proteins and chlorophyll, which negatively affect plants' growth. To determine the overall effect of aerosols on plants, research (Yan, X., et al.) has been conducted using leaves of *euonymus japonica*, an evergreen shrub. Data on PM and protein identification were collected. The study concludes that aerosols have a direct effect on plant photosynthesis and protein expression, and that aerosols overall are more beneficial for plants by facilitating diffused solar radiation [13].

## 5. Strategies / Suggestions on Reducing Aerosols Pollution

There are multiple ways to produce aerosols anthropogenically. This section proposes several main sources and corresponding strategies.

### 5.1. Traffic and Transportation

Diesel vehicles are one of the main and most common sources of aerosol emissions. Due to gas combustion, cars emit smoke-forming substances such as nitrogen oxides, particulate matter, carbon monoxide, etc.

To reduce aerosol pollution caused by traffic, for example, Beijing, China, has implemented traffic restriction policies. Ji et al. has found that concentration of organic carbon (OC) peaked at night when diesel vehicles with heavy-duty were allowed to operate between 00:00 and 06:00. Average OC was lower during weekdays compared to weekends without restrictions [14]. From an environmental perspective, traffic restrictions successfully reduce carbon emissions and can serve as a potential solution for large cities with large numbers of vehicles. However, traffic restrictions bring inconvenience to local residents and the actual situation should be considered. The government should fully consider citizens' opinions before imposing traffic restrictions, as this policy may not work everywhere.

A more widely adopted strategy is to encourage the use of hybrid or electric cars, which consume electricity rather than oil and release only water. Although electric cars consume more energy to produce and release more greenhouse gases due to their batteries, they have a more positive impact on the environment on average in the long run. Offering incentives and building more charging stations are ways to promote the use of electric vehicles.

### 5.2. Industry

Industry is one of the most significant and common sources of aerosols. Industrial facilities such as power plants and refineries emit large amounts of aerosols into the atmosphere. In particular, coal combustion accounts for 20-33% of the total organic aerosols due to heating in winter [2]. Cap-and-trade is a policy that limits industrial emissions. The government sets "caps" for industry, which are strict limits on pollution. Any violations will be punished. The trade component is where companies sell and buy emission allowances freely, providing strong incentives for companies to reduce emissions by creating a free market [15].

## 6. Conclusion

The composition of aerosols has been extensively studied to determine their effects on climate, human health, and plants. Aerosols have cooling and warming effects on the atmosphere. The overall effect is affected by many factors and should be determined according to actual situations. Long-term exposure to aerosols can cause respiratory and cardiovascular disease and even mortality in extreme cases. Nevertheless, aerosols have a positive effect on plants by scattering sunlight and promoting the photosynthetic process. However, aerosols pollution is expected to be controlled because the adverse

