NASA Facts

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Aerosols: More Than Meets the Eye

You can't really see individual aerosol particles with your eyes—but you can see the impact they have all around you. Aerosols are extremely important to life on Earth. Every time you see a cloud form, you are seeing aerosols at work. Without them, cloud formation would be next to impossible in Earth's atmosphere. Likewise, aerosols play an important role in pollinating plants. The tiny pollen particles that drift from plant to plant on the breeze, or are carried by animals, are actually aerosols.

Aerosols range in size from around 10 nanometers (1 nanometer is a billionth of a meter) upward to around 100 micrometers (1 micrometer is a millionth of a meter). **Figure 1** helps to put these tiny sizes in perspective and shows some common aerosol types viewed under a powerful microscope.

Aerosols often have serious impacts on society. They can pose a threat to public health. On hot, humid, stagnant summer days, the air quality over urban areas often reaches unhealthy levels and aerosols are a primary culprit. Tiny aerosol particles with diameters less than 2.5 millionths of a meter (1 ten-thousandth of an inch) can work their way deep into the lungs and aggravate or cause breathing problems. The risk is particularly high for the elderly and the very young.

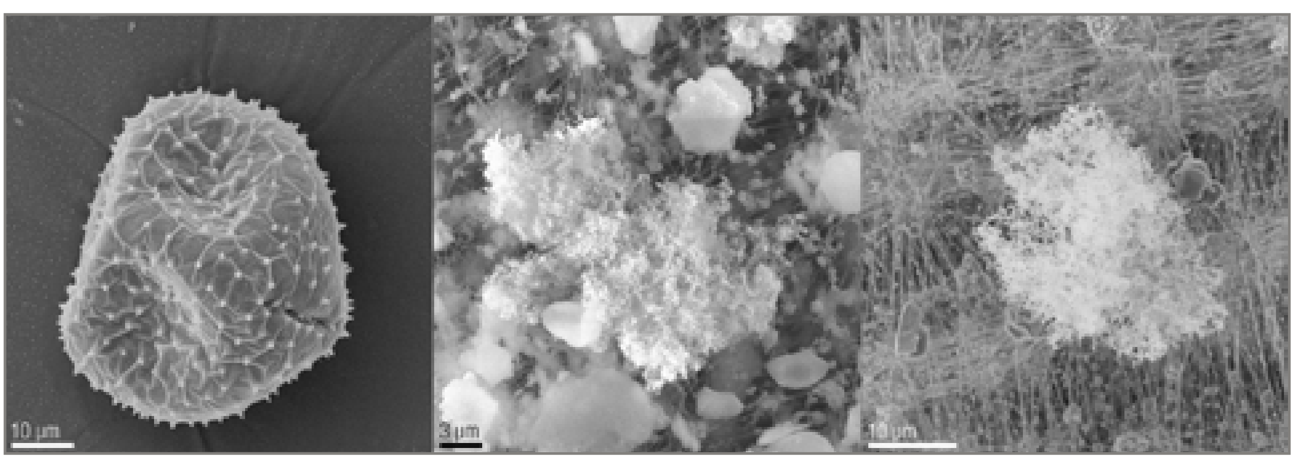
Aerosols can also threaten the safety of aviation by reducing visibility over heavily polluted areas. During volcanic eruptions, a major source of aerosols, planes have to be rerouted around the eruption for fear of having particles ingested into their jet engines.

Aerosols even impact global climate. When present in sufficient amount and for a long enough time, aerosols can lower Earth's average temperature.

A Guide to Classifying Aerosols

As scientists try to understand and predict the many influences of aerosols on our health and our environment, it helps them to categorize aerosols into different types. The most common ways to classify

Figure 1: From left to right, pollen, ash (from a Malaysian forest fire in 1997), and soot as viewed under a scanning electron microscope (SEM). This gives an idea of the different sizes and shapes of aerosol particles. Images courtesy U.S. Environmental Protection Agency. (Image credit: Bob Williams.)



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aerosols are source and chemical composition. The classification methods scientists choose are based on what they are trying to accomplish. Doctors researching asthma might want to categorize aerosols by source. On the other hand, researchers trying to model the effect of aerosols on rainfall in urban areas might find it best to categorize by composition.

Categorizing by Source

Industrial and Urban pollution. Major cities produce large amounts of aerosols as a result of industrial activity, automobile emissions, and so forth. The burning of fossil fuels (primarily coal and oil) to produce energy also produces large amounts of aerosols. Industrial and urban activities are the largest source of human-produced aerosols. As we might expect, the concentration of industrial and urban pollution is greatest in the Northern Hemisphere, where most of the planet's population—and therefore urban and industrial activity—is located.

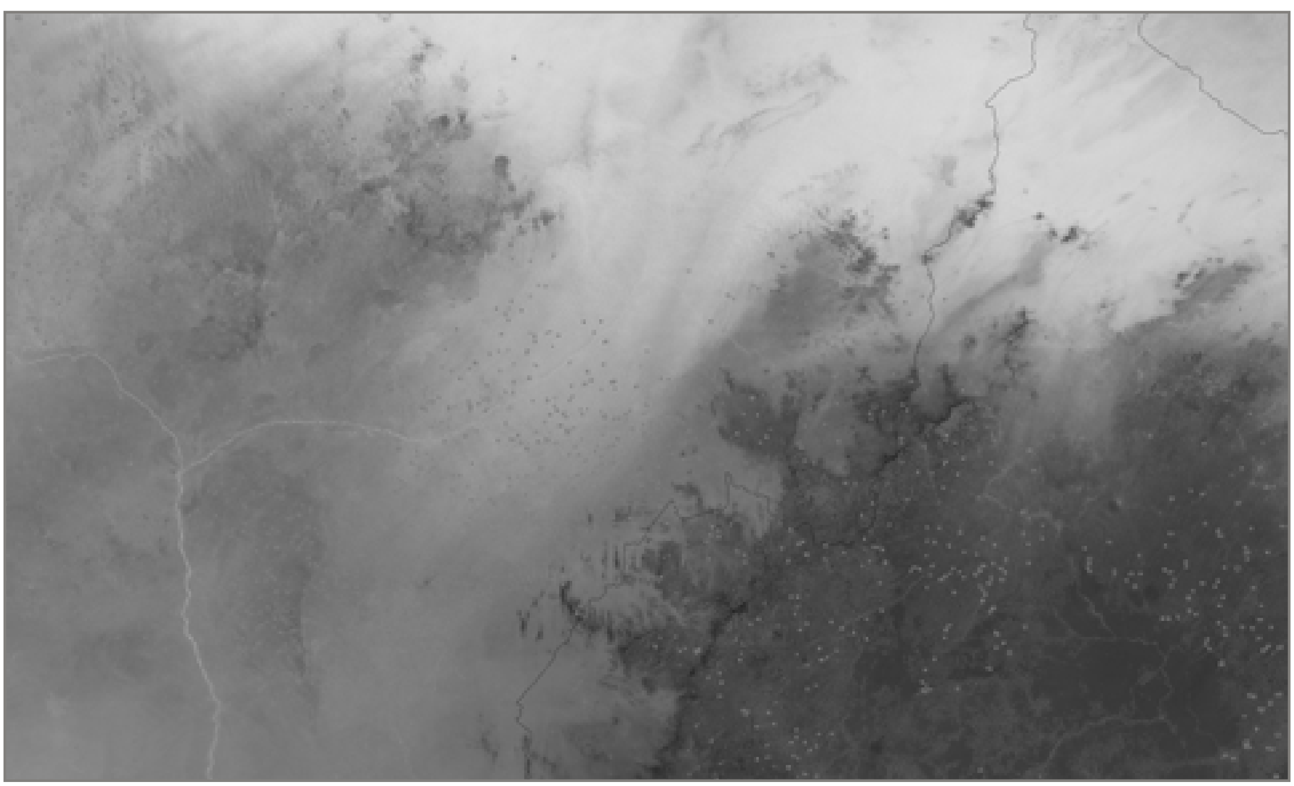
Biomass burning. At any moment, many fires are burning on Earth's surface. Some of the fires result from natural causes like lightning strikes, but humans set many others, usually for agricultural purposes: to clear natural vegetation away for cropland [see **Figure 2**], to renew pasture grasses in rangelands, to maintain native plant communities in natural areas, or to manage wildfire risks.

Desert dust. As the wind sweeps over Earth's vast deserts (such as the Sahara in North Africa), it picks up scores of sand and dust particles and sweeps them along. These are larger particles that would fall out of the atmosphere after a short time were it not for the fact that they are swept to high altitudes (3650 meters [12,000 feet] and higher) during intense dust storms. At the higher altitudes, the winds blow faster, carrying the particles over longer distances. Dust is truly a world traveler. Satellite images have tracked desert dust streaming out over the Atlantic from northern Africa's Sahara Desert and from China's Taklamikan Desert to the U.S.

Volcanic eruptions. Volcanic eruptions release tons of aerosol particles and gases into the air. The gases contain sulfur dioxide which converts to sulfuric acid and then forms into tiny particles. While they remain in the atmosphere, volcanic aerosol particles reflect sunlight and cool the Earth's lower atmosphere and surface.

A typical eruption releases a cloud of ash into the lower atmosphere (14.5 km [9 miles] or lower) and it

Figure 2: NASA satellite observations help us distinguish aerosols from different sources as they mix together over central Africa. Ripples of brighter-colored dust are blowing south from the Bodele Depression in Chad into Nigeria and Cameroon and stand out from the darker smoke produced by biomass burning associated with land clearing in the African Sahel. Occasionally, dust and smoke originating in Africa make it all the way to Europe and the Americas. (NASA image courtesy Jacques Descloitres, MODIS Rapid Response)



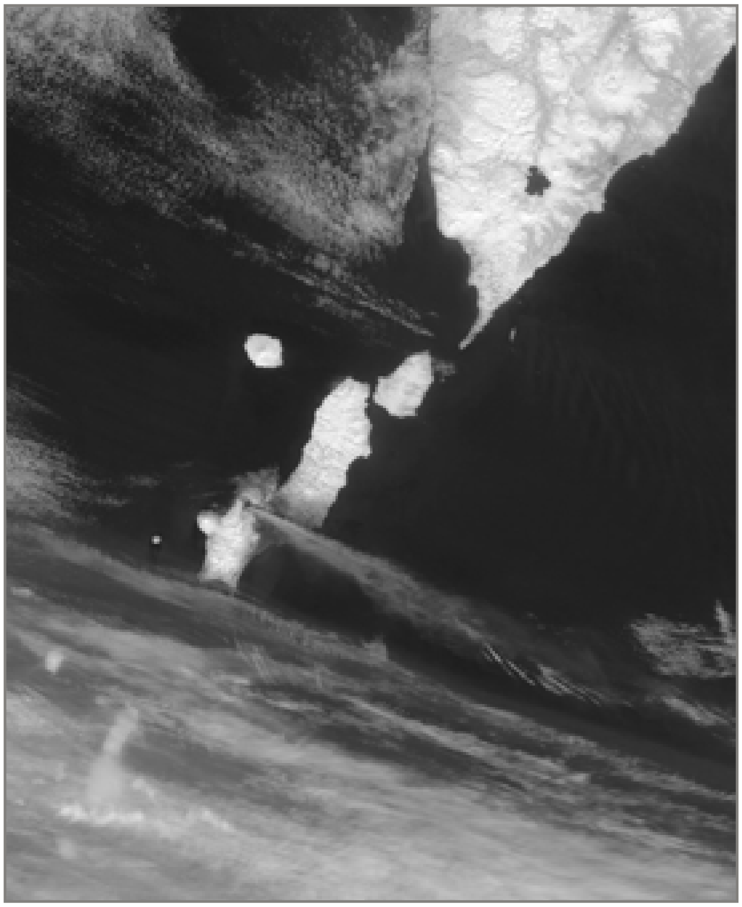


Figure 3: This is what a volcanic plume looks like when viewed from space. Volcanic eruptions release tons of aerosol particles and gases. The gases contain sulfur dioxide, which reacts with water in the atmosphere to create a plume of sulfuric acid particles. As shown here, the prevailing winds can sometimes spread the plume several hundred miles from the source. This image shows the Chikurachki Volcano on Paramushir Island located between Japan to the south and Russia's Kamchatka Peninsula to the north and was acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra satellite on May 13, 2003. (Image credit: NASA MODIS Team.)

slowly spreads out following the prevailing wind patterns [see **Figure 3**]. The plume usually lasts for only a few weeks before rain washes the aerosols out of the atmosphere. A typical eruption can have significant impact on the local weather for a short time after the eruption but long-term global climate impacts are not usually significant. Occasionally, though, a more powerful eruption occurs that releases many more particles than a typical eruption and blasts them much higher into the atmosphere (between 24-50 km [15-31] miles). Particles that make it up to these higher altitudes will tend to remain in the atmosphere much longer because there is no rain to wash them out. Sometimes the aerosol particles can linger for several years and the winds in the upper atmosphere eventually spreads the plume out, creating a thin layer of aerosols that circles the globe. As a result, the global climate impacts of these more powerful eruptions (like Mount Pinatubo in 1991) tend to be much more significant.

Sea spray. Wind blowing across the open ocean stirs up the sea and creates a constant thin blanket of aerosols, called sea spray, over the ocean surface. Over remote portions of the ocean, far removed from other sources, sea spray is the primary source of aerosols. Sea spray is mostly composed of sodium chloride (salt), but the ocean surface also emits other substances into the atmosphere including large amounts of the compounds necessary to lead to the formation of sulfur-based aerosols (see below).

Biogenic processes. Biogenic means resulting from the activities of living things. Numerous forms of biogenic aerosols fill the air and are spread by wind across the planet. Pollen produced by trees and other plants, mold spores, and airborne bacteria and viruses all would fall under this category.

Classifying by Composition

Carbon-based aerosols. Carbon-based aerosols may contain either organic (from living things) or inorganic forms of carbon. Organic carbon is found in biogenic aerosols like pollen and microorganisms. Inorganic carbon comes from soot, graphite, or elemental carbon. Aerosols with inorganic carbon sometimes go by another name: *black-carbon aerosols*. Biomass burning and industrial and urban pollution are the major sources of black-carbon aerosols. Black-carbon aerosols absorb much more solar radiation than other types of aerosols.

Sulfur-based aerosols. Sulfur-based aerosols come from both natural and human sources. Industrial and urban pollution is a major source of sulfur-based aerosols, along with natural sources such as volcanic eruptions and sea spray. The atmospheric concentration of sulfur-based aerosols produced by humans has grown dramatically since the start of the Industrial Revolution. Currently, human production of sulfur-based aerosols likely exceeds the production from natural sources. Sulfur-based aerosols reflect a lot of sunlight.

Mineral-based aerosols. Mineral-based aerosols are composed of inorganic substances like silicon, aluminum, iron, and calcium. Desert dust and sea salt particles are the primary examples of mineral-based aerosol. Mineral-based aerosols absorb certain wavelengths of sunlight and reflect others.

Known Impacts of Aerosols

Aerosols have a *direct effect* on climate because they scatter incoming sunlight and, as a result, they can cool the Earth's surface immediately below them. The amount of cooling depends on the size, shape, and composition of the atmospheric particles, as well as the texture of the underlying surface. Aerosols can also absorb incoming sunlight and warm the atmosphere. The warming is greatest when the surface beneath the aerosol layer is bright such as a cloud layer or desert.

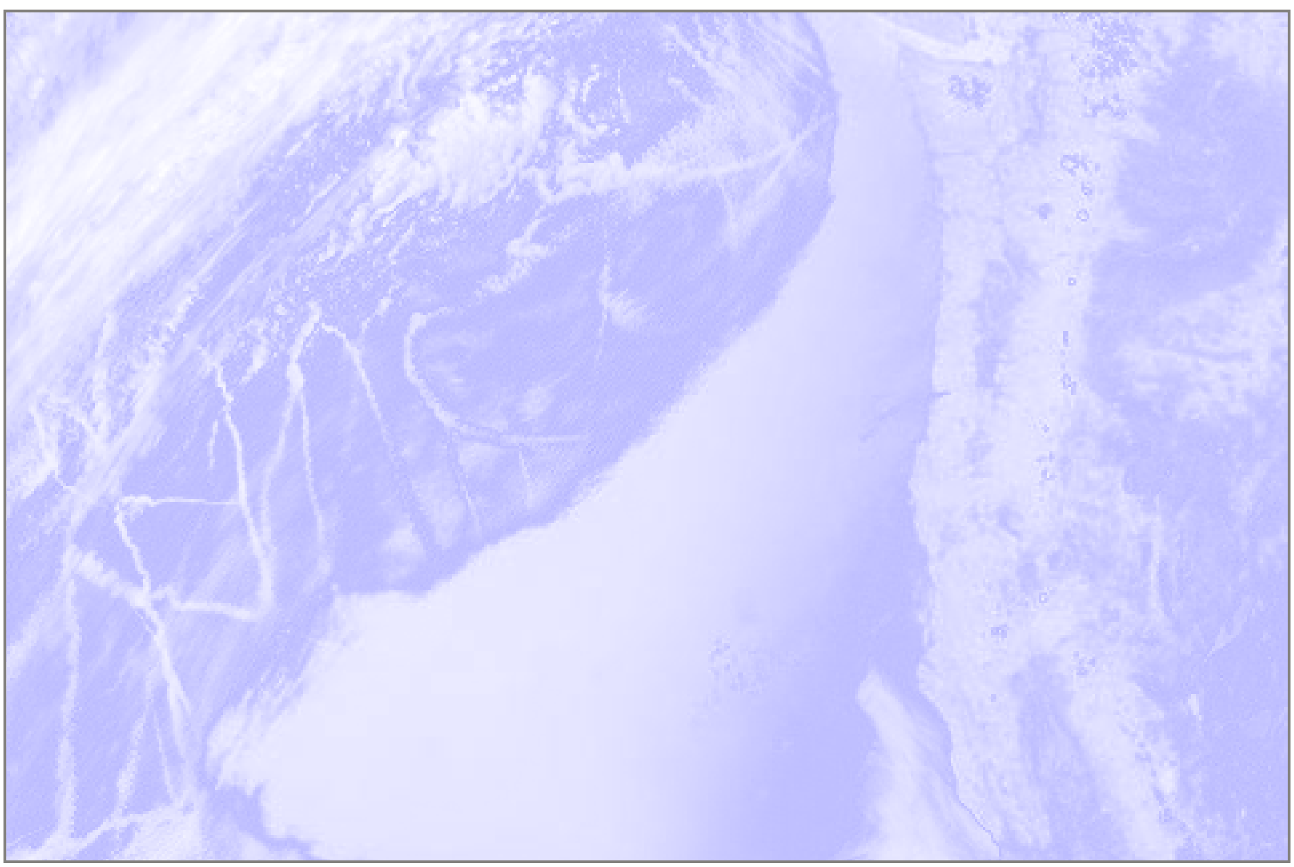
Aerosols can also have an *indirect effect* on climate [see **Figure 4**]. Changes in the quantity or characteristics of aerosols can influence the properties of clouds. Cloud formation would not be possible without the presence of aerosols. Water vapor condenses around aerosol particles to form cloud droplets. The droplets grow, collide, and merge with one another until they become large enough to fall as raindrops. If the amount of aerosols present in the cloud is relatively low, the cloud will be made up of relatively fewer but larger droplets [see **Figure 5a**]. As the amount of aerosols present in a cloud increases, however, the total amount of water in the cloud stays fairly constant. Water vapor gets spread out over many more particles, and the droplets that form become more numerous and smaller [see **Figure 5b**]. Raindrops take longer to form and so the clouds tend to last longer. Not only that, but the smaller particles tend to reflect more solar radiation back to space more efficiently than the larger particles and contribute to additional cooling. (For more details on the subject of clouds, see *NASA Facts 2005-9-073-GSFC*).

More recently scientists have discovered evidence that aerosol particles can also have a *semi-direct effect* on climate. Scientists have begun investigating how aerosols from biomass burning affect cloud formation, particularly in tropical regions. One study using satellite imagery over the Amazon Rainforest in South America shows evidence that smoke can actually choke off the formation of clouds altogether. Rather than the near-daily patchwork of cumulus clouds that shades the surface, a layer of black-carbon aerosols spreads above the forest. While this layer of aerosol particles does provide some *shading*, it is less than the clouds would have provided. When smoke replaces clouds above the forest, the end result is more solar radiation reaching the surface—in other words, the net result is warming.

The Difficulty of Predicting How Aerosols Impact the Earth's Climate

Scientists face a number of challenges when it comes to representing aerosols in the computer simulations or models they use to predict climate. Perhaps the biggest challenge is accurately representing the impact that aerosols have on incoming solar energy. To do this, scientists need to understand the physi-

Figure 4: This satellite image shows an example of the effect aerosols have on clouds. As ships cross the Pacific Ocean, their exhaust releases tiny aerosol particles around which water droplets cluster, resulting in narrow strips of clouds in the ships' wakes that stand out from the backdrop of lower clouds. The streaks couldn't form without the presence of the aerosols. (Image courtesy NASA MODIS Team.)



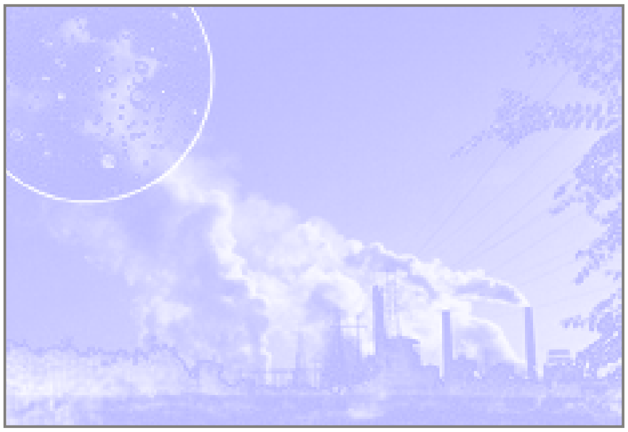


Figure 5a (top) and 5b (bottom): The amount of aerosols present when a cloud forms impacts the characteristics of the cloud. **Figure 5a** shows a "non-polluted" cloud, and **Figure 5b** shows a "polluted" cloud. In both cases, the same amount of water vapor is present, but in the "polluted" cloud, the water molecules are spread out over many more particles and it takes longer for water droplets to grow large enough to fall as precipitation (see insets). (Image credit: top image credit University Corporation for Atmospheric Research, Photo by Jim Coakley; bottom image credit University Corporation for Atmospheric Research. Inset credit: Alex McClung).

cal and chemical composition of individual aerosol particles, so when they are doing climate studies they like to classify aerosol based on chemical composition.

Unfortunately, however, the simplified categories we defined for classifying by chemical composition fall short of adequately representing how aerosols behave in the real world. The dividing lines between the three classification areas rapidly blur. An attempt to classify pollution typically found over urban areas demonstrates this. Industrial and urban pollution often contains both carbon-based and sulfur-based aerosols, meaning that pollution originating in an urban area rarely if ever fits neatly into one of the three categories. As pollution lingers over an urban area for a few days, carbon-based particles will attract tiny sulfur-based droplets creating a single particle with a carbon-core surrounded by a solution of sulfur-based compounds. The properties of the *hybrid* carbon-sulfur aerosol particles are quite different than either a carbon-based aerosol or a sulfur-based aerosol. Likewise, desert dust is composed of mineral-based aerosols, but when it moves over an urban area or mixes with smoke from biomass burning [see **Figure 6**], carbon-based aerosols often attach to the mineral-core.

There are also other properties of aerosols that make it difficult to predict what impact they have on climate. Aerosols usually last for only a few days before rain washes them out of the atmosphere. This is quite a contrast from greenhouse gases which, once released, tend to remain in the atmosphere for years or even decades. Because they last so much longer, greenhouse gases will tend to be evenly spread out over the whole globe which makes it easier to predict the impact they have on global climate. Aerosols, on the other hand, tend to be much more localized and, as a result, their climate impacts tend to be more localized. The type and amount of aerosols on Earth is far from constant and varies greatly from day to day, place to place, or season to season. Because aerosols vary so much over relatively short distances and short amounts of time, it becomes harder to figure out the net impact aerosols are having on global climate.

Studying Aerosols from Space

During the last 30 years, scientists have identified major aerosol types and they have developed general ideas about how the amount of aerosol varies in different seasons and locations. But key details are still missing. Because we still have so many unanswered questions about these tiny particles that are so fundamentally important to life on Earth and to understanding our climate, it's critical that scientists continue gathering information about them.

Scientists use information from ground-based studies, aircraft, and Earth observing satellites. Satellite observations offer the potential of achieving the continuous global coverage that is required to understand aerosols more completely.

The Earth-Sun System Division in NASA's Science Mission Directorate is helping to provide these satellite measurements. Several current Earth observing satellite missions can make continuous, global observations of the planet at a reasonable cost. Others will be added in years to come. For example, the Afternoon Constellation or *A-Train* is a grouping of satellites flying in very close proximity to one another that

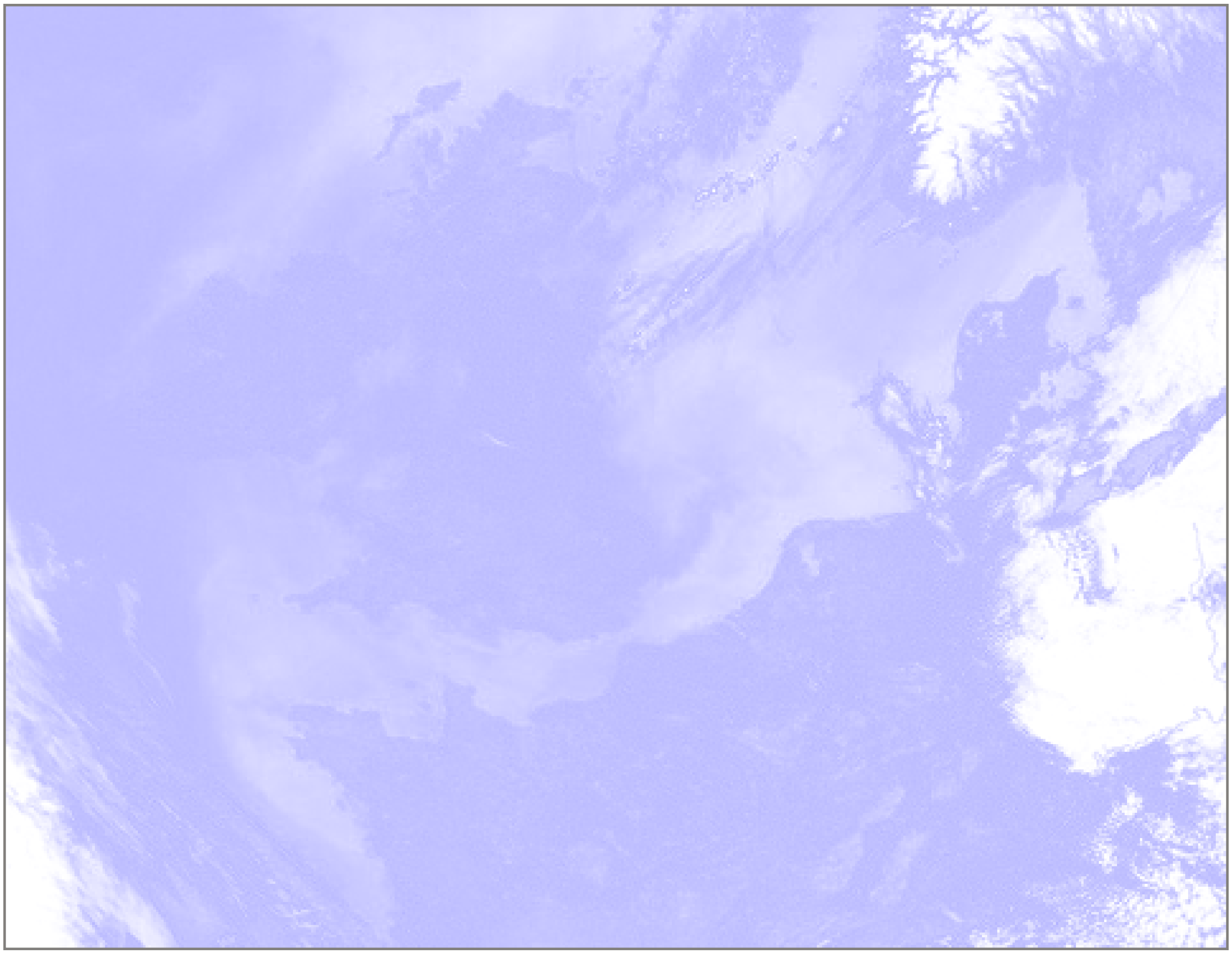


Figure 6: This is a classic illustration of how different types of aerosols mix together in the atmosphere and complicate our efforts to characterize their impact on climate. On April 18, 2003, a mixture of dust from the Sahara Desert, air pollution from Europe, and smoke from numerous fires burning in the United Kingdom (left of center) and the Republic of Ireland (farther left) and elsewhere, all merged over the Atlantic Ocean. This image was acquired by MODIS on NASA's Aqua satellite. (Image courtesy NASA MODIS Team.)

will provide unprecedented ability to study aerosols from space (for more information please see *NASA Facts 2003-1-053-GSFC*).

Summary

Using all of this information from Earth-observing satellites, along with ground-based observations and aircraft data obtained by teams of scientists all over the world, researchers will have at their disposal the most comprehensive information on aerosols they have ever obtained. This information should help them better determine the composition of aerosols, how aerosols are transported around the atmosphere, the role that aerosols play in reflecting and absorbing sunlight, and the indirect and semi-direct effects aerosols have on the properties of clouds. These observations are important for developing improved computer simulations of the Earth's climate, both for seasonal and longer-term climate predictions. In addition, as this new information gets incorporated into the tools used to issue air quality forecasts, scientists may also be able to predict when the air quality will be unhealthy further in advance than is currently possible, which could potentially save lives for at-risk populations.

The Earth-Sun System Division in NASA's Science Mission Directorate is dedicated to connecting these Earth observations to practical applications in society so that its *science results serve society,* and the maximum number of people possible benefit from NASA research. This is a manifestation of NASA's vision to *improve life here* and its mission to *understand and protect our home planet*.

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