

State of the Science FACT SHEET



Aerosols, Weather, and Climate

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

*Aerosols—microscopic solid or liquid particles suspended in air—significantly affect the Earth’s weather, air quality, and climate. The uncertainties associated with aerosol climate effects are much larger than those of greenhouse gases like carbon dioxide. Improving our understanding of the role of aerosols in the Earth System is essential for providing more accurate weather forecasts and reliable climate projections as well as information needed for future climate adaptation and mitigation. Aerosols are also the component of air pollution most responsible for disease and death both within the United States and abroad. **This fact sheet summarizes NOAA’s efforts to improve the understanding of the impact of aerosols on weather, air quality and climate.***

Aerosols have many sources in nature and from human activities (Figure 1). Some aerosols are directly emitted into the atmosphere (e.g., mineral dust, soot, sea salt, and volcanic ash), and others are formed from reactions within the atmosphere. In the lower atmosphere aerosols reside for a few days to a few weeks before being removed by precipitation and other processes, while at high altitudes in the stratosphere they can remain for months or years before being carried to lower altitudes and removed.



Figure 1. Natural and human-caused sources of atmospheric aerosols are shown on the left. NOAA’s research and operational tools used to address aerosol-weather-climate interactions are shown on the right.

How Do Aerosols Influence the Earth System?

Aerosols profoundly affect weather and climate by both warming and cooling the Earth (Figure 2). This occurs through aerosols’ interaction with solar radiation (sunlight). Aerosols reflect solar radiation and reduce sunlight at the Earth’s surface, thus exerting a cooling tendency on the Earth system. Some aerosols, including soot, also absorb sunlight, thereby warming the atmosphere. The balance between heating and cooling for an aerosol type depends on whether the particles are over land, water (a dark surface), or snow (a white surface), and above or below clouds. Emissions of aerosols and gases that form them have increased since the start of the Industrial Revolution in the mid-eighteenth century. The net effect of global aerosol changes is a cooling of the Earth (Figures 2 and 3), which offsets a substantial portion of the warming by carbon dioxide and other greenhouse gases (Figure 3), as reported in the Intergovernmental Panel on Climate Change (IPCC).

Aerosols also affect weather and climate by modifying cloud amount, cloud distribution, and cloud brightness. Some clouds become brighter, some last longer, and some evaporate more quickly when more particles are present. Aerosols can change the amount, timing, and location of rain and snow through their influence on cloud properties and cloud amounts.

Aerosols influence land and ocean life by modifying the amount of sunlight and trace nutrients a region receives. Aerosols contribute to poor air quality and harm human health. Aerosols that are smaller than 2.5 μm in median diameter penetrate deep into human lungs, leading to respiratory and other diseases and premature death from air pollution. As the climate changes, so too do the emissions of natural aerosols such as dust from deserts, smoke particles from wildfires, and particles formed from ocean sources. NOAA scientists study these complex processes using field observations, computer modeling, and measurements from satellites.

What Are the Uncertainties in the Role of Aerosols in Climate Change?

Despite continuing advances in aerosol research, the uncertainties in understanding aerosols—their properties, distribution, and effects on clouds and solar radiation—remain.

- Aerosols are complex and consist of many different chemical compounds. Their composition and size affect how they absorb and scatter light, how much water they contain, how effectively they act to form cloud droplets and ice particles, and how long they reside in the atmosphere.
- Aerosol composition and abundances vary significantly throughout the lower atmosphere and on daily to seasonal timescales. This makes it challenging to adequately measure their presence and assess their changing environmental impacts.
- Processes controlling the formation, transport, and removal of aerosols are complex and not yet fully understood, challenging the development of models that predict the abundance and composition of atmospheric aerosols.
- Aerosols can change the size of cloud droplets and how they form snow or rain. Aspects of these processes need more study to enable confident predictions of aerosol effects on precipitation and of how much sunlight clouds reflect back to space, cooling the planet.

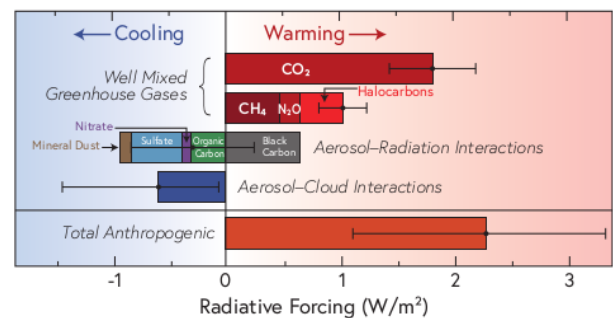


Figure 2. The calculated globally averaged radiative forcing (heating) in the atmosphere due to changes in CO₂ and other well-mixed greenhouse gases, and due to interactions of tropospheric aerosols with solar radiation and clouds (adapted from IPCC for the year 2011, relative to 1750). On a global scale, the net cooling effect of aerosols has partially offset the warming by greenhouse gases. The bottom bar shows the net human-caused (anthropogenic) forcing, accounting for warming and cooling by gases and aerosols. Note that not all forcing agents are shown in the figure. The relatively greater uncertainties in aerosol effects are shown by their larger error bars.

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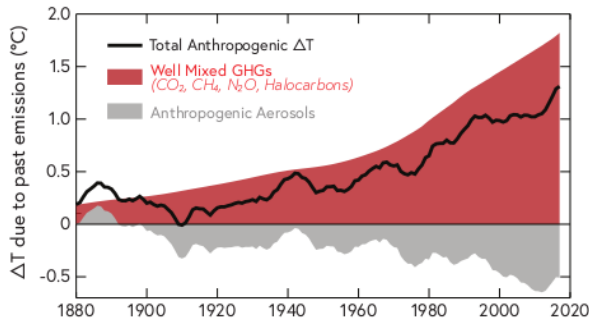


Figure 3. Simulated change in temperature due to past emissions. Anthropogenic aerosols (gray) decrease temperature, however this decrease is offset by the increase in temperature (red) due to greenhouse gases (GHGs). The net temperature change (black line) is positive; the Earth is warming. Figure courtesy of Erik Larson (NOAA/CSL).

How is NOAA Addressing Aerosol-Weather-Climate Interactions?

TOOLS

- NOAA engages in large field studies with aircraft, ships, and ground-based observations to measure aerosol amounts and properties and how they vary with meteorology and source. To this end NOAA also develops and uses state-of-the-art instruments and works with national and international agencies to improve the accuracy and reliability of aerosol measurements.
- NOAA monitors aerosol particles globally at numerous ground sites to understand trends in aerosol amount and properties, aerosol sources and removal, and their effects on the Earth's energy balance. Aircraft, in some cases remotely piloted, sample atmospheric aerosol near some of these sites to evaluate aerosol effects at different altitudes and locations.
- NOAA uses satellites to monitor global aerosol abundances and emissions from agricultural and forest fires. NOAA satellite observations also yield information on clouds, aerosol-cloud interactions, and aerosol-radiation interactions. Satellite data are also used to infer pollution levels harmful to human health.
- NOAA develops state-of-the-art computer models to simulate and understand the distribution of aerosols and their properties, and their effects on clouds and precipitation, the reflectivity of the planet, weather, and climate (Figure 3). These models range in scale from high-resolution models of cloud systems to regional and global models.
- NOAA uses laboratory, field, and modeling studies to characterize the role of aerosol particles in influencing precipitation. This issue will be of increasing importance in a future warmer climate with changing rainfall patterns and increased frequency of droughts and flooding.

RESULTS

- **Better air quality and weather forecasts.** Near-real-time data from satellites are provided to forecasters for air quality and weather forecasting for smoke from fires, dust from dust storms, and haze from urban/industrial pollution. Observations are analyzed to detect aerosol changes over space and time scales, characterize fire-related aerosol sources, and investigate feedbacks between fire activity, weather, and other physical factors.

- **Improved understanding of climate change.** NOAA scientists work to understand the processes that control where aerosols are found (sources, atmospheric transport, chemical transformation, and deposition) and their properties (amount of light scattered or absorbed, ability to form clouds and undergo further chemical evolution). These studies, together with the long-term monitoring that provides a continuous record, allow testing of climate models and validation of satellite-derived aerosol products.
- **Better forecasting and communication of hazards.** NOAA provides air quality forecast guidance to help protect human health and the economy. NOAA models and satellite data inform the public and aviation industry of the movement of natural and anthropogenic aerosols such as those from volcanic ash, fires, dust, and stratospheric perturbations.
- **Clearer information to policymakers.** NOAA synthesizes information on aerosols, climate, and weather to provide clear, concise, and policy-relevant but policy-neutral summaries for use by decision-makers.

Resources for Additional Information

Air Resources Lab [arl.noaa.gov]: Development of emissions datasets and algorithms and field and modeling studies to improve predictions of aerosols and their sources and removal.

Center for Satellite Applications and Research [star.nesdis.noaa.gov]: Development and applications of satellite observations relevant to aerosol detection, variability, and quantifying abundance.

Chemical Sciences Lab [csl.noaa.gov]: Laboratory and field measurements using aircraft, mobile labs, and ground-based instruments to characterize aerosols and assess impacts of aerosols on air quality and climate change.

Climate Program Office [cpo.noaa.gov]: Competitive research support for all types of aerosols measurement and modeling studies.

Environmental Modeling Center [emc.ncep.noaa.gov]: Operational air quality predictions for the U.S., operational predictions of aerosol distributions globally, and aerosol impacts on weather-to-seasonal predictions.

Geophysical Fluid Dynamics Lab [gfdl.noaa.gov]: Development and application of numerical models to advance understanding of past and future aerosol interactions with Earth's climate systems.

Global Monitoring Lab [gml.noaa.gov/grad]: Long-term monitoring networks provide a continuous record of aerosol properties for trend studies and climate model evaluation.

Global Systems Lab [gsl.noaa.gov]: Developed the HRRR smoke model and instrumental in WRF-chem model development and maintenance.

National Centers for Environmental Information [ncei.noaa.gov]: Development, production, archival, and dissemination of long-term satellite aerosol climate data record.

Pacific Marine Environmental Lab [pmel.noaa.gov]: Shipboard and UAS measurements to characterize aerosols and assess impacts of aerosols on air quality and climate.