

State of the Science FACT SHEET



Tropospheric Aerosols and Climate

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

This document describes NOAA's research on tropospheric aerosols and climate. Aerosols and greenhouse gases significantly affect the Earth's climate. The uncertainties associated with aerosol climate effects are much larger than those of greenhouse gases. Improving our understanding of the role of aerosols in the Earth System is essential for providing more reliable climate predictions and projections and the information needed for future climate adaptation and mitigation.

Aerosols are suspensions in air of microscopic solid or liquid particles. Aerosols have many sources in nature and from human activities (Figure 1). Some aerosols are directly emitted into the atmosphere (e.g., mineral dust, black carbon, sea salt) and others are formed from reactions within the atmosphere (e.g., sulfate, nitrate, organic aerosols). Aerosols reside in the troposphere for a few days to few weeks before being removed by precipitation and other processes.



Figure 1. Highly diverse sources of atmospheric aerosols (small images). Aerosols are emitted into the atmosphere both naturally (green circles) and as a result of human activities (orange circles). They also are created and modified by chemical processes in the atmosphere (blue circles). These sources vary regionally, leading to highly variable amounts of aerosols in different parts of the globe, as shown in the middle circle (pollution aerosol plume over the North Atlantic from the United States; and the natural Saharan dust over the tropical Atlantic).

How Do Aerosols Influence the Earth System?

Aerosols profoundly affect climate by both warming and cooling the Earth (Figure 2). One way in which all aerosols affect climate is through their **interaction with solar radiation** (sunlight). Aerosols reflect solar radiation and reduce sunlight at the Earth's surface, thus exerting a cooling tendency on the system. In addition, a fraction of aerosols, including black carbon, 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.

Aerosols also affect climate by **modifying cloud amount, cloud distribution, and cloud brightness**. Some clouds become brighter, some last longer, and some evaporate more quickly than when no 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 can also influence weather patterns through their modification of the Earth's heat balance.

Emissions of aerosols and aerosol precursors have increased in the industrial era, contributing to radiative forcing of climate. The

net effect of global aerosol changes is a cooling of the Earth (Figures 2 and 3). The aerosol cooling has offset a substantial portion of the warming by CO₂ and other well-mixed greenhouse gases in the industrial era (Figure 3), as reported in the Intergovernmental Panel on Climate Change (2013).

Aerosols also have **important couplings** with other aspects of the Earth System. They influence the terrestrial and marine biosphere by modifying fluxes of photosynthetic active radiation and biogeochemical nutrients, and affect air quality and human health. Deposition of aerosols can modify the albedo of snow- and ice-covered surfaces. Naturally occurring aerosols are sensitive to climate e.g., mineral dust, carbonaceous particles from wildfires, secondary organic particles from biogenic emissions, sea salt and sulfate produced from marine emissions of dimethyl sulfide.

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 large.

- Aerosols are complex and consist of many different chemicals. 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.
- Unlike greenhouse gases, which are fairly uniform over the entire Earth, aerosol composition and abundances vary significantly throughout the troposphere and on daily and seasonal timescales.
- Processes controlling the formation, transport, and deposition of aerosols are complex and not yet fully understood, which causes model predictions of the abundance and composition of atmospheric aerosols to be difficult and highly uncertain.
- Aerosols can change the way cloud droplets grow to form snow or rain. Aspects of the processes are inadequately understood, inhibiting firm predictions of aerosol effects on precipitation.

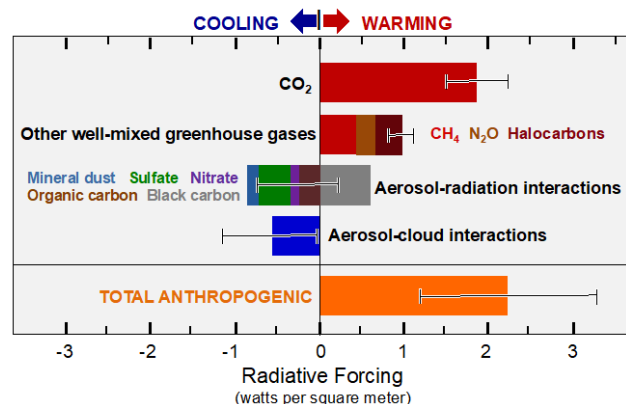


Figure 2. The calculated globally averaged radiative forcing of the atmosphere due to changes in CO₂ and other well-mixed greenhouse gases, and due to interactions of tropospheric aerosols with solar radiation and clouds (adapted from IPCC AR5 for the year 2011, relative to 1750). On a global scale, the net cooling effect of aerosols has partially offset the warming by greenhouse gases. The orange bar shows the net anthropogenic forcing, accounting for warming and cooling by gases and aerosols. Note that not all forcing agents are shown on the figure. The relatively greater uncertainties in aerosol effects are evident by their larger error bars.

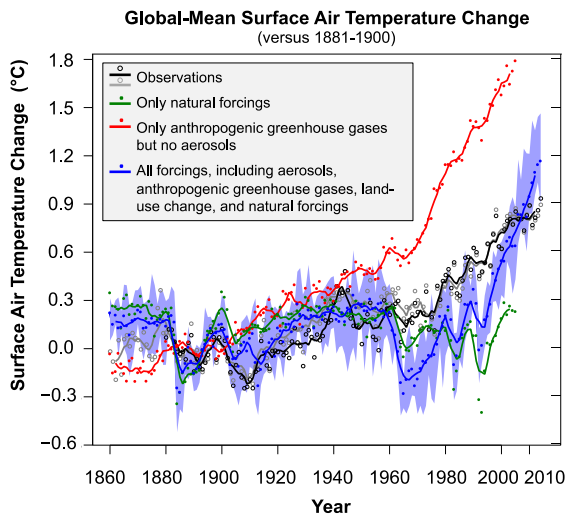


Figure 3. Global annual-mean surface air temperature change from 1860 to 2014, relative to the average temperature over the years 1881-1900. Measurements from two different databases are shown in black and gray dots and lines. Results of NOAA/GFDL CM3 model runs are shown in the colored dots and lines: average of three ensemble runs with only natural forcings, including volcanic and solar forcings (green dots and line); average of three ensemble runs with only anthropogenic greenhouse gases (red dots and line); and average of five ensemble runs with all forcings, including anthropogenic greenhouse gases, aerosols (including those from volcanoes), land use changes, and solar forcing (blue dots and line, with shading showing the range across all five model runs). Clearly, neither anthropogenic greenhouse gases alone, nor natural forcings alone, are able to reproduce the observations. Inclusion of aerosols, along with other known changes, in the climate model provides better agreement of the model with observations of temperature.

How is NOAA Addressing Aerosol-Weather-Climate Interactions?

- NOAA engages in large field studies with aircraft and ships to enhance understanding of the processes that affect aerosol distribution (sources, atmospheric transport, chemical transformation, and deposition) and properties (amount of light scattered or absorbed, cloud nucleating ability). 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.
- NOAA monitors aerosol particles at global monitoring sites to enhance understanding of trends in aerosol abundances and properties, aerosol sources and sinks, and their effects on the surface radiation budget. Aircraft, in some cases remotely piloted, sample atmospheric aerosol to evaluate aerosol heating and cooling at different altitudes and locations.
- NOAA develops and uses state-of-the-art instruments to measure aerosol abundances and properties in the atmosphere, and works with national and international agencies to improve the accuracy and reliability of aerosol measurements.
- NOAA uses operational satellites to monitor global aerosol abundances and emissions from biomass burning and forest fires. Near real-time products are provided to field forecasters through dedicated web servers for air quality 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 and other physical factors. NOAA satellite observations also yield information on clouds and aerosol-cloud interactions.

- 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 projected warmer climate as rainfall patterns are expected to change and the frequency of droughts and flooding is expected to increase.
- NOAA synthesizes observations and model results to assess uncertainties in aerosol distributions, physical and chemical properties, and climate effects by a concerted effort from aerosol, cloud, radiation, and climate scientists, using observations and theoretical calculations.
- NOAA provides air quality forecast guidance to help protect human health and the economy, and develops improved predictions of natural and anthropogenic aerosols.
- NOAA synthesizes aerosol information in policy-relevant terms for use by decision makers.

Resources for Additional Information

OAR Earth System Research Laboratory and Pacific Marine Environmental Laboratory – Intensive field, laboratory, and modeling studies to enhance understanding of aerosol emission and formation in the atmosphere, and climate-related processes. Long-term monitoring networks to provide a continuous record of aerosol properties. www.esrl.noaa.gov; www.pmel.noaa.gov

OAR Geophysical Fluid Dynamics Laboratory – Develop and use of numerical models to simulate and understand global aerosol distributions, properties, and influences, on time scales ranging from weather to climate (days to seasonal to decadal to century); and to provide predictions and projections from regional to global scales. www.gfdl.noaa.gov

NOAA Climate Program Office – Competitive research support for developing improved understanding of the climate system and observational capabilities required for advancing climate research and predictions. www.climate.noaa.gov

OAR Air Resources Laboratory – Field studies to improve the understanding of sources and deposition of aerosols and their precursors, development of regional air quality models to predict and analyze aerosol distributions, long-term measurement of climate and related land-surface processes, and analysis of climate and dust trends and variability. www.arl.noaa.gov

NESDIS Center for Satellite Applications and Research – Development and applications of satellite observations: aerosol variability, effects on the radiation balance, near real-time data, long-term fire datasets from geostationary satellites. www.star.nesdis.noaa.gov/

National Weather Service – Development, testing and implementation of NOAA's operational air quality predictions for the U.S. available at <https://airquality.weather.gov/>; operational predictions of aerosol distributions globally; and the Next Generation Global Prediction System to include aerosol impacts on weather predictions.