

# State of the Science FACT SHEET



## Aerosols and Climate

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

This document represents the state of the science as described by NOAA researchers. NOAA's Aerosol-Climate activities include targeted research to understand the processes that control atmospheric aerosol distribution and properties, monitoring to assess how aerosols are changing over time, and modeling to quantify how aerosols affect climate. This document focuses on aerosols in the lower atmosphere (troposphere).

Aerosols and greenhouse gases affect Earth's climate. However, our understanding of the aerosols' effect on climate is much less certain than that of greenhouse gases. Improving our understanding of the impacts of aerosols on climate is essential for providing more reliable climate projections and the information needed to cope with (adaptation) and reduce (mitigation) climate change.

### What are the Impacts of Aerosols on Climate?

Aerosols are suspensions in air of microscopic solid or liquid particles that profoundly affect Earth's climate even though their mass in the atmosphere is nearly a hundred thousand times less than that of CO<sub>2</sub>. They mostly reflect sunlight and thus cool Earth's surface. However, a fraction of aerosols, black carbon, has the opposite effect of absorbing incoming light and warming the atmosphere. The scattering of light by aerosols is visible as haze. These interactions with incoming solar light are referred to as "Direct Effects."

Aerosols also modify cloud amount, cloud distribution, and cloud brightness. Aerosols may change the amount, timing, and location of rain and snow through their influence on cloud properties and cloud amounts. These effects are referred to as "Indirect Effects."

The net contribution of the direct and indirect effects is to cool Earth. They partially counter the effects of greenhouse gases that heat Earth's surface and lower atmosphere. The cooling by human-induced aerosols offsets significantly the heating by human-induced greenhouse gases.

The uncertainty in the expected global temperature response resulting from various climate change agents is due in part to uncertainty in aerosol properties, distribution, and effects on clouds.

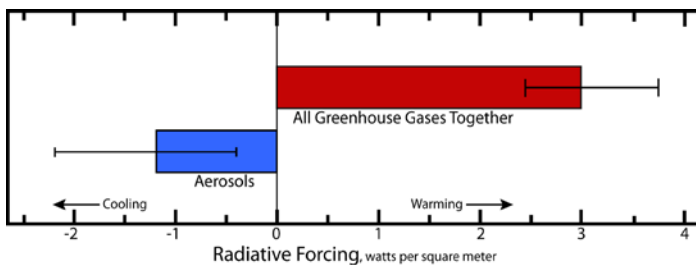


Figure 1. The calculated globally averaged radiative forcing of the atmosphere due to changes in greenhouse gases (red), and anthropogenic tropospheric aerosols (blue) (adapted from IPCC AR4 for the year 2005, relative to 1750). On a global scale, the cooling by aerosols has partially offset the warming by greenhouse gases. However, the uncertainty in the contribution to cooling is very large. Further, the radiative forcing by aerosols varies greatly in space and time.

Global-Mean Surface Temperature Change Since 1861

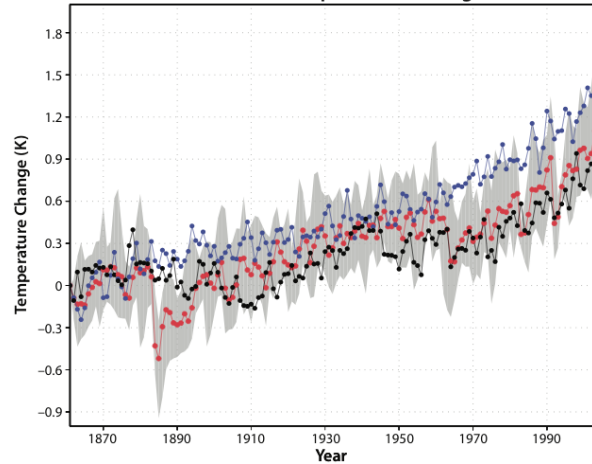


Figure 2. Global annual-mean surface temperature change from 1861 to 2003. Measured data (black dots and line) are taken from IPCC AR4 and references therein. Results of NOAA/GFDL CM 2.1 model runs: average of three ensemble runs with only anthropogenic greenhouse gases (blue dots and line) and five ensemble runs with all forcings, including anthropogenic greenhouse gases, aerosols (including those from volcanoes), land use changes, and solar forcing (red dots and line). The shaded gray area shows the range of results from the latter five model runs. Clearly, anthropogenic greenhouse gases alone do not reproduce the observed trend. Inclusion of aerosols, along with other changes, in the climate model leads to better agreement between observations and modeled results in terms of both overall temperature increases and the temperature changes with time.

### Why are there Uncertainties in the Role of Aerosols in Climate Change?

There are many challenges in understanding the role of tropospheric aerosols in climate change:

- Aerosols consist of many different chemicals. Their composition and size affect how they absorb or scatter light, how much water vapor they absorb, how effectively they act to form cloud droplets, and how long they reside in the atmosphere.
- Unlike greenhouse gases, which are fairly uniform over the entire Earth, aerosol composition and concentrations vary tremendously in space and time.
- Aerosols can both warm and cool Earth. Black soot warms the Earth; white haze cools it. The amount of heating or cooling depends on whether the particles are over land, water (a dark surface), or snow (a white surface) and whether or not clouds are present. The warming and cooling may be large enough to affect regional weather patterns.
- Aerosols have multiple effects on clouds. They make some clouds brighter, may make clouds last longer, and may make some clouds evaporate more quickly.
- Aerosols affect clouds on local scales. Examples include "ship tracks" that form when ship exhaust modifies clouds over the ocean. Scientists do not yet fully understand how all the different local effects add up on the global scale.
- Aerosols can change the way cloud droplets grow to form snow or rain. However, scientists still do not understand all aspects of this process well enough to make firm predictions about how precipitation is affected by aerosols.



**Figure 3.** 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 (red 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 is NOAA Addressing Aerosol-Climate Interactions?

Aerosols are currently the least understood driver of climate change. Understanding and quantifying the role of aerosols in climate change are essential for judicious policy decisions and are being addressed by NOAA through various activities:

- NOAA develops state-of-the-art instruments to measure aerosol concentrations and properties, and uses these instruments to investigate aerosols in the laboratory and the atmosphere.
- NOAA works with national and international agencies to improve the accuracy and reliability of aerosol measurements.
- NOAA measures aerosol particles at a number of monitoring sites to enhance understanding of trends in aerosol concentrations and properties as well as aerosol sources and sinks. Small aircraft have profiled the atmospheric aerosol to obtain information on heating/cooling by aerosols at different heights.
- 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 uses operational satellites to monitor global aerosol concentrations and biomass burning and forest fires. The data collected are analyzed to detect changes in aerosol over various temporal and spatial scales, to characterize fire-related aerosol sources, and to investigate feedback between fire activity and other climate factors.
- NOAA develops sophisticated computer models to study the effect of aerosols on clouds, the reflectivity of the planet, and climate. 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's air quality program addresses some of the air quality aspects of aerosols because of the effects of aerosols on human health.
- NOAA synthesizes information in user-friendly 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 processes that affect aerosol properties. Long-term monitoring networks to provide a continuous record of aerosol properties. <http://www.esrl.noaa.gov>; <http://www.pmel.noaa.gov>
- **OAR Geophysical Fluid Dynamics Laboratory** – Development and use of climate models to study climate variability and change, provide multi-decadal to centennial scale climate projections, and explore the decadal predictability of climate. <http://www.gfdl.noaa.gov>
- **NOAA Climate Program Office** – Competitive research support for developing a predictive understanding of the climate system and observational capabilities required for advancing climate research. <http://www.climate.noaa.gov>
- **OAR Air Resources Laboratory** – Intensive field studies to improve the understanding of the transport and deposition of aerosols and collaboration on the design of regional climate models. <http://www.arl.noaa.gov>
- **NESDIS Center for Satellite Applications and Research** – Development and use of long-term records of satellite observations to study aerosol variability and its effects on the radiation balance <http://www.star.nesdis.noaa.gov>; creation of long-term fire datasets from geostationary observations <http://cimss.ssec.wisc.edu/goes/burn/wfabba.html>; and development of enhanced fire monitoring capabilities from next generation operational geostationary and polar orbiter satellites.