climate research

How Do Aerosols Affect Earth's Climate and Our Health?

BRIAN CAIRNS AND BARBARA CARLSON

ON THE CAMPUS OF COLUMBIA UNIVERSITY, RESEARCHERS AT THE NASA GODDARD INSTITUTE FOR SPACE STUDIES ARE TRYING TO PIECE TOGETHER THE PUZZLE OF HOW THE EARTH'S CLIMATE SYSTEM WORKS.

The aim is to better understand this complex system thereby improving computer models that can be used to predict the sensitivity of climate to changes produced by natural phenomena and human activities. One of the most difficult challenges in unraveling the climate puzzle is the role of aerosols in regulating planetary temperature. People from a range of disciplines and backgrounds are working on the multiple dimensions of this *scientific problem*, including our scientists, engineers from private industry and students and faculty from university and precollege partners. Collectively, knowledge and skills are being gained in the areas of *measurement* of aerosols from the ground and space, *scientific analysis* of aerosol type, size, concentration and distribution, *applications* to public issues concerning health and *classroom impact* by involving students and teachers in aerosol research.

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Although aerosols represent only a tiny fraction of the mass of the atmosphere (less than one part per billion), they have the potential to cool climate by reflecting sunlight to space (a direct effect) and indirectly by altering cloud properties. Through processes that mix chemicals in the atmosphere and by providing surfaces on which chemical reactions can occur aerosols can even modify concentrations of greenhouse gases.

It is broadly agreed in the scientific community that the average surface temperature of the Earth has increased in the past century by several tenths of a degree *(IPCC, 1992; 1994)*, and it is generally acknowledged that the bulk of this temperature increase is probably the consequence of increasing atmospheric amounts of anthropogenic greenhouse gases. Interpretation of observed climate change is complicated not only by measurement uncertainties but also by the fact that climate can fluctuate naturally without any external forcing. However, if increasing amounts of greenhouse gases were the only forcing agent then global warming would have already emerged above the level of climate fluctuations. Unfortunately, the climate problem is not that simple. Other forcings exist that are sufficiently large that they compete with the forcing provided by greenhouse gases. Thus, unless all of the major climate forcings are measured, it will not be possible to interpret the significance of observed climate change nor to accurately predict future trends.

To place the aerosol forcing in perspective, the present day forcing due to greenhouse gases is roughly +2.0 to +2.8 W/m^2 while the present day global mean forcing (direct and indirect) due to man-made aerosols is estimated to be between –0.3 to –2.5 W/m^2. Unlike greenhouse

What are aerosols?

Atmospheric aerosol particles are traditionally defined as those particles suspended in the air having diameters in the range of 0.001 to 10 µm. They are formed either through chemical reactions in the atmosphere or result from the dispersal of surface materials.

Where do aerosols come from?

The earth naturally produces aerosols through volcanic eruptions, dust storms, burning of biomass in forest and grassland fires, living vegetation (pollen, spores, organic molecules), and sea spray. Humans contribute aerosols to the atmosphere by burning fossil fuels that produce smoke, soot and gases (sulfates, nitrates and volatile organic compounds) that can react to form aerosol particles. Agriculture can also be a source of aerosols through over-cultivation that leads to soil erosion and the creation of dust aerosols.

How are aerosols removed from the atmosphere?

This occurs through direct uptake at the surface (dry deposition, like the dust that settles on furniture) or through precipitation (wet deposition, like acid rain and snow). The efficiency of these removal processes depends on the type and size of aerosol, and on location and time. Aerosols transported to higher atmospheric levels have longer residence times than those at lower altitudes because removal by precipitation is less efficient and settling to the ground takes longer. Typically, small sulfates released or formed near the earth's surface remain in the atmosphere for several days, with the actual lifetime depending on the frequency of precipitation.

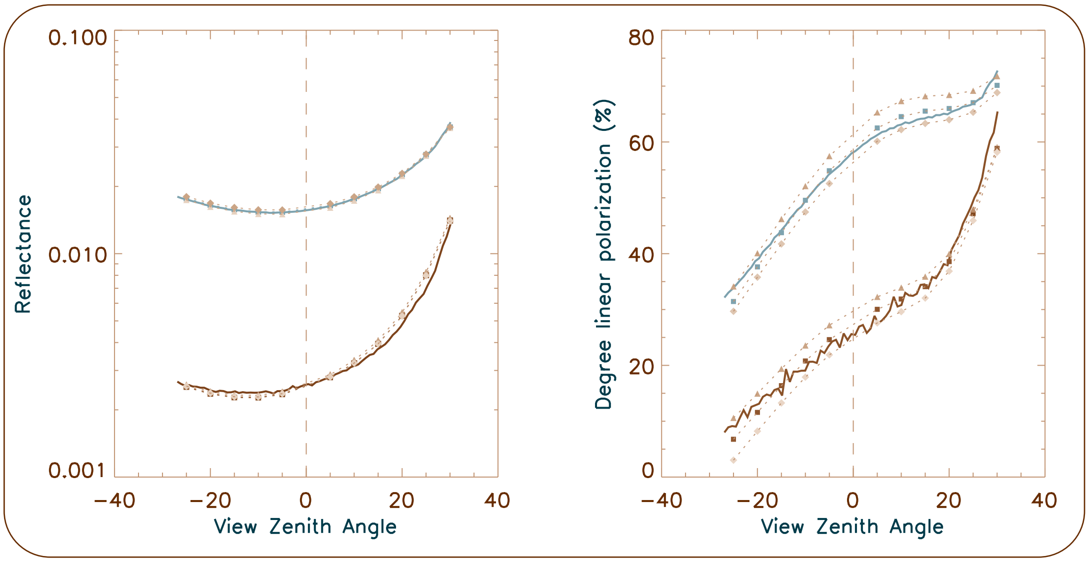


FIGURE 1

Data from the Research Scanning Polarimeter (SpecTIR Corporation) show that polarization measurements (right) are more sensitive than intensity measurements (left) for detecting small differences in aerosol refractive indices.

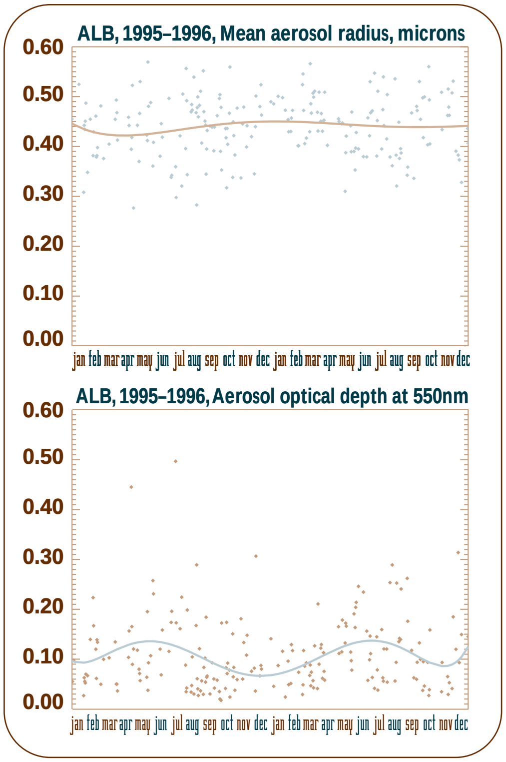
gases that stay in the atmosphere for decades, most aerosols have short lifetimes measured in days. The short atmospheric residence time combined with the highly nonuniform geographic distribution of aerosol sources results in a highly nonuniform aerosol forcing which requires a more comprehensive observation program to measure and monitor atmospheric aerosols than is required for greenhouse gases. Although aerosols are important to earth's climate, they are poorly characterized in climate models and observations that might improve this state of affairs are extremely limited.

The New York City (NYC) junior high, high school and undergraduate students and faculty involved in the ICP ground-based aerosol-monitoring project are working on a science problem of considerable importance to NASA and people around the globe. One aim of this project is to help scientists characterize aerosols using automated sunphotometers, handheld sunphotometer and polarimeter instruments, as well as LIDAR measurements. Hand-held sunphotometers and polarimeters made in a high school or college classroom are deployed at schools across the NYC area during intensive observation periods (IOPs) and provide valuable information on the spatial variability of aerosols. This spatial information is important for understanding the uncertainties in using automated sunphotometers to validate satellite-based aerosol retrievals. Information on how aerosols are vertically distributed obtained from LIDAR measurements can contribute to improved modeling of transport and deposition. Our study also is concerned with the impacts of aerosols on public health. To do this, students conduct asthma surveys and examine existing asthma incidence data more carefully with regard to possible chemical and aerosol causes.

The GISS/ICP Aerosol Measurement Program

Once every minute during the course of the day, sunphotometers of the Multi-filter Rotating Shadow-band Radiometer (MFRSR) type positioned on the rooftops at GISS in Manhattan and Medgar Evers College in Brooklyn take measurements of the brightness of the Sun's beam and the brightness of the sky at six wavelengths. These measurements provide students, faculty and scientists with an expanding database and climatology to analyze the amount of solar energy being absorbed, reflected and scattered in the Earth's atmosphere. The six spectral bands are located at 410, 500, 610, 670, 870 and 960 nm. Measurements of the brightness of the direct beam of the sun at these wavelengths can be used to infer the amounts of ozone, nitrogen dioxide, water, and aerosol between the surface and the sun (the column amounts) in NYC. Complementary measurements are taken during IOPs where students point hand-held sunphotometers toward the sun to collect data at a single wavelength (500 nm) throughout each day over the course of a week to study solar intensity and aerosol optical depth for their urban locales. NYC is just one site of the GISS Solar Irradiance Research Network that consists of 22 MFRSRs operated by US-based science collaborators with local schools. ICP students and faculty are a part of this nationwide effort to reduce the significant uncertainty in our understanding of aerosol properties and the consequent aerosol radiative forcing.

The only type of remote sensing measurements that are useful for the determination of aerosol composition are polarimetric measurements, which are sensitive to the aerosol refractive index. GISS scientists have been working to develop instruments and analysis tools to accurately measure and interpret the polarization of scattered light. For example, figure 1 shows measurements taken from an aircraft over the ocean. The solid lines represent data at 865 nm (upper curve) and 2250 nm (lower curve) while the dashed lines represent three different model simulations. These model simulations show the effect of perturbing the refractive index by +/–0.02. As can be seen it is not possible to use intensity measurements to distinguish between models with refractive indices that differ by 0.02. By contrast the climate research



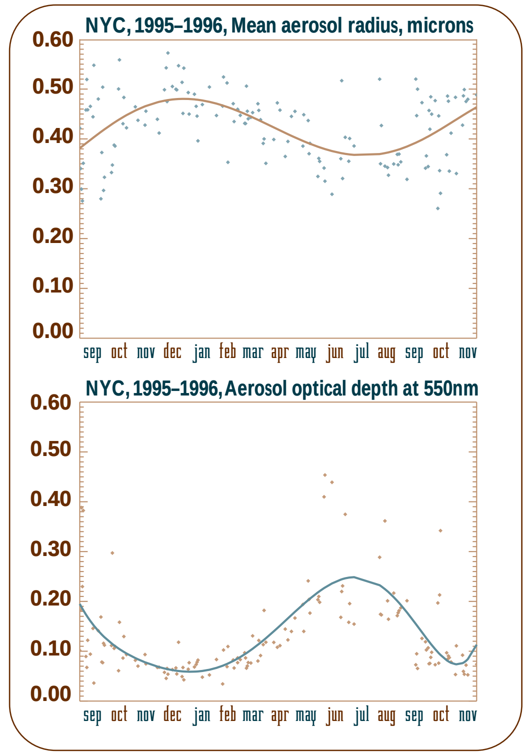


FIGURE 2

Retrievals from ground-based measurements made by MFRSRs at the Atmospheric Sciences Research Center at SUNY Albany, and the Solar Irradiance Research Network at NASA GISS, can be used to derive an aerosol climatology.

polarization measurements demonstrate the power of polarization to discern small differences in refractive index between different aerosols.

In the new Remote Sensing Lab at City College of New York (CCNY), students and their faculty mentors Drs. Fred Moshary, Barry Gross and Reza Khanbilvardi are in the final stages of equipping a mobile van with environmental instrumentation, including LIDAR, to take measurements of airborne particulates in the city as part of the IOPs. The van is also equipped with a Michelson interferometer that can be used to determine surface ozone levels and look for the presence of other trace gases.

Scientific Analysis

Members of the ICP aerosol team have analyzed daily MFRSR data. Figure 2 shows a comparison of the results we have obtained for the mean aerosol radius (upper panels) and visible aerosol optical depth (lower panels) for Albany, NY (left panels) and New York, NY (right panels). These instruments are separated by roughly 130 miles. A comparison of the upper panels reveals that the aerosols in Albany and New York are comparable in size, with an average radius of 0.45 µm. However the aerosols in New York exhibit an annual variation in mean radius with smaller aerosols found in the summer, while the aerosols in Albany do not appear to exhibit a well defined annual variation in size. Nonetheless, as shown in the lower panels, aerosol optical depth has an annual cycle in both Albany and New York, with larger aerosol optical depths occurring in the summer months. Not surprisingly, average summer aerosol optical depths in New York are larger than those in Albany, 0.25 versus 0.14, respectively.

These ground-based measurements can be used to test and improve the aerosol products derived from NASA satellite observations such as EOS Terra where the MODIS and MISR instruments will take measurements that should significantly improve the representation of aerosols and aerosol processes in climate models.

Applications to Public Issues

Aerosols are of interest since their small size allows them to enter the air sacs deep in the lungs where they may be deposited and lead to adverse health effects. Rashele Cross, a senior at Townsend Harris High School in Queens, and Christine Fleming a senior at DeWitt Clinton High School in the Bronx have been consulting with medical researchers at Mount Sinai Hospital to study whether there is a relationship between aerosol (particulate matter), pollutants, and the growing incidence of asthma. Andre Cassell, a senior at Bronx High School of Science, is conducting a complementary study of trends in aerosol sources in NYC and their compositional changes. The studies conducted by these students are of particular concern since asthma hospitalization rates have doubled over the last ten years despite significant advances in the treatment of asthma.

Rashele began by investigating the relationship between the sunphotometer measurements of aerosol optical depth and the Environmental Protection Agency (EPA) measured particulate concentrations. Since optical depth is a measure of how much aerosol is present in the atmosphere we would

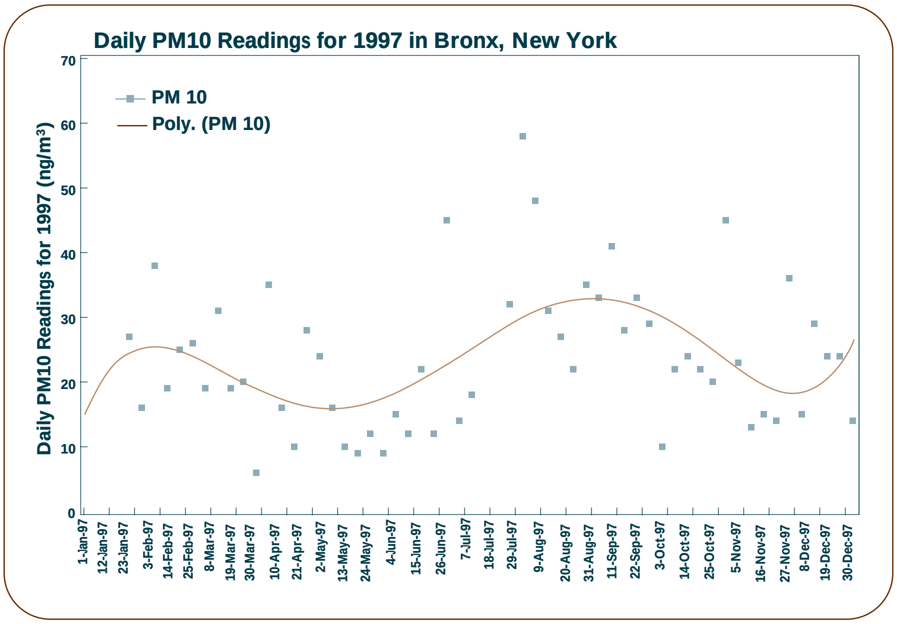


FIGURE 3

EPA measurements of particulate matter show that aerosol concentrations peak in the summer.

expect there to be a relationship between sunphotometer derived optical depth and the particulate matter concentrations measured by the EPA. Figure 3 (above) shows the annual variation of PM10, particles of size 10 microns or less, concentrations measured in the Bronx in units of $\mu g/m^3$ (weight of particles in micrograms per one cubic meter of air). As with the sunphotometer data previously shown, the aerosol/particulate concentrations peak in the summer.

If aerosols play a significant role in triggering asthma, then we would expect that the seasonality of asthma would follow the seasonal variation of particulates, namely more asthma attacks in the summer. In order to investigate this, Christine analyzed the hospital admission data provided by Mount Sinai as well as data obtained from her own survey. She surveyed 1431 students at DeWitt Clinton High School.

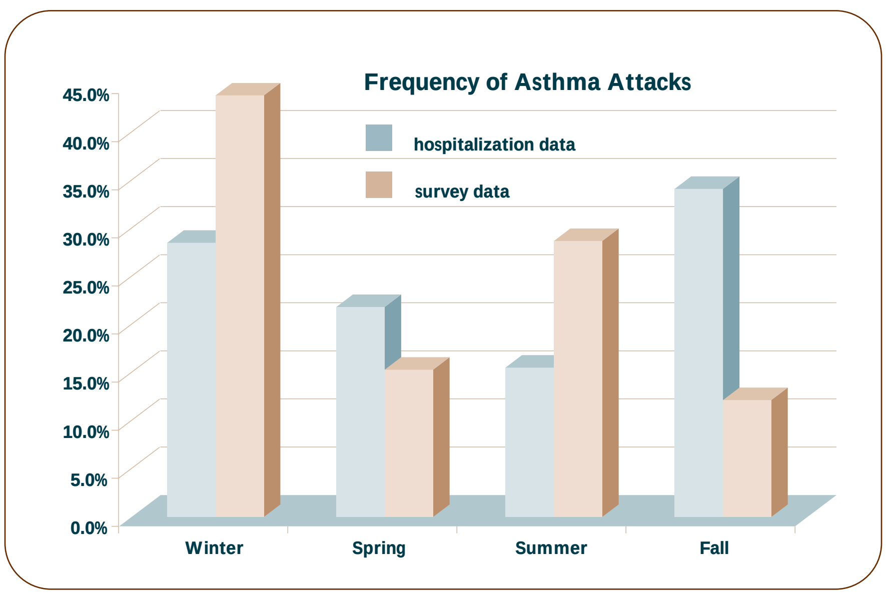
FIGURE 4

Comparison of results from a survey of 1431 high school students with asthma hospitalization data supplied by Mt. Sinai Hospital indicate a greater frequency of asthma attacks in the fall and winter.

Since the survey was given during school in the science classes, the sample is random with respect to asthma. As seen in figure 4 (below), Christine found that asthma attacks are more common in the fall and winter than in spring and summer when the aerosol/particulate concentrations are the highest.

Since sunphotometers measure direct beam extinction, they are insensitive to the composition of the aerosol, which is important for understanding the sources of aerosols. Therefore, Andre Cassell examined aerosol deposition data from the National Aerosol Depostion Program in order to investigate potential changes in aerosol composition with time. We know aerosols are removed from the atmosphere by both wet (rain/snow) and dry (gravitational settling) deposition, hence he analyzed the data from both data sets. Andre found that although atmospheric amounts of sulfate are decreasing, probably as a result of the Clean Air Act, there have been increases in nitrogen species. In particular, he found that the deposition fluxes of nitrate and nitric acid as well as an increase in atmospheric concentrations of nitric acid and nitrate at the stations near NYC.

Diesel and gasoline combustion engines are major sources of the nitrogen oxides that react to form nitric acid and nitrate aerosol particles. Thus, it is reasonable to expect that the concentrations of these particles (as well as that of the precursor gases) would be increasing due to increasing vehicular traffic.



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Rashele investigated the changing composition of the aerosol. Figure 5 shows the comparison between the nitrate fraction for all aerosols (total suspended particulates—TSP) and PM10 (inhalable particulates) measured in the Greenpoint section of Brooklyn. As can be seen the nitrate fraction is increasing for the smallest particles. This increase is occurring over the same period where the mortality data for New York show an increase in the mortality rate.

Classroom Impact

In addition to involving teams of students and faculty in the research, this project has several classroom applications. For example, students at LaGuardia Community College in Queens are exploring the uses of polarization as a remote sensing tool. In Professor James Frost's Electronics Projects course students design, build and test hand-held polarimeters that are used to take measurements of the polarization of skylight. Their peers in Professor Beverly Rosendorf's Visual Basic course develop algorithms for analysis of data that is collected using a database search of model calculations to find the aerosol model that best fits the observations. A new Remote Sensing course taught with Professor Fred Moshary at CCNY, exposes engineering students to a range of earth science related problems using remotely sensed data. This past summer, high school physics faculty and GISS scientists developed a series of demonstrations and labs for learning about the science of measurement, instrumentation, aerosol atmospheric effect and modeling physical and chemical phenomena. These lessons address new state science standards for students to learn about energy, mathematical analysis, and the interactions between land, air and water in modeling the world we live in.

The ICP aerosol project incorporates characteristics of an ideal research team experience that we are attempting to evolve. It is motivated by a priority research question in NASA's study of earth's climate system. It involves measurement activities and scientific analysis whereby students and faculty from pre-college through undergraduate levels can contribute. Opportunities for students to use the scientific knowledge gained in their investigations are being applied to issues in the public interest. The research is being translated into significant impacts on classroom learning via scientist-faculty collaboration.

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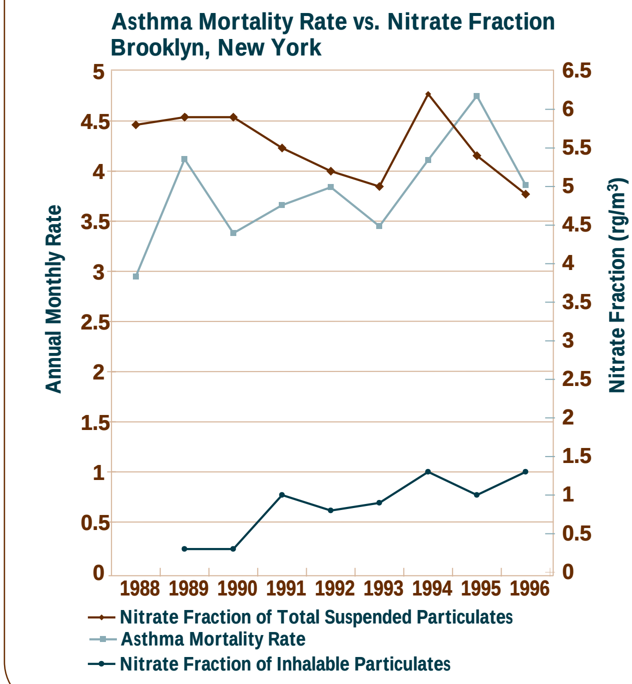

FIGURE 5

Comparison of asthma mortality rate and nitrate fraction in Brooklyn NY for the period 1988–96 shows that the nitrate fraction of total suspended particles has decreased, asthma mortality rate has increased, and nitrate fraction of inhalable particles has increased. DATA SOURCES: <u>nitrate fraction</u>: NY State Dept. of Environmental Conservation's Ambient Air Quality Monitoring Network; <u>asthma mortality</u>: Centers for Disease Control and Prevention.

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