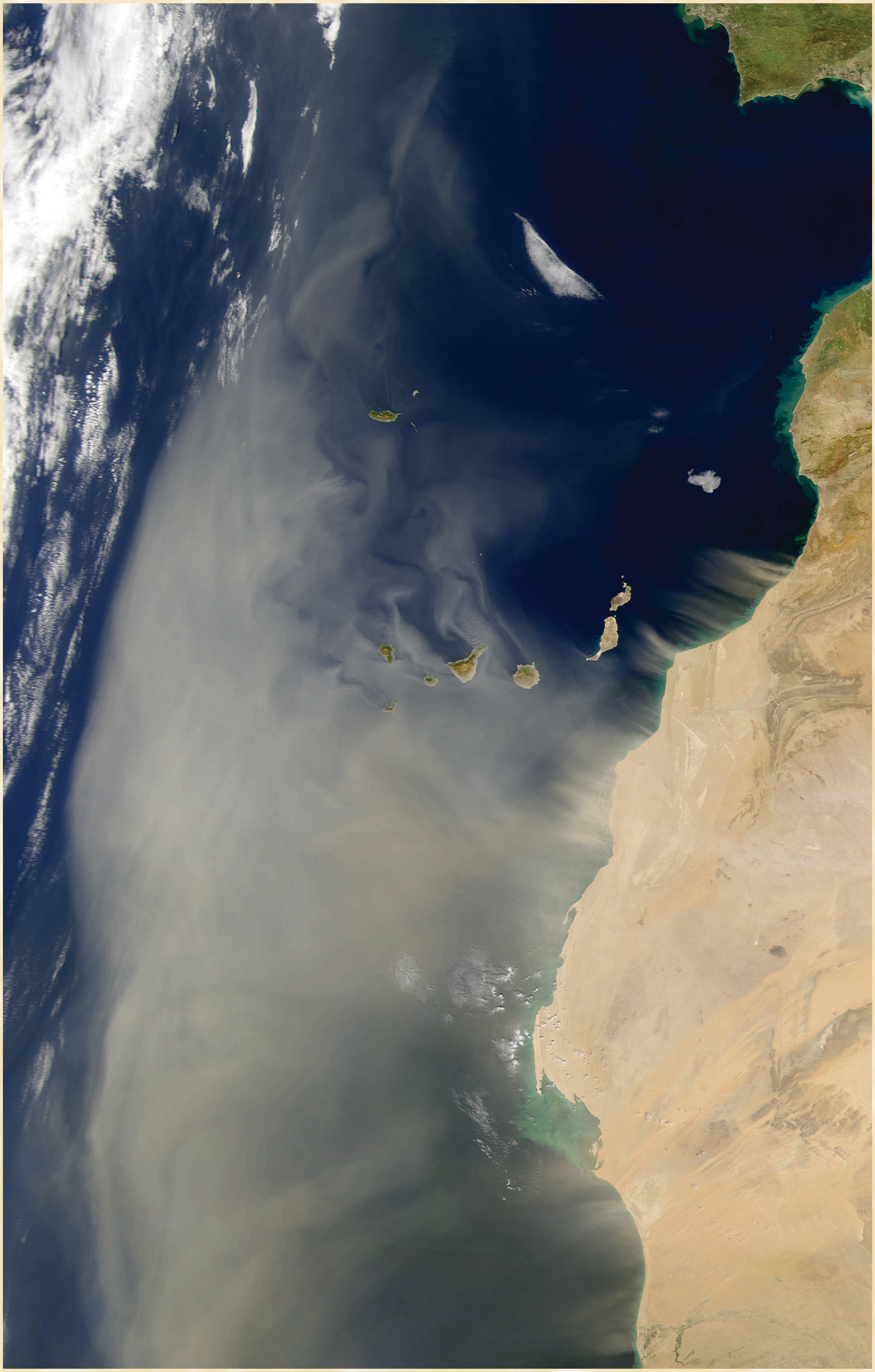
DUST *in the* WIND

On a blistering June day in West Africa, standing on the bank of the Senegal River, one might look east and see what appears to be a blood-red curtain billowing the length of the horizon. When the curtain arrives, daylight disappears, and the land is covered in a dark red, gritty-tasting night. Going inside offers little protection—wind-blown dust soon penetrates shutters and plaster cracks, leaving a thin red layer everywhere; rooms feel like mine shafts. This is a dust storm in Africa's arid Sahelian band, the southern fringe of the Sahara Desert from Mauritania to Chad.



Background: PhotoDisc; right: NASA

Evolution of a dust storm. Satellite images capture a massive dust storm traveling from northwest Africa (right) over the Canary Islands (center) and across the Atlantic toward North America.

Every year, Sahelian dust storms, which can rise up to 4 kilometers into the sky, launch masses of dust—estimated from 500 million to over 1 billion tons—into the atmosphere. By comparison, Mount Pinatubo's massive 1991 volcanic eruption sprayed just 29 million tons of comparable ash.

Eight weeks before a Sahelian storm reached Florida last June, a dust cloud from another direction made headlines. In April 2001, two dust storms from Mongolia's Gobi Desert passed over the Aleutian Islands to the Pacific Northwest, penetrating North America. Between April 14 and 18, the first, large storm—at one point roughly the size of Japan—blanketed Colorado with a fine, whitish coating. A second, smaller storm dumped on the Pacific Northwest region the following week. Storms from both Africa and Asia appear to be growing more frequent.

Although dust itself is small—most particles range in diameter from 0.01 to several dozen micrometers—the subject is huge. Hannah Holmes, author of *The Secret Life of Dust*, states it boldly: "It regulates the weather. It influences the climate. Its powers seem unlimited. . . . This stuff makes the world go around." Dust can also sway the fates of nations and wars: recently a broadcast series of daily satellite images of dust plumes in Asia was stopped because some of them originated over Afghanistan, and knowledge of their whereabouts had military value, according to an unnamed official at the National Oceanic and Atmospheric Administration (NOAA).

Increasingly, the global dust "budget," as scientists refer to the total amount of matter in global circulation, is attracting scrutiny for its changing patterns, its possibly far-reaching effects on climate and ecosystems, and its potential impacts on public health. Dust and other particulate matter that occurs naturally (from volcanic eruptions, forest fires, live vegetation, and sea spray) makes up 90% of airborne aerosols; about 10% of aerosols in the atmosphere are caused by humans, mainly as residues from automobile and industrial exhausts.

That 10% used to be the main concern for health, but researchers see growing importance in naturally occurring dust storms. Dust motes averaging less than 2.5 µm in diameter are in the range of particles that research is showing may have serious health consequences. In addition to the mineral composition of the particles themselves, dust can carry with it a variety of hitchhikers including bacteria, fungi, and chemical contaminants, all of which may adversely affect health and the environment.

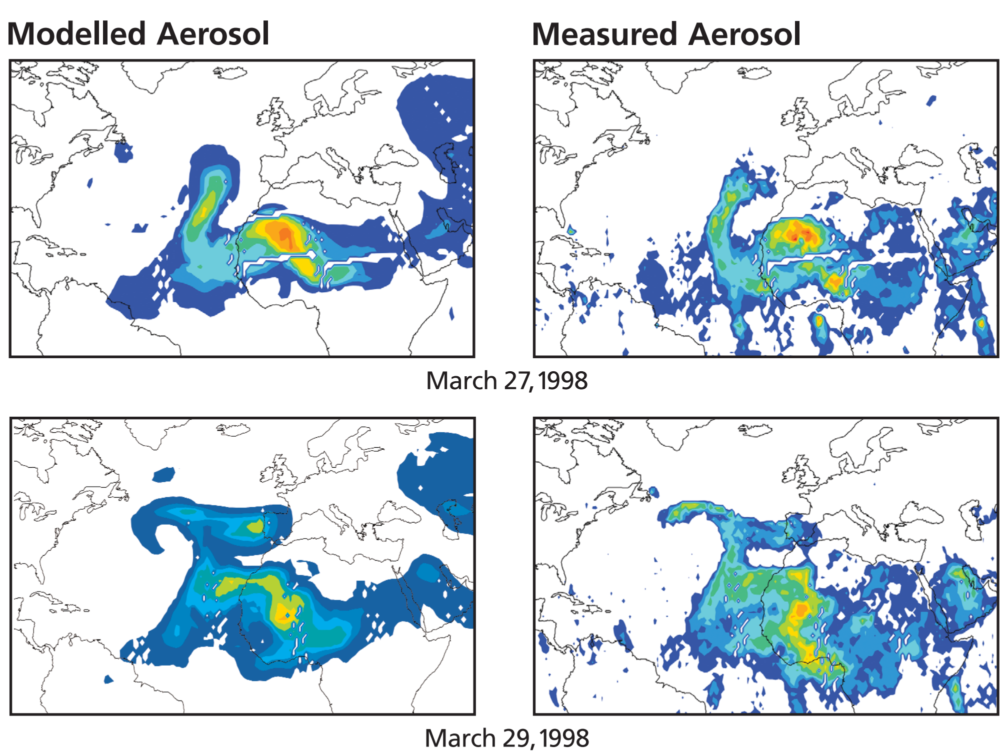
Students of Storms

The naturalist Charles Darwin was on the trail of dust in the early 1830s. Aboard the HMS *Beagle* when it docked in the Canary Islands, Darwin noted the common sight of dust accumulation on ships during the Atlantic passage, where it could foul the instruments and cover the decks in a fine, reddish film. Darwin speculated on where the dust came from and where it ultimately settled. Since then, others have followed his lead.

One fellow observer is Joseph M. Prospero, director of the University of Miami's Cooperative Institute for Marine and Atmospheric Studies. Like his Shakespearean namesake, Prospero knows about storms. He has studied dust storms from the Sahel and their trail across the Atlantic for nearly 40 years.

Prospero first became interested in dust while studying the mineralogy of deep-sea sediments. At that time, it was generally believed that most mineral sediments in the open ocean are transported from the continents by large rivers. But in the mid-1960s researchers found that, in many ocean regions, some sediment minerals were clearly not associated with rivers. For example, a trail of quartz in the North Atlantic shows a distinct pattern that links it to the western coast of North Africa. Many African soils are quartz-based, but North and West Africa do not have rivers large enough to explain the deep-sea quartz deposits. "Clearly something else was going on," Prospero says. Anecdotal evidence, including Darwin's observations, suggested that African winds might be the source.

Since then, Prospero has monitored dust concentrations at stations in the Caribbean and South Florida with an eye to whether they correlate with dust storms from Africa. In the 1970s, when the present Sahelian drought began, the incidence of dust clouds reaching Florida increased. Prospero's measurements, probably the longest aerosol record in existence, have formed the basis for a series of analyses involving researchers from



Tracking dust. Images produced using the GOCART model (left) closely predict actual satellite measurements taken by the Total Ozone Mapping Spectrometer (right). Both sets of images show dust blowing from Africa across the Atlantic Ocean toward the United States.
Source: http://www.gsfc.nasa.gov/topstory/20010917dust.html

NASA

Where dust is born. The GOCART model identified 10 main sources of dust: 1) the Salton Sea, 2) Patagonia, 3) the Altipläno, 4) the Sahel region, 5) the Sahara Desert, 6) the Namibian desert lands, 7) the Indus Valley, 8) the Taklimakan Desert, 9) the Gobi Desert, and 10) the Lake Eyre basin.

Mountain High Maps, Matt Ray/EHP

the National Aeronautics and Space Administration (NASA), the U.S. Geological Survey (USGS), and others.

One such researcher is Paul Ginoux of the Georgia Institute of Technology in Atlanta. Due to the size of their dust sources and jet stream flows, the Asian and African events are the most significant for North America, says Ginoux. (The Intertropical Convergence Zone along the equator acts as a sort of wind barrier to separate the storms of the Northern and Southern Hemispheres.) Ginoux has simulated dust storms from Africa and Asia with the Global Ozone Chemistry Aerosol Radiation and Transport (GOCART) model developed by Georgia Tech researcher Mian Chin with NASA's Goddard Space Flight Center in Beltsville, Maryland. GOCART uses meteorologic data from NASA's Earth Observing System satellite, which allows direct comparison of the model with observations.

Using seven categories of particle size (ranging from 0.1 to 6.0 µm in radius) and air stream movement, GOCART assesses dust sources and estimates annual emissions and their path. In comparing the African and Asian dusts, Ginoux and others suspect that Asia's dense population and industrial cities make the Asian variety a more significant transporter of pollutants. The two storm sources also have a different seasonality: in the Northern Hemisphere, the African dust storms peak in the summer, whereas the Asian storms come mainly in the spring, formed by passing cold fronts that create huge plumes; the wedge-like fronts rise up to 8 kilometers high.

Ginoux and his colleagues have identified 10 main sources of global dust events including the Sahara Desert, the Sahel region, the Namibian desert lands of southwestern Africa, the Indus Valley in India, the Taklimakan Desert north of the Himalaya, the Gobi Desert in Mongolia, the Lake Eyre basin in Australia, the Salton Sea in southeastern California, the Altipläno stretching between Bolivia and Peru, and the Patagonian region of the Andes Mountains.

Lungsful of Dust

Recent advances in remote sensing technology permit an increasingly sophisticated understanding of the timing and characteristics (particularly the size) of dust that crosses the ocean. The size of the dust motes is significant because the U.S. Environmental Protection Agency (EPA) has set standards for ambient airborne particulate matter of up to 10 µm in aerodynamic diameter (PM_{10}) and that less than 2.5 µm in diameter ($PM_{2.5}$).

Dust particles as large as 10 µm can deposit in the lung airways and cause bronchial airway constriction. Particles up to 4.0 µm are considered respirable, meaning they can penetrate to the gas-exchange region of the lungs and interfere with lung function. Particles less than 2.5 µm, so-called fine particles, are now believed to have the greatest impact on human health. Such particles are able to move past the filtering mechanisms at the entrance to the lungs and can introduce infection directly to the lung tissue, as well as coat the interior lung surface and reduce its ability to function. According to Prospero, one-third to one-half of the dust mass that comes to the United States from Saharan clouds is smaller than $PM_{2.5}$.

Surprisingly little is known about the health effects of aerosols, despite early attention by public health officials in the 1930s, when a phenomenon called "dust pneumonia" claimed lives in the American Dust Bowl. The Dust Bowl was caused when fragile grasslands, made vulnerable by overcultivation of wheat and poor land management, were cleared of topsoil by a combination of drought and heavy winds, and severe dust storms swept the U.S. Great Plains.

"Unfortunately, until recently there has been very little daily monitoring of fine particles," says C. Arden Pope III, a professor of economics and leading expert on the subject at Brigham Young University in Provo, Utah. In an overview published in the August 2000 issue of *EHP Supplements*, Pope outlines the main mechanisms and hazards of fine particles. In urban areas, a large portion of $PM_{2.5}$, including sulfate and nitrate particles,

Menacing motes. Unchecked agriculture and sustained drought led to the 1930s Dust Bowl in the U.S. Great Plains.

originates from combustion processes and photochemical reactions.

Traditionally, inorganic fine particles have been viewed as generally nonthreatening, though heavy exposure to even relatively harmless particles can overwhelm the body's system for screening hazards from the lungs and impair respiratory function. New research is showing that fine dust can also be a threat to people with cardiovascular illnesses if it inflames the alveoli in the lungs, which in turn may release harmful cytokines and thicken the blood. This reaction may put some people, including the elderly, the very young, and people with heart disease, flu, and asthma, at risk of cardiac death, according to Pope. But he cautions that such broad categories of threat are inadequate, as the risk varies depending on level and length of exposure.

Morton Lippmann, director of the human exposure and health effects core at the Institute of Environmental Medicine at New York University, agrees that dust clouds themselves are not likely to pose a real health risk; they mainly present an added complication to the problem of aerosols and the application of the EPA's particulate matter standards.

It's difficult to compare the health risks from dust with other types of aerosols, but Joe Mauderly, director of the National Environmental Respiratory Center in Albuquerque, New Mexico, suggests one approach. First, gauge the size of the particles; in the case of intercontinental dusts, most fall in the relatively more hazardous $PM_{2.5}$ range. Second, factor in the particles' relative toxicity. In Mauderly's view, as Asian and African dusts are mostly crustal—surface particles consisting mainly of crystalline rock—they are relatively less toxic than industrial soots. Finally, assess the concentrations to which people are exposed. In short, he says, "you could approximate the transported dust impact by the additional concentration it adds to the baseline $PM_{2.5}$ concentration at any given location at any given time."

A reasonable default may be to consider the magnitude of effects proportional to the effects of $PM_{2.5}$, although Mauderly cautions this method is not precise. "In fact," he says, "the estimates of health risks from $PM_{2.5}$ of any kind are far from precise, but it is a reasonable approximation based on what is known so far."

Prospero maintains that the African dust poses a risk higher than might be expected from local crustal particles because of its size and concentration. "Fine-particle concentrations in African dust are much higher than for dust from American soils," Prospero says. "When you breathe the dust out West, you end up with a lot of mud on the inner surface of your nose," he says, a sign that the body is effectively screening it. That's not the case with dust storms on the East Coast, in which finer particles can penetrate the lung's defenses, particularly in people with weak immune systems.

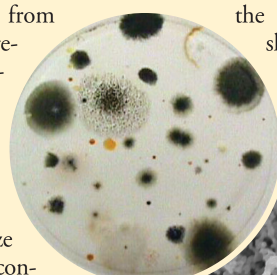
Applying Mauderly's rule of thumb to measurements taken in Florida, the combination of particle size (43% in the $PM_{2.5}$ range) and concentration (in July 1983, $PM_{2.5}$ concentration reached 49–74 µg/m^3 for three days in Miami) suggests that the larger storms expose a significant portion of Miami's population to short-term concentrations of fine particles higher than the EPA's 24-hour standard of 65 µg/m^3. That's a worst-case scenario for a short period, Prospero admits. "Although dust concentrations in themselves are unlikely to trigger a violation of the twenty-four–hour $PM_{2.5}$ standard, dust in conjunction with emissions from local and regional sources could conceivably present a problem." Such a combination is likely, given the storms' seasonality: in the U.S. Southeast, dust concentrations peak in the summer when pollution concentrations are also highest.

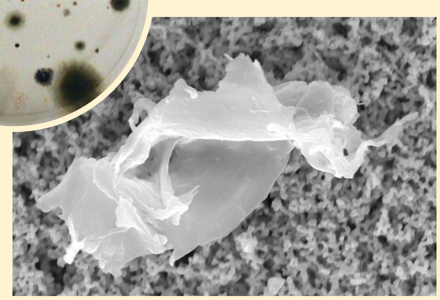
An added hazard may come from the African dust's mineral components. Research suggests that fine iron particles—the source of the reddish color of the African dust—can cause the generation of hydroxyl radicals on the lung surface that can scar lung tissue over time and decrease its effectiveness.

Intercontinental Hitchhikers

Besides particle size, another important feature of transcontinental dust clouds is the microbes they transport. It was once thought that bacteria could not survive transport across ocean distances, but that understanding is changing. It's now known that bacteria and fungi can attach to dust particles and cause allergic reactions and diseases, and may be related to recent increases in asthma rates.

Asthma is one of the first respiratory problems that dust clouds might be thought to exacerbate, but owing to the many causes of asthma, confirming that connection proves difficult. Asthma rates in South Florida and the Caribbean have indeed risen sharply in recent years. But the reality is, asthma rates in many places have doubled since 1980, and the reasons are





Unhealthy hitchhikers. An organic particle (above) and bacteria were both collected from African dust storms that reached St. Johns, USVI, in June 2001.

Top to bottom: NOAA/Department of Commerce; USGS; USGS still unknown. “When you look at asthma,” says Holmes, “there are intriguing coincidences like that all over the place.”

New research provides more evidence that intercontinental dust storms may transmit viable pathogens. Dale Griffin, a microbiologist at the USGS Center for Coastal Geology in St. Petersburg, Florida, screened dust samples collected by USGS marine biologist Virginia Garrison on St. John in the U.S. Virgin Islands. On St. John, Garrison used a vacuum pump to capture dust samples in sterile canisters, both during dust storms and on nondusty days. Griffin subjected the samples to R2A agar, a medium used to cultivate a broad spectrum of bacteria, to find microbes whose resistance may have been depleted by ultraviolet (UV) light exposure but that might possibly have survived the journey. The study results, published in the 14 June 2001 issue of *Aerobiologica*, showed that Griffin and his colleagues were able to isolate over 200 viable bacteria and fungi where scientists previously considered such successful transport impossible due to the UV exposure involved in the five- to seven-day crossing from Africa to St. John.

“We found opportunistic pathogens that can affect compromised immune systems, as in older people and the very young,” says Griffin. “Most [can cause] skin-type infections: rashes, open sores, some subcutaneous nodules.” They also found pathogens known to affect crops such as cotton, peaches, and rice. Griffin continues to look for the citrus canker pathogen, which is endemic to many parts of the world, including Asia and Africa, and which occasionally appears in Florida, where outbreaks have done substantial ecologic and economic damage through the destruction of citrus crops.

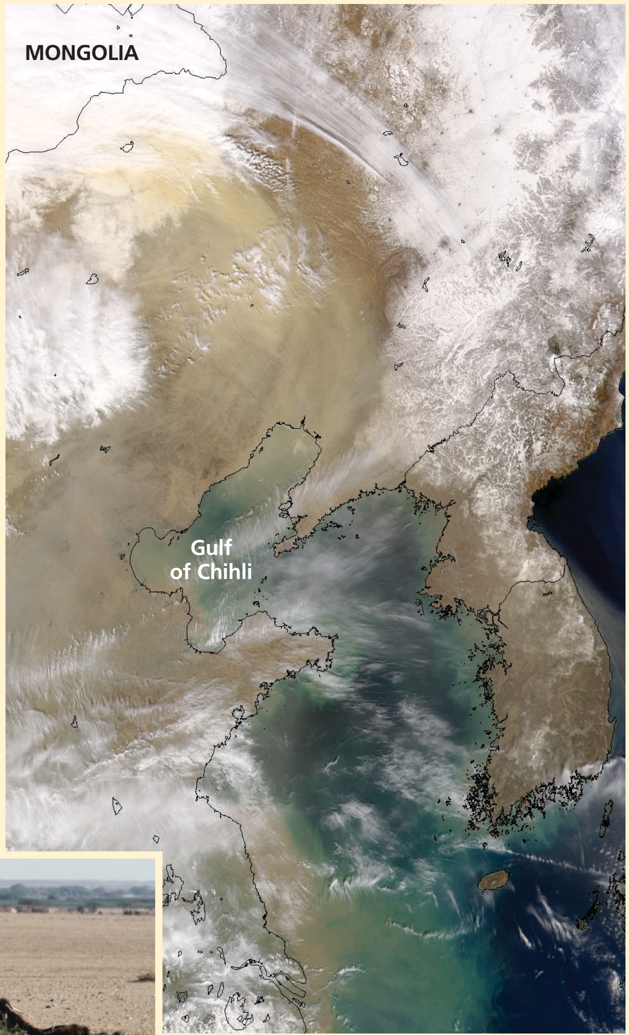
Griffin suggests that the microbes survived because in such thick clouds of dust, the UV exposure at the bottom can be just half the level of that at the upper surface, so microbes in the lower layer could be shielded enough to survive. Furthermore, crevices in the African dust particles, which can be made of organic matter such as leaves, may shelter bacteria safely to landfall.

Contaminated Cargo

Compared with the clouds from Africa, Asian dust shows higher concentrations of human-caused air pollutants such as sulfates. For that reason, the Asian aerosols may be more problematic. China as a whole is experiencing a crisis of airborne dust. The dust storms from the Mongolian region of China start from severely eroded soils, caused by intense grazing in that region spurred by programs to boost crop production. As the dust clouds from these eroded lands pass over Beijing and other large cities, they gather industrial pollutants. The resulting dust storms can reduce visibility enough to close airports—and worse.

According to Holmes, noxious aerosols kill 1 in 14 people, and pneumonia, often from breathing dirty air, is the leading cause of death among children in China. Holmes estimates that 1 million Chinese people die each year from airborne dust. “It is as though the entire population of Maine died of dust poisoning year after year after year,” she says.

Indirectly, aerosols can harm nutrition by reducing crop yields both through erosion of soil nutrients and by shading crops from needed UV light. A 1998 report by the U.S. Embassy in Beijing titled *PRC Desertification: Inner Mongolian Range Wars and the Ningxia Population Boom* notes that the map of poverty in China largely overlaps that of desertification, environmental devastation, and social change.

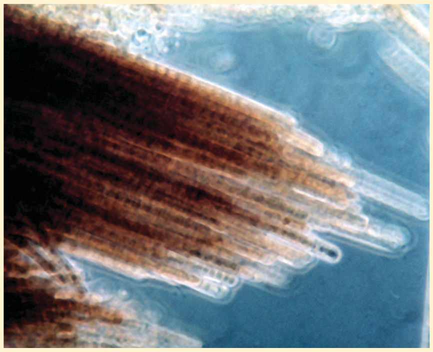


Source of the storm. A 5 March 2001 dust storm stretches across northeastern China (above). The heaviest visible concentrations of dust are between the Gulf of Chihli and the Mongolian border. Desertification due to overgrazing and overfarming has created ripe conditions for dust storms throughout much of rural China (left).

Top to bottom: NASA; FAO/R. Faidutti

The history of coccidioidomycosis, or San Joachim Valley fever, a flu-like illness endemic to the American Southwest and parts of Mexico, testifies to the bacterial hazards that can ride on wings of dust. Dust storms are a common event in the American Southwest between July and September. The Centers for Disease Control and Prevention (CDC) have tracked a gradual rise in coccidioidomycosis incidence in Arizona, California, and New Mexico. In Arizona between 1980 and 1995, the CDC noted an increase in annual cases from 200 to over 600. The agency linked this rise to the increase of two key vulnerable populations: the elderly and persons with HIV infection, whose numbers increased by 79% in that state in the first half of the 1990s.

Hantavirus is another dustborne virus. Although first spotted in the American Southwest in 1993, it has since been found worldwide. The virus appears to be associated with eroded soils, suggesting a link with deforestation, according to the Food and Agriculture Organization of the United Nations. Deforestation can create a habitat for diseases such as Lyme disease and hantavirus because ticks, mosquitoes, rodents, and other disease vectors excel at colonizing degraded landscapes, says Julie Lyke, an



Far-reaching consequences. A red tide off the coast of Florida that killed thousands of fish and other organisms may have been the result of a combination of waters full of the iron-loving bacterium *Trichodesmium* (right) and iron-rich dust from Africa, half a world away.

Top to bottom: The Charlotte *Sun Herald*/Paul Schmidt; Florida Marine Research Institute

international forest analyst with the U.S. Forest Service. (Dust storms can also originate in such landscapes.) Humans contract hantavirus primarily by breathing in airborne mouse dung; when the air is dry enough and there is sufficient wind, the virus can rise high enough in the air for people to inhale it. Although treatable, hantavirus is often deadly because it can cause the lungs to fill with fluid rapidly, often even before the victim can visit a doctor.

More commonly, dust storms of local origin may pose hazards not from disease but from the actual particles they stir up, such as concrete dusts from construction sites and industrial areas. According to a statement by state environmental regulator Neil Carman in a press release by the Texas chapter of the Sierra Club, concrete dust can damage lung tissue due to its small particle size and toxicity. Will Stefanov, an environmental geologist at Arizona State University in Tempe, has used remote sensing to identify the sources and destinations of airborne dust and how they move, in both rural and urban settings. In cities, construction sites and other disturbed surfaces are the most significant dust sources. An example of the latter is the huge clouds of dust generated in the terrorist destruction of the World Trade Center towers. Researchers are continuing to monitor the concentrations of particulate matter in the air around Ground Zero. The next stage of Stefanov's research will look at the physical, chemical, and biological analysis of the dust transported.

From Dust to Blooms

USGS biologists have studied dust storms for possible effects on ecosystems. Gene Shinn, a senior geologist at the USGS Center for Coastal Geology, became interested in one of Prospero's graphs of African dust activity when he saw a pattern that he recognized from photographing coral reefs off the U.S. coast. In research published in volume 2, issue 1 (2001), of *Global Change & Human Health*, Shinn and coauthors suggest links among the drought that Sahelian Africa has experienced since the 1970s, variability in North Atlantic weather regimes, dust deposition, and outbreaks of toxic algal blooms.

One of the clearest links so far is between iron deposited by African storms and algal blooms. The September 2001 issue of *Limnology and Oceanography* contains a study coauthored by Jason Lenes, a graduate student at the University of South Florida's College of Marine Science, on *Trichodesmium*, a bacterium that produces its own nitrogen and has triggered the most serious red tides in the past 20 years.

Lenes and his coauthors note that *Trichodesmium* handles a scarcity of iron—a limiting factor in its growth—by using dissolved and particulate iron that falls with rain. *Trichodesmium* colonies have developed "a little evolutionary trick," Lenes found, in which they enfold the dust within themselves to maximize cells' iron exposure and free more iron for growth. In 1999, the year of the study, toxic red tides triggered by *Trichodesmium* killed thousands of fish and over 100 endangered manatees off the coast of Florida. Public health warnings kept people out of the waters, but even walking along the beach near a major red tide could expose people to toxins aerosolized at the surface. "I wouldn't be surprised if some people were affected, [if there were] coughing and sneezing episodes that perhaps weren't reported," Lenes says.

Another bad year for red tides came in 2001. According to Lenes, a large toxic bloom formed in the fall and drifted for months between Pensacola and St. Petersburg, a distance of over 400 kilometers. Lenes again saw a correlation between African dust and *Trichodesmium*—the bacteria increased around the time of the summer dust storms in Africa. "Soon after, you started getting the red tide bloom," he says. With the resulting harm to marine life, red tides also hurt Florida's fishing and tourism industries, with some studies estimating the damage at $25 million per year.

Researchers find that dust clouds also may dim the outlook for sea life more broadly. Roughly 80% of the sunlight that reaches the ocean goes toward evaporating moisture and creating the planet's freshwater supply. When that sunlight is diminished, notes V. Ramanathan, an atmospheric physicist at the University of California at San Diego, the earth's hydrologic cycle may be slowed. "That impacts the water budget of the planet," says Ramanathan, lead author of a 7 December 2001 article in *Science* on the results of a multinational, multiagency research effort to investigate the movement of aerosols over the Indian Ocean. The authors found issues similar to those seen in the African and Asian clouds: movement of aerosols (for example, an urban haze over Bombay) out over the ocean, with far-reaching consequences for what had formerly been considered a localized problem.

Getting to the Nitty Gritty

Another multinational effort, the Asian Pacific Regional Aerosol Characterization Experiments (ACE-Asia), has examined aerosol transports in East Asia with support from NOAA and the National Science Foundation. In the spring of 2001, ACE-Asia experiments focused on how airborne aerosols affect climate. Initial results suggest that the dust storms may indeed affect global climate patterns. However, because dust clouds both absorb energy and reflect light away from the earth's surface, it's not yet clear whether the overall effect is warming or cooling. ACE-Asia plans to study the clouds again this spring.

NOAA has been eyeing Asian dust clouds for some time, says Russ Schnell, director of observatories for NOAA's Climate Monitoring and Diagnostics Laboratory in Boulder, Colorado. The agency's large Mauna Loa Observatory in Hawaii has tracked the arrival of Asian dust events each spring for over 20 years. "Most people outside the NOAA community never paid much attention to this dust until recently," says Schnell, reached by e-mail during a trip to Antarctica. Sometimes the dust reaches the Hawaiian station in just 3 days, although 5–7 days is more typical.

In recent years, NOAA has expanded its tracking of Asian dust appearances in the continental United States with measurements from a new monitoring station in Trinidad Head on the California coast. This station will study the flow of dust and its pollutant passengers in the spring of 2002 within a larger NOAA program called the Intercontinental Transport and Chemical Transformation Study. According to Schnell, this study will use aircraft and expanded ground measurements along the West Coast to study the chemical effects of gas and aerosol flows from Asia on eastern Pacific air.

That kind of jet-setting research to get literally into the the eye of the dust storm may be a trend. "I'm hoping in the next year to run out and get in front of a dust cloud from China," says Griffin. Aboard a plane equipped with sampling equipment, he plans to test the same storm at three locations: near its point of origin (over Japan or Korea), midjourney (over the Aleutian Islands), and at a destination on the Pacific Northwest coast. Inside the cloud, Griffin plans to use a large vacuum pump to sample up to 20,000 liters of air at each site. "The challenge," says Griffin "is in reading the cloud movement"—and keeping up with it.

Dust Clouds' Silver Lining

Dust researchers caution against thinking of dust clouds as just devils that drive farmers from their land and make little children cough. The clouds also bring important nutrients crucial for rain forests in the Amazon basin and elsewhere. Griffin cites studies suggesting that rain forests on Hawaii's northern islands could not exist on the nutrient-depleted soils there without dust from Asia.

Devotees of dust have launched a movement to "remineralize" soils around the world for a rejuvenated agriculture. The Web site **http://Remineralize-the-earth.org/** posts studies that show that minerals in rock dust help reconstitute soils better than N-P-K fertilizers (which are also easily leached to groundwater and have been associated with nitrogen runoff, which may lead to toxic algal blooms). Remineralization started in Germany and remains most popular in Europe, where big companies sell dust products in Germany, Switzerland, and Austria, according to Joanna Campe, who manages the Web site's forum. The rock-crushing industry views this trend with enthusiasm.

Even toxic algal blooms might have as-yet unknown benefits for marine ecosystems, says Lenes. He draws an analogy with forest fires, which forest scientists once considered disastrous until decades of fire suppression policies backfired and brought a drastic reassessment. Now fires are seen to play an important role in forest regeneration. "The same could be true for red tides," Lenes says. For that reason, the Ecology and Oceanography of Harmful Algal Blooms, or ECOHAB, program (Lenes's project at the University of Florida) aims for a comprehensive look at the marine ecosystem, its shifts in species, its temperatures, and its chemistry. Lenes expects a complete model in two or three years.

Because the exact mechanisms and effects of transcontinental dust storms are still under study, any response to them may be premature. Early proposals range from better land use management of eroded soils in China to better, more narrowly targeted forecasts of dust events for susceptible populations. Ginoux admits that a lot of work remains to be done before modeling health effects. "There is definitely a need for collaboration," he says. He invites microbiologists and others to help develop parameters—such as UV exposure thresholds—for modeling the microbes most important to human health. With such parameters, GOCART could forecast concentrations of those microbes likely to affect specific populations. "The tools are ready," Ginoux says, "they just need refinement."

With future sifting, siting, and researching of these whirling masses, scientific understanding of dust and how it affects people, climate, and ecosystems will continue to evolve. Darwin would probably approve.

David A. Taylor

NOAA/Department of Commerce

Cloud watchers. Scientists at the Mauna Loa Observatory in Hawaii have been monitoring the arrival of Asian dust events for over 20 years.