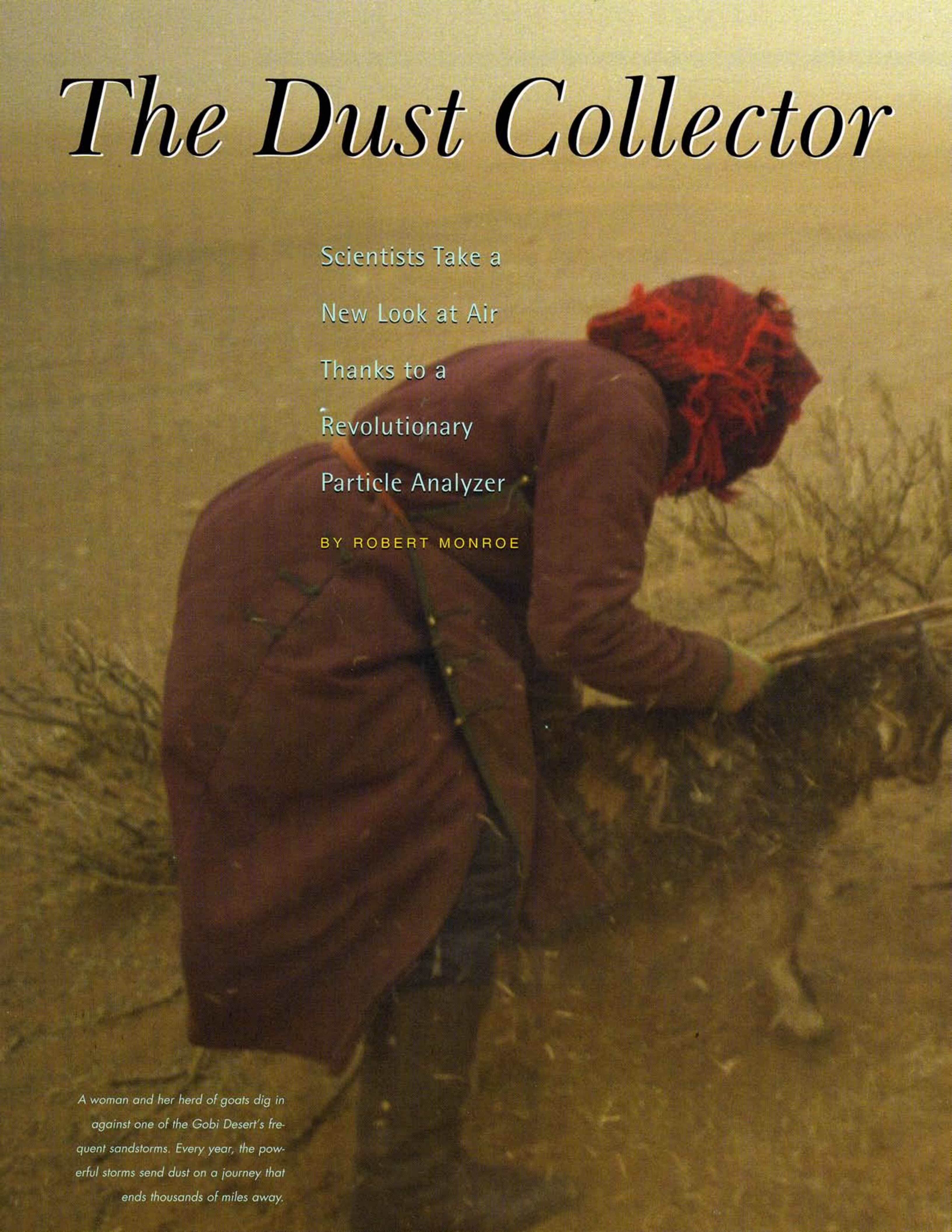
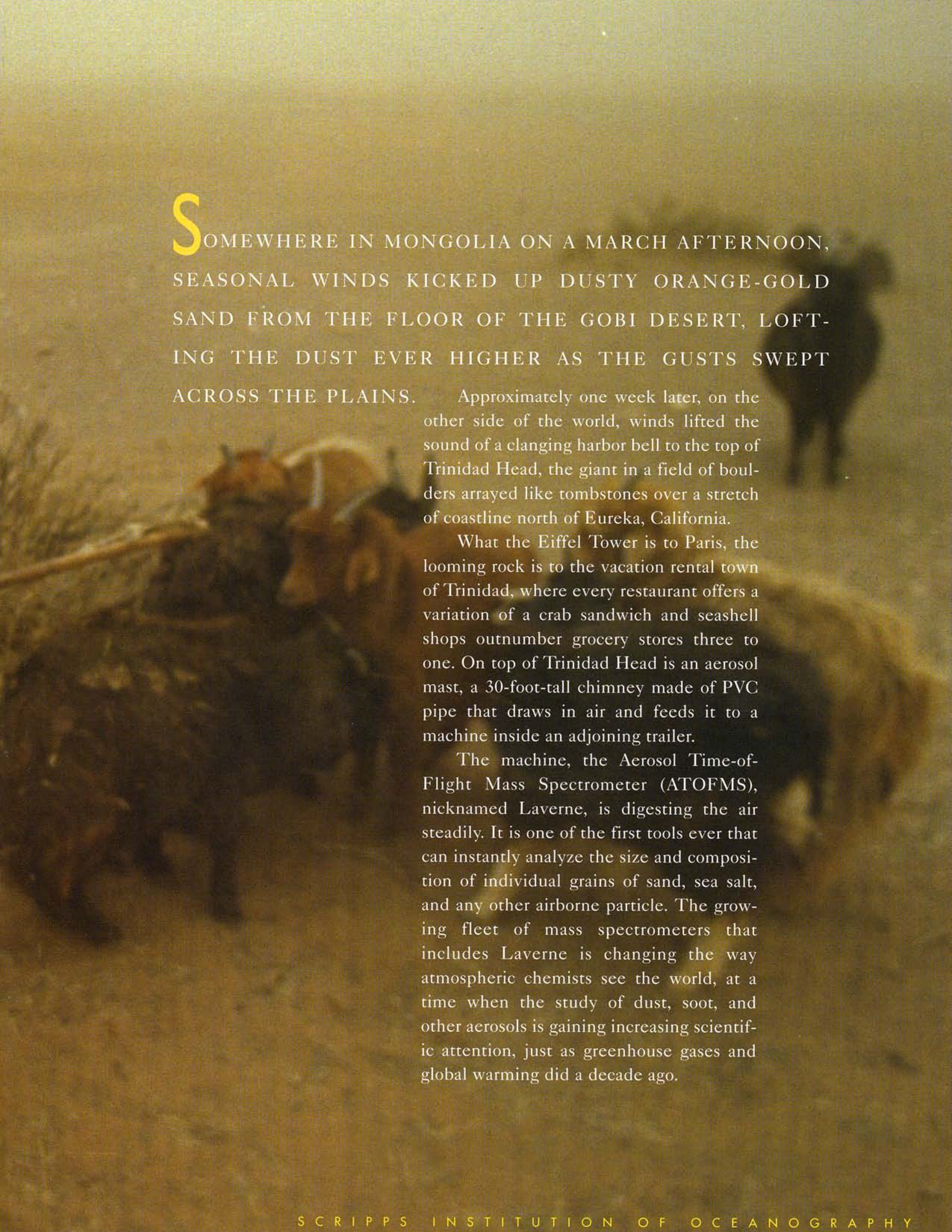
The Dust Collector

Scientists Take a New Look at Air Thanks to a Revolutionary Particle Analyzer

BY ROBERT MONROE



A woman and her herd of goats dig in against one of the Gobi Desert's frequent sandstorms. Every year, the powerful storms send dust on a journey that ends thousands of miles away.



SOMEWHERE IN MONGOLIA ON A MARCH AFTERNOON, SEASONAL WINDS KICKED UP DUSTY ORANGE-GOLD SAND FROM THE FLOOR OF THE GOBI DESERT, LOFTING THE DUST EVER HIGHER AS THE GUSTS SWEPT ACROSS THE PLAINS. Approximately one week later, on the other side of the world, winds lifted the sound of a clanging harbor bell to the top of Trinidad Head, the giant in a field of boulders arrayed like tombstones over a stretch of coastline north of Eureka, California.

What the Eiffel Tower is to Paris, the looming rock is to the vacation rental town of Trinidad, where every restaurant offers a variation of a crab sandwich and seashell shops outnumber grocery stores three to one. On top of Trinidad Head is an aerosol mast, a 30-foot-tall chimney made of PVC pipe that draws in air and feeds it to a machine inside an adjoining trailer.

The machine, the Aerosol Time-of-Flight Mass Spectrometer (ATOFMS), nicknamed Laverne, is digesting the air steadily. It is one of the first tools ever that can instantly analyze the size and composition of individual grains of sand, sea salt, and any other airborne particle. The growing fleet of mass spectrometers that includes Laverne is changing the way atmospheric chemists see the world, at a time when the study of dust, soot, and other aerosols is gaining increasing scientific attention, just as greenhouse gases and global warming did a decade ago.

Above, *Rendered a lush green by nearly 203 centimeters (80 inches) of rain a year, Trinidad Head (left) dominates the seascape. The weather station there hosted Scripps researchers such as graduate student John Holecek (insets and below), who operated ATOFMS during a test in April.*

The machine is obtaining information in seconds that used to take months to acquire. In the process, it is letting scientists consider strange and paradoxical concepts: the ocean might be a key

source of aerosol particles, the structures that hold clouds together might be airborne clusters of marine microorganisms, and the pollutants in the air posing the greatest risks to our health might be the ones air-quality officials don't measure.

Laverne is helping to reveal how particles can transform themselves and climate itself as they travel

over thousands of miles, which is exactly what brought it to Trinidad. Scripps researchers positioned the machine on the coast to record an important annual trans-Pacific event. The Gobi Desert dust was falling on Trinidad Rock, delivered by the month's first storms like airmail to a waiting recipient.

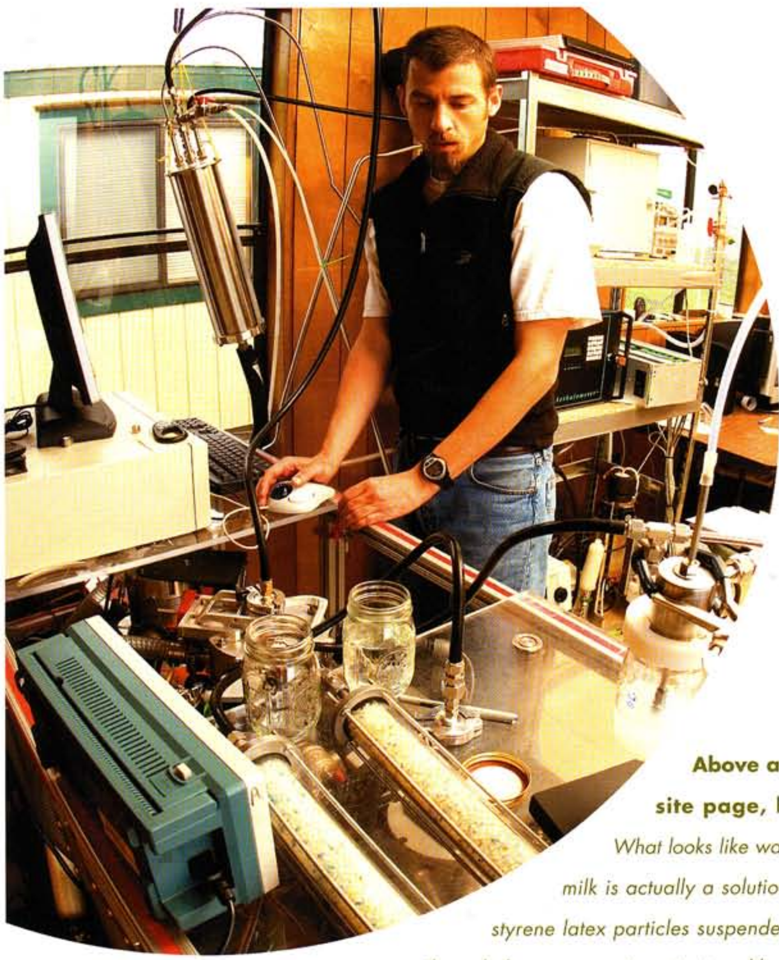
ONE PARTICLE AT A TIME

It's not just Mongolian dust that the mass spectrometer is measuring. In the mix of California air on any given day could be the soot from the smoke of burning fires in Indonesia and the diesel exhaust of a city bus in New Delhi along with material from local sources. Set up on a different continent, ATOFMS would be analyzing aerosols like dust and soot from New York City that fall on Europe after similar journeys that reach heights up to 6,100 meters (20,000 feet).

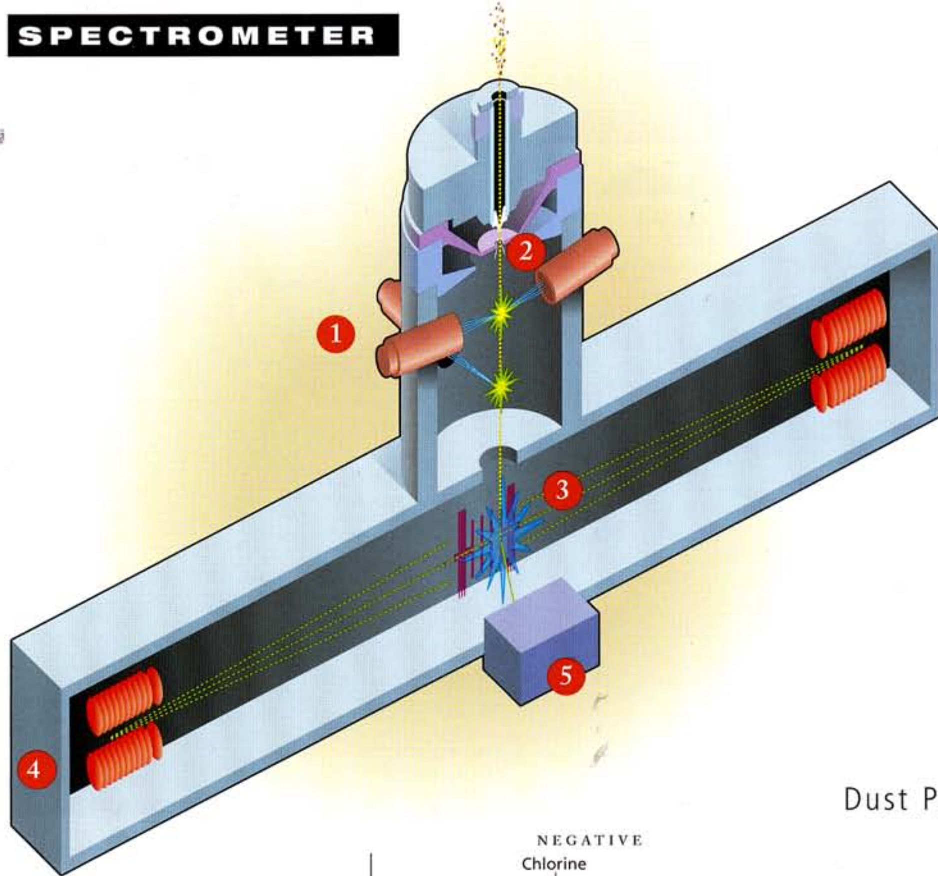
Laverne also records the arrival of particles that were once in the oceans, including sea salts, of

course, and other chemicals. According to ATOFMS's inventor, Scripps scientist Kim Prather, other particles blown in from the ocean might have once been on land, dipped in the ocean, and come back out by ejection from bubbles at the surface, chemically altered by the dunking. While servicing Laverne during the Trinidad trip, graduate student John Holecek pointed out on a computer screen a reading of magnesium, part of the "fingerprint" of a commonly seen aerosol in marine environments all over the world. It's possibly a marine microorganism.

"I believe the ocean could represent a significant source of particles in the atmosphere that very few people have really explored," said Prather in her Urey Hall office on the UCSD campus. "If you burst bubbles in sea spray, you're going to kick out all the other stuff that's there too. There's really no other way to distinguish those particles unless you're looking at one particle at a time—and that's how we're doing it."



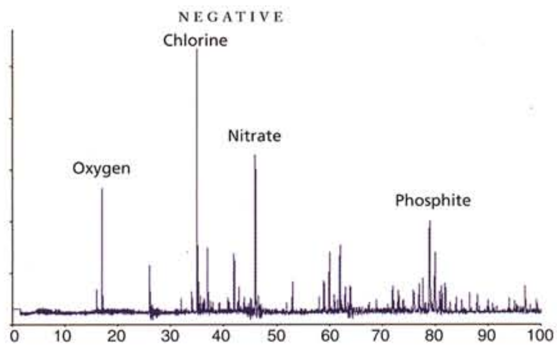
Above and opposite page, bottom, *What looks like watered-down milk is actually a solution of polystyrene latex particles suspended in liquid run through the mass spectrometer to calibrate it. The particles come in sizes ranging from 300 to 3,000 nanometers. The known quantity let the researchers ensure that ATOFMS could correctly measure the intensity of particle signals received during the two-week sampling run.*

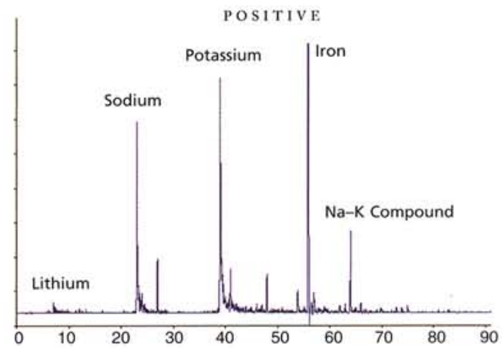


Mass spectrometers are some of the most commonly used tools in ocean and earth science. A version invented by Kim Prather, the aerosol time-of-flight mass spectrometer (ATOFMS), collects particles that pass through a beam of light focused by ellipsoidal mirrors (1). A pair of low-power lasers (2) sizes and tracks the particles, which are then fed to a third laser at the center of a chamber (3). The high-power laser blasts the particles into positively and negatively charged ions that are routed by reflectrons (4) at either end of the chamber to a detector (5). The time it takes for the particles to reach the detector indicates their mass-to-charge ratio.

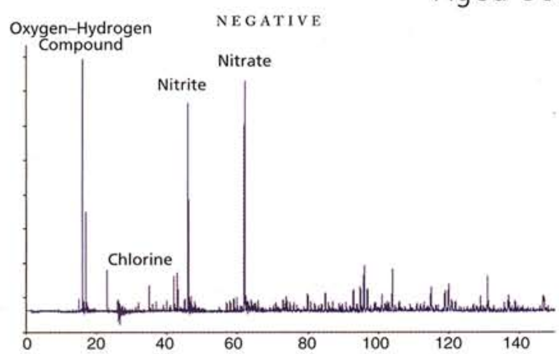
Follow along with your periodic chart to read the "fingerprints" of particles commonly illustrated in ATOFMS computer readouts. The dust particle at top contains potassium, iron, aluminum, chlorine, and nitrates as well as lesser quantities of still more elemental compounds. Sea salt, makes itself known in atomic mass peaks of sodium (23 in the positive-charge spectrum) and chlorine isotopes (35 and 37 in the negative). By the presence of other compounds of calcium and nitrates that have glommed onto it, researchers can tell that the particle has been in the atmosphere for at least several hours and possibly up to a week. At bottom, an abundance of carbon in the form of a single atom, pairs of atoms, and larger clusters reveals that the particle was likely formed through a combustion process, such as in a car or truck, or through the burning of biomass or coal.

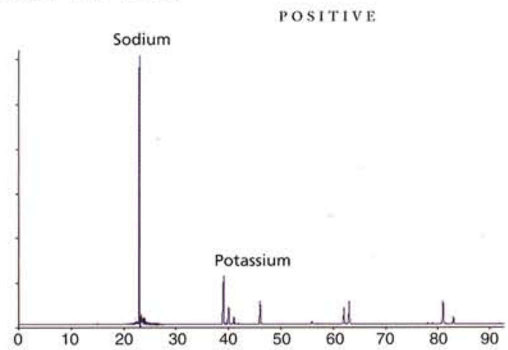
Dust Particle



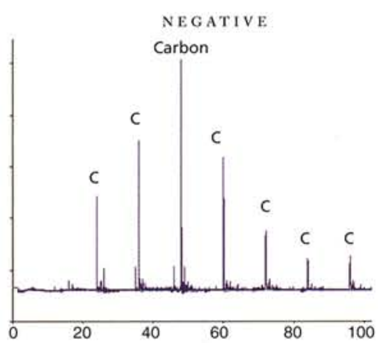


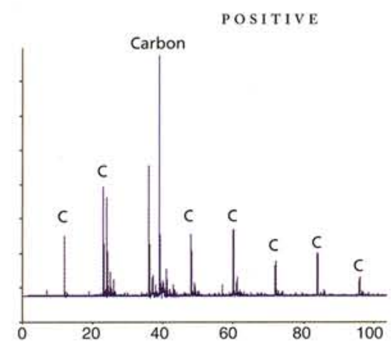
Aged Sea Salt Particle





Elemental Carbon Particle





Prather, an atmospheric chemistry professor, came to Scripps in 2001 from UC Riverside, where development of the first ATOFMS, "The Beast," took place in the early 1990s. Before the move to Scripps, she had taken part in the Indian Ocean Experiment (INDOEX), headed by Veerabhadran Ramanathan, director of the Center for Atmospheric Sciences at Scripps. INDOEX marked the first use of the mass spectrometer in an international field experiment. The Cloud Indirect Effects Experiment (CIFEX), conducted this past spring in Trinidad as a follow-up to INDOEX, examined the effects of aerosols on cloud formation, precipitation, and other aspects of climate.

"The aerosol–climate link is one of the most important sources of uncertainty in predicting how the climate system is going to respond to human activities," Ramanathan said. "The ATOFMS is a major development that will help reduce this uncertainty."

Now Prather heads one of seven research laboratories at Scripps and UCSD that look specifically at aerosols in the atmosphere. She and her team join a cadre of researchers who study particles in the ocean and recently collaborations between the two camps have begun. In the Prather lab, refinement of ATOFMS remains a priority. The next mass spectrometer to be deployed, Shirley, will be mounted on an aircraft and will be able to process particles exponentially faster than Laverne.

Already Laverne represents a vast leap in analytical capability. The task of sifting through airborne particles until now has involved filters, sticky paper, and hun-

***Above,** Salt from the relentless sea spray of the northern California coast was a common input for ATOFMS, which took in air through an aerosol mast (left) built to minimize contamination from local land-based sources.*

THE BREAKDOWN ON PARTICLES

ATOFMS is but one kind of mass spectrometer. One of the most commonly used instruments in ocean and earth science, mass spectrometers help researchers learn what chemical and atomic components are in samples of soil, water, and air. Most spectrometers analyze gases that don't need to be broken down. With ATOFMS, particles are first blasted into individual components, then those components are charged, and the resulting ions are accelerated through a chamber. Different ions take varying amounts of time to reach the detector, depending on their different weights. By measuring those times, researchers like Prather can see what combinations of elements and compounds are within a particular grain of soot or dust. The result comes in the form of a computer display showing the mass spectra of particles, with peaks revealing the presence of various elements.

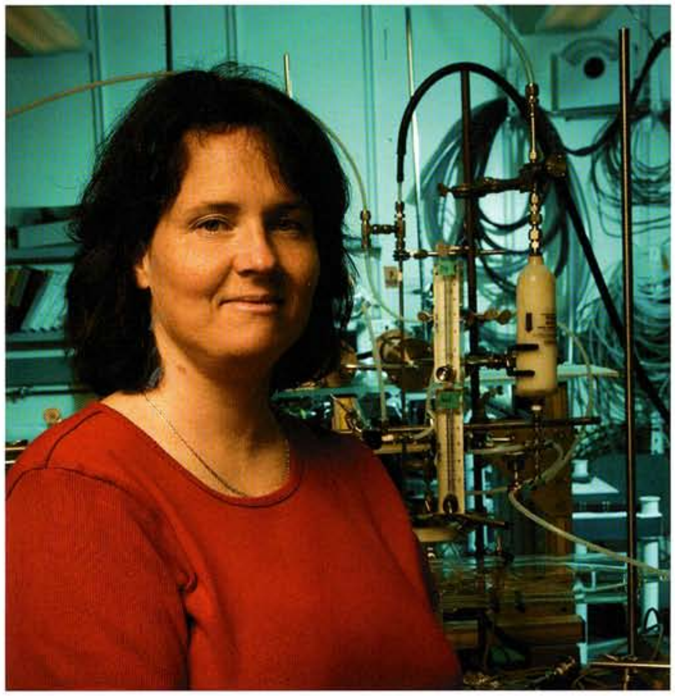
dreds of hours of tedious labor. Researchers selected individual particles for analysis but were not able to tell at which point in the collection period the particles were captured or where they came from. The difficulty and expense of aerosol analysis may explain why there have been only a limited number of research laboratories worldwide chemically analyzing individual particles in recent years.

"Using traditional microscopy methods for examining individual particles, people write papers on 35 particles—we can now analyze 350,000," Prather said.

Prather's modification allows researchers to measure and record particles as they pass through a beam of light upon which a laser is trained. The size of a particle is important. There's an enormous difference between soot from a gas-burning engine and a grain of dust, for example. Because some naturally produced particles grow and take on chemical components during their windborne journeys, size can be an indicator of age and probable point of origin.

Laverne analyzes 60 to 180 particles a minute, and even at that rate, it is still missing

most of what is being taken in. In fact, it is only looking at one in a million of the very smallest particles, a rate Shirley promises to improve upon. Prather's goal of analyzing half of all particles entering the spectrometer requires ATOFMS's laser to fire 1,000 times a second.



Opposite page, *At her UCSD lab, Kim Prather and John Holecek dissect an ATOFMS unit disassembled for cleaning.* **Top,** *The diffusion drier drys air before it enters ATOFMS.* **Left,** *For Prather, the future promises continued commercial production of her mass spectrometer and a wider array of users.*

THE AIR WE BREATHE

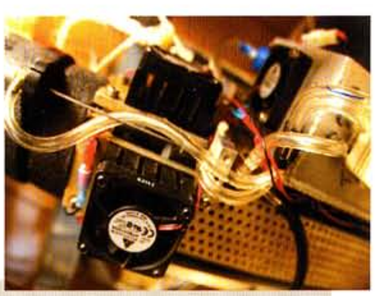
The more particles that can be analyzed in real time, the more thoroughly researchers can study changes in the composition of air. ATOFMS can tell from hour to hour what was in the air, but minute-by-minute changes could be even more telling. More than just earth science researchers are interested in that knowledge. For the past six years, Prather has used the spectrometer as part of studies at the EPA Particulate Health Effects Center based at the University of Rochester in New York. The center is led by Günter Oberdörster, a professor of environmental medicine who has found that some of the smallest particles in air pollution are some of the most ubiquitous and potentially most dangerous in terms of health effects. They are also components of pollution and air-quality management that agencies are not equipped to track.

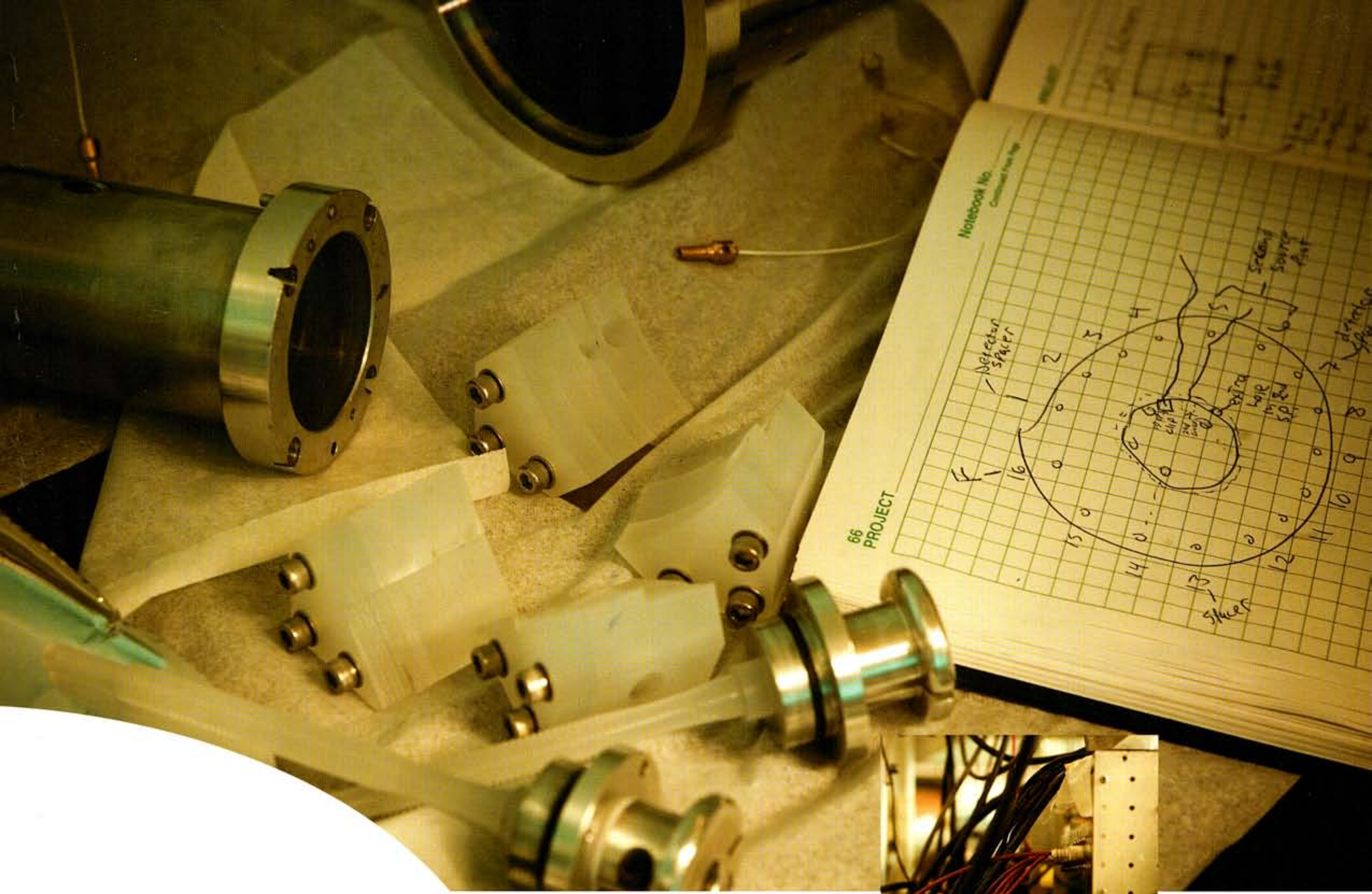
"HOW WE ARE AS USERS OF THE LAND INFLUENCES WHAT GOES IN THE OCEAN AND WHAT IN TURN GOES OUT OF THE OCEAN. YOU CAN SHUT DOWN BEACHES BUT YOU CAN'T SHUT DOWN THE ATMOSPHERE." —KIM PRATHER

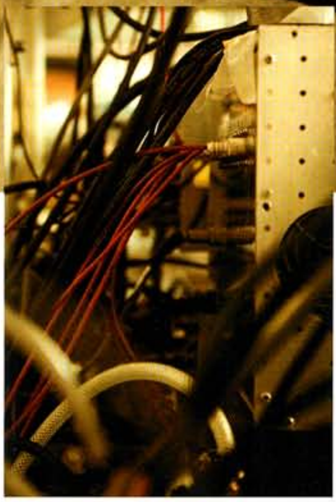
According to Oberdörster, a motorist driving down the highway is exposed to upwards of 10 million particles of carbon and metals per cubic centimeter. He has found that some of those particles lodge in the brain, traveling there through the olfactory nerve after being inhaled. Others are small enough to reach other organs as well.

"These nanometer-sized particles behave very differently from larger particles in that they can enter the bloodstream and go anywhere in the body," Oberdörster said.

Oberdörster credits ATOFMS with providing the detailed data that enable him to correlate health effects with particle emissions from specific sources, a task otherwise impossible.







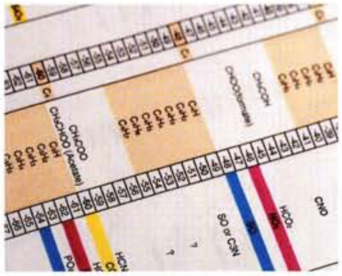
Above, *Notes on ATOFMS assembly flank components of a unit, the commercial version of which sells for $400,000.*

"To find out what individual particles contain makes it much easier to determine where they came from," he said.

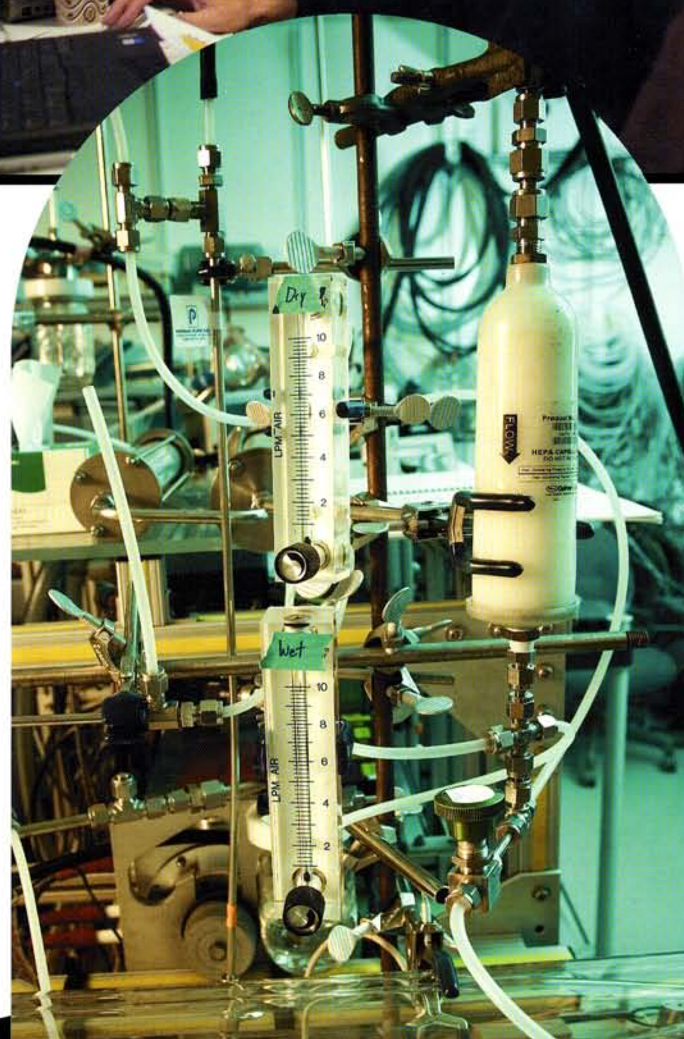
A private company, TSI, Inc., has produced the first commercial versions of ATOFMS, garnering honors in *R&D Magazine's* "R&D 100" award in 2000. Prather envisions a day when air-quality agencies will all have their own versions of it, using ATOFMS to pinpoint who the biggest polluter in an area is and when specifically during the day the pollution is at its worst. The public health component of ATOFMS dovetails with Prather's other main research focus at the moment, air–sea interaction.

"How we are as users of the land influences what goes in the ocean and what in turn goes out of the ocean," Prather said. "You can shut down beaches but you can't shut down the atmosphere."

For her own studies, Prather is interested in testing her theory about the structure of clouds with the machine's help. Most atmospheric chemistry researchers think that sea salts and other minerals form what are called "cloud condensation nuclei," the aerosols around which water vapor collect to create clouds. Prather is building on a 30-year-old theory about bacte-



Below left, *Kim Prather and John Holecek review data gathered during the Cloud Indirect Effects Experiment (CIFEX) in April.* **Below right,** *Veerabhadran Ramanathan, seated at left in the experiment's operations center in Trinidad, heads up CIFEX.*



ria and ocean bubbles to create her own hypothesis. It's possible, she says, that microorganisms are drawn into bubbles that later pop at the ocean's surface, sending the creatures drifting into the atmosphere. Those windblown colonies, Prather contends, have been shown to be very effective at forming clouds. By looking at individual particle signatures, ATOFMS can easily distinguish between such microorganisms and the more abundant sea salt, something that has been impossible to do with filters.

It's one of many answers blowing in the wind. Only now, with ATOFMS, can researchers hope to catch it.