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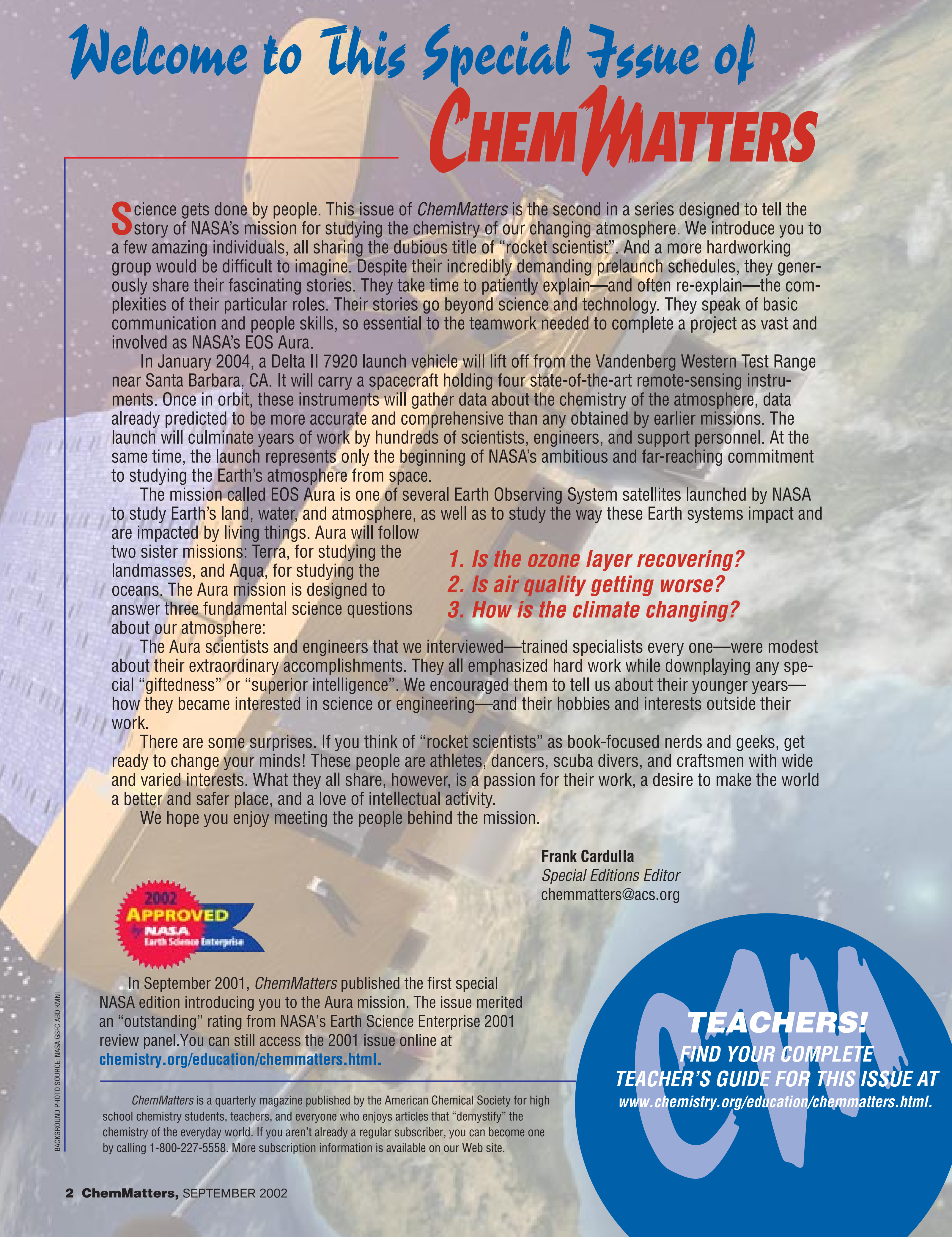

BACKGROUND PHOTO SOURCE: NASA GSFC ABD KMNI

Welcome to This Special Issue of CHEMMATTERS

Science gets done by people. This issue of *ChemMatters* is the second in a series designed to tell the story of NASA's mission for studying the chemistry of our changing atmosphere. We introduce you to a few amazing individuals, all sharing the dubious title of "rocket scientist". And a more hardworking group would be difficult to imagine. Despite their incredibly demanding prelaunch schedules, they generously share their fascinating stories. They take time to patiently explain—and often re-explain—the complexities of their particular roles. Their stories go beyond science and technology. They speak of basic communication and people skills, so essential to the teamwork needed to complete a project as vast and involved as NASA's EOS Aura.

In January 2004, a Delta II 7920 launch vehicle will lift off from the Vandenberg Western Test Range near Santa Barbara, CA. It will carry a spacecraft holding four state-of-the-art remote-sensing instruments. Once in orbit, these instruments will gather data about the chemistry of the atmosphere, data already predicted to be more accurate and comprehensive than any obtained by earlier missions. The launch will culminate years of work by hundreds of scientists, engineers, and support personnel. At the same time, the launch represents only the beginning of NASA's ambitious and far-reaching commitment to studying the Earth's atmosphere from space.

The mission called EOS Aura is one of several Earth Observing System satellites launched by NASA to study Earth's land, water, and atmosphere, as well as to study the way these Earth systems impact and are impacted by living things. Aura will follow two sister missions: Terra, for studying the landmasses, and Aqua, for studying the oceans. The Aura mission is designed to answer three fundamental science questions about our atmosphere:

1. ***Is the ozone layer recovering?***
2. ***Is air quality getting worse?***
3. ***How is the climate changing?***

The Aura scientists and engineers that we interviewed—trained specialists every one—were modest about their extraordinary accomplishments. They all emphasized hard work while downplaying any special "giftedness" or "superior intelligence". We encouraged them to tell us about their younger years—how they became interested in science or engineering—and their hobbies and interests outside their work.

There are some surprises. If you think of "rocket scientists" as book-focused nerds and geeks, get ready to change your minds! These people are athletes, dancers, scuba divers, and craftsmen with wide and varied interests. What they all share, however, is a passion for their work, a desire to make the world a better and safer place, and a love of intellectual activity.

We hope you enjoy meeting the people behind the mission.

Frank Cardulla
Special Editions Editor
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2002 APPROVED by NASA Earth Science Enterprise

In September 2001, *ChemMatters* published the first special NASA edition introducing you to the Aura mission. The issue merited an "outstanding" rating from NASA's Earth Science Enterprise 2001 review panel. You can still access the 2001 issue online at **chemistry.org/education/chemmatters.html.**

ChemMatters is a quarterly magazine published by the American Chemical Society for high school chemistry students, teachers, and everyone who enjoys articles that "demystify" the chemistry of the everyday world. If you aren't already a regular subscriber, you can become one by calling 1-800-227-5558. More subscription information is available on our Web site.

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ANDREA RAZZAGHI

Getting People and Hardware Working Together

The Delta II 7920 launch vehicle rests magnificently but quietly on its launch pad. You know that the mere push of a button is all it takes to release the powerful explosion capable of lifting this 235,000 kg (520,000 lb) monster into the sky. It doesn't matter how many times you have seen it. Your reaction is the same every time. Awesome!

Hundreds of millions of dollars have been spent. Hundreds of skilled scientists, engineers and support personnel have devoted many thousands of hours over several years working to ensure the success of its mission. The complexity of the preparation staggers the imagination. Can all of this effort come together to make the mission a success? Will the spacecraft attain the correct orbit? Will the four science instruments on board activate and operate according to plan?

All four instruments aboard this NASA earth-observing spacecraft called Aura represent groundbreaking engineering designs. Despite being pretested to survive the stresses of launch, the data-collecting instruments still await their final tests in the environment of space.

> "You've got to get the data down. That's why you're up there to start with."

COURTESY OF NASA-GSFC

Andrea Razzaghi, third from left, works with her team at Goddard Space Flight Center to prepare Aura for launch.

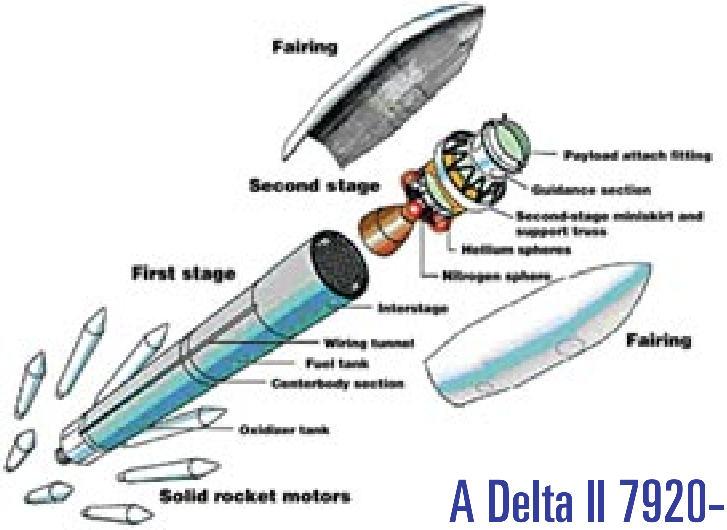
How do you put all the pieces together in the right way at the right time to achieve success? Ask Andrea Razzaghi. Getting everything and everyone to blend their separate roles is both her challenge and her responsibility. At NASA's Goddard Space Flight Center near Washington, DC, it's her job. Razzaghi manages the work involved in designing the spacecraft—getting the interfaces to the instruments successfully built, and demonstrating that everything works together on the "observatory", NASA's name for the spacecraft and its instruments. Razzaghi's role is referred to as integration and test. ***Her job ends successfully only when the observatory is in its correct orbit and the instruments are successfully sending their data back to Earth.***

Symbiosis means teamwork

You probably heard the word *symbiotic* in your biology class. Biologists use it to describe a case in which different species mutually benefit one another—like bees pollinating flowers at the same time flowers are dishing up nectar for the bees. There's a similar kind of symbiosis going on with a couple of related NASA projects. The Earth Observing System (EOS) involves a series of satellites, chief among them being Terra, designed to study the Earth's land; Aqua, designed to study its waters; and Aura, designed to study the atmosphere.

Aqua and Aura have an almost symbiotic relationship between them. Although they carry different science instruments, the launch vehicles that rocket everything into orbit and the spacecrafts that carry the instruments are essentially the same. And both missions are better off as a result.

Some of Aura's toughest engineering challenges were solved as Aqua advanced toward its April 2002 launch date. Razzaghi humorously refers to EOS Aqua as Aura's "engineering model"—a mission for making sure that Aura's hundred-million-dollar instruments all work right. But symbiosis means that Aqua benefits from the deal too. Since Aqua's launch date was scheduled first, it was able to use pieces of Aura's newer hardware for its testing program. In some cases, the Aqua team actually made use of parts intended for Aura. Sometimes it saved more valuable time and money to use Aura's newer hardware than to try and fix Aqua's. The Aqua engineers jokingly refer to Aura as their "spare parts" program.



COURTESY OF NASA

A Delta II 7920-10 launch vehicle will carry the Aura "bus" into orbit.

As might be expected on a complex project, Aura has its share of what Razzaghi calls "nitty-gritty technical problems". Some of the most significant challenges have centered on the *command and data-handling system*—arguably, the most important part of the entire mission. With this system, you get your commands into the spacecraft and its instruments, and you get your data out. The command and data-handling system relies on an array of computers and processors on board the satellite. Once the complex system is launched, no one touches it again. All you can do is send it commands from the ground. Razzaghi describes this troublesome challenge as "getting it right".

It's largely a matter of timing. The processors on the satellite receive information from many different sources at the same time, including the four instruments and all of the spacecraft subsystems. This information then needs to be relayed to the ground. Thus, there is some delicate timing related to the rate at which data are received, processed, and resent. Razzaghi calls it the "relay race".

NASA calls the spacecraft that supports the instruments in orbit a "bus". A normal bus carries passengers. Aura's passengers are the four science instruments named with acronyms MLS, HIRDLS, TES, and OMI.

Balancing all input and transmission of data is a very challenging task. One misstep, and even these sophisticated computers can do the same thing as the one on your desk—freeze and crash. That's bad enough when it happens on a personal computer, but as Razzaghi says, "We can't afford to have that happen aboard the satellite!"

Launch of a rocket scientist

Jokingly referring to her typical workweek as consisting of nonstop meetings, she draws on a blend of both technical expertise and people management skills. And how did she decide to become a "rocket scientist"? Razzaghi says that she always had an interest in how things work. Growing up, she had her share of traditional "little girl" toys like Easy Bake Ovens—the usual "Suzie Homemaker stuff", as she refers to it. But helping her parents restore an old house introduced her to the wonders of a workshop full of interesting tools and problems to solve. Add this to a typical life filled with friends and school activities, and it's not hard to see how Razagghi's many skills and interests began to take shape.

While in high school, science and math, subjects that prepared her for pursuing her engineering degrees from Brown and Catholic Universities, were favorites. But ask her today if English is one of the most important subjects in high school, and her loud reply is, "YES!" She explains that speaking well and writing well are critical skills, important both professionally and personally. Her strongest advice for high school and college students is "Get to know your teachers. Talk to them. Ask them questions. You can learn so much more easily if you do!"

And for fun? One of her favorite hobbies is dancing, especially "Middle Eastern" dancing. She jokingly asks, "Isn't that what most aerospace engineers do?" But please, don't call it "belly dancing". Razagghi says that most Americans have a notion of that dancing that is "different from what we do." Although born and raised in America, learning foreign languages fascinates her. Fluent in Farsi, she also speaks some Spanish and bit of Dutch.

In the face of her personal striving for excellence, Razagghi admits that one of her professional difficulties is knowing when to accept good enough. She explains, ***"Engineers are perfectionists, but if you always waited until something is perfect, you'd never get anything done."*** She offers a thoughtful example. "If we wanted perfection, we wouldn't have a working automobile or computer today. You need to know when you've done enough engineering. You need to know when it's time to stop." And experience has taught her that as the Aura launch day approaches, the perfectionists get vocal. "Everybody who's ever had any doubts comes out of the woodwork and starts yelling, STOP!"

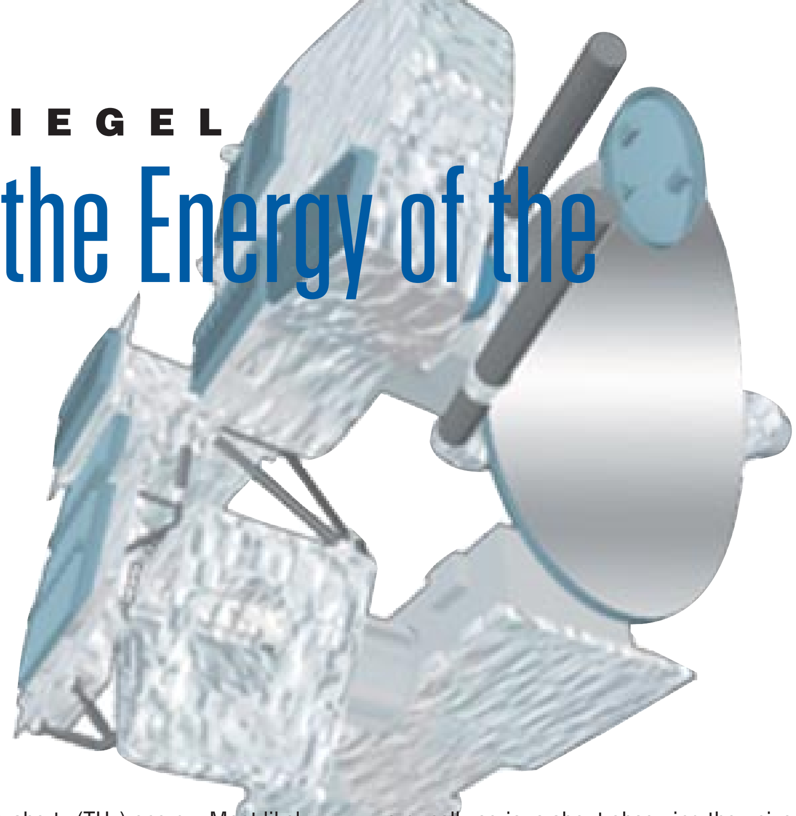
COURTESY OF ANDREA RAZZAGHI

Andrea Razzaghi vacationing with her family.

What's the difference between a scientist and an engineer? Razzaghi says that scientists are the dreamers. They think of what they want to do and what they want to accomplish. Engineers? "We're the ones who build the machines so the scientists can make their discoveries."

PETER SIEGEL

Studying the Energy of the Universe



> "This technology used to study the Earth's atmosphere is also applicable to the study of the atmospheres of planets like Venus, Mars, and Jupiter—even the gas, dust, and stars in other galaxies."

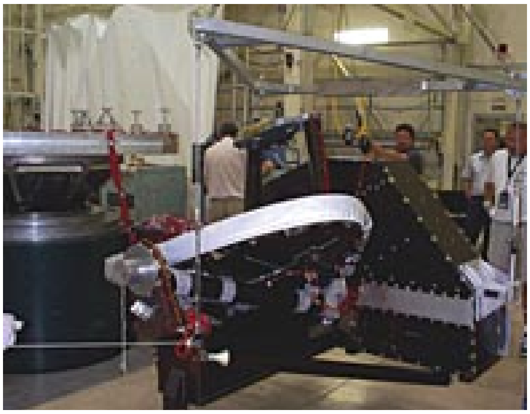
It's called terahertz (THz) energy. Most likely you've never heard of it or given it any thought at all. But NASA scientist Peter Siegel has studied it for most of his career, and he'll never run out of places to find it. At least 98% of the detectable radiant energy in the universe falls within this THz, or far infrared part of the electromagnetic spectrum—a band of long wavelengths outside our range of visible light, just beyond infrared, and just before the even longer radio wavelengths begin.

Siegel explains that much of the electromagnetic energy arriving from far-flung sources in the universe gets shifted down in frequency into the infrared. If you've studied some physical science, you may have heard of the Doppler effect—that's the way physicists explain why the pitch of a train whistle becomes lower after the train passes us and moves away. In astronomy, a similar thing happens with incoming light. Astronomers call it the *red shift* (see Figure 1). ***Because the universe is expanding, objects all around us are moving away like outbound trains.*** That means that any light the objects emit gets shifted down to lower frequencies farther and farther in the direction of red light—thus the name. At the same time, this radiant energy from stars is being scattered, absorbed, and reradiated at longer wavelengths as it encounters interstellar gas and dust. As a result, approximately 50% of the radiant energy in our own Milky Way galaxy is only detectable at far-infrared and THz frequencies. And for the universe as a whole, it's likely that as much as 98% of all the energy comes to us in this wavelength range. So if you are really serious about observing the universe, standard optical telescopes won't deliver even a fraction of the show that scientists get by gathering information delivered by THz-detecting instruments!

Your chemistry book has a table of metric system prefixes. ***Take a look, and you'll see that tera stands for 1 trillion, or 10^{12}.*** Hertz is a frequency unit that stands for waves or cycles per second. That means that terahertz electromagnetic radiation has frequencies of about 10^{12} hertz, a trillion cycles (waves) per second, and a corresponding wavelength (distance between wavelets) of less than 1 millimeter (see Figure 2).

A trillion sounds enormous, but for electromagnetic radiation, THz is pretty middle-of-the-road. Although it's 1000 times higher than the frequency of the radiant energy zapping your food in a microwave (2×10^9 Hz), THz energy lies well below the frequency of the infrared radiation emitted from the person sitting next to you. Bodies, living or not, with temperatures around room temperature, generate radiant energy at about 1.5×10^{14} Hz—a frequency easily detected with night vision cameras.

THz radiation is not easily observed on the Earth. Radiant energy emitted from hotter objects makes it more difficult to detect the signal being emitted by much colder sources. The larger amounts of radiant energy emitted by hotter objects makes it difficult to detect weaker amounts of energy emitted by colder objects. In addition, water and oxygen in the atmosphere strongly absorb THz energy, so that the signal, even a few meters away from a strong THz



COURTESY OF JPL

source, drops quickly to zero.

It's not surprising then, that most of this THz energy goes unnoticed. As a result, we're missing out on some fascinating observations of planets like Venus, Mars, and Jupiter; satellites like Europa and Titan; comets and asteroids; gaseous regions of interstellar space where new stars form; and even gas, dust, and stars in other galaxies. And last but not least, we're missing some important information about our own atmosphere.

The MLS team levels the instruments to prepare it for a prelaunch test.

Terahertz reveals what's in the air

Siegel heads up a group of more than 20 scientists and engineers specializing in terahertz technology at the Jet Propulsion Laboratory (JPL) in Pasadena, CA. Siegel points out that there are strong THz sources in our upper atmosphere, such as OH, HCl, and water, which can tell us much about the chemical processes that govern the ozone cycle and global warming. Because water and oxygen in our lower atmosphere absorb most of this THz energy, it is virtually impossible to detect this radiation by looking up through the atmosphere from the ground. ***What little is known about the THz sources in the upper atmosphere has come from measurements made at high mountaintop observatories,*** observatories at the South Pole (which is both high and very dry), high-flying aircraft (like NASA's ER2), and special high-altitude (100,000 feet) helium balloons.

Siegel's group looks forward to placing their THz sensors aboard Aura where they can continually map the entire upper atmosphere from the vantage point of space. Aura, with its anticipated long-term global coverage, offers the best opportunity to date for deploying such technology.

The THz group is part of a NASA team headed by Dr. Joe Waters at JPL. Together, they are integrating the THz sensors in the design of the Microwave Limb Sounder (MLS), one of four science instruments scheduled to ride aboard the Aura spacecraft. MLS will use THz and slightly lower-frequency millimeter- and submillimeter-wave sensors to determine the presence and distribution of a wide range of atmospheric constituents, including water vapor, chlorine monoxide, sulfur dioxide, hydrogen chloride, and the hydroxyl radical—molecules that directly and indirectly affect the quality of life on Earth. As a group, these and the other molecules being measured by MLS are involved in stratospheric ozone destruction, thus impacting long-term climate changes, such as global warming.

Identifying atmospheric gases remotely via an orbiting instrument speeding around the Earth at greater than 7 km per second is not as easy as making a laboratory measurement. Identification depends on two characteristics of the molecules that make up these gases: They all absorb and emit energy, and each individual molecule has its own particular pattern or spectrum of light frequencies that it will absorb or emit.

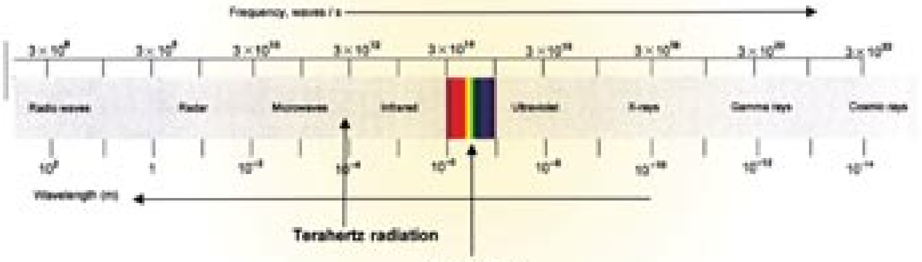


Figure 2. Terahertz radiation has wavelengths just beyond infrared.

By comparing the spectrum of an unknown molecule with the spectra of known molecules, the molecule can easily be identified. A more involved analysis even allows scientists to determine the abundance of the particular substance, as well as the surrounding temperature.

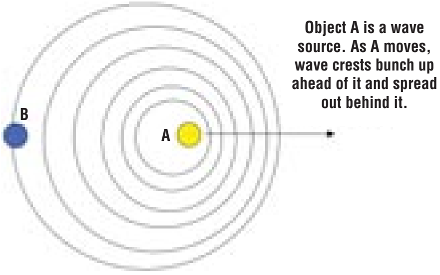


Figure 1. The Red Shift. If A is emitting light waves, an observer on stationary object B "sees" light with longer and longer wavelengths as A moves away.

By measuring the THz radiation coming from our own atmosphere, the MLS team hopes to refine our atmospheric models and enable us to understand and monitor the rate at which our ozone is being consumed and reformed by natural causes and by human-generated pollutants, such as chlorofluorocarbon compounds, commonly called CFCs. These important measurements will help determine whether the ozone layer is responding as expected to the measures taken by nations that have signed the Montreal Protocol, a 1987 international agreement to phase out CFCs and hydrofluorocarbons.

A fascination inspired by the moon race

Siegel's interest in science goes back to his high school days. Inspired by a love of science fiction, he describes himself as a "product of the 1960s moon race"— that exciting time when the decades-long dreams of amateur astronomers and space enthusiasts of all ages finally came true as Neal Armstrong placed the first human footprint on the Moon in July 1969.

Although the demands of his profession leave little time to spare, Siegel still likes to do some woodworking along with tropical fish keeping, ham radio operating, and most recently, scuba diving. Siegel's attitude about his "rocket science" achievements is remarkably relaxed. Maintaining that he is not gifted with a "superior intelligence", he attributes his success to the passion he has for his work. According to him, "There is nothing that competes with the feeling you get when after hours, days, weeks, or even years of work on a problem, you get the answer—even if it's not the one you expected!"

ACTIVITY

Measuring Gro

Ozone. You hear the word in the news; you hear the word in weather reports during the summer months; you hear the word in ads for swimming pools and spas. And in this issue of *ChemMatters*, you read the word in nearly every article. You might be surprised to hear that the word "ozone" comes from the Greek word *ozein*—to smell. That's the name its discoverer, German scientist Christian Friedrich Schönbein gave it in 1839, a name he thought best described the acrid-smelling gas in his lab.

Schönbein wanted to show that this triatomic form of oxygen (O_3) was a natural part of the atmosphere, not just a laboratory-concocted curiosity. He devised a method to measure ozone that turned out to be both easy to do and sensitive even to low levels of O_3 in the surroundings. His invention is known today as the *Schönbein paper*. You can make a batch of it and try it out for yourself by using the directions included in this article.

Today, scientists are fascinated by the laboratory findings of 19th and early 20th century chemists who used this sensitive paper to record ozone levels in *Schönbein units*. Their records are proving to be particularly useful for determining long-range trends of ozone concentrations in the air we breathe. To make meaningful comparisons, researchers are carefully examining the experimental methods used by these early scientists so that they can duplicate them in current studies—an excellent argument for keeping good laboratory records! You never know who might need the details about how you performed an experiment and obtained your results.

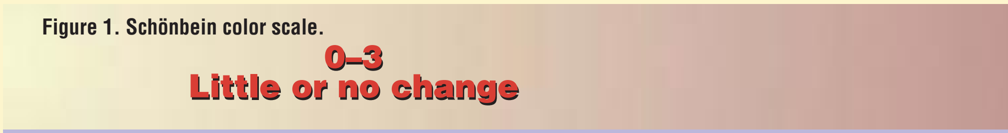
The Schönbein paper records reveal dramatic changes in Earth's atmosphere. Ground-level ozone appears to have increased at least three-fold globally since preindustrial times.

Is this a problem? Ground-level ozone is toxic to living things. Highly reactive O_3 interacts with living tissue, donating oxygen atoms freely in a process known as oxidation—a process that accelerates cellular aging. Breathing too much ozone over time impairs our lung capacity, setting us up for a variety of illnesses, including asthma. (See the *ChemMatters* September 2001 article "Asthma—Attack From the Air".) Other animals and plants suffer, too. Several important crop species respond to today's higher ozone levels with lowered rates of photosynthesis and productivity.

Although the way in which ground-level, or tropospheric, ozone forms is well described, its distribution in the atmosphere and the means to control it are topics of ongoing research and political debate. (See the September 2001 *ChemMatters* article "Ozone—Molecule With a Split Personality".) By all accounts, human activities are responsible for the recent increase in global ozone. NASA's Aura mission will gather important global data for determining the sources and distribution patterns of O_3.

According to science writer Jeannie Allen in an article soon to be published on NASA's Earth Observatory Web site, there is still much to be learned about this toxic gas: "We don't

Figure 1. Schönbein color scale.



Making Schönbein paper

1. Wear **goggles** and a **safety apron** for this procedure. Be sure to wash your hands when you are finished.
2. Heat 100 mL of water in a 250-mL beaker until it begins to boil.
3. In a separate container, mix **5 g of soluble starch powder such as cornstarch** in a **small amount of cold water (about 10 mL)**. Mix to make a slurry. Remove the water from the heat using "hot mitts" and mix the starch slurry into the hot water while stirring.

PHOTO BY TONY FERNANDEZ, ACS

4. After the starch has dissolved, add **1 g of potassium iodide** and stir well. Cool the solution.
5. Lay a **piece of filter paper** on a smooth clean surface and carefully brush the starch/KI solution onto the filter paper using a **small paintbrush**. Turn the filter paper over and do the same on the other side. Apply the starch/KI solution as uniformly as possible.
6. Allow the paper to dry.
7. Cut the dry filter paper into 1-inch wide strips and store them in a ***zip-closing bag*** out of direct sunlight.

und-Level Ozone

know very much about ozone chemistry at night, nor do we know enough about the transport of gases between the lower and upper layers of the atmosphere. We have a great deal to learn about tropical ozone chemistry. We still cannot predict our chemical weather."

Make and test your own ozone indicator

Schönbein indicator paper is based on the ability of ozone (O_3) to oxidize other substances. To make a batch of your own, you begin by painting a strip of filter paper with a starch and potassium iodide (KI) mixture. Then, if ozone is present, it will oxidize the iodide ion (I^-) in the potassium iodide (KI) to yield elemental iodine (I_2). This elemental iodine in turn reacts with starch to produce a dark blue-black starch iodine complex.

$$2KI + O_3 + H_2O \rightarrow 2KOH + O_2 + I_2$$

$$I_2 + \text{starch} \rightarrow \text{blue starch/iodine complex}$$

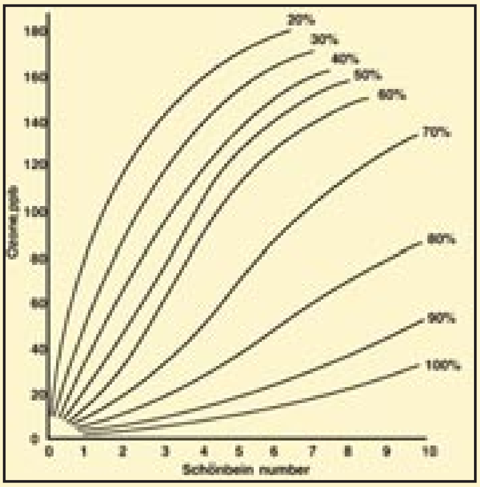


Figure 2. Relative humidity number chart.

Using the Schönbein method

During the 1880s, readings using the Schönbein method peaked at about 10 parts per billion (ppb) in a given volume of air. Today, tropospheric ozone readings average 35–40 ppb around the globe in even the most remote regions. In the United States, summertime levels in suburban and rural areas frequently range from 80 to 150 ppb for several days at a time. Urban levels can exceed those by a wide and unhealthy margin.

After a few trial runs, your class might want to plan a long-term study of ozone levels in your area. You might study the effects of seasons, temperature, and locations. And if you share your findings with *ChemMatters*, we will post your results on our Web site. Contact us at chemmatters@acs.org.

This lab activity was adapted from Project Learn, a program of the National Center of Atmospheric Research, Boulder CO. Another version of the activity appeared in the NSTA publication *The Science Teacher,* December 1995.

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Allen, J. Chemistry in the Sunlight (article in preparation for posting on the Earth Observatory Web site at **http://earthobservatory.nasa.gov.**)

Testing for ground-level ozone

Decide on a variety of locations for exposing the indicator paper strips. Some should be indoors, some outdoors. Then follow these steps for collecting and recording your data.

1. Dip a strip of test paper in distilled water and hang it at a data collection site. Choose a collection site that is out of direct sunlight and away from locations where it might be disturbed. Record the location, date, and time the site was tested.
2. Expose the paper for approximately eight hours.
3. To observe and record test results, again dip the paper in distilled water. Observe the color and determine the Schönbein number using the Schönbein color scale in Figure 1.
4. Determine the relative humidity of the data collection site by using a bulb psychrometer or by consulting local weather data. Round off the relative humidity reading to the nearest 10%.

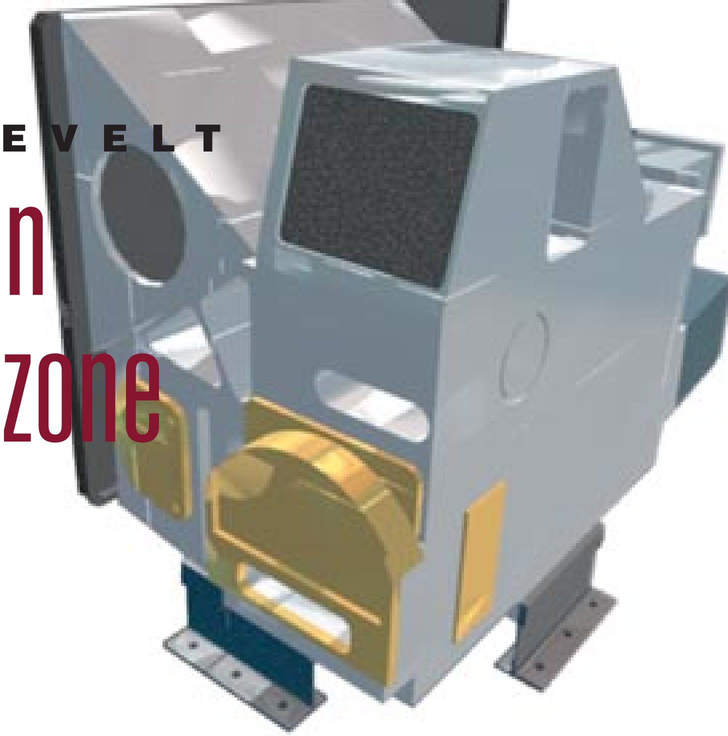
PHOTO BY TONY FERNANDEZ, ACS

Because high relative humidity makes the paper more sensitive to ozone, you need to correct for this factor.

Refer to the relative humidity number chart in Figure 2. Along the bottom of the chart, find the point that corresponds to the Schönbein number that you recorded. From that point, draw a line upward until it intersects with the curve that corresponds to your humidity reading. To find the ppb ozone concentration, draw a perpendicular line from the Schönbein number/relative humidity point of intersection to the left side of the chart.

PIETERNEL LEVELT

Shining Light on Atmospheric Ozone



> "I have always been fascinated with the explanations for how complex systems work."

A scientist, an athlete, a parent, a manager, a problem-solver—Pieternel Levelt of the Netherlands is all of these things. Yet when she tells people where she works, the Royal Dutch Meteorological Institute, many assume she is a weather forecaster. And that is one thing, she quickly points out, she is not!

But there is a connection between her important work and the weather—global weather, that is. Pieternel is interested in how our planet's atmospheric ozone, the fragile layer so critical to shielding us from damaging ultraviolet radiation and so important to changes in the Earth's climate, is affected by our own human activities.

At NASA, she heads an international team of scientists and engineers; NASA calls her a PI, or Principal Investigator). ***Her group's task is to ensure the construction of an instrument for collecting a variety of atmospheric data, calibrate the instrument, develop its algorithms, and have it ready for its ride aboard the EOS Aura satellite scheduled for an early 2004 launch.*** Pressure? Just this: Everything has to work right the first time!

It's easy for Pieternel to trace her interest in science. Her grandfather was a chemist, her grandmother, a physicist, and that's only the beginning! As a child, she went to her father, a professor of geophysics, with her questions about science, and to her mother, a law professor, with questions about math. In all, 9 of her 18 closest family members have strong science backgrounds. Her husband is a physicist. You could say that science is the family business.

Pieternel speaks of an aunt, an award-winning physicist, and her mother as outstanding role models. Their many accomplishments left her with no doubt that women as well as men can have distinguished careers. But she emphasizes that the strong encouragement of her father was important to her every step of the way.

In high school, she liked problem solving—the harder the problem, the better she liked it. She remembers her chemistry teacher, who encouraged her to solve problems her own way, not always by the book. But there were teachers who doubted science was the right choice for a girl. One teacher even laughed when she announced she wanted to be an astrophysicist. There's a popular expression: "Excellence is the best revenge!" Pieternel went on to earn a degree in chemistry and a Ph.D. in physics. And today, she manages the activities of 15 to 20 other scientists.

Often, it's her role as a manager that crowds her schedule and leaves so little time for her

COURTESY OF KMNI

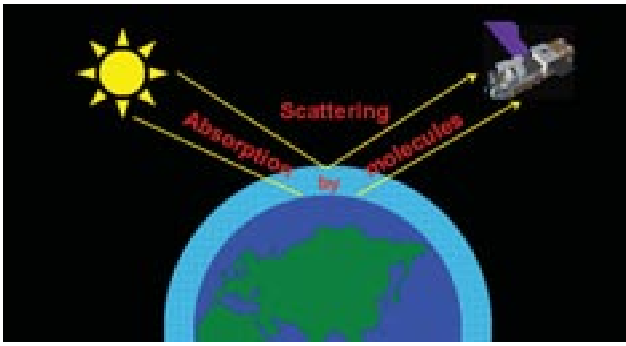


Figure 1. OMI measures UV light that is either reflected from the surface or scattered back from the atmosphere.

COURTESY OF PIETERNEL LEVELT

Triathlon events are among Pieternel Levelt's favorite competitive sports.

many interests—both personal and professional. Her two children, a four-year-old and a two-year-old, and her deep interest in science are top priorities during this countdown to launch date. But Pieternel looks forward to returning to her favorite competitive sports.

When she was very young, it was tennis, gymnastics, and judo. Then, in high school, she started competitive swimming and water polo. She loved both sprints and distance running, doing her first half-marathon in her early 20s. Shortly after that, she found a way to combine her sports by training for triathlons—distance events combining a 1.5-km swim, a 40-km bicycle ride, and a 10-km run. Her personal best triathlon is 2 hours and 12 minutes, and several times, she was rated 12th best in the Netherlands.

Team science

Sports and training with her triathlon club members may re-enter her life at some point. Right now, it's team *science* that occupies her time. Pieternel coaches her team of scientists through the tough challenges involved in building the Ozone Measuring Instrument (OMI), a simple name for a highly technical instrument designed to read both the ultraviolet (UV) and visible light patterns of the solar light reflected from the Earth and the atmosphere. The data will yield daily high-resolution global maps and profiles of ozone—information that scientists have never had on such an ongoing basis. And that's not all. OMI will also measure notorious pollutants in the atmosphere—nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and other "trace gases"—at spatial resolutions higher than ever before. While earlier NASA-launched instruments could collect regional data, OMI will pinpoint data coming from areas the size of a city.

OMI uses UV light to map ozone and pollutants.

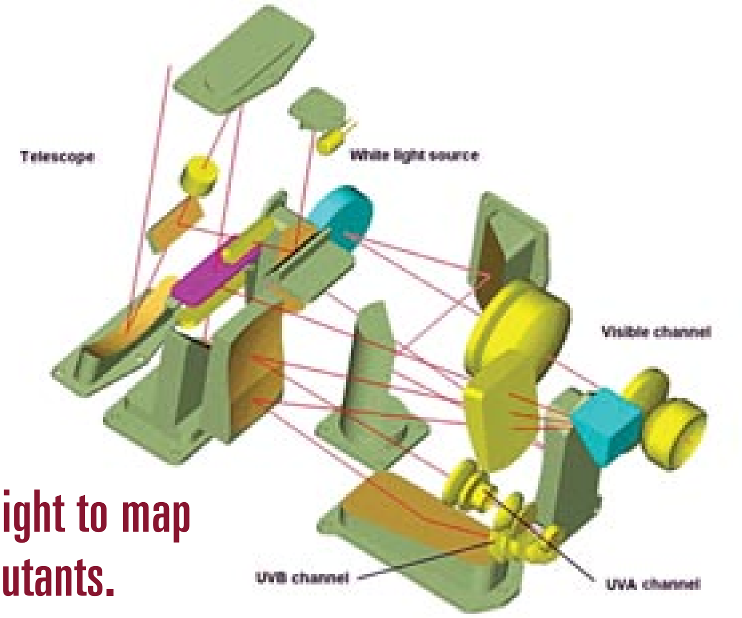
OMI will measure both the amount of ozone in the atmosphere and its vertical distribution by measuring the way ozone molecules absorb certain UV wavelengths. OMI measures both incoming and outgoing radiation using the Backscatter-UV or BUV technique—a method developed for NASA's Total Ozone Mapping Spectrometer, which was launched to monitor global ozone in 1978. The name describes how the technique works. ***UV light emitted by the sun enters the atmosphere. This entering light is called the irradiance.*** That name makes sense, because this is the light that irradiates the Earth.

Some of this light is either reflected from the surface of the Earth or scattered back from the atmosphere. This is called the *radiance*. That name also makes sense, because this is the light that is radiated back from the Earth or atmosphere (see Figure 1).

OMI will measure a broad range of wavelengths, including some wavelengths that are strongly absorbed by ozone and others that are weakly absorbed. Scientists study these measurements to find the telltale spectral signature made by light-absorbing ozone. They look at the amount of the incoming solar irradiance and then they look at the wavelength pattern of strong and weak absorbing wavelengths in the backscattered radiation. By comparing the incoming and outgoing radiation, scientists can derive how much ozone there is in any given locale of the atmosphere.

How is ozone distributed vertically? To answer that question, scientists rely on ozone's, appetite for absorbing light at the shorter UV wavelengths. As they measure at lower and lower altitudes, they would expect to find less and less shorter-wavelength UV—*if* ozone is around to do its job. Measuring the amount of this shorter-wavelength UV light being scattered about by other molecules at a given altitude is the key to determining how much ozone is in the neighborhood.

Besides advising on the construction of OMI, Pieternel's team works with the instrument builders to calibrate the instrument to be sure it sends back reliable, meaningful, and accurate data from its satellite platform 705 km (438 mi) above the surface of the Earth. For this exacting assignment, Pieternel relies on all of the experience that her team of specialists and industrial partners brings to the task.



GRAPHIC COURTESY OF NASAEOS AURA

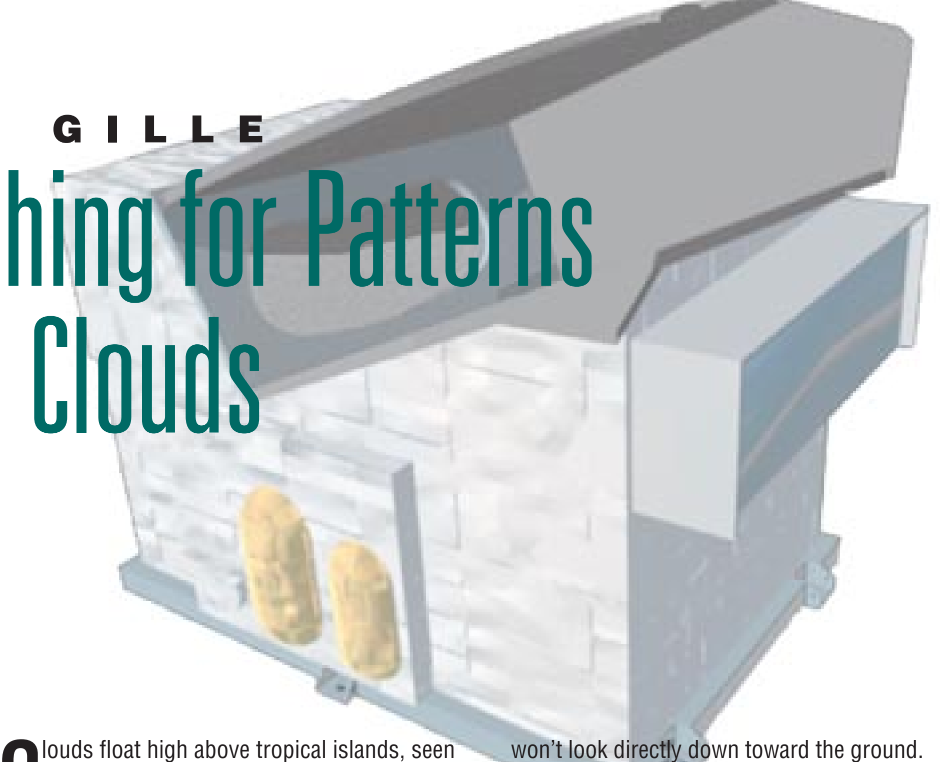
Managing the problem solvers

Accustomed to taking on personal challenges, Pieternel admits she is still learning to manage this group of problem solvers. Sometimes her management skills are tested by the diverse cultural and personal work styles of her international team. Early in the project, she learned that the best strategy is to look for common ground—always starting with "on what do we agree?"

If Pieternel could pursue her dream science project, what would it be? It's actually pretty close to the one she is doing now—minus the demanding deadlines as launch day approaches. She wants to return to the problem that first captured her scientific interest—"How does ozone affect the future of life on Earth?" This time, not only will she have good, reliable data on which to draw, but she'll also have the satisfaction of knowing that her team played an important role in making OMI a state-of-the-art instrument for reading the chemistry of the sky.

JOHN GILLE

Searching for Patterns in the Clouds



> “I work in the intersection between science and engineering—where you first frame the kinds of things you’d like to know and then design something that can do it.”

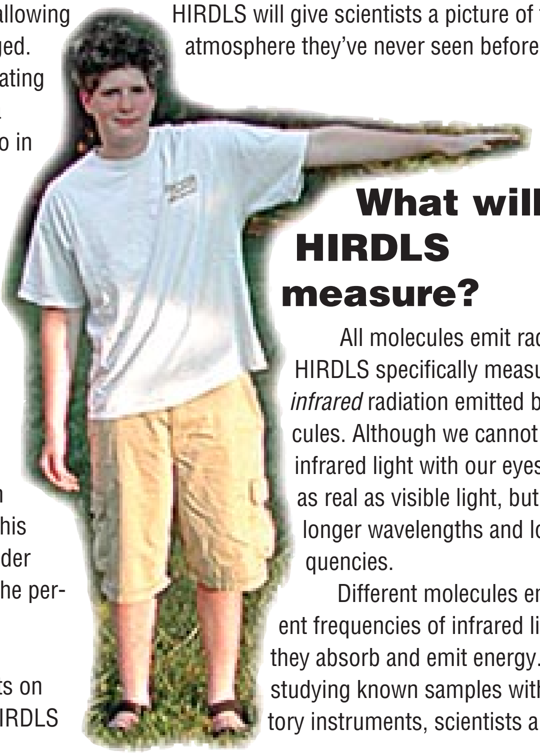
Clouds float high above tropical islands, seen in a warm, humid sky. Raised by warmth from the sunlit earth, up they go like balloons escaping from a careless hand. Perfect images of freedom!

Would it surprise and disappoint you to hear that cloud traffic obeys limits? Most clouds eventually encounter a ceiling, a subtle layer of atmosphere only 4 km thick. This thin layer, scientifically named the *tropopause transition layer*, caps the 15-km layer of denser atmosphere in which we live. It lies just below a vast, almost cloudless, layer called the *stratosphere*, which finally tapers off at 50 km above the Earth.

This tropopause ceiling, most evident in the tropics, puts the lid on clouds while allowing water vapor and ozone to be exchanged. How this works is the mystery captivating the research interests of John Gille, a physicist at the University of Colorado in Boulder and the National Center for Atmospheric Research, a facility perched in the mountains above the city.

Gille looks forward to gathering important atmospheric data with an instrument that his team of scientists is developing—a remote sensor scheduled to ride aboard NASA’s satellite EOS Aura in 2004. The planned orbital destination at 705-km altitude (438 miles) should position this High Resolution Dynamic Limb Sounder (HIRDLS, pronounced “hurdles”) in the perfect spot for probing the mysterious tropopause transition layer.

Like two of the other instruments on board Aura (OMI is the exception), HIRDLS won’t look directly down toward the ground. HIRDLS is a *limb sounder*. And we know your next question. ***A limb sounder can basically be thought of as a horizon scanner.*** To picture it, raise your arm (make that your *limb*) off to the side. Now move it so it points slightly upwards or slightly downwards. You’ve just modeled the kind of *limb* scan HIRDLS will make across the horizon, as seen from space. With a similar motion, HIRDLS will sweep through a vertical range of perhaps 10–80 km in about 10 seconds at each of six different directions! These repeated scans produce a tight array of interlacing data points with tremendous vertical resolution. That’s why Gille thinks that HIRDLS will give scientists a picture of the atmosphere they’ve never seen before.



COURTESY OF JEANNIE ALLEN

What will HIRDLS measure?

All molecules emit radiation. HIRDLS specifically measures the *infrared* radiation emitted by molecules. Although we cannot see infrared light with our eyes, it is just as real as visible light, but with longer wavelengths and lower frequencies.

Different molecules emit different frequencies of infrared light as they absorb and emit energy. By studying known samples with laboratory instruments, scientists already know what frequencies a vast variety of molecules emit. So if HIRDLS measures at these frequencies, they will know what molecules are present in a particular part of the atmosphere. Scientists then figure how much of each kind of molecule is present by carefully measuring how much energy at each specific frequency of infrared light is present.

Simple? Not quite. The amount of radiation emitted by molecules also depend on their temperature. So how does Gille's HIRDLS team get around that problem? Carbon dioxide (CO_2) comes to the rescue.

CO_2 information can be used to determine the temperature at any point in the atmosphere. Here's how that works. The energy emitted from a set of molecules depends on two things—their concentration and the temperature. Since CO_2 doesn't react with other molecules in the atmosphere, its concentration at any given altitude is fairly stable. Scientists have been able to show that CO_2 follows a predictable pattern as it gradually becomes less concentrated the higher you go above the surface of the Earth.


PHOTO COURTESY OF NCAR

Engineers suit up in a "clean room" for work on the HIRDLS instrument.

So if you know the altitude, you know the concentration of CO_2. By measuring the amount of energy emitted by CO_2 at this altitude, the HIRDLS team can figure out the temperature. That information is useful in determining the concentration of other molecules, such as water vapor or ozone, at the same altitude. They measure the amount of energy these molecules are emitting and use the temperature to figure out the concentrations.

Of course, if you took only one scan over a long horizontal distance through the atmosphere, it would be difficult to determine how much of any particular molecule was present at a specific point along the path. That's why many measurements are made along many different overlapping paths.

Measurements? These are a little tougher to read and interpret than the digital readout from a laboratory balance or thermometer. It takes a lot of brainstorming—the combined work of a whole team of engineers, physicists, and mathematicians—to figure out how to make the HIRDLS data readable and meaningful to scientists on the ground. And if that sounds easy, guess again. In Gille's words, "Things that you thought would be easy can suddenly turn out to be hard." And with the clock ticking toward a 2004 launch date, that's what pressure is all about.

One of the biggest challenges is getting the algorithms right. Perhaps you've heard of *algorithms* in one of your science or math classes. An algorithm can be a procedure for solving a mathematical problem. Gille's team is working to develop algorithms to be applied to the incoming HIRDLS data. With the right algorithms built into the software programs, streams of data will be organized and arranged in useful patterns that enable scientists to draw important conclusions about the nature of the atmosphere.

Gille's talented team includes "card-carrying engineers", who design, build, and test the hardware; software engineers, who develop the programs and code for crunching the data; and scientists, who make sure the instrument is set to measure the important and interesting chemistry of the atmosphere. ***It's Gille's job to keep everyone on the same page.*** He believes that success hinges on everyone carrying out their own responsibilities while having some understanding of what's going on in other parts of the program.

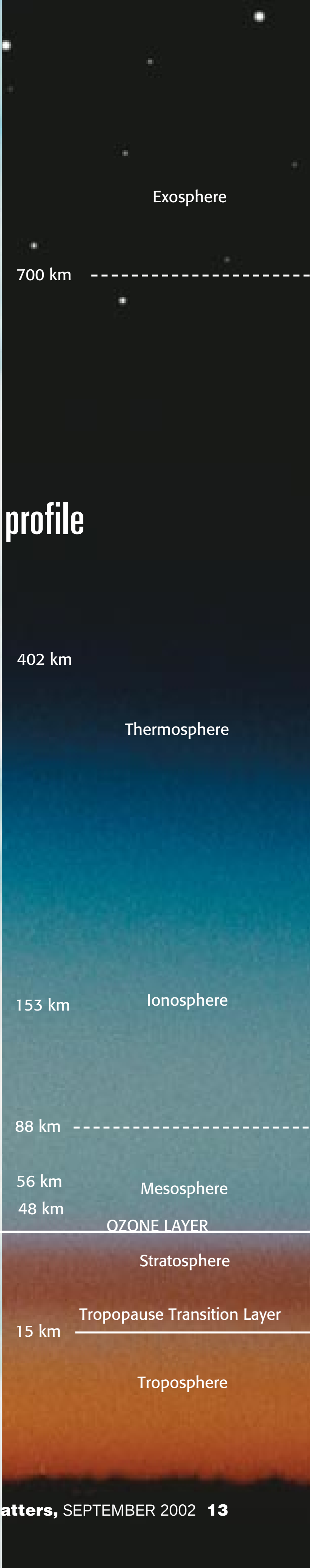
A scientist is born

Gille's fascination with physics started in elementary school. He's not certain what sparked his interest, but it might have been the challenge of understanding a hard subject. News coverage about nuclear physics fascinated him. Chemistry, physics, and math were his high school favorites. Attending high school, he recalls having excellent chemistry and physics teachers. His math classes at Teaneck High School in New Jersey were good, but Gille says that "they didn't get as far as they do now." So he taught himself some calculus, "just by reading myself."

Managing to get in some skiing and hiking for fun, he describes a career in science as marvelous and fascinating. He loves working on problems where science and engineering intersect. "I really enjoy taking a set of scientific questions and then calling on available technology to design something that will find the answers."

In the final analysis, John Gille believes you have to know what you genuinely love, and then ***go after it with all your ability and energy.*** "I think space is a wonderful way to get a lot of the kinds of data we need to understand some of the real social problems we're facing. But it's not the only way." ▲

Atmospheric profile



ANNE DOUGLASS

Making the World Safe for Blondes

> “We only have one Earth. It is important that the results of our ‘experiment’ are ones we can literally live with.”

When Anne Douglass tells you what she does for a living, she laughs and says she is “making the world safe for blondes”—not exactly the way her job is described in her NASA employment file. Is this the beginning of some kind of ‘dumb blonde’ joke? When she offers no punch line, you’re left thinking about what she means.

Douglass guides a team of NASA scientists working to answer fundamental questions about our planet and its atmosphere. One of those questions has to do with the amount of ozone present in the atmosphere’s upper reaches. As this stratospheric ozone decreases, more harmful ultraviolet (UV) radiation penetrates to the Earth’s surface.


COURTESY OF NASA GSFC

Anne Douglass and team members.

It’s this harmful UV radiation you try to block with your sunscreen and shades—the kind with the bad reputation for causing sunburns and skin cancers.

People with light-colored skin—like blondes—are particularly susceptible. Anne Douglass’s job description makes sense. And it goes without saying that “making the world safe for blondes” makes it that much safer for the rest of us as well.

Officially, Douglass is listed as the coleader for the Validation Working Group on NASA’s EOS Aura space mission, a satellite mission scheduled to launch January 2004. On board the Aura “bus” will be four instruments for reading the chemical composition of the atmosphere. So it’s easy to guess that *validation* has something to do with making sure the readings are correct. When you are talking about making measurements from spacecraft, the whole subject of validation becomes especially important, as well as very complex.

Right or wrong answers

Think about this example. When you write up experiments in your high school chemistry lab, your teacher can usually check your results. That’s because your teacher probably made up the solutions, prompted you about the methods, provided the balances you used, and planned the outcome. The final answers could be predicted in advance.

But when it comes to dealing with Mother Nature, there aren’t any predetermined right answers. For a mission like Aura, scientists must pay scrupulous attention to make sure that all measurements are accurate. Whether the answers are right or wrong depends on exactly that.

For measuring the concentrations of gases in the vast mixture that we call *atmosphere*, the Aura mission relies on a set of four remote-sensing, satellite-based instruments. It is also supported by instruments located on balloons, airplanes, and ground installations. A key strategy in validating data is to use all of these instruments to check on one another. By making overlapping, redundant readings from a variety of instruments, NASA scientists get a good idea about accuracy.

All instruments have their strengths and limits. Ground-based systems often work by gathering real samples of the atmosphere, making the data very accurate and verifiable. Instrument repairs and recalibrations are easy to make in between readings. However, these earthbound instruments read relatively small areas for short periods of time. Their operations are limited to what they can detect locally or overhead.

Satellites are able to cover the entire globe. Without collecting any actual air samples, they collect huge amounts of data for longer periods of time. However, effective calibration before launch is especially important. Once launched, the orbiting instruments can't be repaired or recalibrated. Furthermore, while the onboard remote sensors measure conditions in the upper atmosphere fairly easily, they encounter problems when they try to look downward through the lower atmosphere, or *troposphere*.

Because the satellite-based sensors look downward to measure concentrations of gases, these measurements of the troposphere can be obscured by clouds, dust, aerosol particles, or other interferences. Since these measurements are so difficult to get right, it is especially critical that they are validated by readings from other instruments. That way, scientists can have confidence in the results.

Validation—It's like this

Here's what validation might look like closer to home. Suppose someone in your household buys an old kitchen scale at a flea market. Does the thing work? Can you believe the measurements it makes? There are several ways to find out. You could take some preweighed food items off the shelf, weigh them, and check that the reading on the scale matches the weight stamped on the labels. Or you could weigh a small object from your backpack on the digital balance at school, bring the object home, and weigh it on the kitchen scale. You get the idea. Comparing measurements from a variety of sources to validate data is a common practice in science, and it sometimes makes good sense in everyday life. On the Aura project, it's a matter of comparing the readouts from several instruments, which are all simultaneously focused on the same atmospheric neighborhood.

Of course there's a little pride involved. Douglass talks about the friendly rivalries between the scientists who measure "in situ" and those who measure from satellite, or other remote platforms. The term *in situ* is Latin for "in place", in this case, "in the atmosphere". Each working group is partial to its own type of measurement.

The scientists operating ground-based instruments especially enjoy this story of the now famous discovery of the polar ozone hole. Joe C. Farman and his co-workers of the British Antarctic Survey had been measuring ozone levels with their ground-based instruments for several years before recording precipitous declines in the early 1980s. Interestingly, there were NASA satellites making ozone measurements during this same period, but the low readings picked up over the Antarctic were thought to be "outliers", readings too far out of the expected range of values. As a result, the data were bypassed.

Ground-based ozone readings made at Britain's Halley Station in Antarctica were the first reports of the polar ozone hole.

Once the ozone hole was validated by means of ground-based instruments, NASA switched off the bypasses, and the data were clearly present. Validation gives scientists confidence in their data—the confidence they need to draw important conclusions.

Steps along the way

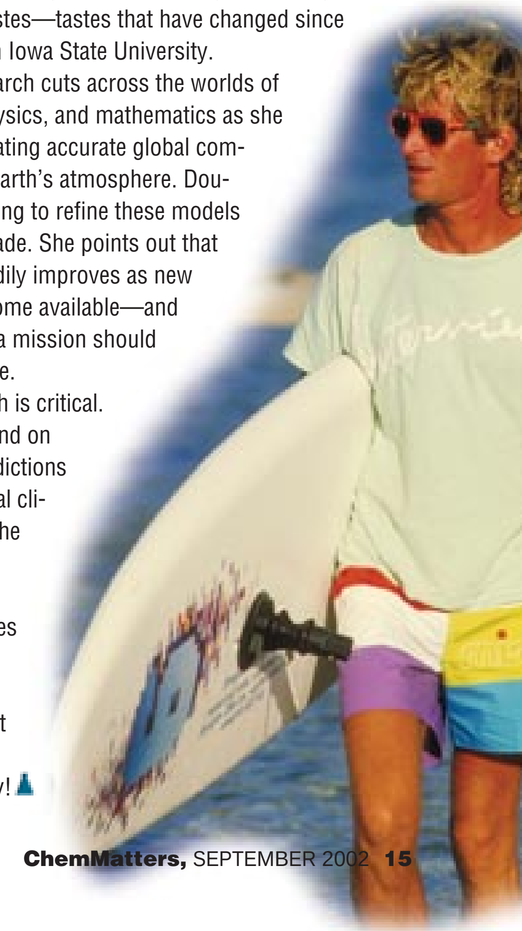
Anne Douglass not only leads the Aura mission validation team, but as a scientist, she conducts her own research. And lately, ***she also finds a little time for her newest pastime—tap dancing!*** Always devoted to the old MGM movie classics, she jumped at the opportunity to take a class at a local community center. Dancing poses a tough challenge, but Douglass meets it the way she's met many others, with determination and hard work—attributes that make her both a good scientist and a good student.

Douglass's interest in science and mathematics started in high school. She was inspired by her math teacher, Sister Barbara Garland, an excellent teacher and an effective role model, who demonstrated that women can excel in math and science. Garland selected Douglass for special classes in math in which she was encouraged to develop her own approach to problem solving.

In college, Douglass was attracted to physics because it told the story of how the world works. She especially liked analyzing crashes and collisions, explaining them with mathematics. In contrast, the worlds of biology and chemistry were "too smelly and messy" for her undergraduate tastes—tastes that have changed since receiving her Ph.D. from Iowa State University.

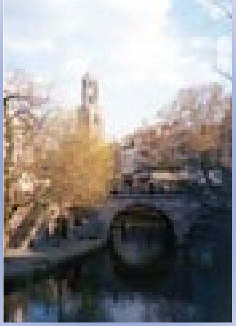
At NASA, her research cuts across the worlds of biology, chemistry, physics, and mathematics as she plays a key role in creating accurate global computer models of the Earth's atmosphere. Douglass has been working to refine these models for more than a decade. She points out that their accuracy steadily improves as new and *valid* data become available—and data from the Aura mission should be the best to date.

The research is critical. The world's scientists depend on good models for making predictions about future changes in global climate and the rates at which the changes occur. And, on the basis of these predictions, world leaders consider policies necessary for the health of a changing planet. A tough assignment? No one said that keeping the world safe for blondes was going to be easy! ▲



The GLOBE Program: Postcard From the Netherlands

The city of Utrecht in the Netherlands is famous for its medieval buildings and beautiful canals. The Netherlands is also the site of several GLOBE schools, including one in Utrecht, where students are learning to collect ground-level ozone and aerosol data. NASA and the Dutch Meteorological Institute (KMNI) plan to compare their findings to data collected by the satellite-based remote sensing instruments aboard NASA's Terra, Aqua, and Aura spacecraft.



GLOBE stands for Global Learning and Observations to Benefit the Environment. The project engages students from many countries in collecting and sharing important research data with other GLOBE sites, as well as with the scientific research community.

David Brooks of Drexel University in Philadelphia heads NASA's GLOBE Aerosols Monitoring Project in the United States. Last April, Brooks visited three GLOBE school projects in the Netherlands while attending an international meeting of EOS Aura scientists and engineers. He was anxious to observe and speak with these students who were using a new hand-held instrument called a the*“sun photometer*. Brooks helped develop this compact and portable instrument for measuring the density of light-blocking aerosols in the atmosphere.

Here, Brooks describes his April 2002 visit:

The weather was—so I was told—unusually cooperative, with good conditions for making sun photometer measurements when I was at two of the three schools. At these schools, we were also able to check the calibration of sun photometers against a reference instrument.

The schools we visited were the equivalent of U.S. middle and high schools. Each has several hundred students and is located in an urban area. Air quality and other environmental concerns are important in each of these cities.

The picture shows me working with (left to right) Nora Molenaar, Sophie Kramer, and Eveline van Ingen, students at College Blaucapel, Utrecht, to check the calibration of their sun photometer. These students are at level 4, equivalent to a sophomore in U.S. high schools. Sophie Kramer is planning to make aerosol measurements until she graduates, to fulfill the school requirement for a *three-year(!)* individual research project.

Although you cannot see the logo in this picture, I'm wearing a very cool GLOBE/Netherlands shirt given to me by Yvette Bellens, assistant GLOBE coordinator for the Netherlands. Yvette and Stephanie Stockman, from Aura's education and outreach program, accompanied me on this trip.

The students are using a battery-powered, two-channel GLOBE sun photometer.

Here's how it works: The right-hand switch allows selection of the green or red channel for display on the digital panel meter. Sunlight enters the case through the round hole barely visible on the top of the case (the end pointing toward the sun). The sunlight detectors, green and red light-emitting diodes (LEDs), are located on a printed circuit board in the rear of the case. Although LEDs are usually light emitters, in this instrument, they also serve as light detectors.

The sunlight also shines through the round hole in the metal bracket on the front of the case. You can see the bracket's shadow and the sunlight shining through the bracket on the front of the case. By centering the sunlight spot on the red or green circles on the rear alignment bracket, students can align the sunlight coming through the hole in the case onto the red or green detectors.

The digital panel meter—the dark rectangular shape on the front of the case—displays the output voltage from the sun photometer. Although the photo doesn't capture it, the person using the sun photometer can see the voltage display. Students record aerosol optical thickness (AOT), a measure of aerosol concentrations in the atmosphere, by noting the detector's output voltage, the location of the observing site, the precise time of the measurement, and the barometric pressure at the time of the measurement. They may record and store these readings in a computer, through an output jack on the right side of the case (not visible in this picture).

PHOTOS COURTESY OF DAVID BROOKS

You'll find information about becoming a GLOBE school and getting a project started at your school on the Web at **www.globe.gov.** If your school is already involved, and you would like to share your experiences with *ChemMatters*, we would like to hear from you. Contact us at **chemmatters@acs.org.**

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