Special Edition NASA

ChemMatters®

DEMYSTIFYING EVERYDAY CHEMISTRY

SEPTEMBER 2005

AURA LAUNCHES!

NASA's Incredible Ongoing Mission to Monitor Global Atmospheric Chemistry

AURA LAUNCH JULY 15, 2004

The countdown begins, and there's tension in the air.

For the EOS Aura spacecraft, a failure would destroy years of work by hundreds of scientists, engineers, and technicians. In terms of cost, it would mean $785 million in development and hardware costs—gone in an instant.

It's nerve-wracking to see your work strapped to a rocket, ready and waiting for a launch that will take it into orbit.

Then, after three previous launch opportunities were canceled, here's what happened in the early morning hours at Vandenberg Air Force Base in California.

From the launch controller: **5:51 A.M.** – The NASA Launch Manager has completed his final poll. All technical issues have been closed out and a go has been given to release the hold. **5:55 A.M.** – The spacecraft is on internal power. **5:59 A.M.** – T–3 minutes and counting. The spacecraft has been given its go for launch. **6:01:59 A.M.** – T–10, 9, 8, 7, 6, 5, 4, 3, 2, 1 ...we have ignition. ...and liftoff of NASA's Aura spacecraft on a mission to understand and protect the air we breathe! **6:03 A.M.** – The first set of solids has burned out. First set of six solid boosters have been jettisoned. **6:04 A.M.** – The last three solid motors have been jettisoned. **6:05 A.M.** – The launch vehicle is 42 miles in altitude. **6:06 A.M.** – Vehicle is 134 miles downrange, 48 miles in altitude and traveling at 8,400 miles per hour. First stage, main engine cutoff. Second stage, ignition. **6:07 A.M.** – First stage has been jettisoned. **6:12 A.M.** – The vehicle is 101 miles in altitude. **6:13 A.M.** – Second stage engine cutoff. **6:14 A.M.** – Aura's nominal orbit has been achieved: 373.26 miles by 100 miles, at 98.2 degrees inclination. **6:54 A.M.** – Malindi tracking station in Kenya has acquired signal from Aura. Second stage continues to be in good health and is rotating slowly about its axis. **7:00 A.M.** – The second stage has restarted and cut off as planned. The new orbit of the spacecraft after the second stage burn is 372.57 miles by 364.85 miles with an inclination of 98.217 degrees. **7:06 A.M.** – Malindi tracking station has confirmed that the Aura spacecraft has separated from the second stage. Mission Director's Center confirms a good launch!

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CHEMMATTERS®

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Why Did I Get This Special Issue?

If you are a regular subscriber, the answer is easy. You renewed your subscription early enough to be on our mailing list, and this is the first of the five 2005–2006 issues.

If you are not a current subscriber, you received the issue compliments of NASA's Educational Outreach. Please share this issue with other chemistry teachers.

This is our fourth special NASA issue exploring EOS Aura, a satellite that is now providing the most accurate picture to date of Earth's changing atmosphere. You can download complete copies of this issue or any of the past special issues (September 2001, September 2002, and October 2003) with teacher's guides, and you can subscribe to *ChemMatters* at http://chemistry.org/education/chemmatters.html.

TEACHERS!
FIND YOUR COMPLETE TEACHER'S GUIDE FOR THIS ISSUE AT www.chemistry.org/education/chemmatters.html.

HOW EARTH GOT ITS AURA

NASA

By Jeannie Allen

Apollo 11 astronauts captured this famous image of Earth on July 16, 1969. Most of Africa and parts of Europe and Asia are visible. Although the focus was on travel to the moon, their photos of the beautiful, mysterious, and fragile planet Earth captivated both scientists and the public. NASA's Earth observing programs soon followed.

The Apollo astronauts' photography not only revolutionized humanity's view of our planet, it also kindled a scientific interest in studying the Earth system from space. Soon after Apollo, NASA launched a few satellites to study changes in the weather and the land. NASA scientists' appetites were whetted for more. "With the Earth Observing System missions, we wanted to throw out a broad net to see what we could learn about the Earth," says Mark Schoeberl, Aura Project Scientist. That was how Aura—NASA's mission for studying the chemistry of Earth's atmosphere—began.

Aura on the drawing board

When you start a school science project with a group of other students, what is the first thing you think about after deciding on your idea? It's probably a list of who-will-do-what based on the talents and interests of the group. That's how it is with a NASA Earth observing mission: enlisting people with the right skills is the first and most important step. Designing, building, launching, and operating NASA's Aura satellite required an incredible variety skills and ways of thinking to be contributed by experienced and talented people from all over the world.

The Aura satellite mission, launched after years of planning in July 2004, called on the combined skills of two distinct professional communities, each contributing their own brand of expertise, each supporting the work of the other. First, it was the group of Aura *scientists* who raised the key questions about the Earth's atmosphere: How is the climate changing? Is the ozone layer recovering? Is the air quality of the lower atmosphere changing? After identifying the kinds of data they needed to collect for getting answers, the scientists turned to a group of *engineers and technicians* to design and build the instruments needed to do the job.

Some engineers and technicians do extremely delicate work, even to the point of finding the right type of lubricant for a screw in one of the science instruments. For other engineering tasks, the work is less delicate. While assembling the launch vehicle, Aura engineers had to attach the huge solid rockets with sledge hammers.

But a project like Aura takes more than rocket science. Budget people—specialists who understand how to manage the financial side of construction—keep necessary funds on track. The mission calls for mathematical experts for analyzing and validating streams of downloaded data from both the spacecraft in orbit and the numerous ground systems capturing simultaneous information. The mission requires system administrators and project support personnel to coordinate the various project activities. And finally, Aura employs program managers who keep the big picture in mind and make sure all the parts of the process move forward on schedule. As for any science project, teamwork and communication are important keys to success.

New technologies for new observations

How different is the air today from the air your parents breathed when they were in high school? Earth-observing missions have revealed that some fundamental changes have occurred. Over the last few decades, the global climate has warmed, air quality has worsened in some areas, and the ozone in the stratosphere—the layer that protects us from harmful ultraviolet radiation—has thinned. All of these changes are intertwined. Changing temperatures affect atmospheric chemistry, and the chemistry, in turn, affects temperatures. Aura's ambitious goal is to collect enough information to make sense of this intricately related change.

Designing the instruments needed to observe subtle changes in the atmosphere required developing new instrument technologies. Working closely together, four teams of engineers and scientists took on the challenge. "People were always refining the technology as the project progressed," says Ernest Hilsenrath, Aura Deputy Project Scientist. Sometimes, instruments from previous missions were refashioned for new requirements on Aura. Aura's Tropospheric Emission Spectrometer (TES) was one of those. John Loiacono, Aura's Deputy Project Manager, recalls that "we were building optics for TES that were similar to previous instruments we had built, but TES's optics were much larger in order to meet TES's requirements. Just trying to get larger optics built with the same specifications was difficult. We had large optics that had to be glued together, only to have them fall apart while undergoing vibration testing. There were times when we wondered whether or not we'd be able to build what was required. Those were some dark days, but as I look back, very exciting and challenging!"


NASA

John Loiacono


IMAGE COURTESY OF THE IMAGE ANALYSIS LABORATORY, NASA JOHNSON SPACE CENTER

Scientists examining the AURA "bus"before launch.

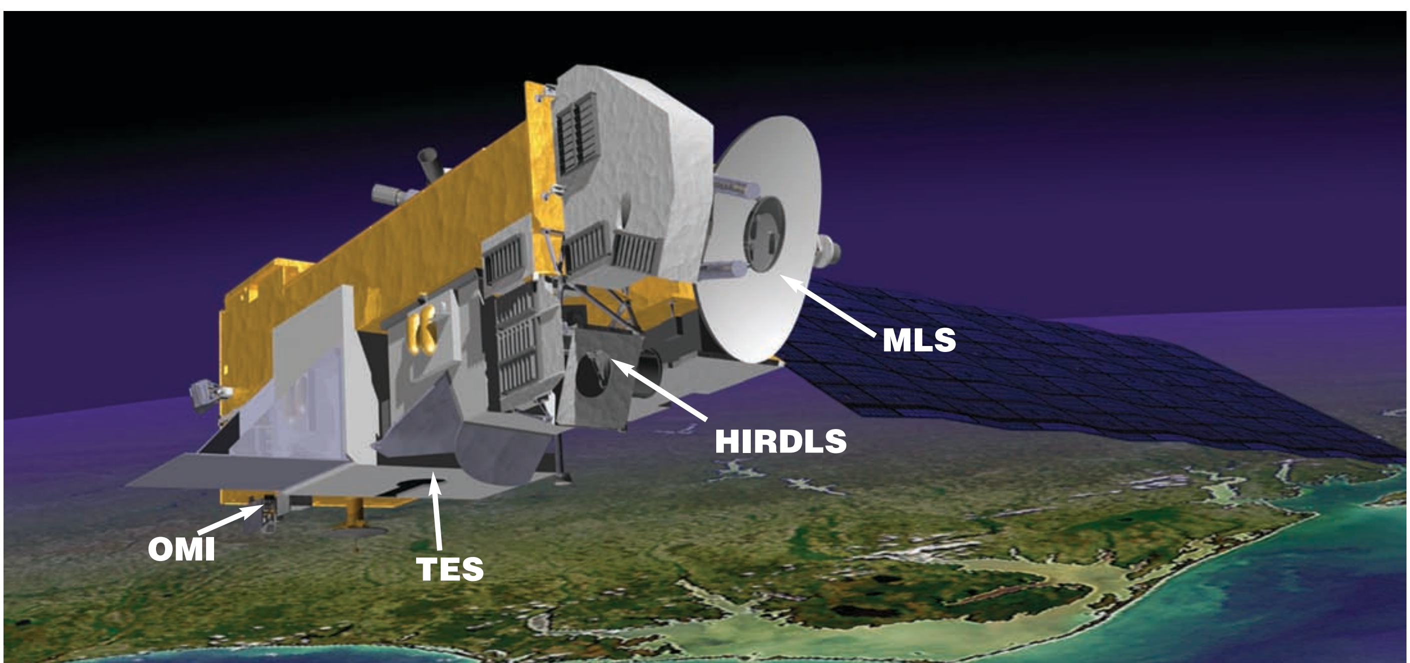
Once the instruments were designed, engineers and scientists had to figure out where to place each of the instruments on the satellite or "bus" that would carry them through space. The four instruments view the same part of the atmosphere almost simultaneously, each one measuring chemicals in different ways. The scientists wanted to have some of the data overlap so that the instruments would provide checks on one another's measurements. That meant it was important to have all four instruments working in a coordinated and synchronized fashion.

There were many more engineering challenges facing the teams. It was important to consider when each of the instruments would be on the Sun side and when they'd be on the dark side, so that there wouldn't be too much or too little heat around any of them. Then there were the many subsystems: data, power, telemetry, thermal, onboard attitude control, and fuel to keep the bus and instruments pointing in the right direction. Furthermore, the satellite had to be balanced in terms of its weight. Each instrument required a certain amount of power, data rate, and bandwidth for transmission to Earth. Solar cells had to be a certain size to obtain the required amount of power. Onboard computers had to be programmed to run the satellite, taking commands from software engineers on Earth, and sending the data down.

Getting the data down

Obtaining data about the chemistry of the atmosphere is what the Aura mission is all about. That called for data engineers and scientists to decide how they wanted to set up the data system so the data could be retrieved, archived, and distributed. What hardware and software would they need? What file formats should be used? Where should the data arrive on Earth? Who would retrieve and archive it? Like many NASA missions, Aura has several international partners. How would the data be transferred to the scientists around the world for their research?

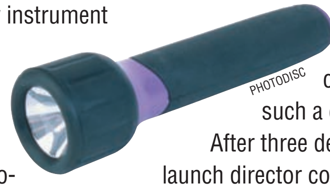
Earth-orbiting satellites transmit data at regular intervals to properly equipped ground stations. Computers are programmed to understand the numeric language of these binary numbers. File formats provide ways of organizing the numbers—streams of ones and zeros—so they can be stored and retrieved in a standard way. Data also must



NASA/GSFC

The High-Resolution Dynamic Limb Sounder (HIRDLS) and Microwave Limb Scanner (MLS) scan horizontally. Tropospheric Emission Spectrometer (TES) and the Ozone Monitoring Instrument (OMI) look downward.

be identified in terms of where they were obtained in space. Data engineers use labels consisting of grid, point, and swath. As raw instrument data are received at the ground station computers, they are sent to science team computers where they are organized and translated to represent temperature, ozone amounts, or cloud classifications—all of which has meaning for scientists seeking answers to their research questions. Finally, programming and design specialists create a variety of means to display the data as images, animations, tables, text, and data arrays—displays that reveal patterns and allow comparisons between measurements.


PHOTODISC

Show time!

After years on the drawing board and months of final processing and testing, the Aura satellite was assembled at Norththrup Grumman Space Technology, then prepared for launch at Vandenberg Air Force Base (VAFB) in California. Getting it to the launch site required some planning. The Aura spacecraft with its four instruments were placed in a large can for shipping to the launch pad. "It looked like a soup can, only it was about two stories tall," said Loiacono. "The can protected the spacecraft and instruments from dirt and dust while it was transported to the pad. If dust particles were to collect onto the optics in the instruments while on the ground, it could be catastrophic to our measurements and observations while in orbit."

Before the arrival of the canned spacecraft, the first and second stages of the rocket or "launch vehicle" and the solid rockets arrived by truck, to be stacked one on top of the other by crane operators. Launch vehicle assembly personnel labored to secure the first and second stages and to install the solids to their attach points. Every satellite and launch vehicle integration has its unique set of assembly problems to solve. "Have you seen the TV show, *Orange County Choppers*?" asks Loiacono. "That was sort of the dynamic at the launch pad. Highly skilled workers were performing flawlessly, trying to maintain a schedule, and problems kept popping up."

Loiacono describes his role as launch time approached, "My job was to ensure that the ground system located at Goddard Space Flight Center in Greenbelt, MD, and the Aura spacecraft on top of the launch vehicle at Vandenberg Air Force Base were ready for launch. Soon after launch, the ground system begins to control the spacecraft, so all the computers, ground antennas, and personnel need to be ready to 'receive' the spacecraft data after the launch vehicle inserts it into orbit."

Before launch, data from the spacecraft are transmitted through cables that come down the pad over to a building several miles away. In this building, a small team monitors the spacecraft systems for many hours before launch. If this team sees anything that tells them something is wrong with the spacecraft, the launch is put on hold. The ground system and spacecraft monitoring crews need to react properly and correctly or a billion-dollar spacecraft can be lost.

Even a missing flashlight can be a crisis. At speeds 6 times that of a speeding bullet, any loose object in the spacecraft becomes a wrecking ball. When a technician couldn't account for his flashlight after returning from the launch pad, everyone scrambled. Loiacono even made a 3:00 a.m. call to a technician just returned to his home in The Netherlands. After a thorough investigation, the flashlight was never found, but the team concluded it was not on the spacecraft or launch vehicle. New checkout procedures will be enforced to make sure such a crisis never comes up again.

After three delays, Loiacono gave the final go for launch. The launch director conveyed it to the Boeing engineer who sent the actual command to the launch vehicle to ignite. The Aura spacecraft lifted off the launch pad on July 15, 2004 at 3:00 a.m. PDT.

"If you have ever watched a launch on TV, you may have seen people in my position," says Loiacono. "You would see people sitting and staring at computer screens, and it appears very boring. But that's not how it really is! There's a tremendous amount of information I had to process that was coming from display monitors, as well as critical information from people talking to me in my headset. This activity is analogous to reading information on your computer monitor while you are made to listen to a CB radio and have to follow several conversations on multiple CB channels, all at the same time. With the information so important, my heart was racing as we launched."

Aura orbits the Earth from North to South, then North again, coming close to the poles, but missing them by about ten degrees. In all, the spacecraft makes about 15 complete orbits in a 24-hour period. The launch site in central California was chosen so that the satellite started its journey out over Pacific Ocean toward the South. With this trajectory, the booster rockets would fall into the ocean and not onto inhabited land.

NASA/GSFC

After launch, the ground system begins to control the spacecraft, so all the computers, ground antennas, and personnel need to be ready to "receive" the spacecraft after the launch vehicle inserts it into orbit.

"To me, the everyday accomplishments of our engineers are just astounding," says Hilsenrath. "These are enormously complicated satellites, and they fly at 7 kilometers per second (25,200 km or 15,750 mph). Yet our engineers are so skilled that they put the satellites into orbit, position them within meters of the target location with other satellites flying extremely close by, and track their flight within meters of the desired flight path."

First the celebration, then more hard work

A successful launch means cheering and congratulations. But Mark Schoeberl says, "Now the hard work starts!" He remarks that scientists and engineers have important concerns. "What happened to your instrument on the way up to orbit? It's very delicate and may have changed a little when it was put on the spacecraft, or when it launched. You try to calibrate it on the ground and test as best you can before launch. But you're not up in space with it."

How do you build confidence in your data? Scientists validate the data they get from Aura by collecting data about the same parcels of air with other instruments and comparing them to Aura data. As the Aura mission proceeds, dozens of instrument-carrying aircraft flight campaigns (See "Flight of the WB-57" on page 8) are in the works along with special high-altitude instrument-carrying balloon flights and sites for making stationary ground-based measurements. Using Aura data, other scientists will evaluate and revise current atmospheric models to make predictions about future changes in Earth's atmosphere and climate.

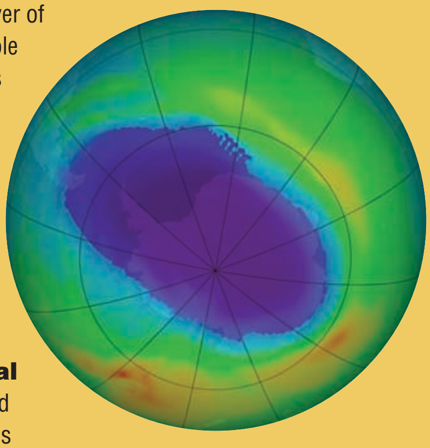
"We have very promising results in these first few months since launch, but it's just the beginning. We're still testing, still making sense of the data," says Anne Douglass, Aura Deputy Project Scientist. "Some things are working 'super-duper'; and we also have some puzzles to work out." One stunning Aura achievement has to do with measuring ozone. On previous Earth observing missions, tropospheric ozone amounts have been difficult to measure because the instruments on satellites could not penetrate clouds. "One extremely exciting Aura result is the TES instrument retrieving ozone data in the presence of clouds. That is really cool," says Douglass. Other Aura instruments are pinpointing local sources of air pollution in ways never before possible.

Atmospheric scientists like Paul Newman of the Goddard Space Flight Center anticipate years of data analysis and investigations. Newman speaks for the group: "It's going to be fun!"

Jeannie Allen is a science writer at the NASA Goddard Space Flight Center in Greenbelt, MD.

Early Aura mission achievements

Antarctic ozone: Aura's MLS did the most comprehensive survey ever of the most recent Antarctic ozone hole event. It measured the amounts and sources of the ozone-depleting radicals and the reservoir gases as the ozone hole grew and then dissipated.



OMI captured data on the 2004-2005 Arctic ozone hole.

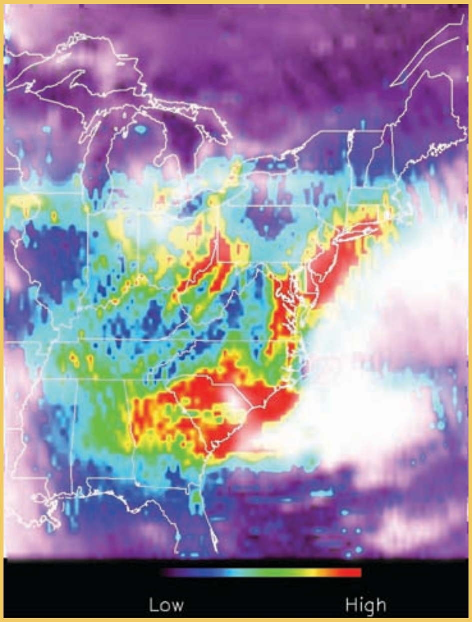
Arctic ozone: Aura monitored this winter/spring's Arctic depletion. What started out looking like a major depletion event just fizzled out with the spring arrival of lower-latitude (warmer) air.

Effectiveness of the Montreal Protocol: Aura's OMI instrument provided another data point to assess the effectiveness of the agreement to phase out ozone depleting substances.

Biomass burning: Products such as O_3, CO, and formaldehyde were tracked by OMI and TES and found in the middle of the South Atlantic Ocean coming from both South America and Africa. There were hints of this track from local measurements, but Aura data confirmed the source.

Active volcanoes: OMI detected ash and SO_2 from several Western Pacific volcanoes that were active in the spring of 2005. MLS saw a small amount of SO_2 reaching the stratosphere. SO_2 reaching the stratosphere indirectly depletes ozone. MLS observations of Manam volcano in January of 2005 recorded HCl emissions that were three times larger than the volcanoes El Chichon and Pinatubo observed by a previous Earth observing satellite.

NO_2 accumulations over urban and industrial areas



Red and yellow indicate unexpectedly high levels of nitrogen dioxide Aura observed over most of the East Coast states on January 27, 2005. The OMI on board Aura, which made these measurements, has high spatial resolution and a strong signal, giving it the ability to map regions of poor air quality.

Coal burning in China: OMI has detected SO_2 from coal burning in China. Until now, the amount of acid rain generating SO_2 could only be estimated from a particular coal's SO_2 content and the actual amount burned.

Climate change: OMI is providing data to quantify the energy-absorbing properties of tiny airborne particles called aerosols. Aerosols are thought to be one of the key factors in climate forcing, but little is known about their actual effect.

Flight of the WB-57 NIGHT INTRUDER

Is the Earth getting warmer? More polluted? Are the polar ozone holes growing every year? Or shrinking? Answering questions like these requires reliable data—data that NASA's orbiting Aura satellite mission provides. But before the information can be deemed useful, a group of scientists must ensure that it is accurate.

Ellington Airfield, Houston, TX. Getting up at four in the morning isn't his idea of fun, but for NASA scientist, Paul Newman, it is just the beginning of a long day on a three-week Aura validation mission. His job is part of the Aura Validation Experiment (AVE), a set of experiments that will test the accuracy of the information gathered instruments on board the Aura spacecraft—information that could elucidate the chemical makeup of the Earth's atmosphere.


NASA/AVE
Paul Newman

Today, he joins with a group of 40 scientists preparing to put instruments on a high flying plane known as the WB-57 "Night Intruder". They're loading sensitive detectors and sampling equipment in time for an 11:00 a.m. takeoff. After they bolt their instruments onto the plane and check the electronics, they're done. Time for breakfast.

While scientists eat, the flight crew checks on the plane and payload as the plane is fueled for the six-hour ride. A few hours before takeoff, the crew is given a flight plan and briefed on the goals of the science mission planned for today.

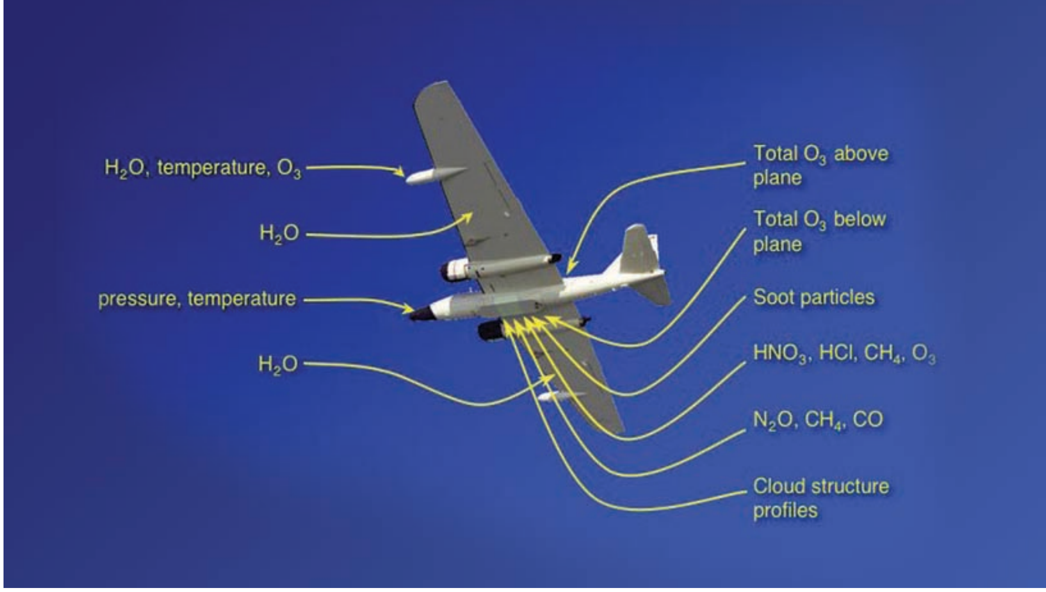
A short briefing

High above the Earth, the instruments aboard the orbiting Aura spacecraft provide scientists with global information 24 hours a day, 7 days a week. The Aura instruments are constantly scanning different surfaces (land and water), varying cloud conditions, and areas experiencing pollution.

Validation flights by the WB-57 generally run every other day. Yesterday, Paul and a few other mission planners looked at meteorological maps, forecasts of chemistry, cloudiness, and other atmospheric factors to figure out what their targets are for this day. In particular, they look for a good time and place to make a "coincident" measurement—that's when instruments on board the plane and the Aura spacecraft can be measuring the same piece of the atmosphere at the same time. They know where the orbiting spacecraft is going—that part is very predictable. Aura's orbit takes it over the poles 14.8 times a day as it covers the whole Earth rotating below.

Today, the weather might just cooperate. There are clouds stretching from the Gulf of Mexico into Kansas, but clear air is forecast at a favorable coincidence point for an Aura overpass.

The overall goal of today's flight is to provide observations that will align with data collected by all of the Aura instruments. But, in particular, the conditions seem right to acquire an extensive vertical profile for the orbiting Microwave Limb Sounder (MLS)—an Aura instrument engineered to measure ozone-destroying chemicals, as well as the critical ozone layer itself in the upper troposphere and stratosphere.



NASA

The instruments aboard the WB-57 take a combination of remote and direct measurements of the physical and chemical properties of the atmosphere during the flight.

Aura's MLS also differs from the other instruments on board in the way it is mounted. MLS rides in Aura's "front seat", instead of the bottom of the spacecraft where the other instruments are found. As a result, MLS observes a different slice of the atmosphere, referred to as the MLS observational track. It will be this track that the WB-57 will follow for much of today's flight.

About 30 minutes before takeoff, the pilot, Rick Hull, and backseater, Dominic Del Rosso, come out wearing bright orange full-pressure suits—space qualified suits. They will breathe pure oxygen because the mission calls for them to fly between the upper troposphere and lower stratosphere, as high as 63,000 feet at times. At that altitude, atmospheric pressure is 0.06 Atm or 1/15th normal atmospheric pressure—a pressure so low that, even with 100% oxygen, human lungs cannot absorb enough oxygen. If cabin pressure were to fail, the crew would have 9–12 seconds of "useful" consciousness, that is, if they weren't wearing their pressure suits.

PAUL NEWMAN/NASA

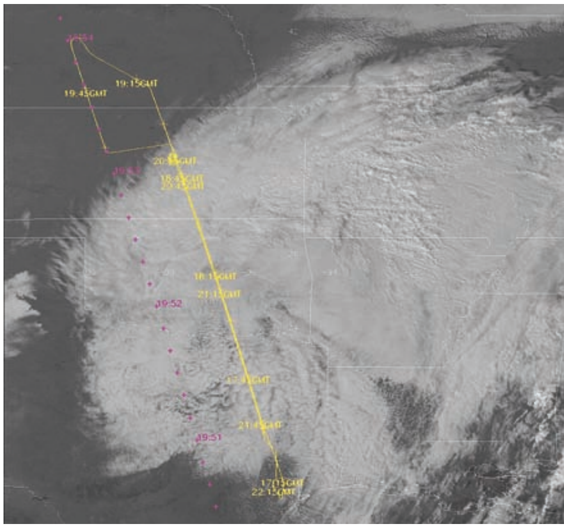
Extreme measurements in the WB-57. Trained in aerospace engineering at the University of Minnesota, Shelley Baccus got her job with NASA right out of college. As a "backseater", she monitors the payload of instruments and looks for measurement opportunities, all while wearing a spacesuit during a pre-Aura validation flight in Costa Rica. About being on the AVE flight crew, "It's all great experience if you want to be an astronaut."

The right place at the right time

After the final check of the craft and instruments, the WB-57 taxis down the runway and takes off, headed northwest toward Nebraska at 45,000 feet. About a half an hour into the flight, they pass over a measuring station where a balloon is launched twice daily for taking direct measurements of temperature and water vapor. It's a useful direct measurement that they've built into the flight.

Upon entering southern Nebraska, Rick turns the WB-57 westward and climbs to 60,000 feet to intercept the spacecraft track. Everything is looking good. Since taking off from Ellington Airfield, cloud heights have increased from 5,000 to 30,000 feet. But for their rendezvous with the Aura spacecraft overpass point, they want clear air. Today, they get exactly that.

At 1:53 p.m., a milestone occurs: 426 miles above them, Aura, going 15,700 miles per hour, and the WB-57, going 450 miles per hour, fly over the same piece of land at the same time. Although the atmosphere doesn't change significantly over a few hours, they will get the best data for comparison now. Fifteen minutes later, Rick turns the plane around and heads back in the direction of Ellington Airfield along the MLS observational track. There is one more major step in the flight plan.



NASA

The yellow line represents the WB-57 flight track. It is superimposed on a black and white picture taken from a weather satellite. The Aura spacecraft (cyan dots) and MLS instrument tracks (yellow dots) are also shown.

A long spiral path

Once back on the MLS track, the crew executes a downward spiral from 59,000 feet to 29,000 feet. The instruments on board continue measuring throughout the corkscrew descent to create an extensive vertical profile comparable to the data from Aura's MLS. Today's mission calls for them to make a final upward spiral, but air traffic control says there is too much congestion in the area, so they climb to 59,000 feet and head home.

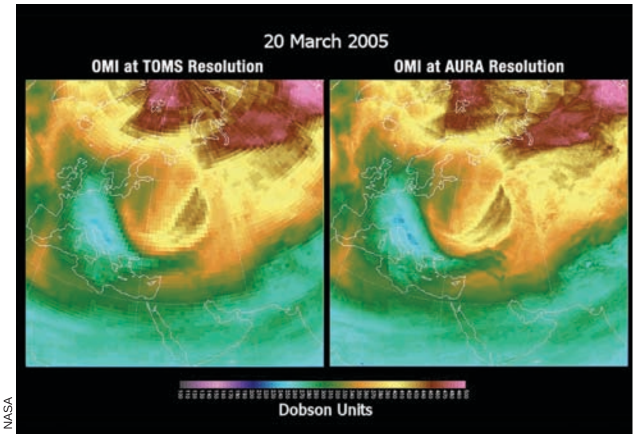
NASA

The WB-57, science team, pilots, and crew from the pre-Aura validation experiment in San José, Costa Rica.

The plane lands at 4:28 p.m. and immediately the scientists scramble around the plane and begin offloading their instruments. After debriefing the flight crew, the scientists download the data from their instruments to a shared computer so colleagues around the world can examine the data. Analysis indicates that the instruments worked well during the flight. Data from this validation flight will result in valuable comparisons between the instruments on Aura and the plane.

It's ten o'clock—time for bed. Tomorrow, some of the team will check, repair, and calibrate their instruments, while Paul plans a flight mission for the next day. It's a two-day routine that is both exhilarating and exhausting. "When you are in the field," Paul says "it's just continuous. You really lose track of what day of the week it is. You are not even sure if it's Saturday, Sunday, or whatever."

Kevin McCue is editor of *ChemMatters.*



NASA

Precision. The instruments aboard Aura provide a greater degree of resolution of the Earth's ozone than has been seen before. Take a look at the two pictures. The one from the Aura satellite's OMI instrument is much clearer. They might remind you of the difference between pictures from a low-megapixel camera and higher-megapixel camera. With a high-megapixel camera, you can make bigger print at photo quality. That's because the higher-megapixel camera can reliably capture more information (more dots or pixels) per picture.

Or take another example—imagine a meter stick with only decimeter divisions; if you measure a book with a friend, the best you might be able to say is that the book is about 36 cm long. Your friend might say 37 cm. With a normal, more precise meter stick, you should be able to estimate to the hundredths place, say 36.55.

The instruments on Aura are extremely precise and were extensively calibrated before launch. Then again, they were also bolted on a rocket and launched into orbit where they're expected to work for 5+ years without a repair or tune-up. Validation measurements help spot check the quality of Aura measurements over time.

YOUR MISSION: VALIDATE...A STICK!

Here's an activity where you will simulate what it is like to validate Aura data. You'll make a homemade measuring stick "in orbit" and then try to validate it by comparing measurements with a group that has a meter stick. Just like "real" world, you will have a limited amount of time and resources. (See the online Teacher's Guide for more detailed instructions.)

What you will need

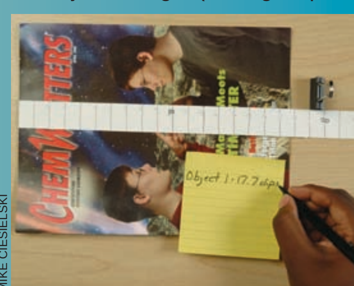
One meter stick and an unmarked stick of cardboard about 2/3 of a meter long.

Four identical pairs of objects with various lengths (under 2/3 of a meter long).

Three watches with a stopwatch function.

What to do

1. First, divide into two equal groups. One group (called validation) will receive a meter stick, the other (called satellite), will receive a long piece of cardboard from which they will make a homemade meter stick. Both groups will have calculators, pencils, paper, paper clips, and index cards. The ultimate goal is for the satellite group to obtain the same length as the validation group on a 4th and final measurement.
2. The instructor and the two teams start their stopwatches. The satellite team "launches" to the opposite end of the room (or another room). After the time starts, the two groups should not talk to each other.
3. T = 1 min. The satellite group should quickly make their homemade meter stick. Make standard units by using a paper clip or length of paper as a guide. Number the new units and call them the "clip". The validation group should practice making measurements.
4. T = 8 min. Instructor puts out two identical objects out for 3 minutes. During these 3 minutes, each group sends one member at a time to measure and record the object's length (at longest point). Try to make five measurements.



MIKE CIESIELSKI

5. Calculate average length for object 1 and send a copy of this information to the other team on an index card. (i.e. Object 1, book, length = 20.12 cm or 25.5 clips).
6. T = 11 and 14 min—objects 2 and 3 are placed out. Repeat steps 4 and 5.
7. T = 17 min. Object 4 is available for 3 minutes. Measure and calculate the average length of the Object 4. DO NOT SEND this information to the other team. Instead, the validation team will send the final length to the instructor. The satellite team will convert their final average length into centimeters using a conversion factor derived from previous measurements and then send it to the instructor. (Possible correction algorithm—object 1(cm)/object 1(clips) $\times$ object 4(clips) = corrected length of object 4 in cm).
8. If there is time, the two teams should switch roles.

Mission debrief

Gather both teams and look at all of the data and calculations. Did the final measurements match? Why or why not? Discuss accuracy and precision. Would it have helped your precision to have more divisions on your ruler?

What's So EQUAL About EQUILIBRIUM?

By Michael Tinnesand

It is a word you hear all the time. Get off a wild carnival ride and it takes a while to restore your sense of *equilibrium*. The directions for setting up a new fish tank advise you to wait until the water reaches *equilibrium* before you add fish. When growing communities finally see population increases level off, the news might report the area population is nearing *equilibrium*.

Have you heard the word in science class? Physical science classes sometimes talk about levers and pivots at equilibrium. Astronomers debate whether the universe is expanding, contracting, or reaching an equilibrium. And one of the most important and reported discussions in science is about the atmosphere and climate change: What is happening to the Earth's atmosphere that might upset its equilibrium?

It's easy to get confused about a word used in so many ways. One of the most common misconceptions about equilibrium is that it means things have stopped changing. But let's think about the community example—the one in which the population has reached an equilibrium. When a population is growing, the number of people new to the community is greater than people leaving the community. Babies are born; new people move in; numbers grow. But that's not the whole story. At the same time, people move away and people die.

PHOTODISC

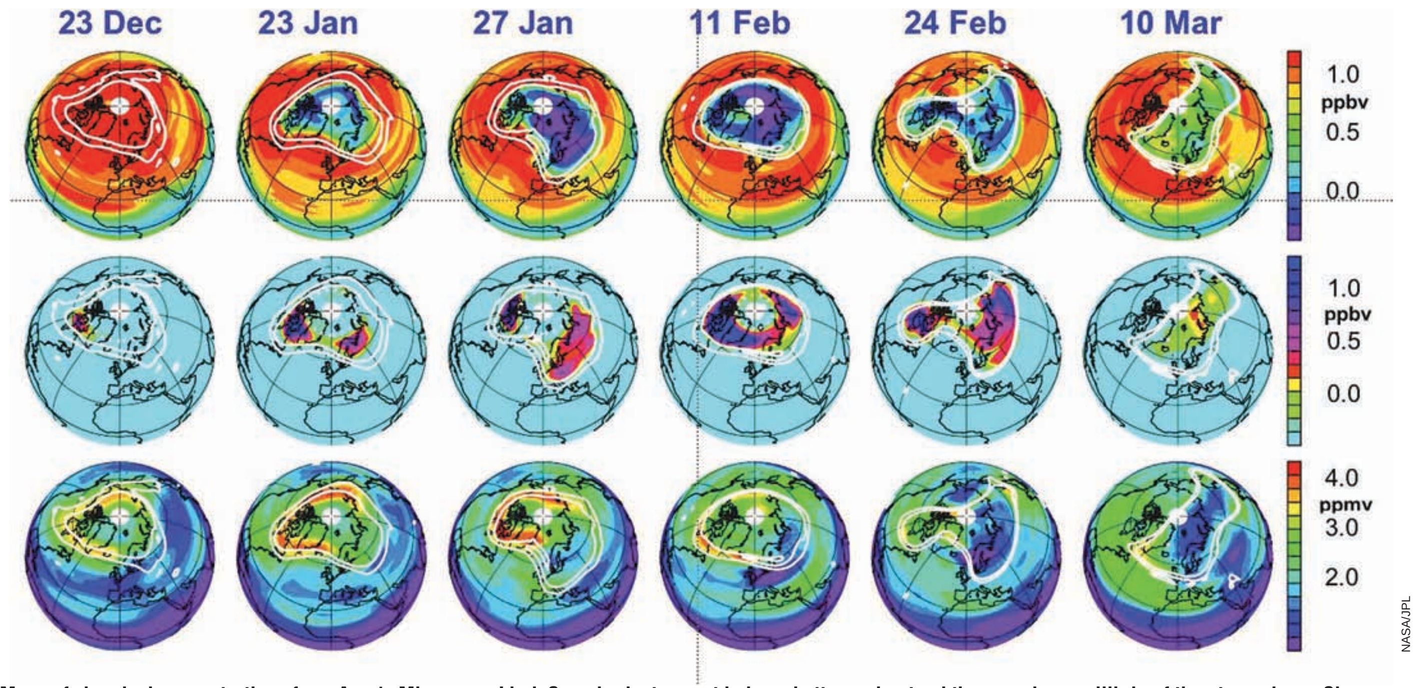
CRAIG ERICKSON,WWW.CLOQUETMN.NET

But, let's do the math. When the population is growing, the rate of adding new people is greater than the loss of people who leave or die. At some point the population may reach a stable number. Has change stopped? No. People still move into the community and they still leave; it's just that they are doing it at equal and opposite rates. Equal opposing actions. That's equilibrium.

Take the example of the fish tank. Perhaps you fill the tank with water from your tap and find it is fairly cold and contains a lot of dissolved chlorine. As you let it sit for a few days, the temperature gradually begins to rise and the smell of chlorine begins to decrease. Finally, the tank reaches a steady state where the temperature is constant. You test for chlorine and find that the amount is staying constant as well. So, the tank has stopped changing, right? Wrong! Scientists call this situation a *dynamic* equilibrium. And understanding how this kind of balancing act works is important to understanding a great deal about how the world works.

Here's what's going on with the chlorine concentrations in the fish tank. Two things are happening at once. Chlorine is leaving the tank to mix with and dissolve in the surrounding room air. Initially, this rate is pretty large, because there's a lot more chlorine in the water than in the air. But it's possible for some atoms of chlorine in the air near the tank to find their way back into the aquarium. Possible. But, with a whole room full of air in which to escape, chlorine is very, very unlikely to do that. Eventually, the amount of chlorine in the tank stabilizes. Most of the chlorine has left the tank, so the rate of chlorine still leaving has become very small. Here's the important point: Although the concentration of chlorine in the tank is constant, there is still a very small amount leaving and a very small amount entering the water. The leaving and entering rates are the same—that's *dynamic* equilibrium.

Now think about the chemical reactions you've observed and described in class. It's



Maps of chemical concentrations from Aura's Microwave Limb Sounder instrument help us better understand the complex equilibria of the atmosphere. Shown above are the concentrations of hydrogen chloride (top), chlorine monoxide (center), and ozone (bottom) for selected days during the 2004-2005 Arctic winter.

easy to get the impression that reactions only go in one direction. In fact, the way most textbooks show and represent reactions in written equations just reinforces this one-way-street idea. Take the reaction of hydrogen with oxygen. When hydrogen burns, it reacts rapidly with oxygen, giving off a great deal of energy. The reaction is usually represented as

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Heat}$$

The way it's written, it looks like the hydrogen reacts with the oxygen and makes water until the reactants run out. End of the story. But, again, the system is not that simple. It turns out that the reverse reaction can also happen. Given enough energy input, water can break down into component hydrogen and oxygen atoms. But since water is so stable, it doesn't happen often. In this reaction, equilibrium is reached when virtually all the reactants have been used up, lowering the formation of more water to almost nothing. This action is opposed by an equal vanishingly small number of water molecules breaking down into separate atoms. It's an equilibrium—a *dynamic* equilibrium.

So why doesn't this discussion come up when the textbook describes the reaction of hydrogen with oxygen? It is because this reaction, like many others you are learning about, is so favorable to the formation of products that it is barely worth mentioning that the reverse reaction is also taking place.

Some chemical reactions, however, are a different story! The reaction of hydrogen with nitrogen to make ammonia is a good example. The formula for this reaction is always written as

$$3H_2 + N_2 \rightleftarrows 2NH_3$$

Why the different reaction arrow? Under typical standard conditions, equilibrium for this reaction is reached well before all the reactants are consumed. With the double arrow, the chemist shows that when a reaction "stops happening", it has really just come to an equilibrium of the forward and reverse reactions. The reaction for making ammonia (NH_3)—a component in fertilizers and other products—is very important. Chemists worked for many years to learn how to shift this equilibrium to favor the products. As a result, industry can produce vital ammonia in a cost-effective manner.

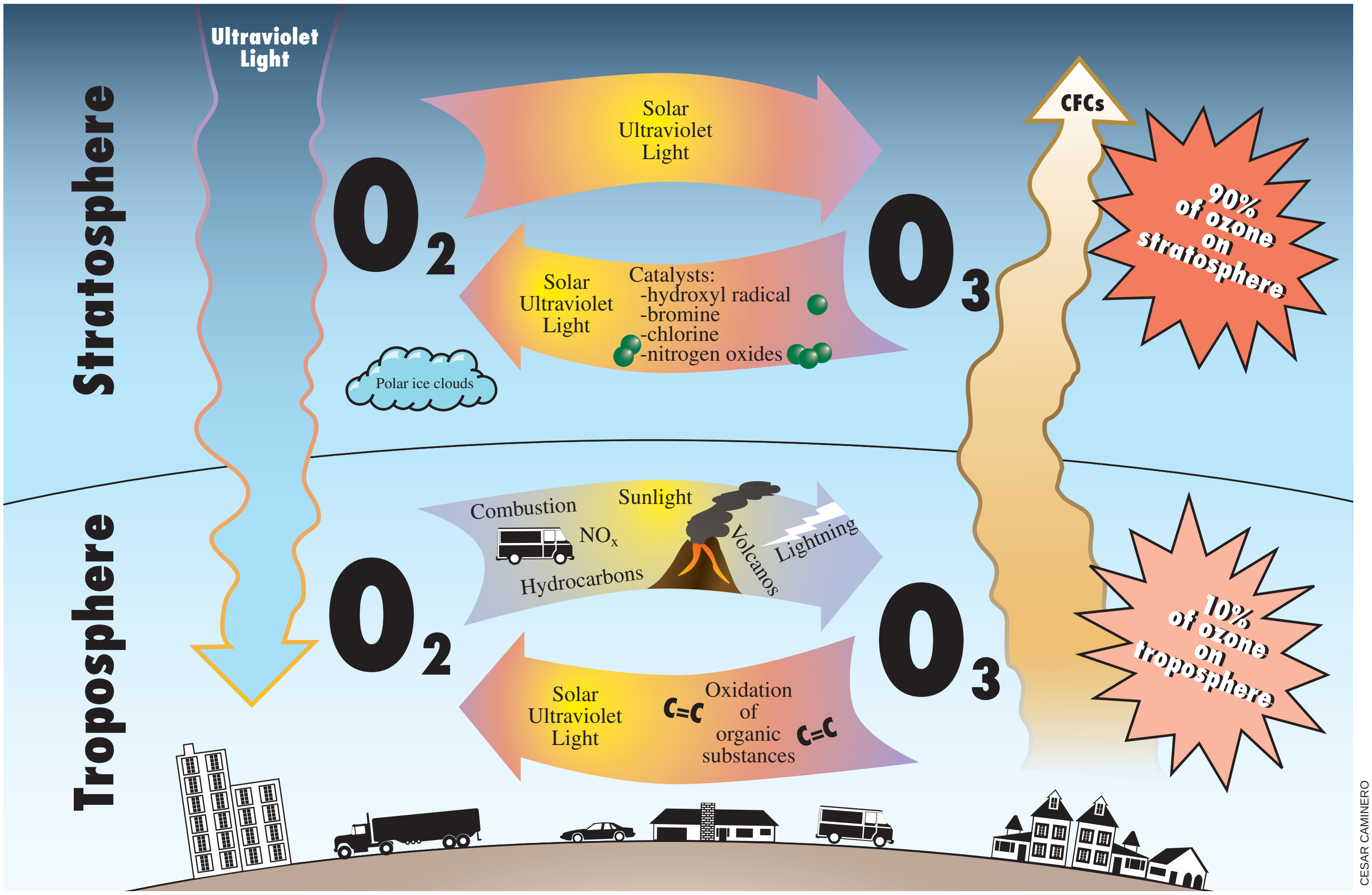
The idea of a shifting equilibrium is another important concept. Think back to our example of the population in a community. The population number may be in equilibrium for a long time. But suppose something happens to shift one of the rates—like maybe a new industry moving into the area. This might cause the rate of people moving into the area to increase, raising the population. Eventually, this higher population will result in crowding, housing shortages, and even higher death rates. As a result, the rate of people leaving will finally balance the rate of people entering the area, establishing a new dynamic equilibrium.

In a similar way, a chemical equilibrium can shift. It may be influenced by factors like increasing the concentration of reactants, removing products, and changing the pressure or temperature. This principle was summarized in the late 19th century by French chemist and engineer Henri-Louis Le Chatelier.

The chemistry of the Earth's atmosphere contains many examples of various equilibrium systems, each complex on its own. But they become even more complex when the relationships among all of these chemical systems are taken into account. We would have fewer worries if the atmosphere retained its long-term equilibrium. But such is not the case. Natural and human-generated changes are constantly influencing our atmosphere, making it essential for us to study and understand the complex web of chemical reactions that define our atmosphere.

Examples of various systems and factors that influence their equilibrium abound.

Consider the ozone (O_3) layer in the stratosphere. The ozone layer is important because it absorbs and screens out a portion of the ultraviolet light coming from the sun. Without the ozone layer, the amount of UV reaching the earth's surface would reach dangerous levels. This thin layer of O_3 reaches peak concentration in the upper atmosphere between altitudes of 19 and 23 km.



The concentration of various substances in the atmosphere depends on complex and interrelated reactions. In the stratosphere, ultraviolet light creates ozone. Catalysts such as bromine and chlorine break ozone down to form oxygen. If the rate of ozone formation is the same as the rate of ozone destruction, the amount of ozone in the stratosphere will remain constant. In the troposphere we have a slightly different story. Most of the ozone is caused by combustion, either from human activities or natural sources. The reaction products react in the sunlight to form ozone. Ground level ozone is destroyed when it reacts with substances such as organic material, or when it is exposed to UV light.

Ozone forms when ultraviolet light from the sun breaks oxygen molecules apart. This atomic oxygen can join existing O_2 molecules to form O_3. By a reverse reaction, chemicals in the upper atmosphere cause the ozone to break apart. During times of increased sunspot activity the amount of ultraviolet light from the sun increases. This increase in UV light increases the rate at which ozone is formed.

By these naturally opposing reactions, the net effect is this: More ozone eventually leads to more ozone breaking down. The equilibrium is reestablished at a high concentration of ozone. But the opposite shift can also happen. An increase in the concentration of substances that react with ozone to break it down can increase the rate of ozone destruction. If the rate of ozone formation stays constant, then the total amount of ozone will fall until the rate of destruction falls and a new equilibrium is established at a lower ozone concentration.

This is exactly what was observed in the 1970s. Chemists noticed that the concentrations of ozone were decreasing—well beyond what could be explained by natural processes. It was soon discovered that the concentration of ozone-depleting substances was increasing, mostly due to human use of gases for refrigeration and spray can products. Fortunately, worldwide efforts to reduce production and use of these damaging substances seem to be helping, and recent measurements indicate that the ozone concentrations may be stabilizing.

At the same time, scientists have observed a cooling in the stratosphere. This may be, in part, due to an increase in the insulating layer of greenhouse gases (H_2O, CO_2, CH_4, O_3, N_2O, and others). Their increase in concentration means less solar energy is radiated back into the upper atmosphere as heat. When temperatures drop below –88 °C, thin clouds form. The presence of stratospheric clouds in the polar regions appears to increase the rate of ozone destruction. The surface of ice crystals in the stratospheric polar clouds can accelerate reactions between O_3 and substances that destroy ozone. The overall effect is a shift in the equilibrium and a decrease in the ozone levels at the Earth's poles.

On a global scale, equilibrium gets very complicated. System after system, changes occur in intricate and sometimes unexpected ways, both in response to natural conditions and also because of human action. Aura and the other scientific satellites in orbit are gathering data that will play a crucial role in developing an understanding of our atmosphere. As hard as it is, understanding these equilibria and how one thing leads to another is a vital step in deciding strategies for preserving the lives and well-being of all who call this planet home.

Michael Tinnesand is associate director for Academic Programs at ACS and formerly taught chemistry in Hillsboro, OR.

CLEARING THE AIR:

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A 2004 report published by an international partnership of Earth-observing organizations called IGOS (Integrated Global Observing Strategy), traced several changes in the atmosphere to human activities:

Climate change and the greenhouse effect	Automobile exhaust, industrial emissions, even cattle "emissions" are loading the atmosphere with greenhouse gases like CO_2 and methane (CH_4) that trap energy as heat at the Earth's surface.
London-type smog (Largely eliminated in developed countries, but still a global problem)	Visible soot and sulfur dioxide gas emitted from industries and home heating become trapped at ground level during certain weather patterns.
Los Angeles-type smog or "summer smog"	Automobile exhaust and industrial emissions react in strong sunlight to form unhealthy pollutants like ground-level ozone that are trapped by static weather patterns.
Ozone depletion in the stratosphere (The emissions that cause the depletion have been greatly reduced as a result of an international treaty.)	Chlorofluorocarbons, or CFCs, released from some industrial processes, react with and destroy the fragile layer of atmospheric ozone that filters out life-harming UV radiation.
"Brown clouds" over and downwind of high population areas	Industrial, agricultural, and vehicular emissions and soot often travel by wind currents far from the source.
Acid rain	Sulfur and nitrogen emissions from smokestacks, vehicles, and ships are oxidized in sunlight to form the sulfates and nitrates that result in acidic precipitation harmful to plant and animal life.
Coastal waters overloaded by nitrogen nutrients	Nitrogen-containing vehicle emissions and agricultural fertilizers dissolve in coastal waters where they result in "blooms" of algae that deplete the water of oxygen as they decay.

Welcome to the Anthropocene. What? It means the age of humans, and, according to paleontologists, we're living in it. Although insects outnumber us, our human lives impact the planet more than any other living thing, past or present.

Earth isn't just a planet, it's a system, a kind of complex wonder where oceans, land masses, air, and living things all intimately affect one another to create the familiar surroundings we call home. Take, for example, the atmosphere in which we live and breathe. Here, we find the right amount of oxygen to maintain life, trace gases that react and cleanse the air, a UV-protecting stratospheric ozone layer, and enough greenhouse gases to ensure adequate warmth.

Because nature itself impacts air quality with volcanoes, forest fires, ocean turbulence, and ordinary seasonal variability, it's often difficult to sort out any problems for which human activity is responsible. But evidence is mounting to show that gas-powered machines and the humans they serve gobble resources and spew pollution at volumes and rates that challenge the ability of our Earth system to recover.

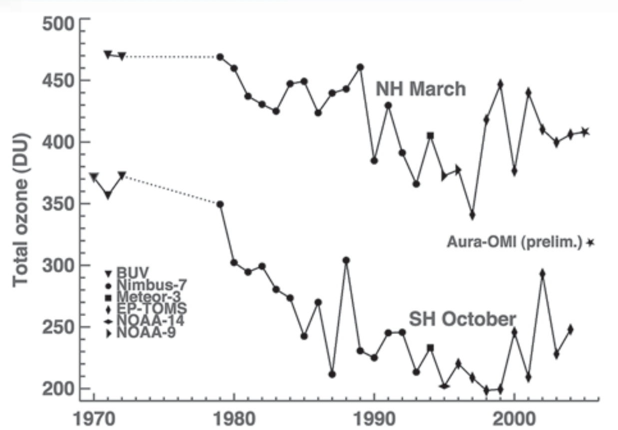
Who wants to live in a world with vanishing coastlines, brown clouds of thick smog, and foul-smelling polluted water? An even harder question is: Who wants to do something about it? Motivating people to clean up is never easy—especially when there are neighbors refusing to pitch in.

REATMENTS

Hopeless? Not quite. Heard the one about the ozone hole over the South Pole? No? it's because what only 30 years ago loomed as a global crisis, is now slowly but steadily improving. As early as 1970, chemists warned about the widespread use of chlorofluorocarbons (CFCs). Released from some industrial processes, CFCs react with and destroy the fragile layer of atmospheric ozone that filters out life-harming UV radiation.

Chemists were clear about the dangers, but the ozone problem was not going to be solved in the laboratory. Instead, the solution required global cooperation of industries, scientists, leaders, and diplomats. The end result of years of discussions was the 1992 "Montreal Protocol". Presently, more than 180 countries are signed in agreement to phase out, by a set of intricately devised strict timetables, all ozone depleting chemicals.

NASA/ AURA



NASA satellites have monitored total ozone over both the northern hemisphere (NH) and the southern hemisphere (SH) for nearly 35 years. Following an alarming downward trend due to stratospheric ozone depletion in the 1980s and 1990s, total ozone data collected in recent years indicate some recovery. The latest NH data point supplied by the Aura satellite's OMI instrument is regarded as "preliminary", as it awaits validation from other monitoring instruments.

Today, chemists warn us about other problems in the atmosphere. Greenhouse gases, especially those released from the burning of fossil fuels, are made of molecules that allow the lower atmosphere to retain more energy from the sun. The surface warming that results is uneven on a region-to-region basis, but, overall, the net effects of rising surface temperatures are seen as negative. Besides melting glaciers and ice caps, rising seas, eroding coastlines, and altered rain patterns, warming may cause fertile agricultural areas to become arid deserts.

By now, you may be wondering whether someone plans to do something to reduce the alarming annual increase in greenhouse gas emissions. In fact, a treaty to do just that went into effect in February of 2005. The Kyoto Protocol is a 1997 United Nations pact that legally binds 39 developed countries to cut their emissions of greenhouse gases by 5.2% of 1990 levels by 2012. Will it be as effective as the Montreal Protocol?

Mario Molina, MIT chemist, shared a 1995 Nobel Prize with University of California-Irvine chemist Sherwood Rowland and Dutch chemist Paul Crutzen for their ozone research. In a recent online *Tierramerica* interview, he expresses his concern: "The Kyoto problem is more complicated because it is related to the use of energy. It is more difficult to replace fossil fuels (the combustion of which contributes to global warming) than it was to find a substitute for ozone-destroying CFCs." In other words, it's easier to redesign a refrigerator than it is to redesign the power grid.

Kyoto is also challenged from the start by global politics, the most significant challenge being the fact that the United States didn't sign. A resolution passed by the U.S. Senate in June 1997 states that the United States should not agree to any binding commitment for reducing greenhouse gas emissions unless developing countries also agree to specific commitments. (Kyoto exempts developing countries from the protocol.)

Does that mean that the United States, the world's largest industrial power and the world's largest consumer of fossil fuel, plans to do nothing about curbing greenhouse gas emissions? No. But it does mean that the United States plans to act independently as it responds to the challenge of global climate change.

By some proposals recently considered in the U.S. Congress, power companies, transportation, industries, and commerce units might receive emission allowances according to a complex formula based on their current emissions of six greenhouse gases. That's where it gets interesting. As in some elaborate card game, players can trade emission credits with each other and even with players from Europe engaged in a similar trading scheme set up by the rules of the Kyoto agreement to which they subscribe. As long as the overall goal of reducing emissions down to 2000 levels remains on track, the trading can continue.

LOGO COURTESY OF THE UNITED NATIONS

For many of us, it's difficult to understand what makes this so hard. The old-fashioned approach of "if there's a problem, fix it" just doesn't seem to be working here. Maybe it's because the stakes are so high and the economic sacrifices are so large that lawmakers and industry lobbyists want to be sure that they are attacking a problem that really exists. Dr. Linda Mearns of the National Council on Atmospheric Research in Colorado cautions against inaction or "policy paralysis" in the face of uncertainty. Speaking at a 2003 session for science journalists, she commented that most U.S. policy goes forward with far less certainty about the outcome than what is known about climate change. Should we wait for more data? That's tricky. She states that "When data are gathered to eliminate uncertainty, knowledge and meaning suffer in the process."

So what is a lawmaker to do? Vote for cutting emissions and risk getting local voters upset over restrictions on vehicle use and local industries upset over expensive emission controls? To do so, the congressional leader wants scientists to say. "If you don't do this, here are the absolute negative consequences. Guaranteed!" But science only speaks in terms of probable outcomes, not certainties.

This much is clear: Failing to act is a decision—one that may prove more costly in the long run than the economic punch we'd endure by capping emissions now. *Probably*, but not certainly. This isn't easy, is it?

Helen Herlocker is Administrative Editor of *ChemMatters.*

Student Gardens Monitor Air Quality

We can gather data to find out about good or poor air quality with scientific instruments such as the ones on board NASA's Aura satellite, but we can also gather information by carefully observing the effect of air quality on the living things around us. Plants, for example, take in air through leaf pores, and are affected by atmospheric chemistry in the process. Ground-level ozone is known to hurt plants when they take in too much over time. Many common species of plants such as common milkweed (*Aesclepias syriaca*) and cut-leaf cone flower (*Rudbeckia laciniata*) display specific discolorations in their leaves when exposed to excessive ozone. Students, teachers, volunteers, and scientists have learned to use these color changes as "bioindicators" of ozone air quality.

At Great Smoky Mountains National Park, North Carolina, students come from several local middle and high schools to investigate the effects of ozone in a special ozone biomonitoring "garden". The ozone garden is part of a National Park Service "Hands on the Land" program that brings students to their public lands for environmental research projects. In recent years, poor air quality has harmed both the vista and the vegetation of the park. Today, park staff members are growing common species of plants known to show ozone's effects.

A powerful oxidant, ozone combines readily with other chemicals inside plants. Compounds resulting from oxidation by ozone interfere with cellular energy production in the mitochondria. As a result, ozone slows photosynthesis and overall plant growth.

Students measure plant growth and examine the leaves for symptoms of ozone overexposure. When students see purpling or stippling on leaves, they note the change as one of the first common signs of overexposure. Continued overexposure to ozone makes plants turn yellow (chlorosis) and eventually die.


NATIONAL PARK SERVICE PHOTO

Amanda Johnson from Tuscola High School in Waynesboro, NC, looks for brownish-purple markings and yellowing on plant leaves in Great Smoky Mountains National Park. Such discolorations can indicate high ozone amounts in the air. Amanda's work contributes to park researchers' assessment of air quality in the park.

During the growing season, students from area high schools examine the plants every two weeks. "Using students to collect data has been a win-win situation", said Susan Sachs, Education Coordinator at the Appalachian Highlands Science Learning Center in Great Smoky Mountains National Park. "We have better information to pass onto the researchers who are often only in the park for a couple of weeks each year, and the students gain an in-depth understanding of one of the effects of air pollution in their community."

Ozone biomonitoring complements and supports ozone measurements made by scientific instruments like the ones on board EOS Aura. For information about biomonitoring in Great Smoky Mountains National Park, see http://www.nps.gov/grsm/pksite/index.htm.

And for more information about the Park Service's Hands on the Land Program, go to http://www.handsontheland.org/about.htm.

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