ESRL Quarterly

News from NOAA's Earth System Research Laboratory

Fall 2009

Inside

N_2O: Not One of the Usual Suspects

Chlorine-free nitrous oxide now top ozone-depleting emission

Nitrous oxide is better known to the public for inducing giggles in dentists' offices than for wreaking havoc on Earth's protective ozone layer. It bears little resemblance to the perpetrators of ozone-layer destruction currently regulated under the international Montreal Protocol agreement—those chemicals all contain chlorine or bromine atoms, unlike nitrous oxide. But now that global actions have curtailed the use of those culprits, a new ESRL study has taken a fresh look at nitrous oxide (N_2O). Nitrous oxide emissions have become the most significant ozone-depleting emission by people and are expected to remain so throughout the century, researchers in ESRL's Chemical Sciences Division (CSD) concluded in a paper published in *Science*.

The scientists evaluated, for the first time, how the human-related emissions of nitrous oxide stack up against the emissions of other ozone-depleting substances in terms of the potential impact on the ozone layer. With the emissions of chlorine- and bromine-containing chlorofluorocarbons (CFCs) and halons declining sharply as a result of the Montreal Protocol, nitrous oxide emissions have now emerged as the most significant among all anthropogenic ozone-depleting substances, the scientists found. Nitrous oxide emissions by people—from agriculture, industry, and other activities—are already more than twice as high (in terms of potential ozone impact) as the ozone-depleting substance with the next highest emissions, trichlorofluoromethane (CFC-11, a refrigerant).

"The dramatic reduction in CFCs over the last 20 years is an environmental success story," said lead author A.R. Ravishankara, CSD Director. "But anthropogenic nitrous oxide is now the elephant in the room."

A layer of ozone in Earth's stratosphere protects the planet's surface from damaging ultraviolet radiation from the Sun, and ozone-layer depletion is associated with skin cancer and crop damage. The Montreal Protocol of 1987 and its amendments phased out many ozone-depleting chemicals and have been credited with preventing millions of cancer cases—but the Protocol does not include nitrous oxide.

Even so, atmospheric scientists have long understood that the chemical is involved in the depletion of stratospheric ozone—it is the main source of oxides of nitrogen which can eat away at ozone. ESRL researchers Ravishankara, John Daniel, and Robert Portmann (CSD) took that knowledge several steps further, to evaluate nitrous oxide in the same way as the ozone-depleting substances regulated today. The research team first pinned a number on the N_2O molecule's ability to destroy the ozone layer, and then used that number to

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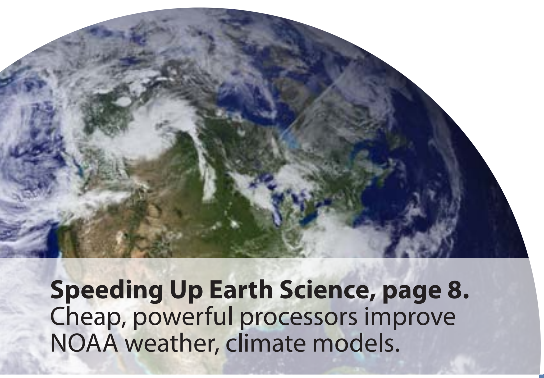

Speeding Up Earth Science, page 8. Cheap, powerful processors improve NOAA weather, climate models.

Exploring Earth

NOAA-museum partnership aims to engage educators, visitors, scientists, more

Planet Earth won't fit on a tabletop exhibit at a science museum—even at the seemingly magical Exploratorium in San Francisco. So Exploratorium staff spent a week at the Earth System Research Laboratory in August, brainstorming with researchers about how to convey system science to the public in an engaging way.

"This visit has been incredibly stimulating, and also humbling," said Mary Miller, online media producer for the Exploratorium and director of a new educational partnership between NOAA and the Exploratorium. "There's this amazing sense of mission and responsibility," Miller said. "NOAA scientists are … just so interested in having the public understand what they do."

In July, NOAA and Exploratorium staff announced a five-year partnership to co-develop interactive exhibits, online learning experiences, professional development workshops,

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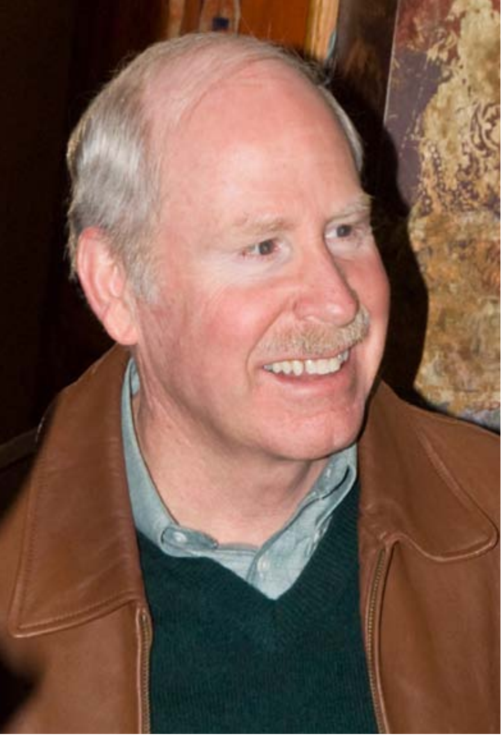
NOAA "teacher in the lab" Diane Stanitski cleans sensitive instruments during a mission to an ocean/climate buoy. **See page 7.**



Director's Corner

Greetings from Venice where I am attending the OceanObs'09 Conference. I am co-author on a white paper on the global ocean observing system, but for me this conference is mainly a chance to understand a part of Earth system science that I have not had much experience with. This is the second OceanObs—the first was held in France 10 years ago, and is credited with propelling the significant increases in ocean observations, assimilation, understanding, and prediction of the last decade. For me, the similarities to the physical atmospheric problem are striking. The moored buoy networks (e.g., TAO, PIRATA, and RAMA) and ARGO floats are now providing, for the first time, the equivalent of the radiosondes for the atmosphere; profiles of state variables at a large number of points over the global ocean. The amazing satellite technology that provides surface altimetry of the ocean to heights of a few centimeters is, in some sense, analogous to the role that surface pressure plays in atmospheric analysis–an indication of the integrated mass field below the ocean surface. (The 30-cm high mound of warm water in the central Gulf of Mexico in late summer of 2005 was an indication of very warm water below, which was important in fueling the surges of Hurricanes Katrina and Rita to Category 5.) Finally, sea surface temperature around the globe constrains the surface thermodynamic field–so combining all three types of observations now gives a relatively complete portrayal of the physical ocean. The ocean community has also made much progress on assimilation with the Global Ocean Data Assimilation Experiment (GODEA).

Like atmospheric science, ocean science can be divided into three domains—physical, chemical, and biological—and understanding has not progressed evenly among all three. In both, initial efforts at full global systems science were primarily in the physical domain. Recently we have seen significant progress in global systems chemistry with, for example, ESRL's Carbon Tracker. At OceanObs'09, there was much discussion of how to make progress in ocean chemistry. NOAA was well represented with leaders—such as Richard Feely of the Pacific Marine Environmental Laboratory—who have brought ocean chemistry to the forefront of the global change issue. Conference participants discussed proposals to put sensors for carbon dioxide and oxygen onto the ARGO profilers, which would give researchers a global dataset on important ocean chemistry, to the 2000-m depth that the ARGO system samples. Our atmospheric equivalents are aircraft and tall tower chemistry soundings, which ESRL's Global Monitoring Division is pioneering.

There was a strong feeling at the OceanObs'09 meeting among members of the biological oceanography community that they had not received the needed attention and support that this field deserves. Reasons for this disparity discussed at the meeting include the diversity of biology (for example, there are thousands of species of phytoplankton), the difficulty of observing ocean biology, and the complexity of biological change (e.g., as the ocean becomes warmer and more acidic, determining the resulting Darwinian evolution is very difficult).

At NOAA's Earth System Research Laboratory, we began with the vision of understanding and predicting the whole Earth system. Our strong capabilities in physical and chemical aspects of the atmosphere could be regarded as encompassing one-third of the Earth system. In addition, the global environmental research community must understand the physics and chemistry of the ocean, and terrestrial and oceanic biology.

ESRL is contributing cutting edge efforts to understand the ocean's role in global weather and climate, and in getting that new understanding implemented in the latest generation of computer models. Chris Fairall recently received an AGU medal for his work. He and his team in the Physical Sciences Division (PSD) have garnered wide acclaim for their efforts on air-sea fluxes and how they are parameterized in computer models. A number of other folks in PSD, including Marty Hoerling and CIRES partners Prashant Sardeshmukh and Gil Compo, have been publishing groundbreaking work on the ocean's central role in the climate change we experience on the continents. Dan Murphy led a team, including illustrious Chemical Systems Division colleagues, that published findings in September in the *Journal of Geophysical Research*. Dan and company put the ocean in the context of radiative forcings and the total Earth system response in "An observationally based energy balance for the Earth since 1950." ESRL's strengths in atmospheric sciences are clearly multiplied by our growing capacity in understanding the ocean's role, and by the significant progress that I am hearing about at OceanObs'09.

I leave this fascinating week with a main take-home message: The importance of partnerships within the scientific community. No one organization can cover all of Earth system science–we must work together.

—Alexander MacDonald

By the Numbers
WaterBlitz

195

Number of sites in Rocky Mountain National Park where volunteers collected water samples on August 19. The second annual "WaterBlitz" was funded by the Western Water Assessment, one of NOAA's Regional Integrated Science Assessments and a joint project of ESRL and CIRES. Researchers suspect beetle-caused tree mortality is changing the concentration of nutrients in streams, which could affect ecosystems as well as water treatment downstream. Photo by Morgan Heim, CIRES.

David Hofmann

Pioneer of aerosol and ozone research dies

ESRL atmospheric scientist David Hofmann passed away in Boulder on 11 August 2009. He was 72. Hofmann has described his scientific focus as "simple in concept:" Commit to long-term, specific measurements; attend to the details; and focus on the big issues raised by the measurements. In a world of short-term contracts and annual budgets, such sustained endeavors can prove challenging. Yet Hofmann initiated, led, and upheld many such long-term programs during his 25 years at the University of Wyoming (UW) and 17 years at NOAA—programs to measure and analyze ozone, ozone-depleting chemicals, greenhouse gases, aerosols, and other atmospheric constituents. Most of Hofmann's programs (and the instruments he helped develop for them) are ongoing today, testifying to his scientific foresight, persistence, and lasting influence.

Hofmann retired as Director of ESRL's Global Monitoring Division in 2007, so that he could return to conducting science full time. At the Global Monitoring Annual Conference at ESRL this May, Hofmann presented results on the still-slow recovery of the Antarctic ozone layer. After Hofmann's talk, ESRL Chemical Sciences Division Director A.R. Ravishankara said he was impressed with Hofmann's return to research. "I can see that your retirement is good for the enterprise of science," Ravishankara said.

The quality of Hofmann's work is reflected in the papers he published just before his death—analyses of global trends of anthropogenic carbon dioxide in the atmosphere, and of stratospheric aerosol results from lidars in Mauna Loa and Boulder. Some of Hofmann's earliest research, at UW, also involved analyzing routine measurements of stratospheric aerosol. Perhaps he mused on the fact that his recent work reflected his early work (both broke new ground in stratospheric aerosol science). More likely, he was planning his next research project.

Hofmann's scientific contributions, generosity, wisdom, and humor will be missed. He is survived by his partner, Shirley Purcell, daughters Gretchen and Jennifer, and son Karl.

Western Water Outlook: Grim

But good management can lower the risk of reservoir depletion, study shows

As the West warms, a drier Colorado River system could see as much as a 1-in-2 chance of fully depleting all of its reservoir storage by mid-century, assuming current management practices continue. That's grim news for the roughly 30 million people who depend on the Colorado for drinking and irrigation water.

A research team—including PSD's Marty Hoerling, Andrea Ray, Joseph Barsugli (CIRES), and Bradley Udall (CIRES), and led by CIRES' Balaji Rajagopalan—examined how vulnerable the Colorado River system is to water supply variability and to projected changes in water demand. The scientists found that through 2026, the risk of fully depleting reservoir storage in any given year remains less than 10 percent under any scenario of climate fluctuation or management alternative. During this period, reservoir storage could even recover from its current low level, about 65 percent of capacity.

But if climate change results in a 10-percent reduction in the Colorado River's average streamflow, the chances of fully depleting reservoir storage will exceed 25 percent by 2057. If climate change results in a 20-percent reduction, the chances of fully depleting reservoir storage will exceed 50 percent by 2057, Rajagopalan said.

"On average, drying caused by climate change would increase the risk of fully depleting reservoir storage nearly ten times more than the risk we expect from population pressures alone," said Rajagopalan. "A 50-percent chance in any given year is an enormous risk and huge water management challenge," he said.

The results were published in the American Geophysical Union journal *Water Resources Research*.

Even under the most extensive drying scenario, threats to water supplies won't be felt immediately, the researchers found. Total storage capacity of reservoirs on the Colorado (including lakes Mead and Powell) exceeds 60 million acre feet, almost four times the long-term average annual flow of about 16 million acre feet. As a result, the risk of reservoir depletion will remain low through 2026, even if climate change induces a 20-percent reduction in streamflow.

However, after 2026, the risk of drying increases to 26-51 percent, depending on the effects of climate change and management, with lower risk associated with aggressive management to reduce demand.

The Colorado's flow has been very low in the last 10 years, Hoerling said, averaging only about 10 million acre feet. Reservoirs have dropped to a little more than half capacity, but managers still delivered water where it needed to go. "So the system is working, from a gross point of view," Hoerling said. But climate models and modelers are still struggling to understand the future of the system in a warmer world; some models don't include the high-elevation snowpack critical to the Colorado River System, for example.

"Our models are not yet good enough to inform with the accuracy desired by most decision makers," Hoerling said.

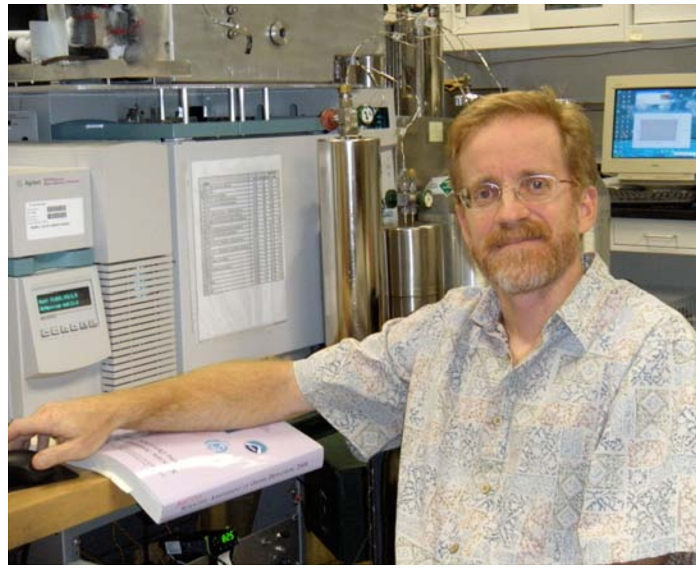
CIRES: the Cooperative Institute for Research in Environmental Sciences is a joint institute of NOAA and the University of Colorado at Boulder.

Lake Powell in 2005.

U.S. BUREAU OF RECLAMATION

Profile: Stephen A. Montzka

The ESRL scientist's work tracking ozone-depleting substances has helped underpin scientific discoveries, international policy



Steve Montzka in the laboratory (above) and at the South Pole (below).

When Steve Montzka was considering a position at NOAA nearly 19 years ago, the job description was daunting. It involved continually analyzing air samples from around the world for chemicals that were eating away at Earth's protective ozone layer. "The work was to do this, day in and day out, for…well, *forever*," Montzka said.

He took the job. Ozone depletion had become a hot topic in atmospheric science, and many of the key players—from NOAA's Susan Solomon to Harvard University's James Anderson—were returning from Antarctica, giving fascinating talks in Boulder, and planning new experiments.

"It was exciting to be involved in this community of scientists at the forefront of the issue," Montzka said. "And frankly, it was a way to stay in Boulder, which my wife was going to do with or without me," he said, smiling.

Since then, Montzka has combined his expertise—in chemistry, atmospheric science, and data analysis—to go well beyond filling a database with 18 years of ozone-depleting gas data. With his colleagues he tracks about 40 different gases now, his papers are very highly cited in the field, and Montzka has worked closely with colleagues across ESRL and NOAA to contribute to national and international scientific assessments read by policy makers around the globe.

"Our bread and butter is still to analyze air samples from remote locations day after day," Montzka said, "but on top of that, there have been all sorts of interesting twists and turns in the science we've been able to do."

From 1989 to 1991, Montzka worked as a postdoctorate researcher with Fred Fehsenfeld and Paul Goldan, studying how plant-produced volatile organic compounds were involved in the generation of rural haze and tropospheric ozone (ozone is a pollutant at low altitudes, but up in the stratosphere, a layer of ozone protects the Earth from damaging radiation).

Soon after starting at NOAA, Montzka participated with Jim Butler (today, Director of ESRL's Global Monitoring Division) in a cruise from Seattle to San Francisco, to study natural oceanic sources and cycling of methyl bromide, a significant ozone-depleter. The chemical has manmade sources, too, as a fumigant pesticide, and the relative importance of each source wasn't clear at the time. "Our data really helped refine the methyl bromide budget," Montzka said. And the cruise itself, on the NOAA ship *Discoverer*, was terrifically exciting. "I felt like I was in a National Geographic special," he admitted.

A few years later, in 1996, Montzka and his NOAA colleagues hit another scientific high: Documenting a drawdown in the global atmospheric concentration of ozone-depleting substances—a direct consequence of a 1987 international treaty, the Montreal Protocol on Substances that Deplete the Ozone Layer, and its amendments.

"Seeing that turnaround in our data and being able to tell others about the Protocol's initial success, well, it was nice to be a part of that," Montzka said.

Since then, the researcher has been involved in groundbreaking measurements of 100-year-old air trapped in Antarctica's snow—which revealed an atmosphere remarkably free of industrial ozone-depleting substances. He helps with aircraft missions that soar into the stratosphere to measure ozone-depleters directly in the environment in which they wreak havoc. And Montzka and his colleagues have been able to take advantage of policy decisions—the mandated end of most methyl chloroform production, for example—to gain insight into fundamental atmospheric processes.

"It was similar to studying the decay of radiocarbon after the nuclear tests of the 1950s," Montzka said. "We were there, equipped to study the atmospheric changes with the appropriate tools, and we were able to draw some powerful conclusions about the chemistry of the atmosphere and how it rids itself of pollutants."

Two years ago, Montzka shared the U.S. Environmental Protection Agency's Ozone Protection Award of 2007 with other ESRL scientists. He has also shared two Department of Commerce Silver Medals, was named NOAA Research Employee of the year in 2000, and co-authored nine papers that won Outstanding Scientific Paper awards (some of those and other papers that bear Montzka's name have been cited more than 100 times—a very high rate).

Today, he continues to track trace atmospheric chemicals along with his colleagues in the halocarbons research group, especially chemicals that are substitutes for ozone-depleting substances. Some of those chemicals are milder ozone-depleters, and others are potent greenhouse gases—so Montzka is collaborating increasingly with ESRL's carbon cycle and greenhouse gas experts.

He's also a bit busier than usual now, because he's one of two coordinating lead authors of Chapter 1 of the 2010 Scientific Assessment of Ozone Depletion, conducted by the World Meteorological Organization and the UN Environment Programme. The assessments, published every four years, update scientists, policy makers, and the public on the status of ozone depletion.

The extra work is worth it, Montzka said. "We at NOAA get to take the pulse of the global atmosphere weekly—those samples are a tremendous resource. Using them to address science issues is great fun, and being able to address policy issues as well makes it very rewarding."

Storm Spoiler

ESRL's FIM model excels during summertime hurricane trials

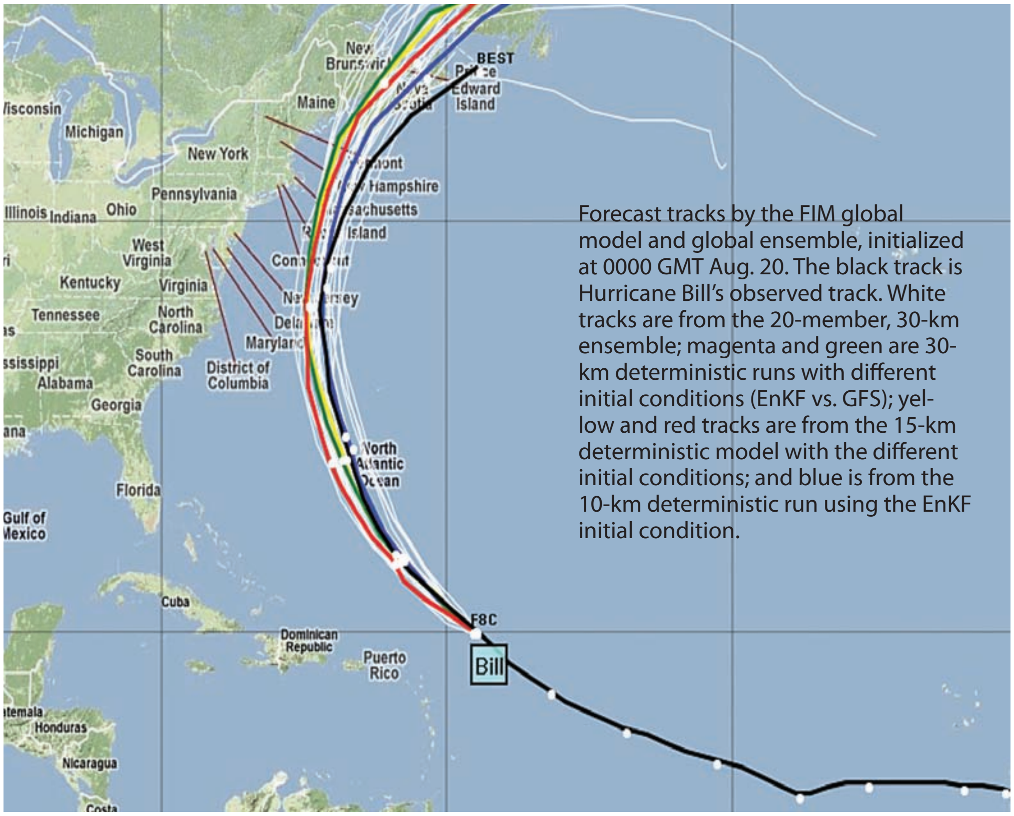
Hurricane Bill couldn't outrun FIM. The ESRL-developed forecast model kept pace with that storm and others this summer in a series of supercomputer-based hurricane forecast experiments.

"The results are preliminary, but the track forecasts seem to be looking better when the model is run at higher resolution (30 km vs. 15 km vs. 10 km)," said ESRL's Stan Benjamin, Chief of the Assimilation and Modeling Branch of ESRL's Global Systems Division. "At higher resolution, we are seeing intensity improvements, too, based on this season's tropical storms so far," Benjamin added.

He and colleagues from across NOAA, supported by the Hurricane Forecast Improvement Program, HFIP, used TACC supercomputers to run FIM at high resolutions this summer. Although forecasters have improved hurricane track errors by about 50 percent during the last 20 years, HFIP has set a goal of further, significant improvements in track and intensity forecasts and forecast lead time.

It's hard to spin up a realistic, intense hurricane in lower-resolution models, such as the operational Global Forecast System (GFS), which usually runs at 40 km. The storms alter the wind and other systems in which they're embedded, and those changes can then push around the storm itself. Researchers calculate they need resolutions of 5-15 km to perform this kind of modeling, and those resolutions require intense computing power (shifting FIM from 30-km resolution to 10-km resolution required 27 times more computing power).

So this summer, Benjamin and his colleagues used more than 12 million processor hours at TACC to run hurricane forecasts on FIM at 30-, 15-, and 10-km resolution, to study the effect of resolution on forecast accuracy. The team is also comparing the effectiveness of two methods that could be used to initialize the models. The first is a traditional data assimilation system, used operationally with GFS, that ingests real-time meteorological data from a broad region around developing hurricanes. The second is an experimental system, developed at ESRL, which treats those data first with a statistical technique called the ensemble Kalman filter, EnKF. Initial data from those trials already suggest that both FIM and the operational GFS can deliver better forecasts using the EnKF.



Forecast tracks by the FIM global model and global ensemble, initialized at 0000 GMT Aug. 20. The black track is Hurricane Bill's observed track. White tracks are from the 20-member, 30-km ensemble; magenta and green are 30-km deterministic runs with different initial conditions (EnKF vs. GFS); yellow and red tracks are from the 15-km deterministic model with the different initial conditions; and blue is from the 10-km deterministic run using the EnKF initial condition.

FIM: Flow-following finite-volume Icosahedral Model
TACC: Texas Advanced Computing Center

Chasing Shadows

ESRL researchers, colleagues develop a new technique for detecting tsunamis from space

Long, shallow tsunami waves racing through open ocean change the roughness of the sea surface ahead of them, and ESRL scientists demonstrated this summer that such "shadows" can be measured by satellite-borne radars. The finding could one day help save lives through improved detection and forecasting of tsunami intensity and direction at the ocean surface.

"We've found that roughness of the surface water provides a good measure of the true strength of the tsunami along its entire leading edge," said Oleg Godin of ESRL's Physical Sciences Division. "This is the first time that we can see tsunami propagation in this way across the open ocean."

Large tsunamis crossing the open ocean stir up and darken the surface waters along the leading edge of the wave, according to the study. The rougher water forms a long, shadow-like strip parallel to the wave and proportional to the strength of the tsunami. That shadow can be measured by orbiting radars and could one day help scientists improve early warning systems. The research was published in the journal, *Natural Hazards and Earth System Sciences*, and Godin's co-authors are from the Physical Sciences Division, ZelTechnology, LLC, and the University of Colorado.

The new study challenges the traditional belief that tsunamis are too subtle in the open ocean to be seen at the surface, and it confirms a theory that Godin published five years ago.

It also helps explain anecdotes that have long puzzled tsunami scientists, and inspired Godin. In 1994, a tsunami shadow was captured on video from shore, moments before the wave struck. Written reports from 1946 similarly document a shadow that accompanied a deadly tsunami on April 1.

Godin tested his theory during the deadly 2004 Indian Ocean tsunami, the result of the massive Sumatra-Andaman earthquake. Godin and colleagues analyzed altimeter measurements of the 2004 tsunami from NASA's Jason-1 satellite. The data revealed clear evidence of increased surface roughness along the leading edge of the tsunami as it passed across the Indian Ocean between two and six degrees south latitude.

The new study identifies a third way of detecting tsunamis. Today, tsunamis that threaten coastal U.S. communities are picked up by an extensive buoy network, NOAA's Deep-ocean Assessment and Reporting of Tsunamis (DART) system. DART uses ocean-floor sensors to measure the pressure changes that accompany passing tsunami waves. A second method uses space-borne altimeters to detect tsunamis by measuring small changes in sea surface height—but only a handful of these instruments are in orbit and observations are limited to points along a line.

Godin's team found that relatively common scientific instruments, microwave radars and radiometers, can pick up the contrast between a rough, dark tsunami "shadow" and the smooth, bright water on either side. From orbit, microwave radars and radiometers can observe a band of ocean hundreds of kilometers wide and thousands of kilometers long. If programmed correctly, they could potentially map an entire tsunami, Godin said.

...NOAA-Exploratorium partnership, from page 1

and more. NOAA Administrator Jane Lubchenco and Exploratorium Executive Director Dennis Bartels made the announcement on the San Francisco pier where the Exploratorium will move within five years. During a brownbag lunch at ESRL, Miller described the scene: "What I really loved was that Dr. Lubchenco said 'This is going to be so cool!' "

Exploratorium staff visited ESRL most recently, but have also toured NOAA's Pacific Marine Environmental Laboratory and smaller NOAA offices in California, and they're planning other trips.

The Exploratorium, a "museum of science, art, and human perception," has long excelled at developing hands-on, experiential exhibits, said Exploratorium senior scientist Thomas Humphrey. Visitors can swirl up a tornado from rising mist or investigate the motion of spinning discs. Now, Humphrey said, the museum's exhibit staff have been challenged to develop a new approach to communicating environmental and Earth system science: Perhaps by instrumenting the museum with state-of-the-art NOAA equipment and letting visitors explore data through visualizations. Or giving visitors access to real-time greenhouse gas and pollution data collected at NOAA's nearby tall tower sites. Or establishing a two-way video connection between NOAA's *Okeanos Explorer* and the museum.

The latter project is already in the works: Exploratorium staff are creating an online presence for the *Okeanos*, so ship scientists can highlight new discoveries in short video clips, blogs, tweets, and other modes.

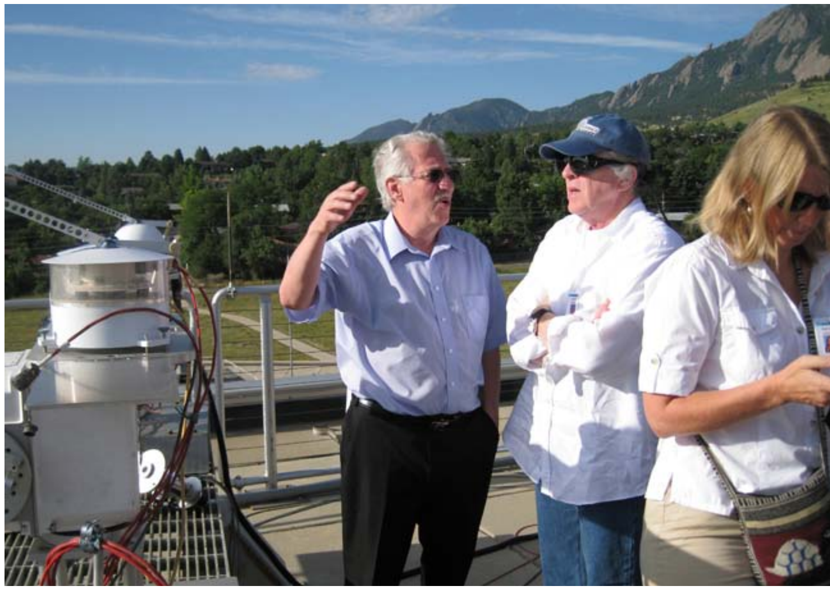
In Boulder, Miller, Humphrey, Exploratorium Associate Director Robert Semper, artist Susan Schwartzenberg, and program and project coordinator Kate O'Donnell spoke with dozens of NOAA scientists about their work and ideas.

Eric Hakathorne in ESRL's Global Systems Division discussed his experience using new media—including the virtual world Second Life—to educate the public. John Miller and Russ Schnell of the Global Monitoring Division discussed NOAA's role as the atmosphere's accountant: ESRL's monitoring programs track the ups and downs of critical greenhouse gases, ozone-depleting substances, and other atmospheric constituents.

Susan Solomon of the Chemical Sciences Division and ESRL Director Sandy MacDonald said they hoped the Exploratorium could help NOAA communicate more clearly about climate change. "This problem humanity is facing is more important than anything out there," MacDonald said.

ESRL scientists also spoke about research into California's atmospheric rivers, which deliver vital water resources to the state but pose a critical flood risk. Exploratorium staff were delighted by the group's raindrop disdrometers, which measure the size distribution of raindrops—important in forecasting floods and debris flows.

"We're thinking about something called 'Anatomy of a Raindrop,'" Miller said. "We'll definitely be continuing to talk with that group."



Top: ESRL's Tim Schneider makes it "rain," to show Exploratorium staff how a raindrop disdrometer works (photo by Barb DeLuisi, NOAA). Bottom: ESRL's Russ Schnell explains rooftop instruments to the Exploratorium's Thomas Humphrey, with Mary Miller at right (photo by Rhonda Lange, NOAA).

This fall, the Exploratorium and NOAA will set up a private blog site, where staff from either side of the collaboration can pitch ideas and comment on them.

Ongoing Collaborations

Long before signing an official partnership, Exploratorium staff were working informally with NOAA scientists and their academic colleagues to communicate about fascinating and important field work. *Ice Stories: Dispatches from Polar Scientists* is an Exploratorium web site that highlights some of those collaborations. Museum staff train researchers to use multi-media tools, from video production and editing to storytelling and blogging. Trained scientists then use those skills to file dispatches from the field. NOAA Corps Officer Nick Morgan (ESRL Global Monitoring Division) will file dispatches on *Ice Stories* this year, from NOAA's South Pole Observatory.

More: http://icestories.exploratorium.edu/

NOAA

Teachers in the Lab

ESRL scientists, university professors collaborate to study air and sea

In a break from their school-year routines standing in front of classroom Smart Carts and holding office hours, university professors Peter Blanken and Diane Stanitski worked in the lab and field with ESRL scientists this summer. Blanken, whose own research is in boundary layer climatology, worked with Dan Wolfe (ESRL's Physical Sciences Division, PSD), and spent hours making measurements at ESRL's 300-meter tall tower in Erie, Colo. Stanitski expanded her ocean-climate knowledge by participating in air-sea flux research in the ESRL lab with Chris Fairall (also PSD), before hopping aboard the University of Hawaii research vessel *Kilo Moana* to collect field data.

Blanken and Stanitski were two of five teachers accepted to participate in NOAA's pilot Teacher in the Lab program, an extension of the Teacher at Sea program, with the purpose of providing teachers hands-on experience working side-by-side with NOAA scientists. Blanken's and Stanitski's summer research projects both focused on the air-surface interface, but in two very different environments. Knowledge of the boundary layer is key for understanding future climate—dynamics in the boundary layer influence energy exchanged between the atmosphere and the surface, and better understanding of those dynamics could significantly improve weather and climate models.

Blanken, an Associate Professor in the Geography Department at the University of Colorado at Boulder, and Wolfe worked in the boundary layer at the Boulder Atmospheric Observatory (BAO) tall tower, to monitor atmospheric profiles of temperature, moisture, wind, and carbon. To human eyes, the view from the top of the BAO is sweeping, but Blanken and Wolfe were more interested in the sensor view, or "sample footprint" at the BAO. The area "seen" by the tower's radiometric and turbulent flux measurements depends on several factors, from sensor height and design to atmospheric conditions such as turbulence and stability. In a series of experiments, Blanken and Wolfe ran sensors up and down the tower on an external carriage, to examine changes in sampling area. The researchers expect to help scientists better understand satellite measurements through comparisons with data from the BAO.

Peter Blanken and the view from the top of ESRL's Boulder Atmospheric Observatory tower.

DAN WOLFE, NOAA

Wolfe and Blanken continue to collaborate, using new and historic BAO data to develop undergraduate-level lesson plans that follow NOAA's Climate Literacy Principles.

Stanitski, an adjunct oceanography professor at the U.S. Naval Academy, and ESRL physicist Fairall are working together on an ongoing "intercomparison" study between precise flux sensors mounted on long-term ocean reference stations and nearby ship instruments. These flux measurements help researchers quantify air-sea exchanges of heat, freshwater, and momentum—key data for understanding and describing how ocean regions respond to atmospheric changes. This summer's cruise was to the Woods Hole Hawaii Ocean Timeseries Station (WHOTS) mooring 100 km north of Oahu, one of a network of long-term ocean reference stations.

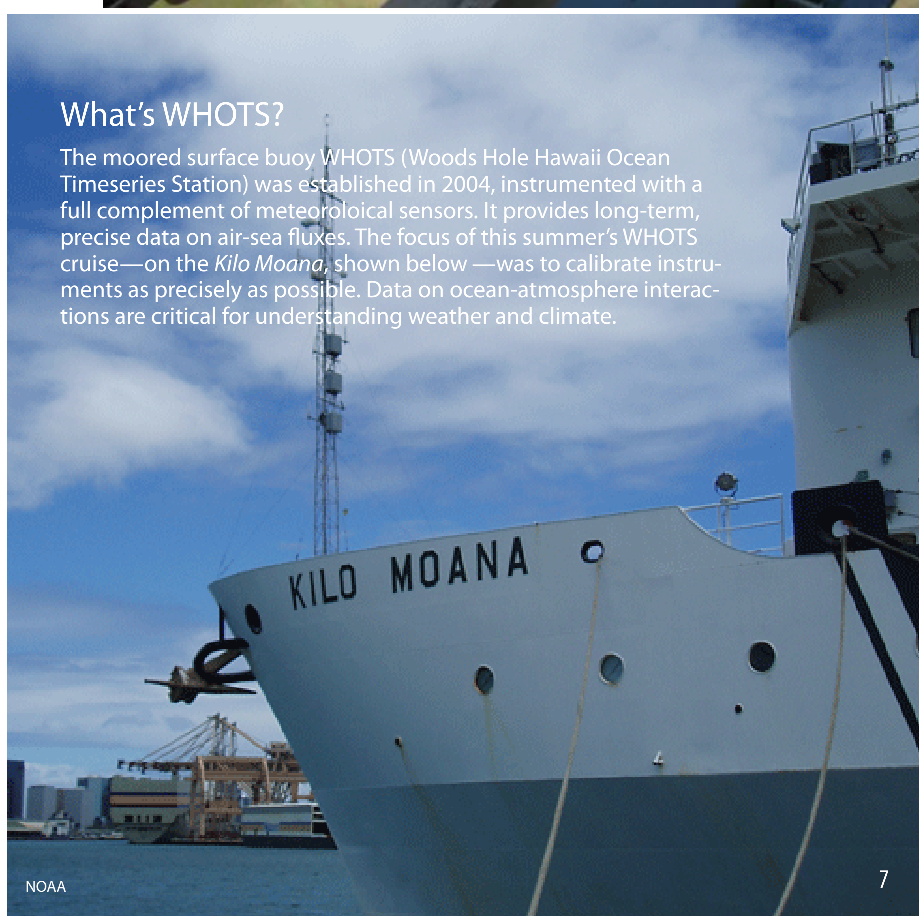
Aboard the *Kilo Moana*, Stanitski launched weather balloons by day and night, crunched large datasets in the lab, mounted radiometers on the ship, and took sea surface temperature readings throughout the cruise. She focused on shortwave and longwave radiation measurements and data from onboard meteorological instruments important to compute air-sea fluxes.

Fairall, Stanitski, and other scientists participating in the WHOTS study plan to co-author a report on the intercomparison findings. Stanitski is incorporating NOAA data into a Global Climate Change course she is teaching at the U.S. Naval Academy this fall. She also plans to write a children's book about careers in the atmospheric sciences, based on interviews conducted with NOAA scientists.

Wolfe, Blanken, Fairall, and Stanitski will co-author a presentation at the American Meteorological Society annual meeting, describing the value of their Teacher in the Lab experience and research conducted during their summer interactions.

What's WHOTS?

The moored surface buoy WHOTS (Woods Hole Hawaii Ocean Timeseries Station) was established in 2004, instrumented with a full complement of meteoroloical sensors. It provides long-term, precise data on air-sea fluxes. The focus of this summer's WHOTS cruise—on the *Kilo Moana*, shown below —was to calibrate instruments as precisely as possible. Data on ocean-atmosphere interactions are critical for understanding weather and climate.



NOAA

Speeding Up Science

Cheap, poweful processors designed for life-like video games improve NOAA weather, climate models

ESRL's Mark Govett felt a bit out of place at a conference in California last fall. He was surrounded by hundreds of video game developers and players, few older than 30. Gaggles of teenagers were in attendance, drawn by a gaming contest involving incredibly realistic electronic simulations of people.

Govett, 52, has worked for 24 years at NOAA, steadily improving the computer systems used to predict weather and climate. The corners of his eyes wrinkle when he smiles.

Like everyone else at last year's GPU Technology Conference in San Jose, Govett wanted to learn more about the latest innovations in computer processing. For most attendees, those innovations would lead to better games. Govett and a handful of others were more interested in how GPUs—graphics processing units—might improve ***science***.

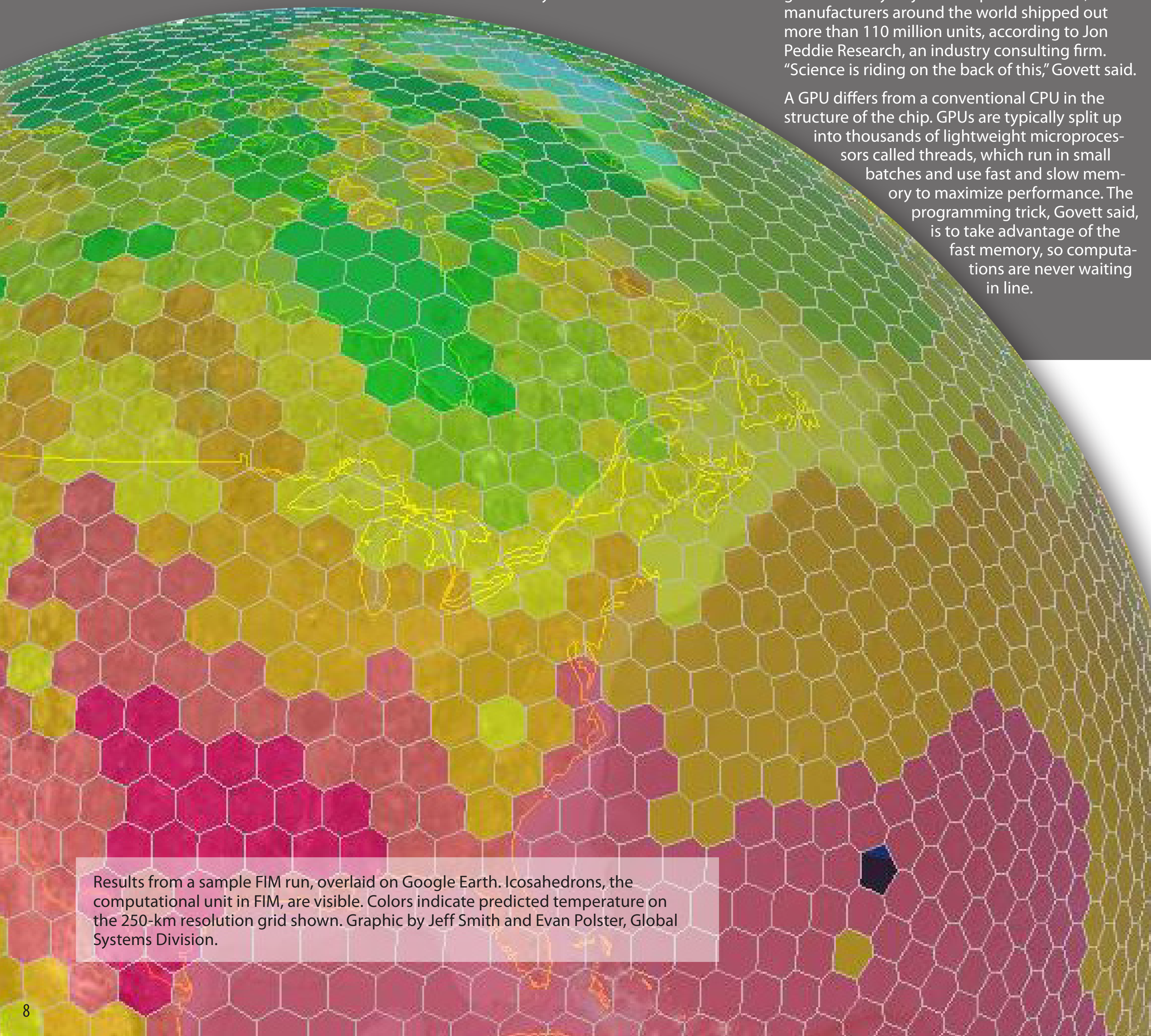
"We are getting to the point where parallel processors based on CPUs cannot do what we need," Govett said. An experimental weather and climate model in development now at ESRL, for example, will eventually require about 200,000 CPU cores to spit out operational forecasts, he estimated. Weather forecasting requires speed: Useful forecast models must run at about 2 percent of real time. ESRL's fastest machine has about 5,000 cores and occupies about 15 closet-sized racks. The space and energy requirements of such banks of machines are becoming onerous. "They're going to require small power plants to run our models," Govett said. "Clearly, we need another way."

...the code runs 25 times faster on a GPU

GPUs may not be the only answer, he said: There are other types of fast, co-processing chips. But for now, Govett and colleagues believe GPUs are one of the most promising. The processors are staggeringly powerful, cheap, and require far less energy and space than CPU-based computing systems. Govett's small team in the Global Systems Division is now leading NOAA's investigation into GPUs, following in the footsteps of ESRL Director Sandy MacDonald. MacDonald helped revolutionize NOAA's computing power 18 years ago, with parallel processors that were many times less expensive—and faster—than Crays and other vector computers of the time.

Powering the improvements in GPUs is the video game industry. In just one quarter of 2008, GPU manufacturers around the world shipped out more than 110 million units, according to Jon Peddie Research, an industry consulting firm. "Science is riding on the back of this," Govett said.

A GPU differs from a conventional CPU in the structure of the chip. GPUs are typically split up into thousands of lightweight microprocessors called threads, which run in small batches and use fast and slow memory to maximize performance. The programming trick, Govett said, is to take advantage of the fast memory, so computations are never waiting in line.



Results from a sample FIM run, overlaid on Google Earth. Icosahedrons, the computational unit in FIM, are visible. Colors indicate predicted temperature on the 250-km resolution grid shown. Graphic by Jeff Smith and Evan Polster, Global Systems Division.

"Vendors have been saying that GPUs have 100 times the performance of CPUs," Govett said. "We asked, To what extent can we take advantage of that?"

Until recently, it wasn't feasible to even try. To program GPUs, researchers would need to write in a low-level machine language that would be impractical. "People knew the promise was huge, but we couldn't work with them yet," Govett said.

Then in 2007, a major GPU manufacturer, made public its language, CUDA, which is similar to C. Most scientists still program in Fortran, so for most academic researchers, it was too difficult to convert their codes to CUDA—it would take too long to get results. But Govett's background is in computer languages, and he was able to write translational software that does 95 percent of the work automatically. "That has allowed us to make progress faster than anyone else," he said.

His team purchased a 16-node GPU from NVIDIA last year. Now, Govett, Craig Tierney, Leslie Hart, Tom Henderson, and Jacques Middelcoff are converting model code to CUDA and optimizing it for high performance on the GPU system.

The initial results have been incredibly exciting, Govett said. Running part of FIM—the Flow-following finite-volume Icosahedral Model, ESRL's experimental weather and climate model being used to improve hurricane prediction—was 15 to 20 times faster on the GPU node than on the CPU, Tierney reported nine months ago.

Now Govett has a large segment of the next-generation NIM model (Non-hydrostatic Icosahedral Model) running on a GPU. NIM is an even more computationally intensive model that is expected to run at resolutions of 3-4 km within two years.

"To date, no global model has been run at such a high resolution in real time because of the compute requirements are so large," Govett said. "It may not even be possible to run the NIM at this fine scale in real time without something like a GPU." In recent experiments, the code has run 25 times faster on the GPU than the CPU. "I'm just so excited about this I'm working on this at night and weekends," Govett said.

He acknowledged that there remain uncertainties in the use of GPUs for high-performance computing. It's not entirely clear yet, for example, how efficiently GPU units will perform when linked in parallel. "But we believe we have good strategies for dealing with that issue," Govett said.

He put up his translational software for free online a few months ago, and users around the world have downloaded it. An industry group has offered a similar product, and Govett's team plans to run tests to compare the efficiency of the two programs.

"GPUs are seen now as the next revolutionary advance in computing, and NOAA is looking to our laboratory to do this kind of research," Govett said. "In terms of atmospheric science, we've come further, faster, with GPUs than anyone else out there. It's very exciting to work at ESRL on this."

Mark Govett. Photo by Will von Dauster, NOAA.

GPU>>CPU

GRAPHICS PROCESSING UNIT A processor with parallel structure, traditionally used to support 3-D graphics. GPU performance is increasing faster than CPU performance and GPUs are cheap, partly because they are manufactured in high volume for computer games. Today's fastest GPUs process at about 2 teraflops, 100 times faster than most CPUs.

Efficiency 50 Gflops per Watt of waste heat

CENTRAL PROCESSING UNIT This all-purpose processor is the core of most computers. CPU performance has doubled about every 18 months (Moore's law), but is running into physical limits. Today's CPUs perform about 20 billion floating-point operations per second—20 gigaflops.

Efficiency 1 Gflop per Watt of waste heat

...N_2O top ozone-depleting emission, from page 1

"weight" N_2O emissions to quantify their potential to deplete the ozone layer.

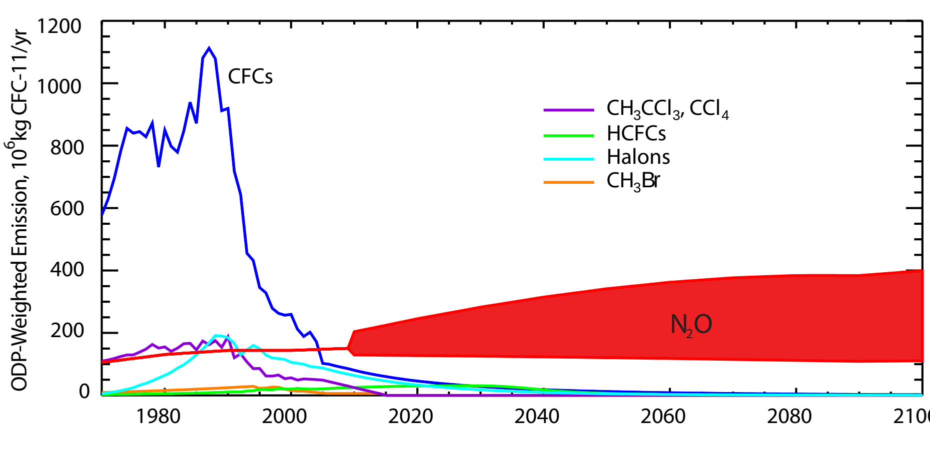
Per molecule, nitrous oxide is comparable to the weakest of regulated ozone-depleting chemicals, the team found. The molecule's "ozone depletion potential" in the year 2000 was 0.017. CFC -11 (the standard by which other ozone-depleting substances are measured) has an ozone depletion potential of 1, and some bromine-containing chemicals have ozone depletion potentials higher than 10. But when Ravishankara and his colleagues used N_2O's number and took its large emissions (today and projected throughout this century) into consideration, nitrous oxide's importance emerged.

"We have demonstrated that N_2O can be thought of as an ozone-depleting substance in many of the same ways as other gases that are currently regulated by the Montreal Protocol," Portmann said.

While the emissions of many of the Protocol's ozone-depleters are dropping, emissions of nitrous oxide are increasing, and N_2O's concentration in the atmosphere continues to rise: It was about 270 parts per billion (ppb) in pre-industrial times, and is roughly 325 ppb today. Though nitrous oxide emission is the single most important ozone-depleting emission by people today, the ozone depletion occurring today is still dominated by the CFCs and other regulated ozone-depleting chemicals that remain in the atmosphere in large amounts because of their long lifetimes and large historical emissions.

"Today's human-caused N_2O emissions represent a larger commitment to future ozone depletion than any other ozone-depleting substance humans are currently emitting," Daniel concluded. "Soon, human-caused N_2O emissions will represent a greater commitment than the anthropogenic emissions of all other ozone-depleting substances combined."

Nitrous oxide—also a greenhouse gas—is emitted from fertilized soils, livestock manure, sewage treatment, combustion and other industrial processes, and a very small amount comes from dental sedation. In nature, bacteria in soil and the oceans break down nitrogen-containing compounds, releasing nitrous oxide. Human activities account for about one-third of global nitrous oxide emissions today. The figure below shows historical and projected ODP-weighted emissions of the most important ozone-depleting substances (from Ravishankara et al. 2009).



Achievement

More news, publications, and honors from NOAA's Earth System Research Laboratory.

News

Quake damages NOAA site

Mark Cunningham, Station Chief of NOAA's baseline atmospheric observatory in American Samoa, has reported that he, his family, and the observatory's groundskeeper are fine following a major undersea earthquake in the region, which triggered deadly tsunami waves, although the home of NOAA's groundskeeper was destroyed. At least 140 died Tuesday, Sept. 29 on the islands of Samoa and American Samoa, according to news reports. NOAA's American Samoa observatory sits on the northeastern tip of Tutuila Island, on a ridge about 42 m above the South Pacific Ocean.

Jim Butler, Director of ESRL's Global Monitoring Division, has been speaking with Cunningham by mobile phone at least briefly every day since the earthquake and tsunami. Cunningham updated his boss on the status of the NOAA observatory, and told him about ferrying people from devastated, low-lying areas to the higher observatory site, and providing shelter. The NOAA observatory has become the second largest designated shelter area in American Samoa due to its elevated location and substantial self-supporting infrastructure, including electrical generation capacity.

"Once again, Mark is a hero when heroes are called for," Butler said. "We owe him a lot." Cunningham received a Bronze Medal from NOAA's Workforce Management Office in 2005, following the Category 5 Cyclone Heta in January 2004. The award praised Cunningham's service in restoring operations to the Samoa Baseline Atmospheric Observatory, which had been pounded by 90-foot-high waves. More: www.esrl.noaa.gov.

NOAA chief visits Barrow, AK

A delegation of leaders—including NOAA Administrator Jane Lubchenco, several members of the White House Council on Environmental Quality, and Congressional staffers—visited ESRL's Barrow Observatory August 19. ESRL Director Sandy MacDonald traveled with the group to discuss the importance of environmental monitoring, especially in the fast-changing Arctic, where the air and oceans are warming and sea ice is retreating. Steve Grove and Jason Johns of ESRL's Global Monitoring Division led a tour of the Barrow Observatory, which Dr. Lubchenco called "a model" for an international network of atmospheric climate observatories. For her, the visit was part of a week of traveling in Alaska with U.S. Coast Guard Commandant Adm. Thad Allen and Nancy Sutley, Chair of the Council on Environmental Quality.

"Climate change is happening faster in the Arctic than any other place on Earth—and with wide-ranging global consequences," Dr. Lubchenco later wrote in a memo to NOAA. "As efforts to explore and understand the Arctic region expand, NOAA will be called upon by a growing number of stakeholders—from the U.S. military to tour operators to commercial shippers—to provide an even greater suite of services to help ensure these activities are conducted safely and efficiently."

Published

ESRL's peer-reviewed publications:

http://www.esrl.noaa.gov/search/pubs/

Publcations by Division:

GMD: www.esrl.noaa.gov/gmd/publications/
PSD: www.esrl.noaa.gov/psd//pubs
CSD: www.esrl.noaa.gov/csd/pubs/
GSD: www.fsl.noaa.gov/publications/

HFCs threaten climate

Chemicals called hydrofluorocarbons (HFCs) are likely to play an increasingly significant role in future climate warming, ESRL's David Fahey, John Daniel (Chemical Sciences Division), and international colleagues projected in a study published in late June. HFCs—used as substitutes for ozone-depleting compounds in applications such as refrigeration, air conditioning, and the production of insulating foams—are greenhouse gases.

"HFCs are good for protecting the ozone layer, but they are not climate friendly," Fahey said. The authors calculated that HFCs, which currently have a relatively small climate contribution (~1% of carbon dioxide emissions), could become 9-19% of business-as-usual CO_2 emissions by 2050, because of growing HFC production and use, especially in developing countries. The study was published in the *Proceedings of the National Academy of Sciences*.

In related policy news… Parties to a Montreal Protocol working group in July discussed whether and how to regulate HFCs, described as "high-global warming potential alternatives for ozone-depleting substances." The Montreal Protocol and its amendments regulate substances that deplete the ozone layer. HFC use is growing rapidly, in part because the protocol has phased out production of chemicals that destroy ozone. In the July meeting report, parties wrote that because HFCs are considered greenhouse gases, results from the December international climate meeting in Copenhagen should be taken into account before the ozone community decides what action to consider.

One month later, the leaders of Canada, Mexico, and the United States included language about HFCs in the August 10 "North American Leaders' Declaration on Climate Change and Clean Energy." The document affirmed the necessity of taking aggressive action against climate change. In it, Canadian Prime Minister Harper, Mexican President Calderon, and U.S. President Obama wrote "…we will: Work together under the Montreal Protocol to phase down the use of HFCs and bring about significant reductions of this potent greenhouse gas." More recently, the same nations submitted language to amend the Montreal Protocol to accept the task of regulating HFCs. The amendment will be discussed in the November annual meeting of parties.

AirCore patented

AirCore, an ESRL-invented "system and method for providing vertical profile measurements of atmospheric gases," will receive a patent October 6, according to the U.S. Patent and Trademark Office. The patent, number 7,597,014, credits Pieter Tans of the Global Monitoring Division for the invention.

AirCore, a long coil of stainless steel tubing, can be lifted to high altitudes by balloon or airplane to collect a high-resolution altitude-specific, continuous sample of air. On launch, one end of the tube is open, letting out pre-filled standard air as the pressure drops. During descent, as the pressure increases, the tube refills with atmospheric air. The small diameter of the tube acts to prevent significant mixing of air from different altitudes through rapid diffusion in the radial direction in the tube. Thus, the air that flows in at high altitude gets pushed toward the back of the tube by air that comes in later at lower altitudes. The tube is closed upon landing to preserve the layers of air inside, which can then be analyzed sequentially for greenhouse gases and other trace gases that do not interact with the walls of the tube.

The system is cheap, rugged, and accurate, according to experiments comparing AirCore mea-

ESRL Director Sandy MacDonald speaks with NOAA Administrator Jane Lubchenco (second from left) and other staff, at the Barrow Observatory in Alaska. Photo by Bill Mowitt, NOAA.

A U.S. Coast Guard C-130 airplane, bearing ESRL instruments to study greenhouse gases in the Arctic. NOAA photo.

surements with those from more expensive flask sampling systems or on-board analyzers.

Other members of the ESRL AirCore team include Colm Sweeney and Anna Karion (CIRES) of the Global Monitoring Division. Russ Chadwick and Randy Collander (CIRA) of the Global Systems Division were involved with the high-altitude balloon testing of the AirCore.

Haze less...hazy

Atmospheric particles called aerosol have complex effects on climate—some particles can cause cooling, others warming, and the particles can also affect the formation of clouds, with their own radiative effects. The Intergovernmental Panel on Climate Change (IPCC) identified aerosol as one of the most uncertain aspects of human-caused climate change. A new ESRL study, which calculated the effect of anthropogenic aerosols in a completely new way (without climate models) has sharpened scientists' understanding of the climate effect of the particles. Daniel Murphy and colleagues in ESRL's Chemical Sciences Division, the University of Leeds, and NASA used observations and basic conservation of energy principles to construct a global energy budget since 1950. The team calculated anthropogenic aerosol's effect at 1.1 Watts/m^2 of cooling, in good agreement with the IPCC's 2007 estimate of 1.2 Watts/m^2. Importantly, the researchers also narrowed the uncertainty around that figure, ruling out, for example, the possibility of significantly larger cooling effects once thought possible.

Target: Arctic feedback

ESRL scientists teamed up with the U.S. Coast Guard this spring, summer and fall, to fly sophisticated instruments over the Alaskan tundra and look for manmade and natural sources of the greenhouse gases methane and carbon dioxide. Recent observations have suggested that the air above Alaska contains early signs of a regional increase in greenhouse gas emissions, which could contribute to climate change around the globe.

Using a Coast Guard C-130 airplane, NOAA researchers swapped out a window for a plate with air inlets. They installed instruments that can measure methane and carbon dioxide levels every other second, and others that capture air for more detailed analysis back in Boulder, Colo. The data should help scientists map natural and manmade emission sites of carbon dioxide and methane.

Billions of tons of carbon are buried in the frozen Arctic tundra, which is now heating up because of human-caused climate change. NOAA is trying to understand what that means for the future of the region: Will warming dry out the tundra, leading to the exhalation of carbon dioxide? Or will warmth let lakes and pools form, allowing microbes to feast on buried organic matter and burp up methane?

"So far profiles north of the Brooks Range indicate significant enhancements in methane emissions near the surface," said Colm Sweeney, from ESRL's Global Monitoring Division and CIRES. "But it's uncertain whether those are local emissions from human activities or outgassing from natural sources."

Honored

Steve Albers (Global Systems Division) was awarded the 2009 R.R. Newton Award for Scientific History, for proposing the idea that records kept by centuries-old astronomers might contain information about then-unknown planets. Albers published a record of mutual planetary conjunctions from 1557-2230. An astronomer used those data to conduct a targeted search of Galileo's manuscripts, and found that the astronomer had seen Neptune in 1612 and 1613, more than two centuries before the planet was officially discovered.

Eight ESRL researchers won NOAA OAR Outstanding Paper Awards, for their contributions to two of the five winning papers: 1) On the global distribution, seasonality, and budget of atmospheric carbonyl sulfide (COS) and some similarities to CO_2, *Journal of Geophysical Research* (by Global Monitoring Division's **Stephen Montzka**, **Brad Hall**, **Jim Elkins**, **Tom Conway**, **Pieter Tans**, and CIRES' **Paul Calvert** and **Colm Sweeney**; and 2) Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the West Coast of North America based on eight years of SSM/I satellite Observations, *Journal of Hydrometeorology* (by Physical Sciences Division's **Paul Neiman**, **Martin Ralph**, and **Gary Wick**, with CIRES' **Jessica Lundquist** and the U.S. Geological Survey's **Michael Dettinger**).

Tracy Hansen, **Thomas LeFebvre**, **Mark Mathewson**, and **Mike Romberg** (Global Sciences Division) were awarded a NOAA Technology Transfer Award "for continuing improvements to the Graphical Forecast Editor (GFE) allowing the system to be used in River Forecast and National Centers, as well as for tailoring GFE systems for the meteorological agencies of Taiwan and Australia."

Martin Ralph also won a 2009 NOAA Administrator's Award, "for exemplary leadership of the NOAA Unmanned Aircraft System Program during its formative stage."

A.R. Ravishankara (Chemical Sciences Division Director) was awarded the 2009 Morino Foundation Fellowship by the Tokyo Institute of Technology, the Morino Foundation, and the National Institute for Environmental Studies. Ravishankara presented his Morino lecture in Tokyo in September.

Susan Solomon (Chemical Sciences Division) won the 2009 Volvo Environmental Prize, for her distinguished work in the Antarctic as well as her exemplary leadership during the last Intergovernmental Panel on Climate Change. Dr. Solomon also earned an honorary degree from the University of Reading, for her contributions to the understanding of ozone depletion and climate change.

Susan Solomon receives an honorary degree from the University of Reading. Photo by the University of Reading.

Tracking the Sun

NOAA site serves scientists, photographers, deep-sea fishers

A redesigned web site that lets users calculate the Sun's precise position, including the times of sunrise and sunset, has captured the interest of thousands of web surfers since early July.

The NOAA Solar Calculator is now one of ESRL's most popular web pages, surpassed regularly only by ESRL's home page, trends in carbon cycle and greenhouse gases, and the ever-popular South Pole live camera.

ESRL's Chris Cornwall redesigned his group's solar calculator this summer, to improve upon a page that has proved far more popular than he imagined. Originally intended to help ESRL researchers install solar radiation instruments in the field, the solar calculator now serves amateur photographers around the world, green architects, robot engineers, and even movie makers.

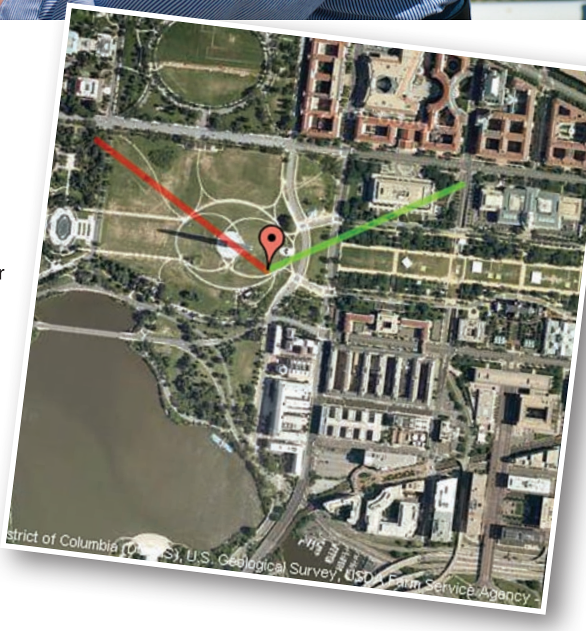
Cornwall is the information technology manager of ESRL's Global Monitoring Division, and his work during the last 12 years has included helping to set up and maintain the group's network of surface radiation monitors. Radiation monitors gather critical on-the-ground information about Earth's energy budget and climate. Such instruments can't capture accurate data unless installed precisely in a north-south direction, Cornwall said. In the field, that can mean aligning instrumentation along the shadow of a plumb bob at exactly solar noon.

"And we miss solar noon a lot," Cornwall said. "You can have a nice clear morning, and suddenly at solar noon you get a cloud. You can't align an instrument without a shadow. Then we need to figure out when the Sun will be exactly 5° off solar noon…"

Cornwall, Chris Lehman, and Aaron Horiuchi created the original NOAA Solar Calculator site for colleagues 10 years ago, opening it up to public use about a year later. The emails have been rolling in since then, from unexpected users:

- A Canadian defense researcher working on navigation by autonomous robots
- An ecologist studying how albacore tuna behavior changes by day and night
- A fire department manager scheduling annual training
- A movie maker who needed to line up and time a sunset shot

Top: Chris Cornwall demonstrates how to align an instrument with the shadow of a plumb bob at solar noon Sept. 4, on the roof of the David Skaggs Research Center. Photo by Will von Dauster, NOAA.



Right: Solar Calculator output. If a photographer wants to capture a picture of the Washington Monument framed by the sunset next Fourth of July, NOAA's Solar Calculator can help pick a spot. In the screenshot at right, the red line (sunset) intersects the base of the Monument when a viewer is positioned to the southeast.

- A green architect designing a passive solar building
- A small business owner who ran deep-sea fishing trips and wanted sunrise times

In July, Cornwall improved the Solar Calculator substantially, taking into account user suggestions. He included a feature to let users pinpoint their location on Google's familiar map interface—something made possible by NOAA's 2007 licensing of Google Earth and Google Maps API. And the visitors arrived, more than 6,000 in August alone.

NOAA researchers still rely on the site to set up sensitive instruments, Cornwall said, and public users have come to depend on it, too.

"Hey you guys, don't you *dare* take down this page," an elementary school teacher wrote him recently. "You gotta keep it working nicely!"

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At NOAA's Earth System Research Laboratory, we observe, understand, and predict the Earth system through research that advances NOAA's environmental information and services, from minutes to millennia on global to local scales. ESRL's partners are the Cooperative Institute for Research in Environmental Sciences at the University of Colorado at Boulder, and the Cooperative Institute for Research in the Atmosphere at Colorado State University in Fort Collins.