ESRL Quarterly

News from NOAA's Earth System Research Laboratory

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Inside

International Study: Climate Change Irreversible

ESRL's Susan Solomon leads study showing effects will last 1,000 years+

Significant sea level rise, temperature increases, and shifts in rainfall are irreversible consequences of people's emission of carbon dioxide, CO_2, according to a new study led by ESRL's Susan Solomon. Climate changes wrought by the greenhouse gas will persist for more than 1,000 years, the new study shows, even if people on this planet instantly stopped emitting carbon dioxide—by curbing the burning of fossil fuels in cars and power planets, among other actions.

"Current choices regarding carbon dioxide emissions will have legacies that will irreversibly change the planet," Solomon said.

Solomon and her co-authors used climate models to ask what would happen if CO_2 were allowed to build up to several different peak levels (all beyond today's 385 parts per million), and if emissions were then cut off completely. The cutoff scenario is not a realistic one—CO_2 emissions are increasing rapidly. Rather, it was selected to demonstrate the longevity of climate impacts.

Not only does some CO_2 persist for millennia in the atmosphere, the planet's surface would remain warmer and sea level would remain higher long after CO_2 levels in the atmosphere began dropping, the authors found. The lingering effect is primarily due to the oceans, which currently buffer climate change. Today, oceans absorb much of the excess CO_2 emitted by human activities, removing it from the atmosphere.

But the ability of the oceans to store carbon dioxide will reach a limit and slow down, notes Solomon. As it does, the ocean's uptake of excess heat also slows, so the atmospheric temperature stays nearly constant for a millennium.

In one of the scenarios considered in the new study, CO_2 was allowed to peak at 450-600 parts per million before being cut off. That triggered persistent decreases in dry-season rainfall in

see p 8

Jonah Pinedale Anticline gas field in Wyoming.

Ozone Smog in Wyoming

ESRL solves mystery of winter highs

Ozone pollution is normally linked to hot summers in big cities, so researchers were puzzled when ozone levels soared dangerously high during the past three winters in a rural Wyoming gas field. At high levels, surface ozone can damage people's lungs and harm ecosystems.

Now, ESRL scientists have figured out how the pollutant forms in the cold, and their results suggest that wintertime ozone formation could be a more widespread problem than believed.

"Rapid production of wintertime ozone is probably occurring in other regions of the western United States, in Canada, and around the world," said ESRL's Russ Schnell, Deputy Director of the Global Monitoring Division. Schnell was lead author of a new paper on the Wyoming ozone problem,

see p 8

HIPPO mission, p 6. The NCAR research jet HIAPER prepares to take off in a test flight for a pole-to-pole experiment.

Director's Corner

How Does ESRL Science Serve Society?

NOAA Administrator Dr. Jane Lubchenco has called for "a new social contract for science" stating that this contract "represents a commitment on the part of all scientists to devote their energies and talents to the most pressing problems of the day . . ." (Lubchenco, 1998). How do we in ESRL see the results of our scientific efforts applied to the pressing problems of the day? Can our science affect the future, without putting us in a position of being advocates of specific policies? As Dan Albritton used to emphasize, we must assure that our policy relevant science is presented from the position of being honest brokers of scientific information.

The foundation of our research is taking observations, and using those observations to develop understanding of the natural world. In this issue there are several articles that illustrate this process, from the pole to pole observing in the HIAPER aircraft, to the Wyoming winter surface ozone and its causes. The use of this knowledge to protect and improve life on earth is the issue that Dr. Lubchenco raised, and that I believe we need to explicitly address.

One very important way we affect policy is by well written papers that describe what we have discovered about nature. Susan Solomon's headline paper in this *ESRL Quarterly* points out that carbon dioxide's effects operate on two time scales, one of which is very long—thousands of years, for reasons related to ocean chemistry. Another part of Susan's work draws on large, organized climate modeling efforts that were summarized in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, projecting profound changes in temperature and precipitation. Susan has subsequently testified in Congress on irreversibility and other global change issues, a very direct way of informing our policymakers.

We also affect the future with assessments such at the IPCC and the Climate Change Science Program. These consolidated results of our science have been very effective in bringing governments to grips with the effect of humans on the planet, and in neutralizing the tendency of policymakers to make decisions based on scientific viewpoints that are widely divergent from those dominant in the refereed literature. The IPCC was awarded the Nobel Peace Prize for clearly summarizing the results of the world community of researchers, a source of great pride for the important role that NOAA and ESRL have played.

There is another important avenue for scientific advances to affect the public and policymakers—through the systems we help to build. In ESRL, we have "systems" as our middle name; our strength is the formidable array of talent and experience we bring to the global earth system analysis problem. The importance of CarbonTracker, developed in the Global Monitoring Division, is an excellent example. It is clear that CarbonTracker is a start on the kind of analysis systems that will be very important in an era when carbon sources and sinks are closely monitored. Another example, featured on the next page, is the fascinating and important work by the Physical Sciences Division to use limited data and the Ensemble Kalman Filter to analyze the full global atmosphere. The ability to start with very few surface observations and recreate the global field with high fidelity has implications for our earth system analysis plans. These techniques can be extended to, for example, greatly improve analysis of global chemistry. Earth system analysis, led in the climate program by ESRL's Randy Dole, will bring together information on the entire earth system—atmosphere, ocean, ice, chemistry, biology, etc. Also, within our Global Systems Division are some of the world's best data, computing and numerical modeling people, and systems. ESRL thus combines the scientists trying to understand the earth system, and the scientific and technical expertise to put improved understanding into analysis and prediction models of weather and climate.

There are many other ways that our science and technology can be policy relevant and make a difference on the "problems of the day." I believe that ESRL is unique in the *breadth of its science* and technology, going from better understanding to the full earth system models on which much policy will be based. ESRL thus directly addresses the great issue for the future: How will the earth system respond as anthropogenic drivers increase in scope and intensity?

—Alexander MacDonald

Lubchenco, J, 1998, Entering the New Century of the Environment: A New Social Contract for Science, *Science,* 279.

By the Numbers

1,679,394

The number of CPU hours—on supercomputers at Lawrence Berkeley National Laboratory—it took to run a "reanalysis" of global atmospheric conditions for 1908 to 1958, based on historic weather measurements. That's 192 years on a single PC (see p 3).

LBNL

The Bassi supercomputer at the National Energy Research Scientific Computing Center, Lawrence Berkeley National Laboratory.

Reconstructing History

Understanding past weather to improve forecasts

Today, weather instruments around the globe collect millions of observations daily, giving forecasters and others a fairly comprehensive view of the global atmosphere and upcoming weather. A century ago, a few hundred observers on land and sea—most in the Northern Hemisphere—recorded a few thousand observations a day, at best. Now, ESRL researchers and colleagues around the world have produced realistic guesses at historic atmospheric conditions, based on sparse observations and an understanding of the way the atmosphere behaves today. This is the kind of detailed information that climate and weather researchers and historians have longed for, but accurate information has not been available beyond the past 60 years. The 20th Century Reanalysis project will eventually provide global surface and lower atmosphere weather data from the 1870s to the present.

Led by ESRL researchers, an international research team used Department of Energy supercomputers to stitch together sparse historic observations into an image of the most-likely atmospheric conditions at the time. Their conclusions, they hope, will not only help historians understand how weather affected key events, but will help climate modelers understand Earth's future.

The 20th Century Reanalysis Project started when NOAA's National Climatic Data Center and the National Center for Atmospheric Research began digitizing and making available original manuscript weather observations from the past 100 years. Building on the availability of these data, ESRL Physical Sciences Division and CIRES researchers Gil Compo, Jeff Whitaker, Prashant Sardeshmukh, and Nobuki Matsui proved to skeptics that by analyzing barometric pressure observations it would be possible to figure out the atmospheric patterns that created past weather conditions.

This research team wanted to produce a more extensive and improved historical dataset by combining the digitized observations from the past 100 years. With the vast amount of historical observations now available, powerful computing resources would be required to generate this huge dataset. Compo and his colleagues won a series of three Department of Energy INCITE Awards, giving them access to supercomputers at Lawrence Berkeley National Laboratory. During more than one million processing hours in the last three years, the team integrated a reanalysis model over many possible weather scenarios, and combined the possibilities with the available pressure observations to produce 6-hourly historical weather maps. The first version of the data is freely available and covers the period 1908-1958.

With the data, researchers will be able to understand a broad range of past weather variations, including conditions that led to historically notable events such as the 1930s Dust Bowl. Some of the data are already in use by researchers in Canada studying atmospheric conditions associated with the fatal Mallory Expedition of 1924. British climbers George Mallory and Sandy Irvine were attempting the first documented summit of Mt. Everest when they disappeared in an unexpected storm.

G.W. Kent Moore of the University of Toronto's Department of Physics has long been interested in high-altitude meteorology, especially around Mt. Everest, and in understanding the weather systems that give rise to really bad storms. "I was always interested in the most famous disappearance with the first serious attempt to summit Mt. Everest," said Moore. "Mallory and Irvine disappeared into what was described as some sort of blizzard. It was never known if they made the summit."

Digging around in original records from the Royal Geographical Society, Moore was surprised to learn that during the expedition, pressure and temperature data had been collected at the base camp. These observations showed a huge pressure drop of 18 mb—the largest drop that Moore had seen in the region's recorded history—which would mean that this was a much more serious storm

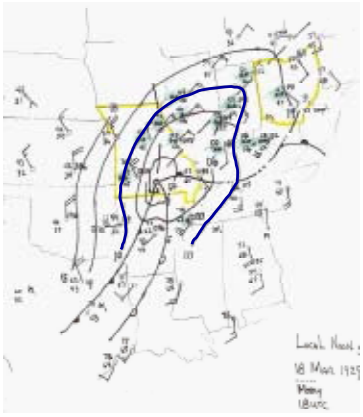
than people originally thought. Interestingly these observations were published in 1926, but no discussion or comments on this major pressure drop ever developed.

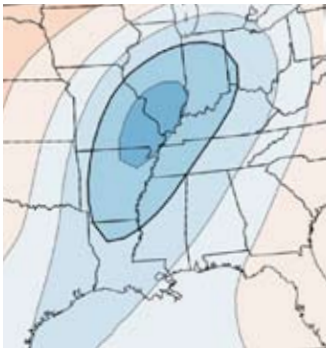
Moore then found out about the 20th Century Reanalysis Project, and asked Compo for a look at the 1908-1958 data, which had just been compiled. The pressure drop was actually due to a large-scale weather system called a "western disturbance," Moore found. Western disturbances are now known to be responsible for much of the bad weather in the Himalayas. "What is remarkable about this incredibly rich data set is that it reconstructs the state of the atmosphere, and for the first time we have a three-dimensional look at it," said Moore. "It's a wonderful tool for looking deeper back in time."

Reanalysis is also a powerful tool for researchers looking forward in time, Compo said. By better understanding historic variability in the atmosphere, researchers can both improve climate models and learn to discern changes in weather variability, which may be associated with climate change.

—Contributed by Barb DeLuisi

On the Web: http://www.cdc.noaa.gov/data/gridded/data.20thC_Rean.html





Above: NOAA photograph of the Dust Bowl and a historic photo of Mallory's fated Everest expedition.

At left: A manual analysis of the atmosphere during the Tri-State Tornado Outbreak of 18 March 1925, the deadliest tornado in US history (courtesy of R Maddox, retired, Tucson, Ariz).

At right: The ensemble mean sea level pressure analysis—which did not use any of the observations shown in the manual analysis—produces a nearly identical pattern.

Climate Services Update

A new National Climate Service (NCS) is taking shape within NOAA, with ESRL's help. In late January, Deputy Undersecretary Mary Glackin announced the appointment of Tom Karl as Director of NOAA's Climate Services, and Chet Koblinsky as Deputy Director.

NOAA Administrator Jane Lubchenco spoke about her commitment to forming a NOAA National Climate Service during her Senate confirmation hearing, a service that would resemble, in some ways, the National Weather Service. "I heard firsthand from businesses and state and local governments about the need for better information and predictions about the impacts of climate change in communities all across this country," Lubchenco said. "From concern about droughts and sea level rise to changes in the chemistry of the ocean, there is a real hunger for more and better information."

There has been strong ESRL involvement in the development of the new Service. ESRL's Randall Dole, chief scientist of the Physical Sciences Division, and Susan Solomon, senior scientist in the Chemical Sciences Division, are co-leading a team of NOAA staff writing one of the NCS foundational documents, which will define strategic goals and principles of the Service. This document will provide basic guidance for the subsequent development of an implementation plan and identification of priorities.

ESRL's Dole, Robin Webb, and Roger Pulwarty participated in early planning activities, which involved input from the private sector and across government. An external review committee, chaired by Eric Barron of the National Center for Atmospheric Research, reviewed an initial draft plan and has submitted recommendations regarding needs for a National Climate Service to NOAA's Science Advisory Board. The National Research Council originally outlined a vision for the agency in 2001.

Designing for Disaster

ESRL's Marty Ralph is part of a multiagency science team developing a severe hazard scenario in California, for a public awareness campaign later this year. Last November, the US Geological Survey and others conducted "The Great Southern California Shakeout." Millions of everyday citizens and thousands of emergency responders participated in the earthquake awareness activity—the biggest of its kind in US history.

Now Ralph, in ESRL's Physical Sciences Division, and colleagues are coming up with a scenario in which the danger comes from the sky, not below ground. The new hazard will involve a devastating—but entirely plausible—winter storm with winds reaching Category 4 hurricane force, up to 20 inches of rainfall in one day, major flooding in both northern and southern California, heavy snow in the Sierra Nevada Mountains, extensive power outages, and heavy surf and coastal erosion.

ESRL scientists and colleagues in the National Weather Service are already involved in detecting and improving the forecasts of severe winter storms in California, which are known to present a major flood hazard in much of California, Ralph said. State officials have made it a priority to plan for one.

Students at the Art Center College of Design in Pasadena, Calif., will help the hazards scenario teams figure out how to communicate effectively with the public about winter storm dangers and about the preparedness drill itself. In January, Ralph talked with design students about winter storms and emergency communications, as part of a "Hazard Communication Forum."

Marty Ralph (left) and students (right) at the Hazard Communication Forum.

From Pole to Pole

HIPPO Mission: a global picture of the atmosphere, greenhouse gases

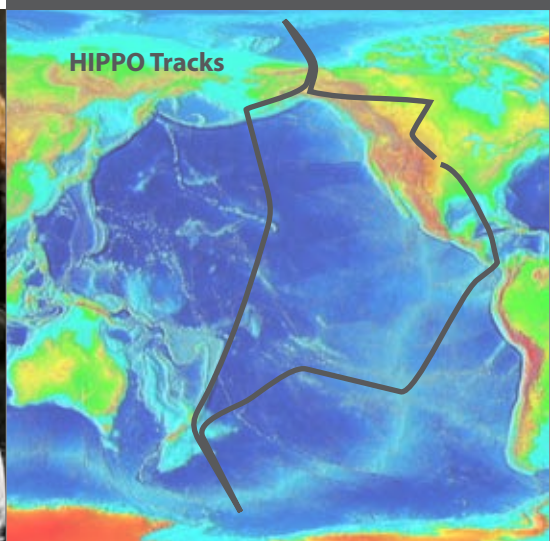
Carbon dioxide and other pollutants are higher in concentration over the Arctic than many scientists expected, and more oxygen is piling up over the Southern Ocean, according to initial data from HIPPO, a multiagency, multiyear mission to paint a three-dimensional portrait of the atmosphere.

In January, a modified corporate jet took a roller-coaster tour of the planet, looping from pole to pole with two ESRL scientists among those on board, and five ESRL instruments. Researchers captured the most detailed measurements yet of greenhouse gases, ozone, particles, and other atmospheric constituents, from 78°N to 68°S latitude and 0 to 15 km altitude. That information is critical for both climate modelers seeking to understand Earth's future, and policy makers, who rely on accurate science for decision making.

Led by Harvard University's Steve Wofsy, HIPPO is jointly operated and supported by the National Science Foundation, the National Center for Atmospheric Research, and NOAA ESRL. The mission was designed to fill the relatively empty observation space between satellites—which often can't profile the vertical structure of the atmosphere—and the ground-based instruments of ESRL's Global Monitoring Division and other networks.

"We're bridging that gap," said Jim Elkins, a HIPPO co-investigator and scientist with ESRL's Global Monitoring Division. "We've had some flights over parts of North America, and some satellites give broad coverage of the stratosphere, but they can have trouble getting down into the troposphere," Elkins said.

An early look at HIPPO data suggests great success, he said. "We got a cross-section of the atmosphere, up and down, from pole to pole. We have never done this before."



During January's journey, a series of 11 flights spanning the globe, HIAPER dipped to within a few hundred feet of the ground and ocean, and soared up into the lower stratosphere, 45,000 feet high. The mission was the first of what will be five globe-spanning journeys in the next three years, spread out among seasons and focused on areas that are not well sampled, especially the Southern Hemisphere and oceans.

"We'd really like to know more about the budgets of greenhouse gases and black carbon particles, the sources and sinks of these materials on the surface of the Earth, how they get into the atmosphere, how they get moved around," Wofsy said during a press conference after January's flights. "If people are going to actually make treaties that ban or restrain the use of these materials, those treaties have to be based on sound scientific knowledge."

NCAR's Britt Stephens told reporters that the CO_2 piling up in the Arctic is likely a result of industrial emissions from the Northern Hemisphere and the wintertime "exhaling" of the terrestrial biosphere. The slightly higher-than-expected oxygen measured over the Southern Ocean may help researchers better understand carbon dynamics in that understudied region, Stephens said.

ESRL's Fred Moore gets ready for a test HIPPO flight out of the Rocky Mountain Metropolitan Airport.

Fred Moore from ESRL's Global Monitoring Division, and Josh Schwarz from the Chemical Sciences Division flew on HIPPO. Schwarz was responsible for a Soot Particle Photometer, SP2, which measures black carbon particles—the instrument was on its first global mission. Black carbon can absorb solar radiation and warm the surrounding atmosphere. "It could have a lot of radiative effects, globally, but it hasn't yet been studied extensively," Schwarz said.

"It really gave us a tremendous aesthetic impression of the whole atmosphere and the connectedness of the globe."
—Steve Wofsy

HIPPO's third set of flights was expected to provide "ground truthing" support for NASA's Orbiting Carbon Observatory, OCO, which failed during launch in February. OCO's loss makes HIPPO data even more valuable, said David Fahey, with ESRL's Chemical Sciences Division and a member of the HIPPO science team. "The datasets are stunning," Fahey said. "These are pseudo-satellite profiles of important gases and particles across a vast region of the remote atmosphere."

The scientists who flew on HIPPO said the first leg of the mission was a stunning one visually, as well. "It's quite an experience to fly an airplane at one point in time above the ice sheets, above the floating ice in the Arctic Ocean, with the waves there and the moonlight illuminating it, and then a short while later to be in American Samoa, a tropical paradise and then a short while later, in New Zealand, and a short while after that in the Southern Ocean," Wofsy said. "It really gave us a tremendous aesthetic impression of the whole atmosphere and the connectedness of the globe."

HIPPO: HIAPER Pole-to-Pole-Observations.

HIAPER: the High-performance Instrumented Airborne Platform for Environmental Research, owned by the National Science Foundation and operated by the National Center for Atmospheric Research.

ESRL Instruments: UCATS, PANTHER, NWAS, SP2, and Classical O_3 measure trace gases, ozone, water vapor, and black carbon aerosols.


DOE/NREL

Geoengineering Problems

Proposals to lessen global warming by shooting light-scattering particles into the stratosphere could significantly reduce solar power production, a new ESRL study shows.

To slow climate change, several climate scientists have described geoengineering schemes, which would attempt to cool the planet by injecting particles into the upper atmosphere. Such "aerosol loading" would be similar to the effect of volcanic eruptions, which create particles that scatter sunlight to outer space and cool Earth's surface.

ESRL's Dan Murphy, in the Chemical Sciences Division, calculated that one unintended consequence of a successful geoengineering scheme would be a significant drop in power generation by concentrating solar facilities—a 20 percent loss in one scenario. Solar and other types of alternative energy are expected to be part of a transition away from carbon-intensive fuels.

Aerosols would not only reflect sunlight to outer space, Murphy pointed out in the paper, published in March in *Environmental Science and Technology*. Particles would also scatter sunlight to Earth as diffuse radiation, reducing the direct sunlight on which concentrating solar facilities depend.

Murphy calculated the reduction in direct sunlight using basic physics, and he verified the numbers with data following the eruption of the Philippine volcano Mt. Pinatubo, in 1991. Every 1 percent reduction in total sunlight reaching the Earth, Murphy concluded, would mean a 4 to 10 percent production loss for concentrated solar power. Passive solar designs would also be less efficient.

Peak-power production could be hit harder than total power generation, because peak demand generally occurs during times of day when the sun takes a longer, slanted path through the atmosphere, Murphy noted.

He charted the output of a concentrating solar plant in California before and after the Mt. Pinatubo eruption, and found a 14 percent drop in annual solar output associated with the volcano, and a 34 percent reduction in summertime on-peak capacity.

Technology Export

Australian meteorologists are now using customized ESRL technology to issue detailed, daily weather forecasts for the Victoria region, including parts of Australia hit hard by wildfires this year. This is the second international technology transfer for the Graphical Forecast Editor, or GFE, which is also being used in Taiwan for marine forecasts.

GFE was developed in ESRL's Forecast Systems Laboratory, now the Global Systems Division, and the system has been operational in the US National Weather Service since 2004. GFE translates the geographical outputs of weather models into gridded data points, so users can click on a location and obtain a detailed forecast.

Before GFE, US forecasters used model output as guidance, then typed out forecasts associated with geographical regions. To obtain a forecast for a particular point, a user would either rely on the regional forecast, or would call up a forecaster and ask for a new analysis at the point of interest.

Now, forecasters in the Bureau of Meteorology's Victorian Regional Forecast Centre are using GFE to prepare gridded databases of forecasting output, from temperature and clouds to precipitation and winds.

In February, devastating bushfires struck central and eastern Victoria, killing at least 210 people and destroying thousands of homes. The fires occurred on an exceptionally hot and windy day, with many places recording a record maximum temperature.

"The GFE provided a number of important operational benefits to support the provision of fire weather forecasts during this event," Jon Gill, GFE Project Manager in the Bureau of Meteorology, wrote in an email. The GFE, combined with other weather packages used by forecasters, enabled "exceptionally accurate" forecasts, Gill said. The Premier of Victoria was able to warn citizens, the day before the worst fires, "I've been briefed on the latest weather forecast for tomorrow and it's going to be, probably by a long way, the worst day ever in the history of the State in terms of the temperatures and the winds."

GFE also helped forecasters send detailed, site-specific forecasts to the field, both leading up to fires and during firefighting, when conditions were changing rapidly and updates were critical, Gill wrote.

Before the fires, the day after the Bureau of Meteorology began using GFE, Gill sent an email thanks to ESRL's GFE Team (Carl Bullock, Tracy Hansen, Tom Lefebvre, Mike Romberg, Mark Mathewson, and Joe Wakefield of the Global Systems Division). "Firstly, you gave us a terrific system to start with…. Secondly, your help in further developing the GFE to our requirements has been superb," Gill wrote.

The State Agency for Meteorology in Spain is in the planning stages for adapting the GFE for their operations. During the American Meteorological Society meeting in January, an official from the Meteorological Society of India asked Lefebvre for detailed information on GFE, and expressed interest in using the system for weather forecasting in India. Several private companies are also using GFE for their operations.

NASA

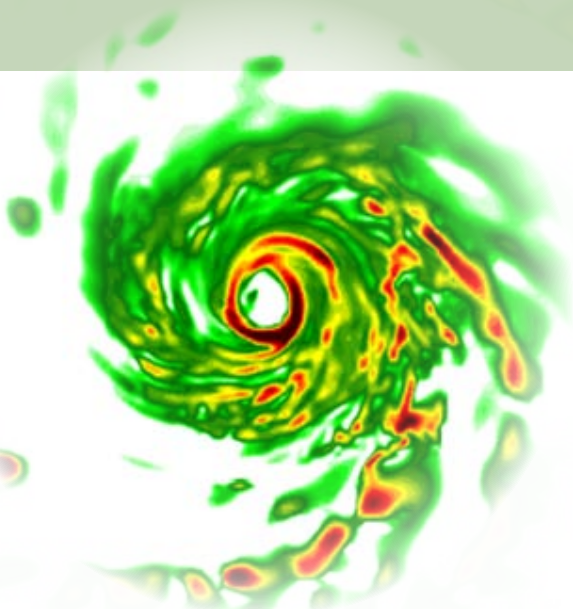
Upcoming @ ESRL

April 28-29: The First NOAA Testbed US Weather Research Program Workshop, to build collaborations and exchange information on a variety of testbed projects, including those from the Joint Hurricane Testbed, the HydroMeteorological Testbed, Collaborative Science, Technology, and Applied Research, the Societal Impacts Program, and the Development Testbed Center.

May 13-14: ESRL Global Monitoring Annual Conference, "21st Century Challenges for Long-Term Monitoring."

May 26: ESRL will host approximately 20 Hollings, Educational Partnership Program and Interdisciplinary Scientific Environmental Technology scholars this summer. Please join Dr. MacDonald as he welcomes the students at a reception.

ESRL to Host Hurricane Computer



A powerful new supercomputer is heading to ESRL this spring, to help scientists improve hurricane forecasts. The Linux cluster will be based on Intel's latest member of its Xeon line, code-named Nehalem.

"This will be a development machine," said Leslie Hart, a High-Performance Computing leader in ESRL's Global Systems Division. "The idea is to develop and improve the next-generation models for hurricane prediction."

Hart said the new computer cluster will have at least 5,000 cores and will occupy about 15 racks, each 84 inches tall. He and his colleagues hope the "Nehalem Jet" is ready to churn out experimental hurricane track and intensity forecasts by August, when the US hurricane season approaches its peak.

Steve Koch, Director of ESRL's Global Systems Division, said ESRL will host the new computer, but researchers from across government and academia will be able to access it for hurricane research. The Nehalem Jet will likely be used to run a variety of research models, from ESRL's experimental FIM (the Flow-following, finite-volume Icosahedral Model) to the National Center for Environmental Prediction's Hurricane WRF (Weather Research and Forecasting) model.

Last season, ESRL researchers and colleagues experimented with FIM (a global model) using model grid resolutions of 15 and 30 km, to generate hurricane track forecasts, including running ensembles of models. FIM forecast the track of Hurricane Ike and several other tropical storms last year with impressive skill several days before landfall. However, running the experiment required intense computing power, and ESRL scientists relied on powerful computers at the Texas Advanced Computing Center. In the future, the new Nehalem Jet computer will enable more accurate forecasts from an improved higher-resolution version of FIM, and some of that work can be conducted in-house more easily.

Running at even higher resolution than FIM is Hurricane WRF, a limited-area regional model that is planned to couple separate models of the ocean, atmosphere, and waves. Computer-intensive experiments may help researchers improve the ocean models, for example, or develop higher-resolution, larger ensembles of models to provide forecasters at NOAA's National Hurricane Center with improved measures of forecast uncertainty.

The new computer will also let researchers experiment with incorporating Doppler radar and other data collected by the NOAA P-3 hurricane hunter airplanes. In theory, those data could improve forecasts, but it is difficult to quickly quality-check and assimilate them into models.

Funding for the new computer and supportive infrastructure—more than $6 million—came from a late decision by the Bush Administration to boost the $4 million budget of NOAA's Hurricane Forecast Improvement Project to about $17 million. The new computer will triple the computing power of NOAA's Research and Development High-Performance Supercomputer, hosted by ESRL, Koch said.

ARA engineer Brian Zadler with an ultralight dropsonde.

Tower Drop

On a calm March morning, ESRL researchers and engineers from Applied Research Associates, Inc. watched as their newly-developed ultralight dropsondes drifted 950 feet down from the NOAA BAO tower in Erie, Colo. at about 10 m per second. "The drops were very successful," said Russ Chadwick of ESRL's Global Systems Division. "We experienced near-laboratory conditions." The palm-sized, bullet-shaped capsules with long tyvex tails carried wafer-thin circuit boards comprising a microprocessor, GPS receiver, battery, and transducers that measure temperature, pressure, relative humidity, and wind speed/direction. The ultralight dropsondes weigh less than half as much as existing dropsondes, which is crucial, because the intention of the collaborative effort is to develop an instrument that can be deployed from ultralight Unmanned Aircraft Systems (UAS). Eventually, solar-powered UAS, capable of traveling for weeks over remote areas of the oceans, could carry dozens of ultralight dropsondes, enabling low-cost collection of key environmental observations.

—contributed by Annie Reiser

Annie Reiser

OZONE. In the upper atmosphere, the ozone layer absorbs some incoming solar radiation, protecting Earth's surface from damage. On the surface, ozone is a pollutant, regulated by the Environmental Protection Agency because it can cause severe respiratory problems in people. Ozone also damages vegetation.

...OZONE

published in the February 2 issue of *Nature Geosciences.*

To form ozone, researchers and air quality regulators have long known that bright sunlight and hot weather can "cook" precursor chemicals—motor vehicle exhaust, industrial gases and other urban and natural emissions—into ozone. For that reason, the chemical is routinely monitored only between April and October in the United States.

In Wyoming's Jonah and Pinedale Anticline natural gas production site, JPA, ozone precursors were probably emitted in many ways by the 24-hour operation—by engines that powered compressors, by drilling rigs, by vehicles, and possibly through leaks and other processes. JPA is one of the largest and most concentrated natural gas fields in the United States.

Ozone precursors emitted there, however, were thought to rise quickly enough in the atmosphere that they shouldn't contribute to ground-level ozone. Regulators also believed that in winter, the Sun was too low in the sky to jump start the chemical reactions that lead to ozone. "Some thought the ozone must be coming from the stratosphere, or from Utah or Los Angeles, or maybe the instruments were defective," said Schnell.

His team focused on several frigid days in February 2008, when instruments near the JPA natural gas fields recorded ozone levels significantly higher than the Environmental Protection Agency standard of 75 parts per billion, ppb, averaged over 8 hours. At times that month, single-hour ozone averages topped 140 ppb, rivaling peak summertime levels of 150 ppb measured in highly polluted US cities.

The researchers discovered that ozone was rapidly produced in the fields when three factors converged: the presence of ozone-forming chemicals from natural gas operations, a strong temperature inversion that trapped the chemicals close to the ground, and extensive snow cover, which provided enough reflected sunlight to ignite the chemical reactions.

Time-series analyses showed a repeated pattern leading to high-ozone events:

...IRREVERSIBLE

several subtropical areas, comparable to the 1930s North American Dust Bowl. Affected areas included southern Europe, northern Africa, southwestern North America, southern Africa, and western Australia—and the effects lasted far beyond the year 3000. Regional impacts of that kind of drying could include diminished water supplies, increased fire frequency, ecosystem changes, and expanded deserts, Solomon and her colleagues wrote.

ESRL Director Sandy MacDonald incorporated the new results into a February talk at the National Renewable Energy Laboratory, part of the Sustainable Energy and Atmospheric Sciences seminar series. "This is a really important paper," MacDonald said. "We're on a real freight train."

Pieter Tans, from ESRL's Global Monitoring Division, said Solomon et. al did an excellent job focusing attention on the very serious problem of carbon dioxide's longevity.

Solomon's co-authors were Gian-Kasper Plattner of the Institute of Biogeochemistry and Pollutant Dynamics in Switzerland, Reto Knutti of the Institute for Atmospheric and Climate Science in Switzerland, and Pierre Friedlingstein of the Institut Pierre Simon Laplace in France.

Their research was widely covered by international media, with reports appearing in the New York Times, The Province (Canada), Gazeta do Sul (Brazil), and Le Monde (France). Andy Revkin, a New York Times reporter, asked John Sterman, an expert in risk perception at the Massachusetts Institute of Technology, for perspective.

"It's important that people not react to Solomon's work with despair," Sterman replied. "The Solomon paper should finally bury the idea that we can wait and see. It further strengthens the case for immediate, strong mitigation. The good news is that it's getting cheaper every day to cut carbon emissions."

On the Web: http://www.pnas.org/content/early/2009/01/28/0812721106.short and http://www.npr.org/templates/story/story.php?storyId=99888903

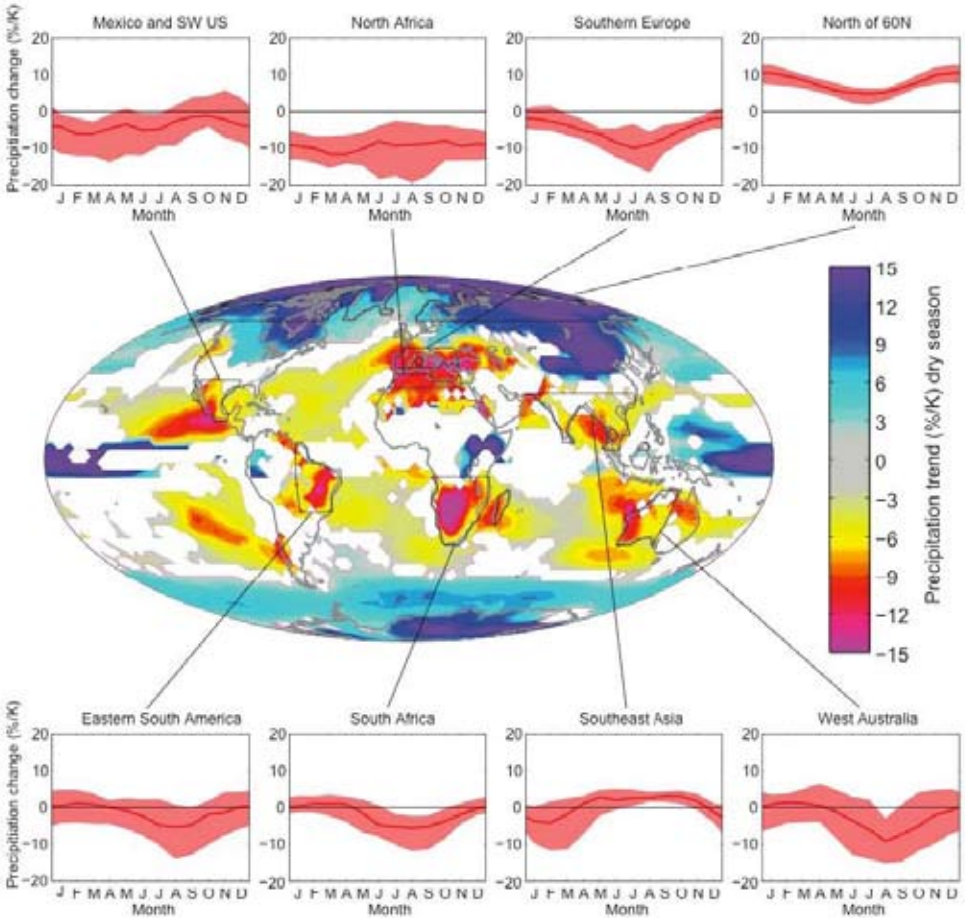


Figure 3 from Solomon et al., PNAS. Expected decadally-averaged changes in the global distribution of precipitation per degree of warming (% change in precipitation per degree of warming, relative to 1900-1950 baseline) in the dry season at each grid point, based upon a suite of 22 Atmosphere-Ocean General Circulation Models, for a mid-range future scenario (A1B). White areas are where fewer than 16 of 22 models agree on the sign of change. Data are monthly averaged over several broad regions for the inset plots. Red lines show the best estimate (median) of the changes in these regions, while the red shading indicates the +/-1-sigma likely range (i.e., 2 out of 3 chance) across the models.

Temperature inversions occurred, chemical-rich air became trapped near the ground, the sun rose, light scattered off the white snow, ozone levels surged, and precursor chemicals fell, consumed by the chemical reactions creating ozone.

"It's as if at night, you spill a bunch of gasoline, and then you just wait for the match of the Sun in the morning," Schnell said.

Schnell's co-authors were Sam Oltmans, Ryan Neely, and Allen White of ESRL; Maggie Endres of the Wyoming Department of Environmental Quality; and John Molenar of Air Resource Specialists, Inc., in Fort Collins, Colo. Ryan Neely is a graduate student at the University of Colorado at Boulder, and is the first recipient of the ESRL-CIRES Graduate Research Fellowship.

—contributed by Anatta

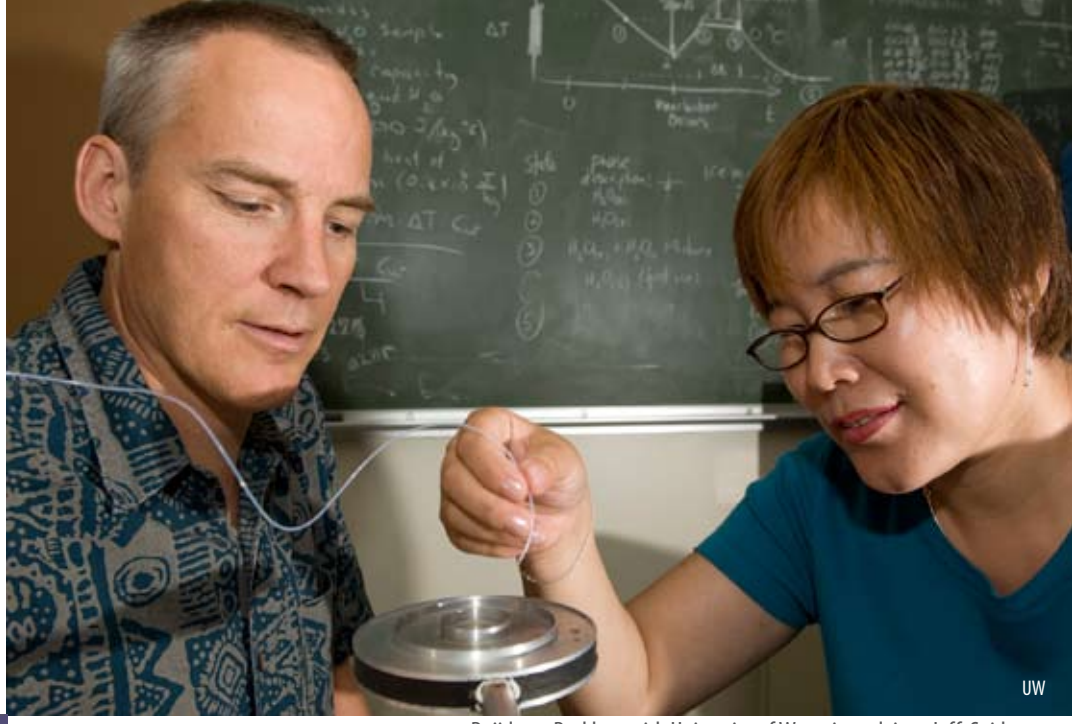
THE NATIONAL ACADEMY OF SCIENCES launched in November 2008 a series of studies called America's Climate Choices, requested by members of Congress seeking guidance on responding to climate change. The study is due in 2010, and its charge is to "investigate and study the serious and sweeping issues relating to global climate change and make recommendations regarding what steps must be taken and what strategies must be adopted in response to global climate change, including the science and technology challenges thereof."

Experts from across the government, private industry, nongovernmental organizations, and research institutions will be organized into four panels, Limiting the Magnitude of Future Climate Change; Adapting to the Impacts; Advancing the Science; and Informing Effective Decisions and Actions.

ESRL's A.R. Ravishankara, Director of the Chemical Sciences Division, will participate in the panel on advancing science (as will Waleed Abdalati from the Cooperative Institute for Research in Environmental Sciences, at the University of Colorado at Boulder). Venkatachalam Ramaswamy, Director of NOAA's Geophysical Fluid Dynamics Laboratory in Princeton, NJ, will participate in the panel on informing decisions and actions.

Susan Solomon, in ESRL's Chemical Sciences Division, and Tom Karl, Director of NOAA's Climate Services, are on the Climate Choices overarching committee, which will integrate the four panels' findings and recommendations into a final report.

Colorado Senator Mark Udall said the National Academies study is a critical one, as is ESRL's involvement. "We need more information to help us understand how to limit the effects of climate change and how to best adapt to the environmental changes climate change will bring," Udall said.



Bujidmaa Borkhuu with University of Wyoming advisor, Jeff Snider.

Master of Science (and international relations)

Bujidmaa Borkhuu, a Mongolian researcher who worked to strengthen that country's link in NOAA's global air sampling network, understands how to network people, too. She will earn a Masters in Atmospheric Sciences this spring from the graduate school where her mentor, ESRL's Russ Schnell, was the first student.

Borkhuu (Bujee) will graduate this spring from the University of Wyoming's Department of Atmospheric Sciences. Schnell, now Deputy Director of ESRL's Global Monitoring Division, graduated in 1974 and has worked more than three decades for NOAA and the Cooperative Institute for Research in Environmental Sciences.

Borkhuu's research at UW deals with a new precision instrument to measure snowfall. More precise snowfall data are needed by weather modelers to improve forecast accuracy, and by water managers and others working on precipitation questions. Borkhuu is comparing data from the new hotplate instrument to conventional snow measurements.

"My calibration is working well," she said, and the instrument is producing accurate data even in high-wind, high-elevation conditions. Borkhuu's instrument is operating on a 30-meter tower above treeline in the aptly named Snowy Range west of Laramie, Wyo.

In Mongolia, Borkhuu was recruited as a key player in NOAA's network, ensuring air samples were properly collected and sent to Boulder for analysis at ESRL. The Mongolian program, begun in 1992, had suffered from gaps in documentation and sampling procedures. When Borkhuu took over, data quality improved and maintained its dependability during her 11-year run. "Bujee brought the Mongolian program up to our high standards," Schnell said. "She also was instrumental in setting up airplane vertical measurements near Ulaanbaatar (the Mongolian capitol)," he said.

Borkhuu knows the importance of data quality assurance better than many, as her mother was a physicist in a laboratory in Ulaanbaatar. As a girl, Borkhuu visited the laboratory and observed her mother's work developing and calibrating instruments. After her graduation in May, Borkhuu is considering a PhD program, but may also look for a job in research, as a scientist who can collect and analyze precise hydrology data, including snow measurements.

Precision in Ping-Pong seems to come naturally to Borkhuu as well. She has been table tennis champion of UW for two years running, and took second place in a February tournament against other Intermountain West college champs.

—contributed by Carol Knight

Achievements, in Brief

The following sections—News, Honored, and Published—highlight a few measures of ESRL's impact.

News

First Public SphereCast

April 1, the Lawrence Hall of Science at the University of California, Berkeley, broadcast a live "SphereCast," in which climate change researcher and Nobel laureate Stephen Schneider used ESRL's Science On a Sphere® to illustrate his talk.

Science On a Sphere®, SOS, is an educational tool invented by ESRL Director Alexander MacDonald, now installed in 35 museums and other institutions around the world. The giant luminous sphere displays animations of scientific data, from hurricanes to climate change.

Lawrence Hall's public SphereCast featured Stanford University's Schneider, who spoke on "Global Warming: Is the Science Settled Enough for Policy?" while referring to data projected onto SOS. Schneider contributed to the work of the Intergovernmental Panel on Climate Change, which shared the 2007 Nobel Peace Prize with former Vice President Al Gore. Schneider's face and voice were broadcast onto flat screens at museums around the world, side-by-side with simultaneous SOS broadcasts. "I am always game to help museums with whatever it takes to entrain the public—gimmicks, new media, cool devices, etc.," Schneider said. "If it takes a new hi-tech gizmo to get people to listen, I'm game, as long as we have something worth their time to listen to."

Visitors

ESRL hosted dozens of visitors in the last three months, from elementary school students to a US Navy Rear Admiral. Three Iraqi scientists, Husam Hanna Habib, Ali Sabeeh Dawood, and Abdul Kareem Mohammad, who work for the country's Ministry of Science and Technology, met with ESRL researchers in February, to discuss weather forecasting, instrumentation, renewable energy, and other issues. The group was in Boulder primarily to work with Randolph Ware, chief scientist for Radiometrics, which builds and sells sophisticated meteorological instruments.

ESRL also hosted the Joint Interagency Coordination Group of the US Northern Command in January, to discuss NOAA research activities and plans in the Arctic, and the information needs of the Northern Command in the region. In December, Kris Sarri, of the US Senate Committee on Commerce, toured ESRL's four divisions, with NOAA officials from Legislative Affairs and the Climate Program Office.

Global Hawk Unveiling

In January, NASA and NOAA officials unveiled two Global Hawks, unmanned aircraft built by Northrop Grumman, which will be used in atmospheric research beginning this spring. The Global Hawks, better known for use in military operations, can fly for up to 30 hours, up to 65,000 feet, and can carry a payload—including scientific instruments—of up to 2,000 pounds. ESRL's David Fahey, Sara Summers, and Robbie Hood attended the Global Hawks January debut ceremony at NASA's Dryden Flight Research Center in Edwards, Calif. This spring, NASA and NOAA will launch GloPac (Global Hawk Pacific Mission), a mission to validate Earth-observing satellite measurements, observe stratospheric trace gases, track dust and smoke crossing the Pacific from Asia and Siberia, and study atmospheric rivers carrying moist air into the US West Coast.

Multicultural Conference

ESRL's PHASE program (Practical Hands-on Application to Science Education) co-sponsored an African heritage youth leadership conference at the University of Colorado in January. More than 80 Boulder Valley School District students attended the conference, organized by the district's Office of Institutional Equity and Multicultural Education. The conference theme was "We are the ones we've been waiting for." ESRL student coordinator Ann Thorne spoke with students about NOAA, about summer internships at ESRL, and about the importance of studying the planet.

Published

ESRL scientists published more than 60 papers in the last quarter, highlights below. More publications can be found at: http://www.esrl.noaa.gov/gmd/publications/, http://www.cdc.noaa.gov/pubs/ [PSD], http://www.esrl.noaa.gov/csd/pubs/, and http://www.fsl.noaa.gov/publications/ [GSD].

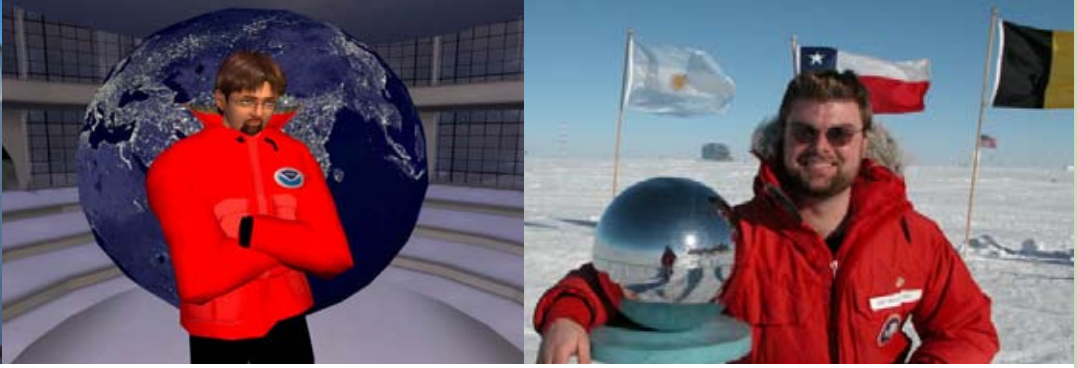
Iraqi researchers Husam Hanna Habib (left) and Abdul Kareem Mohammad (right) inspect a microwave profiler at ESRL's tower site in Erie, Colo. In the background: ESRL's Dan Wolfe (left) and Randolph Ware (right), of Radiometrics Corp.

Alexandrov, MD, B Schmid, DD Turner, B Cairns, V Oinas, AA Lacis, SI Gutman, ER Westwater, A Smirnov, and J Eilers, 2009, Columnar water vapor retrievals from multifilter rotating shadowband radiometer data, *J Geophys Res*, 114. ESRL GPS water vapor observations were used to evaluate the performance of the multifilter rotating shadowband radiometer and its ability to retrieve total column precipitable water vapor amounts for the validation of MODIS satellite water vapor products.

Compo, GP and PD Sardeshmukh, 2009, Oceanic influences on recent continental warming, *Clim Dyn*, 32. The recent worldwide land warming is largely a response to a worldwide warming of the oceans rather than a direct response to increasing greenhouse gases over land. The oceanic influence has occurred primarily by moistening and warming the air over land and increasing the downward longwave radiation at the surface.

Hoerling, M, A Kumar, J Eischeid, and B Jha, 2008, What is causing the variability in global mean land temperature? *Geophys Res Lett*, 35. Most of the observed variability of global mean land temperature during 1880-2007 is caused by variations in global sea surface temperatures (SSTs). The variability in global SSTs have themselves resulted mostly from external radiative forcing due to greenhouse gas, aerosol, solar and volcanic variations, especially on multidecadal time scales. Natural variations internal to the Earth's climate system have had a relatively small impact on the low frequency variations in global mean land temperature. It is therefore extremely unlikely that the recent trajectory of terrestrial warming

Tony Tafoya/NOAA



Eric Hackathorne, the virtual version (left) and in real life (right).

can be overwhelmed (and become colder than normal) as a consequence of natural variability.

Hofman, DJ, JH Butler, PP Tans, 2009, A new look at atmospheric carbon dioxide, *Atm Env*, 43. This paper shows that the anthropogenic global CO_2 growth rate is growing exponentially with a doubling time of 40 years closely tracking human population growth.

Hofmann, DJ and SA Montzka, 2009, Recovery of the ozone layer: the Ozone Depleting Gas Index, *EOS Trans*, 90. This is the first publication of an easily understood and robust index to track the decrease of ozone depleting gases in response to the Montreal Protocol.

Lack, DA, JJ Corbett, T Onasch, B Lerner, P Massoli, PK Quinn, TS Bates, DS Covert, D Coffman, B Sierau, S Herndon, J Allan, T Baynard, E Lovejoy, AR Ravishankara, and E Williams, 2009, Particulate emissions from commercial shipping: Chemical, physical, and optical properties, *J Geophys Res,* 114. This study is the first to provide a global estimate of maritime shipping's total contribution to air particle pollution based on direct measurements. Sixteen scientists from five different institutions used 14 instruments to observe 200 ships from around the world. The data collected provide information on ship pollutants that affect local air quality and the health of people living along coastlines.

Mercer, AE , MB Richman, HB Bluestein, and JM Brown, 2008, Statistical modeling of downslope windstorms in Boulder, Colorado, 2008, *Weather and Forecasting*, 23. This paper studies the potential for improving windstorm forecasting with linear and nonlinear statistical modeling techniques. The research is important to understanding downslope windstorms, which often strike with little warning and produce widespread damage in and around Boulder, Colo.

Michelson, SA and JW Bao, 2008, Sensitivity of low-level winds simulated by the WRF model in California's Central Valley to uncertainties in the large-scale forcing and soil initialization, *J Applied Met and Clim*, 47. This paper is the first to investigate the sensitivity of low-level winds simulated by the state-of-the-art Weather Research and Forecasting (WRF) Model in California's Central Valley to model uncertainties. It reveals the fundamental issues in discerning the error sources in air-quality modeling over complex topography and provides vital clues about how to address them.

Mofor, LA and C Lu, 2008, Generalized moist potential vorticity and its application in the analysis of atmospheric flows, *Prog Nat Sci*, 19. In this paper, the generalized moist potential vorticity is derived to depict the moist effect on potential vorticity anomaly in the non-uniformly saturated atmosphere. This will help us better understand large-scale motions in the atmosphere and oceans.

Murphy, DM, 2009, Deliberate stratospheric aerosols, direct sunlight, and concentrating solar power, *Env Sci Tech*, 43. Please see p 6.

Schnell, RC, SJ Oltmans, RR Neely, MS Endres, JV Molenar and AB White 2009, Rapid photochemical production of ozone at high concentrations in a rural site during winter, *Nature Geosci*. Please see p 1.

Solomon, S, G-K Plattner, R Knutti, and P Friedlingstein, 2009, Irreversible climate change due to carbon dioxide emissions, *PNAS*, 106. Please see p 1.

Honored

Bill Bendel was a co-recipient of NOAA's General Counsel Award, for his leadership installing Science On a Sphere® in the Smithsonian Sant Ocean Systems Gallery ~ **John Daniel** and **David Fahey** shared a Technical Achievement Award from the Environmental Protection Agency with EPA's Steve Andersen, for work on the importance of the Montreal Protocol in protecting climate ~ The American Geophysical Union has appointed **Joost deGouw** editor of the *Journal of Geophysical Research Atmospheres* ~ **Mike Hardesty** was elected to a three-year term on the American Meteorological Society Council, which governs AMS ~ **Eric Hackathorn** was named one of Federal Computer Week's 2009 "Federal 100," an award for those who made significant contributions to federal information technology. Hackathorn leads NOAA's educational efforts in the online world SecondLife ~ **A.R. Ravishankara**, Director of ESRL's Chemical Sciences Division, was the 2008 Centenary Lecturer at the Indian Institute of Science ~ **Susan Solomon** was inducted into the National Women's Hall of Fame, in recognition of her work on the Antarctic ozone hole and as co-chair of Working Group 1 of the Nobel Prize-winning Intergovernmental Panel on Climate Change (IPCC) ~ **Deb Wilson** and **Henry Diaz** won 2008 NOAA Distinguished Career Awards, Wilson for 25 years of administrative and budgetary excellence, and Diaz, now retired, for 33 years of work in climate research and monitoring ~ Twenty-five ESRL scientists received a NASA Group Achievement Award for the July 2007 TC4 mission, on Tropical Composition, Cloud, and Climate Coupling ~ Seven ESRL researchers were finalists for the Governor's Award for Research Impact, for their work on *Climate Change in Colorado, A Synthesis to Support Water Resources Management and Adaptation*. Authors were ESRL's **Andrea Ray**, **Joseph Barsugli**, **Kristen Averyt**, **Klaus Wolter**, **Martin Hoerling**, **Bradley Udall**, **Robert Webb**, and Colorado State Climatologist Nolan Doesken. The Governor's award was won by Bob Sievers, former director of CIRES, for his work developing inexpensive, inhalable, powder vaccines.

Left: University of Colorado student Jerome Jackson (left) and Victor Hernandez, Director of the Student Outreach Retention Center for Equity office (right), during a Boulder Valley School District multicultural education conference.

Right: Russian scientists have installed an ESRL ceilometer on a drifting ice station in the Arctic Ocean.

Far right: Last summer, ESRL's Dan Wolfe and Rob Albee tested the device, which measures distance to cloud bottom.

India and Drought

ESRL scientists help India plan national drought network

ESRL's Robin Webb and Roger Pulwarty traveled to India in January, at the request of government officials there seeking advice about establishing a drought early warning information system similar to the US National Integrated Drought Information System, NIDIS.

Pulwarty and Webb helped develop NIDIS, which integrates drought risk, impacts, adaptation information, and expertise from several government agencies and research institutions

"The Indian officials wanted to talk with us about the organizational part of this, the infrastructure," Pulwarty said. "They've got the scientific and technical capacity. They're just trying to figure out how to make it all work together as an effective information system."

Three Indian researchers from the Department of Agriculture's extension service and the Arid Lands Institute traveled to the United States last summer to talk with experts at ESRL and the US Geological Survey, and to attend a NIDIS workshop in Kansas on the national status of drought early warning systems. Pulwarty, Webb, and Chris Funk from the Geological Survey returned that visit in January, meeting with Indian officials at several levels of government, from the Meteorological Department and the National Institute of Agricultural Extension Management to the Central Research Institute for Dryland Agriculture.

The visit was supported by the US Agency for International Development, USAID, which recently added drought risk management to its list of top risk management concerns. Famines have devastated India periodically, with both political and climate causes. A recent study uncovered a tight relationship between El Niño events and the failure of the Indian monsoon—which may help in forecasting droughts. Monsoon rains are critical for agriculture across India.

Webb said his Indian colleagues face different challenges than he and Pulwarty dealt with when working to create a national drought information system out of parts scattered throughout government. In India, for example, department ministers seek funding from Parliament individually, instead of having a president or prime minister pitch a coordinated budget. That makes funding a new national system challenging. India also lacks a national rangeland policy, although rangeland management is a critical part of dealing with drought.

However, local governments across India already do a good job of collecting on-the-ground information about drought impacts and responses, Webb and Pulwarty said, and there is a solid understanding that any drought information system must have both social and scientific dimensions.

USAID is also funding ESRL's Marty Hoerling and Balaji Rajagopalan, from the University of Colorado's Cooperative Institute for Research in Environmental Sciences, to continue their research studying the effect of climate change on drought and monsoons in India.

Robin Webb (top) and Roger Pulwarty (below).

After President Bush signed the NIDIS Act into law in 2006, the agency took shape under a partnership between the Western States Governors Association and NOAA. NIDIS is hosted by ESRL and supported by the NOAA Climate Program Office. Webb is on the NIDIS science and implementation team, which is chaired by Pulwarty and comprised of representatives from more than 50 federal, state, and tribal agencies.

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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.