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MESSAGE FROM THE NCAR DIRECTOR

The National Center for Atmospheric Research (NCAR) is one of the world's premier scientific institutions, with an internationally recognized staff and research program dedicated to advancing knowledge, providing community-based resources, and building human capacity in the atmospheric and related sciences. In this Annual Report, as well as the accompanying Laboratory Reports, I invite you to learn more about how our staff are collaborating with the broader research community, nationally, and internationally, to produce impressive advances in our understanding of fundamental atmospheric processes and how the atmosphere interacts with and is influenced by other components of the Earth and Sun system. This progress is being driven, in part, by new technologies and their effective utilization at NCAR, including advanced observing facilities for field studies, powerful supercomputing capabilities, valuable research data sets that describe the Earth and the Sun, and widely used state-of-the-science community models that are providing improved capabilities for predictions of weather (including catastrophic events), air quality, hydrology, climate variability and change, and space weather. Moreover, educational and technology transfer activities at NCAR continue to encourage outstanding young scientists into the field and bring new research and technical achievements into the public and private sectors. Although only a small sampling of the many notable accomplishments of the past year, these aspects are illustrated through the accompanying set of 10 highlights of our work.

A major focus of my first full year as director was the completion of NCAR's new strategic plan, which is easily accessible from our main web page. I thus also invite you to review this strategic plan, which will steer NCAR's direction over a period of time that will present significant opportunities and challenges for the atmospheric, geospace, and related sciences. Despite impressive gains in knowledge, our understanding and predictive capabilities remain insufficient for many societal needs. The reality of human-induced climate change is established, but the current generation of weather and climate modeling systems is inadequate to provide the accurate and reliable predictions of regional changes in climate and high impact weather required for adaptation and mitigation strategies. An increasingly sophisticated and technological society remains vulnerable to atmospheric and space weather hazards, air quality remains a major health issue, and we are witnessing the global stresses of food and water shortages.

The new strategic plan lays out a vision for NCAR to help tackle these challenges by focusing on the development, application and analysis of next-generation numerical models, the development and deployment of new observing systems, and the development of new capabilities for extracting useful information from "Big Data." Ultimately, NCAR will only be successful in addressing these challenges by continuing to work synergistically with the broader academic community. This includes relations with university researchers coming to NCAR as both short- and long-term visitors, serving on NCAR advisory committees and working groups, and working as principal investigators on field campaigns. In so doing, NCAR will continue to embrace a leadership role in delivering objective information in support of national and international decisions on mitigation, adaptation, resiliency, and sustainability, and it will continue to actively engage with the stakeholders and the consumers of its science.

For now, please enjoy this Annual Report as but a snapshot of NCAR competencies, facilities, and scientific accomplishments achieved over the past year. In addition, please accept my sincere thanks for your ongoing support and your hard work.

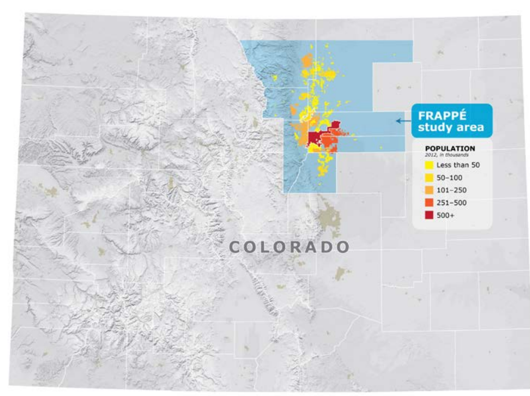
With best wishes for 2015,

Jim Hurrell

‹ 2014 NCAR Annual Report up FRAPPÉ tracks Front Range pollution ›

FRAPPÉ TRACKS FRONT RANGE POLLUTION

NCAR and its research partners successfully conducted a landmark field project last summer to track the origins of summertime ozone pollution over the Front Range of Colorado. The month-long study, known as the Front Range Air Pollution and Photochemistry Éxperiment (FRAPPÉ), tracked emissions from both human-related activities and natural sources.



FRAPPÉ sampled and examined the atmospheric conditions pertaining to air quality north of Fort Collins, Colorado. Study area is indicated in blue.

Summertime air pollution on the Front Range, including Denver, often exceeds federal standards for safe levels of ground-level ozone pollution despite efforts to reduce emissions. Ozone can lead to increased asthma attacks and other respiratory ailments. It also damages vegetation, including crops.

FRAPPÉ focused on the urban corridor from south of Denver to north of Fort Collins, as well as the adjacent plains and mountains. Scientists also measured pollution from upwind areas, including other states and countries. “Our goal is to produce an accurate and detailed view of all the diverse sources of ozone pollution along the Front Range,” said ACD’s Gabriele Pfister, a principal investigator on the project. “We want to fingerprint where the pollution comes from and analyze what happens when it mixes in the atmosphere.”

The researchers used specially equipped aircraft on a total of 15 flights, as well as networks of ground-based instruments and sophisticated computer simulations. “The flights were generally successful in addressing the project goals, even in light of the unusually cool summer,” said ACD’s Frank Flocke, a principal investigator. “The data coverage and instrument reliability was excellent.”

FRAPPÉ was funded by a state-federal partnership, with support from both the Colorado Department of Public Health and Environment and the National Science Foundation.

The NSF/NCAR C-130 aircraft, one of the aircraft involved in FRAPPÉ, is based at NCAR’s Research Aviation Facility (RAF) at Rocky Mountain Metropolitan Airport in Broomfield, Colorado. RAF

Two major projects converge

To provide additional detail across the region, scientists closely coordinated FRAPPÉ with a second air quality mission taking place on the Front Range at the same time. DISCOVER-AQ (Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality) was a major study led by NASA seeking to improve the ability of satellites to

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usefully assess our air quality.

develops and operates instrumented research aircraft for the atmospheric science community.

The DISCOVER-AQ flights and ground observations focused on the northern Front Range, while FRAPPÉ also gathered measurements from the surrounding region. In all, approximately 200 scientists, technicians, pilots, and students from around the country converged on the Front Range for the combined projects.

The researchers quantified emissions from industrial facilities, power plants, motor vehicles, agricultural operations, oil and gas drilling, fires, and other sources. They also measured naturally occurring emissions from trees and other plants that then combine with emissions generated by human activity to form ozone and other pollutants.

Colorado, like other states, relies on a limited number of ground-based stations to monitor air quality and help guide statewide policies and permitting. But a full, three-dimensional picture of the processes that affect air quality, including conditions far upwind and high up in the atmosphere, requires a three-pronged approach with measurements from aircraft, satellites, and the ground. “By bringing together aircraft, satellites, and ground-based instruments, we can analyze the amounts and types of pollutants that are emitted in the Front Range as well as transported from other places, how they evolve, and how air circulation patterns near the mountains move them around,” Flocke said.

“[The research] will help us more fully understand complex questions such as the factors contributing to ozone formation in the region,” said Will Allison, director of the Colorado Department of Public Health and Environment’s Air Pollution Control Division. “And that will help us continue to implement effective measures to reduce air pollution.”

FRAPPÉ and DISCOVER-AQ used similar payloads for their aircraft. The teams conducted wingtip-to-wingtip intercomparison flights during the project, sampling air in the same place to make sure the instrument readings are comparable.

A network of in-situ instruments deployed on the ground, on towers, rooftops, and mobile vans continuously monitored ozone and the gases that reacted to form it. These as well as the aircraft flights were also closely coordinated with measurements from tethered balloons and from lidars (laser-based radars).The researchers drew on forecasts and nowcasts of both weather and air quality from a large number of computer models to assess daily conditions and make final decisions on when to fly and where to gather atmospheric samples.

The data gathered by the projects are going through a quality assurance process before becoming publicly available early January 2015. There will be a FRAPPÉ /DISCOVER-AQ science team meeting in Boulder from May 4-8, 2015 to discuss first results.

In addition to NCAR and the Colorado Department of Public Health and Environment, the FRAPPÉ team includes scientists from the National Oceanic and Atmospheric Administration; Cooperative Institute for Research in Environmental Sciences; National Park Service; Regional Air Quality Council; Global Ozone Project; Western Regional Air Partnership; Environmental Protection Agency; University of Colorado Boulder; Colorado State University; University of California, Berkeley; University of Wisconsin; University of Cincinnati; Georgia Institute of Technology; University of California, Riverside; Aerodyne Inc.; U.S. Naval Academy; University of Rhode Island; University of California Irvine; and Princeton University.

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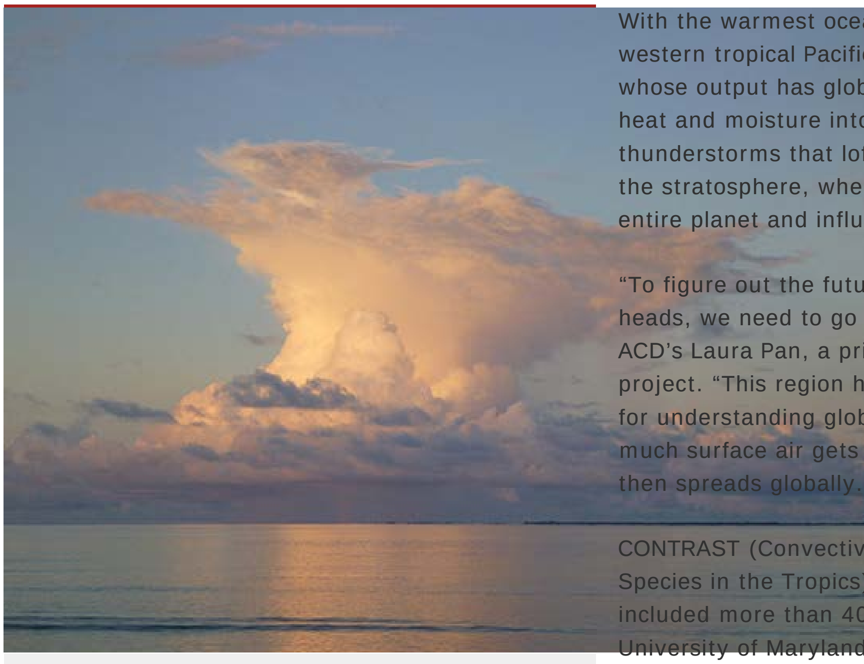
CONTRAST: SCIENTISTS EXAMINE PACIFIC'S "GLOBAL CHIMNEY"

Even though few people live in the western tropical Pacific Ocean, these remote waters affect billions of people by shaping climate and air chemistry worldwide. By conducting a successful field project there last year known as CONTRAST, scientists hope to better understand the region's influence on the atmosphere, including how that may change in coming decades if storms over the Pacific become more powerful with rising global temperatures.



Showers and thunderstorms over the tropics can grow from isolated systems, as shown here in the Maldives, to larger complexes that loft vast quantities of air from the lower atmosphere to the stratosphere. CONTRAST examined how such circulations evolve over the western tropical Pacific, where they can influence atmospheric chemistry over wide areas.

With the warmest ocean waters on Earth, the western tropical Pacific fuels a sort of chimney whose output has global reach. The region feeds heat and moisture into huge clusters of thunderstorms that loft gases and particles into the stratosphere, where they spread out over the entire planet and influence the climate.

"To figure out the future of the air above our heads, we need to go to the western Pacific," said ACD's Laura Pan, a principal investigators on the project. "This region has been called the holy grail for understanding global air transport, because so much surface air gets lifted by the storms and then spreads globally."

CONTRAST (Convective Transport of Active Species in the Tropics) was based in Guam. It included more than 40 scientists from NCAR, the University of Maryland, the University of Miami, other universities across the country, and NASA. It was funded by NSF.

Pan said the 16 flights succeeded in gathering important data. The research team was able to get information on the structure of ozone, the movement of bromine compounds, and other important air chemistry processes. "The field phase measurements were very successful," she said. "We had many good case studies of convective transport."

CONTRAST was coordinated with two other field projects in order to give researchers an especially detailed view of the air masses over the Pacific with a vertical range spanning tens of thousands of feet.

One of these projects, NASA's Airborne Tropical Tropopause Experiment (ATTREX), used a Global Hawk, a robotic aerial vehicle, to study upper-atmospheric water vapor, which influences global climate. The other, CAST (Coordinated Airborne Studies in the Tropics), was funded by Britain's Natural Environment Research Council Facility. CAST deployed a BAe146 research aircraft that will focus on air near the ocean surface.

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Together, the sensor-laden research flights provided a comprehensive view of the atmosphere from the ocean surface, where gases produced by marine organisms enter the air, to the stratosphere, more than 60,000 feet above.

Gateway to the stratosphere

As trade winds flow across the tropical Pacific, they push warm water to the west, where it piles up in and near the CONTRAST study region. The waters around Guam have the world's highest sea surface temperatures of open oceans. They provide heat and moisture to feed clusters of thunderstorms that lift air through the troposphere (the lowest level of the atmosphere) and the tropopause (a cold, shallow region atop the troposphere) and then up into the stratosphere.

Once in the stratosphere—where the air tends to flow horizontally more than rising or sinking—the gases and particles spread out around the world and linger for years or even decades.

Some of the gases, such as ozone and water vapor, affect the amount of energy from the Sun that reaches Earth's surface. The amount of these gases in the stratosphere is important for the planet's climate. Other chemicals, such as bromine compounds, have indirect effects by destroying ozone or otherwise altering the chemistry of the stratosphere. And the gases produced by ocean organisms create a signature of marine biology in the stratosphere.

As atmospheric patterns evolve and sea surface temperatures warm further due to climate change, the storm clusters over the Pacific are likely to influence climate in ways that are now challenging to anticipate. "Understanding the impact of these storms will help us gain ground truth for improving the chemistry-climate models we use to project future climate," Pan said.

The CONTRAST team deployed the NSF/NCAR HIAPER aircraft. Using spectrometers and other instruments on board, the researchers measured various chemicals and took air samples across a wide region, both in storm clouds and far away from them. They targeted both both towering storms that loft fresh air into the stratosphere as well as collapsed storms to examine the composition of the air that remains lower down, in the troposphere.

Researchers from the three coordinated projects met in October to discuss preliminary findings. They are planning a workshop next year, jointly sponsored by SPARC (Stratospheric-Tropospheric Processes and Their Role in Climate) and IGAC (International Global Atmospheric Chemistry), which will involve a broader community to focus on science questions targeted by the field projects.

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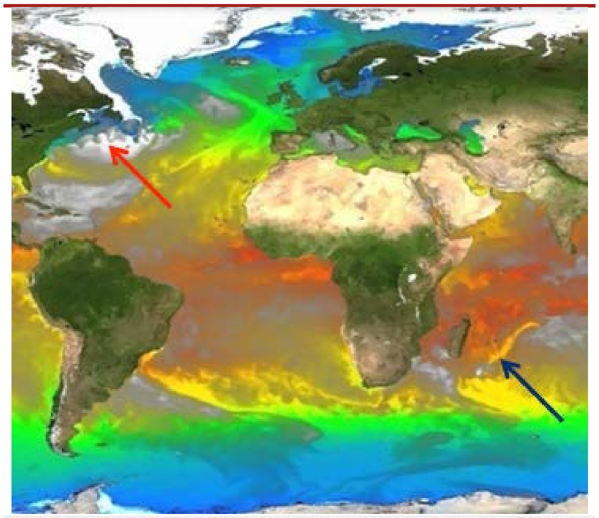
A NEW CLASS OF GLOBAL CLIMATE MODELS

In FY14, NESL/CGD scientist Justin Small and colleagues analyzed the most comprehensive high-resolution simulation ever carried out with an NCAR climate model. It took the power of the Yellowstone supercomputer, based at the NCAR/Wyoming Supercomputing Center (NWSC), to carry out the project. The simulation spanned a century's worth of climate, including critical exchanges between atmosphere, ocean, sea ice, and the land surface.

Ultimately, the new high-resolution version of the Community Earth System Model (CESM-H)—which saw its first century-scale usage in Small's project—is well positioned to generate many new insights into the workings of our past, present, and future atmosphere. First, though, scientists must evaluate the overall quality of the CESM-H, as well as a handful of other, similarly upgraded models around the world. Their goal is to verify how well these new models depict the intricacies of climate, making sure that the advantages are well understood and any flaws are recognized and accounted for. These models are likely to inform the next assessment from the Intergovernmental Panel on Climate Change (IPCC), expected to take place in the late 2010s.

From the earliest days of climate modeling, the biggest constraint has been the finite nature of computing hardware itself. Today, hugely powerful machines and vast data-storage facilities are used to carry out and archive the enormous number of calculations involved in a single century-scale simulation. With this in mind, the NWSC was built to accommodate not only a modern-day supercomputing system on par with Yellowstone, but also the still more massive and complex systems that will be needed years from now.



This image from the century-long simulation produced by the high-resolution Community Earth System Model (CESM-H) shows latent heat flux (gray, with bright white indicating the greatest heat transfer from ocean to atmosphere) overlaid on sea surface temperature (colors, with the coldest in blue and the warmest in red). The arrow at top left highlights the influence of eddies along the Gulf Stream on cold air streaming out to sea from from eastern Canada, while the arrow at lower right shows cooler waters left in the wake of a tropical cyclone in the Indian Ocean. Both types of phenomena are not well simulated by standard-resolution climate models.

Even with Yellowstone, hardware-based limits on climate modeling remain a factor, and every method for dealing with them has its pros and cons. For example, the output from lower-resolution global models can be further refined across specified areas, a technique called downscaling. And some global models now include variable meshes that allow for zoomed-in regions within the larger grid. However, these and similar approaches all require that careful attention be paid to how phenomena on smaller and larger scales interact with each other.

When a high-resolution model grid straddles the entire globe, many of these potential problems are erased. The CESM-H includes a horizontal resolution of 25 km in its atmospheric component, more than 10 times more data points than the standard CESM. Oceans are depicted at resolutions of 10 km or less, also far sharper than in standard

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global models. However, all this requires many more calculations—and, as Small reiterates, "there are real limits on computing power and data storage."

The petabyte-scale Yellowstone can carry out more than 1.5 quadrillion calculations per second, but the CESM-H still gave it quite a workout. The century-long CESM-H simulation was conducted over several months in late 2012 and early 2013, shortly after the supercomputer's installation, as part of the NSF-sponsored Accelerated Scientific Discovery (ASD) program. ASD allowed a carefully chosen set of cutting-edge projects to run their course before routine operations on Yellowstone began.

Some benefits of high-resolution global modeling were already known before the CESM-H project. These include

- more realistic timing and strength of El Niño–Southern Oscillation (ENSO), the single biggest shaper of year-to-year climate variations worldwide;
- more accurate depiction of ocean circulation along west-facing shores, such as the California coast;
- and improved portrayal of heavy rain and snow across land areas, particularly over large mountain-dominated areas such as the Rockies, where topography must be simplified in lower-resolution models.

CESM-H confirmed many of these strengths. In particular, the overly intense El Niño and La Niña events found in many models were much more realistically captured in CESM-H—although Small and colleagues have found it a challenge to prove exactly why the ENSO portrayal had gotten better.

"Myriad processes govern the amplitude of ENSO events," notes Small, "so attributing the cause of the improved ENSO simulation is not straightforward." Small is collaborating with peers at NCAR, NOAA, and the University of Hawaii to unravel the factors at work.

The CESM-H also appears to be the first high-resolution global model to accurately depict the preferred location of the Atlantic intertropical convergence zone, the east-west band where northern and southern trade winds collide and generate showers and thunderstorms. Small and colleagues are now sorting out how much of the improvement is due to the higher model resolution and how much can be attributed to a set of new formulations of atmospheric physics employed in the model. Their strategy includes mixing and matching various model resolutions in a suite of experiments to tease out the important elements.

A number of the world's leading centers for climate modeling are now examining how the new generation of high-res global models could feed into the next IPCC assessment, which will be the sixth in a series of major reports that began in 1990. A key goal will be to make the best use of the limited number of century-scale simulations that computing and funding constraints will allow. Colleagues around the world will craft a common set of guidelines for these simulations. One proposed idea is to focus on the period 1950–2050, which would meet two goals at once: simulating several decades of recent climate, thus allowing model performance to be compared to observations, while also venturing into the middle part of the 21st century, when some of the more worrisome impacts of climate change may become more noticeable.

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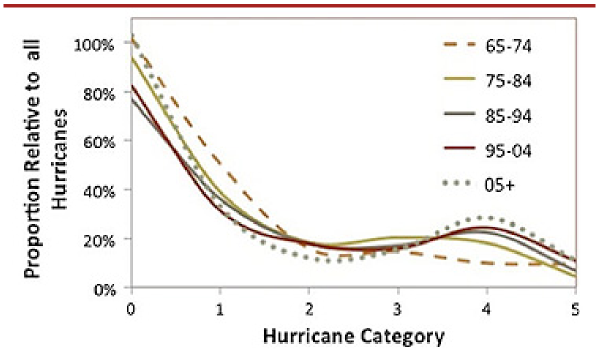
SHARPENING OUR VIEW OF HURRICANES, FUTURE AND PRESENT

For centuries, tropical cyclones have been among the most feared weather phenomena on Earth. Although the behavior of specific tropical cyclones can vary wildly, there's a surprising consistency to the global distribution of these massive storms (the strongest of which are called hurricanes in the North Atlantic and Northeast Pacific and typhoons in the western North Pacific).

Well-defined tropical "genesis regions" produce tropical cyclones each year; many of these storms sweep into midlatitudes, with a few striking such areas as the U.S. East Coast or East Asia. Although some genesis regions may be more productive and others less so in a given year, the action tends to average out. All told, the planet usually sees somewhere between 40 and 60 tropical cyclones reaching hurricane strength (winds of 74 mph) in a given year.

What are the odds that a warming planet will tamper with these long-established patterns? Scientists at NCAR have monitored trends in tropical cyclone (TC) behavior, and simulated the potential influence of increased greenhouse gases, for more than a decade. Research in FY14 bolstered a growing consensus—reflected in the 2013 report of the Intergovernmental Panel on Climate Change—that the world of the late 21st century will most likely see slightly fewer tropical cyclones, but a greater proportion of intense ones.

The record onslaught of Atlantic hurricanes in 2005 (including the horrific Katrina) helped spur a number of studies by Holland and others establishing that recent decades have seen a global jump in the number of Category 4 and 5 TCs, those with winds exceeding 130 mph. Although most modeling work indicates this trend should continue, Holland and Bruyere suggest that we might actually hit a ceiling over the next several decades. The concept is straightforward: once almost every hurricane with the potential to reach Category 4 status now makes the grade, there can be little further growth in the number of those behemoths.



Normally, the strongest hurricanes would be expected to be least numerous. However, as conditions allow for more tropical cyclones to intensify dramatically, recent years have seen a bimodal distribution, with a local minimum in hurricane frequency in the Category 2–3 range and a growing peak at the Category 4 level. (Image courtesy Greg Holland and Cindy Bruyère, used with permission from the 2014 Climate Dynamics paper "Recent intense hurricane response to global climate change," doi 10.1007/s00382-013-1713-0.)
Signs that our planet is already moving in this direction emerge from recent work by NCAR's Greg Holland and Cindy Bruyere (NESL Mesoscale and Microscale Meteorology Division). Interested in the link between rising global temperatures and TC behavior, the scientists calculated how each degree Celsius of global warming attributable to greenhouse gases has already affected the mix of TCs that attain various strengths.

"The implication here is that climate change is not just something in the future—we have already experienced substantial change in Category 4 and 5 hurricanes," said Holland. He adds that the efforts to assess how long this observed increase will continue, and whether a limit is appearing, have fundamental implications for community planning and development.

When Kevin Reed joined NCAR's Advanced Study Program in 2013, he brought a keen interest in future tropical cyclones with him. Reed used NCAR's Community Atmosphere Model (CAM) for

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his dissertation work at the University of Michigan. At UM, Reed explored how well the CAM simulated tropical cyclones across the globe when the model was configured at high resolution—with around 25 kilometers between grid points, compared to the typical resolution in global models of closer to 100-km.

While 25 km isn't quite sharp enough to capture the showers and thunderstorms that feed an individual hurricane, Reed found that this resolution still managed to portray the climatology of a season's worth of tropical cyclones (TCs) fairly well, while cutting back on the expense that a even higher-resolution approach would require.

"Since the 25-km CAM does a reasonable job in the current climate, it suggests that the model is a good tool to study how tropical cyclones may change in our future climate," said Reed.

The next step, after Reed arrived at NCAR, was carried out in collaboration with a number of colleagues in NESL's Climate and Global Dynamics Division. They zeroed in on a two-decade-long slice of climate (2070-2089), using the 25-km CAM together with two different scenarios of how greenhouse gases might increase this century: a middle-of-the-road option, RCP4.5, and the most intense scenario, RCP8.5 (RCP stands for representative concentration pathway).

The globe-spanning experiments produced a crop of tropical cyclones whose characteristics are in line with those found in several other recent studies. The average total annual count of TCs dropped by close to 10% in the RCP4.5 scenario and by almost 20% in the RCP8.5 scenario. Although the CAM's future planet doesn't generate as many TCs as we see today, a higher fraction of those that do form are in the most dangerous range, with sustained winds topping 130 mph (Categories 4 to 5 on the Saffir-Simpson scale).

Even as the world inches toward an uncertain climatic future, attention zooms back to the here and now with the approach of each year's hurricane season. Millions of people scrutinize the seasonal outlooks that are issued at several points in advance of the Atlantic season. Among the groups that issue such outlooks are forecasting teams based at NOAA, Colorado State University, and University College London (tropicalstormrisk.com).

Seasonal hurricane outlooks are based largely on the correlations between sea-surface temperatures, and other features that can persist for months, and the subsequent occurrence of hurricane formation. While the tools used by each group vary somewhat, these outlooks have a common enemy: internal variability, or processes that unfold without being dictated by larger-scale features. Work led by NCAR's James Done (NESL Mesoscale and Microscale Meteorology Division) suggests that such variability can make one season twice as active as another, even when El Niño and other large-scale hurricane-shaping elements are unchanged.

Done and colleagues zeroed in on a single hurricane season (1998) using an NCAR-based version of the Weather Research and Forecasting model. They incorporated the role of internal variability by introducing minor variations in the atmosphere, too small for seasonal forecast models to capture, at the beginning of each model run. The team simulated the 1998 season 16 times, each time with different but equally likely atmospheric features at the start of the key study period (May 1).

Despite the similarity of their starting points, the 16 simulations produced as few as 6 and as many as 12 tropical cyclones in the deep North Atlantic tropics, where a total of 7 TCs actually formed. The wide range of equally plausible outcomes suggests that a large dose of uncertainty may be unavoidable in any particular seasonal outlook.

"It appears there is an upper limit on how well we can predict hurricane frequency in advance of a season," Done said. With more research, he added, it's possible that tools that explicitly include the amount of natural uncertainty could be developed for use in seasonal hurricane prediction. This would help give stakeholders and the public a better idea of each outlook's margin of error.

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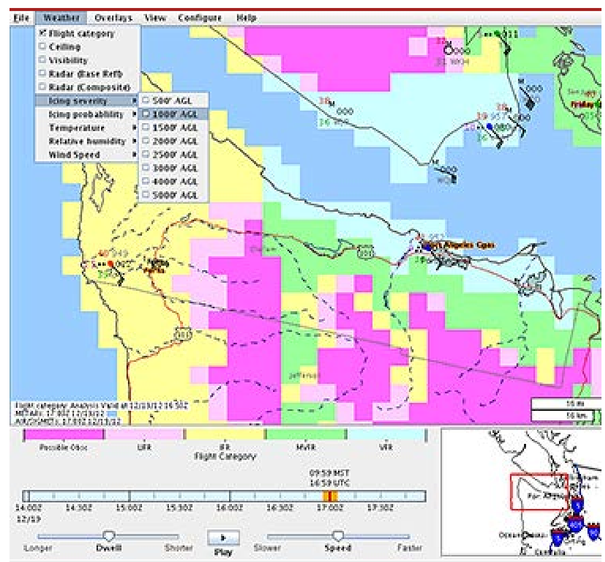
GUIDING RESCUE HELICOPTERS: NEW NCAR TOOL HIGHLIGHTS WEATHER CONDITIONS FOR EMERGENCY MEDICAL FLIGHTS

For many years, NCAR has provided an experimental tool for helicopter rescue pilots who must decide quickly whether weather conditions are safe enough to attempt a low-altitude flight. Recently the NCAR team has made key upgrades to the Helicopter Emergency Medical Services (HEMS) tool that enables it to be more widely used in rescue situations.

The HEMS Tool provides important information for rescue pilots. It runs on a desktop application and gives users a seamless graphical compilation of reported and forecasted winds, visibility, clouds, temperatures, and radar data for the continental United States.

But HEMS is particularly notable in that it creates an "intelligent interpolation" of low-altitude visibility and ceilings (the height of the lowest cloud layer) between observation stations by using algorithms that take into account the terrain, forecasting models and technical assessments. That allows users to view an area as small as 5 kilometers by 5 kilometers anywhere in the country and get actual or estimated data about its visibility and cloud heights. In addition, it presents the data measured in feet above ground level instead of mean sea level, which is generally used by pilots but is less helpful to those who only fly at low altitudes.



HEMS enables rescue pilots to view atmospheric conditions, including ceiling, visibility, wind speed, and icing potential, at various altitudes above ground level.

Since its creation in 2006, HEMS has been available on an experimental site hosted by NCAR. It is expected to become an approved flight planning tool supported by the National Oceanic and Atmospheric Administration (NOAA) at some point next year, increasing its visibility to those engaged in emergency evacuations.

The program's recent updates, which are available on NCAR's site, allow users to track visibility and ceiling trends in order to better determine if conditions are improving or deteriorating. It also adds important topographical data such as contoured elevation lines and enables users to locate landmarks to help with navigation, such as heliports or hospitals. Without that information, the Federal Aviation Administration (FAA) found that helicopter rescue pilots have too often flown from safe conditions on takeoff into unanticipated areas of poor visibility, resulting in crashes into obstacles or terrain.

The HEMS Tool is now used by every major air medical operator in the U.S. and has a potential economic benefit of over $50 million year, according to Christopher Eastlee, president of the Air Medical Operators Association. "Other tools didn't provide high enough resolution and didn't show conditions exactly where HEMS pilots were flying to pick up patients," said Arnaud Dumont, a senior software engineer in NCAR's Research Application Laboratory, which developed the application.

NCAR has a long and successful history with the FAA, NOAA, and other agencies with primary missions focused on safety, protection of life and property and efficiency. Its decades-long collaboration with the FAA goes back to the early 1980s when groundbreaking research was conducted on deadly microbursts that were taking airplanes down around airport terminals.

The HEMS tool is an extension of NCAR's Aviation Digital Data Service (ADDS) program that provides pilots with easy-to-use web access to a variety of critical aviation weather information. It was developed at the request of the FAA after a 2006 review of rescue helicopter crashes revealed that a lack of detailed weather information was often a factor. While good weather information is usually available near airports and large cities, no data are available for many other areas.

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SCIENTISTS HELP REPEL MOSQUITO-BORNE DISEASE WITH MODELS

Every year about 400 million people contract dengue virus, primarily from bites of *Aedes aegypti* mosquitoes, which live in tropical and subtropical regions. Dengue virus can cause dengue fever, also known as "breakbone fever," which has symptoms that may include high fever, severe headache, rash, and pain in the eyes, joints, muscles, and bones. With roughly one percent of dengue fever cases developing into the more severe hemorrhagic fever and no approved vaccine available to treat the disease, healthcare officials are looking for a way to better predict and, in doing so, preventing dengue outbreaks.

Aedes aegypti are daytime biting mosquitoes and prefer human-blood meals. They live where people live, developing in water-filled containers in and near homes. These containers provide perfect habitat for mosquito eggs, larvae, and pupae.

To better predict and monitor dengue outbreaks, researchers in NCAR's Research Applications Laboratory (RAL) and Science and Technology in Atmospheric Research (STAR) developed a prototype risk-mapping framework with a team of scientists from Mexico, Arizona, Colorado, and Virginia. The system utilizes a series of geospatially diverse data sets that characterize weather, likelihood of mosquito habitats, and human and mosquito populations. The data sets are used in a sequence of models, including a newly developed algorithm that approximates mosquito habitat, in order to produce dengue risk maps.

"We combined a variety of models, including the Weather Research Forecasting model, mosquito population and virus transmission models, and an energy balance model that estimates water temperature and water height in containers, which are critical factors in larvae development," says Paul Bieringer, a scientist in RAL and at STAR.

The regions highlighted in orange on the map are primarily at risk from dengue outbreaks. The red lines show the 10-degree C isothermal line, which are the potential geographical limits of the Northern and Southern Hemisphere for year-round survival of *Aedes aegypti* mosquitoes.

To create the algorithm, the team used human population data and satellite images of the study site located near the town of Orizaba in central Mexico. The group turned to Oak Ridge National Laboratory's national database of urban and regional population to obtain the population data. To get an idea of what the environment looked like near Orizaba, the researchers used very high-resolution satellite imagery. Merging the population and environmental data, the algorithm helps researchers estimate the number of containers that could be used by immature mosquitoes for development.

The resulting data and modeling framework generates a map that provides an initial estimate of the rate of mosquito reproduction and the prevalence of transmission of disease from mosquitoes to humans in near-real time.

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The geography of this first study site will aid the researchers in assessing the mapping system. The region's hilly geography results in large variations in rainfall rates and temperature across the landscape, making obvious differences in conditions favorable to mosquito survival and reproduction, and therefore dengue outbreaks, easily identifiable. The project's next step is moving forward with validation of the mapping system's accuracy. If deemed accurate, a similar approach will be used to test the system's utility in other regions where dengue is endemic, Bieringer says.

"The goal of this project is to predict for a given month how mosquitoes respond to changing weather patterns and the related effects on disease prevalence," says Bieringer. "Validating our initial mapping effort will require looking at the available records of dengue incidence in the region to see if our mapping estimations are accurate."

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HCR: HIAPER CLOUD RADAR

As scientists work to improve climate models, one of the biggest uncertainties that they need to resolve is a clear understanding and treatment of cloud processes. Observations are critical to achieving this end. The Earth Observing Laboratory (EOL) develops and operates many of the instruments that the U.S. research community relies on to obtain the required high-quality environmental observations for model validation. Among the latest of these is EOL's HIAPER Cloud Radar (HCR), which is providing researchers with detailed observations of cloud dynamics.

The HCR is one of a suite of instruments developed for the NSF/NCAR Gulfstream V (GV or HIAPER) research aircraft. Before instrument development began, EOL polled the community to identify conceptual design of the HCR to support their climate and weather research. They requested an narrow beam radar capable of detecting and quantifying small amounts of liquid and ice with a second wavelength and/or dual-Doppler capability. The scientists estimated that such a design would significantly extend the utility of radar observations by further reducing uncertainty in radar-based measurements of cloud properties.

EOL built the HCR based on this input, but also had to factor in size and weight restrictions because the instrument would fly in a pod attached beneath the GV's wing. As a result, the HCR became a small, compact radar built in three phases, beginning with the pod-based W-band radar system with scanning capability. In the second phase, which the team estimates will be completed in 2016,a pulse compression will be added for improved sensitivity and polarimetric capability to the W-band system operating at 95 GHz. The third and last phase will add the complementary K_a-band radar operating at 35 GHz; completion of this last phase is estimated to occur in the next two to three years.

The HCR, which operates both on the GV and as a ground-based sensor, opens up new observational opportunities for the NSF research community, says Jothiram (Vivek) Vivekanandan, a senior scientist at EOL and the lead scientist on the HCR development. "The radar's millimeter-wavelength, dual-polarization, Doppler remote sensing capabilities generate measurements that provide the most complete picture of cloud physics available to the atmospheric science community."

The HIAPER Cloud Radar (HCR) sits in the high-tech pod especially developed to house instrumentation during research flights; the pod sits beneath the wing of the NSF/NCAR Gulfstream V.

The HCR precisely detects drizzle, and thin ice and liquid clouds, estimates their microphysical and radiative properties and takes detailed wind measurements. It can also distinguish between ice, water, and super-cooled water droplets (droplets that exist as a liquid at temps below freezing). Data collected by the HCR sensors offer unique observations on the formation and evolution of clouds that will provide critical understanding about the effects of clouds on global and regional climate.

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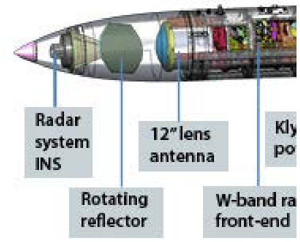

The instrument pod has a diameter of 20 inches (0.5 meters), and a length of 160" (4.1 meters). The HIAPER Cloud Radar, contained within the pod, weighs 420 pounds (191 kg). The cartoon above shows the details of the HCR's current and soon-to-come components.

The HCR also complements existing airborne narrow-band radar available to the research community. The two other airborne radar – used on the University of Wyoming's King Air and NASA's ER-2 – have different characteristics, making the HCR's third set of instrument options useful to climate researchers. The Wyoming King Air and ER-2 have a similar radar that uses the same frequency, but these instruments do not have scanning and a dual-wavelength radar ability. Moreover, when used in combination with the High Spectral Resolution Lidar (HSRL), another instrument developed for use on the GV, the HCR and HSRL mimic the sensing capabilities of the CloudSat and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) satellites. This may prove useful for validating satellite observations and deriving scientific products from remote measurements.

The HSRL and the HCR remain operational between deployments, living in a seatainer at NCAR's Foothills campus, where both instruments will run continuously. In addition to keeping an expensive instrument in use, it gives the team an opportunity to continue learning about the HCR's capabilities, including its accuracy. With this information, laboratory researchers will continue to improve the data product/output.

Especially when flying on the GV (because of the plane's extended distance and altitude capabilities), the HCR opens up exciting observational opportunities for climate researchers. Already, scientists are lining up to include the HCR in field campaigns to attain high-fidelity cloud observations. The Cloud-System Evolution in the Trades (CSET) campaign is scheduled to launch in summer 2015; CSET researchers will look at cloud-system evolution in Pacific trade-wind regions. Other field-campaign HCR requests made for 2016 and beyond include DOWNSTREAM (Dynamics and Observations of the Waveguide: North-South Transport and Rossby Wave Excitation over Atlantic Midlatitudes) and SOCRATES (Southern Ocean Cloud Rain/Radiation, Aerosol Transport Experimental Study). DOWNSTREAM proposes to look at the polar vortex and how jet streams are controlled and affected by clouds and radiation, while SOCRATES aims to observe ocean/atmosphere processes occurring in the remote Southern Ocean.

"Observations, whether day-to-day, or collected during future and proposed field campaigns generate observations that provide critical information that will help us better understand the interplay between climate and weather systems," says Vivekanandan. "Measurements using remote sensing instruments – namely, lidars and radars – not only depict current climate, they offer a means to evaluate climate models' performance. Obtaining these measurements are critical for advancing predictive skills of climate models."

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BIG DATA: GLADE AND GLOBUS+

The National Center for Atmospheric Research (NCAR) has recently implemented an enhanced data sharing service that allows scientists increased access to data as well as improved capabilities for collaborative research. In addition to data sharing, NCAR has significantly upgraded its centralized file service, known as the Globally Accessible Data Environment (GLADE).

Managed by NCAR's Computational and Information Systems Laboratory (CISL), both GLADE and the data sharing service are important upgrades for the high-performance computing (HPC) user community, allowing faster and better access to data and a more flexible virtual workspace.

The Globally Accessible Data Environment (GLADE) is the centralized file service located at the NCAR-Wyoming Supercomputing Center in Cheyenne.

The data sharing service leverages the capabilities of Globus Plus to increase customization options for storage as well as data sharing. Globus, a project of the Computation Institute (a partnership of The University of Chicago and Argonne National Laboratory), is a software service that has been described as a dropbox for big data. It is broadly used in the scientific community. "Plus" refers to a new feature that allows researchers to share data with colleagues outside of their home institutions, greatly improving ease of collaborative work.

"Scientific collaborations are global endeavors, and researchers need to share data with colleagues around the world. As data sets have grown in size and number, the process of moving and managing access to them has become a significant challenge," said Pam Gillman, manager of NCAR's Data Analysis Services Group. "Globus Plus is a robust and user-friendly service that eases the workflow, and it allows users to be more productive by spending less time on the minutiae of data transfers."

NCAR users have been accessing the Globus transfer service for many years. In addition to making data available to external colleagues, the upgrade now allows users of CISL's HPC environment to control the users or groups of users to which the data are accessible. With the sharing service, outside users need only a free Globus account, not a UCAR username/token, to access shared data.

The Globus Plus service has a 1.5-petabyte capacity, and most users can take advantage of the Globus web interface to transfer data. Advanced users or service developers can leverage the Globus Plus features via a command-line interface.

CISL recently added 5 petabytes of high performance storage to the GLADE environment, bringing the total to 16.4 petabytes. GLADE is based on the GPFS file system and provides over 90 GB/s of sustained bandwidth across HPC, analysis, and visualization resources. GLADE file spaces are intended as work areas for day-to-day tasks and are well suited for managing software projects, scripts, code, and data sets.

"We strive to meet the growing needs of our user community, which expand as the data sets grow and require greater and more efficient resources," said Gillman. "These major upgrades are part of CISL's

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ongoing commitment to giving users the tools and services they need to carry out cutting-edge computational research."

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GRASSROOTS EFFORTS ADDRESS THE DIVERSITY ISSUE FOR HIGH-PERFORMANCE COMPUTING

Given the inherently dynamic, ever-evolving environment of high-performance computing (HPC), having a diversity of ideas and perspectives in this arena is critical to advancing the field. The Computational & Information Systems Laboratory (CISL) therefore puts a strong focus on training a variety of future HPC experts early in their studies and careers.

Dr. Richard Loft, director of CISL's Technology Development and head of the lab's diversity and outreach team, leads the lab's successful diversity recruitment effort, along with CISL diversity coordinator Stephanie Barr. Loft, Barr, and the education team have created programs that are developing next-generation HPC expertise to serve the nation's coming exascale-computing needs. In addition to benefitting the lab and NCAR's scientific community, these programs have notable positive impacts on individual students.

One of the lab's longest-running training and diversity efforts is the 11-week-long Summer Internship for Parallel Computational Science (SIParCS). Launched in 2007, this program brings bright, motivated undergraduates interested in HPC to NCAR. Since the inauguration of SIParCS, CISL has made minority-serving institutions (MSIs) aware of this and its other programs. By regularly meeting with MSIs, the lab actively – and successfully – seeks out women, minority, and other underrepresented populations as program applicants. The result: a mix of student interns that has grown increasingly diverse over the past several years. These programmatic efforts have also led to a change in the lab's focus on, and awareness of, diversity issues.

"The most notable changes in our program and recruitment efforts are the result of hiring Stephanie Barr as CISL diversity coordinator in 2012," explained Loft. "Stephanie has led CISL's diversity efforts in relation to intern and employee recruiting, in the process making CISL and NCAR more attractive to populations that historically have been less actively engaged in the computational sciences."

Barr regularly speaks to professors and administrators at MSIs and other universities about NCAR and CISL training and internship opportunities, as well as discussing student career and educational opportunities that could result from such hands-on program experience. She works at a grassroots level to identify what might work best for MSI students and how CISL programs could be modified to better suit these students' needs. In addition to targeted visits to science, technology, engineering, and mathematics (STEM) departments, Barr supports CISL scientists and staff as they carry out the lab's mission to actively seek, train, mentor, and integrate diverse new talent at NCAR.

One example of recent progress in CISL's internship training opportunities originated from an informal interaction between Loft, Barr, and several professors teaching at MSIs. In August 2013, Barr invited a number of MSI-based professors to attend the Rocky Mountain Advanced Computing Consortium's (RMACC's) High Performance Computing Symposium. RMACC is a group of HPC-focused western academic and research institutions. The Symposium enables them to network, attend tutorials, and learn about the latest HPC technology trends. "Inviting the MSI professors seemed like a good way to build collaborative relationships," said Loft.

At the Symposium, the informal conversation turned to the issue of engaging non-traditional students, who make up about two-thirds of the U.S. student population. "Non-traditional" students in this context

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refers to those going to school on a part-time basis, working full-time, supporting dependent relatives, etc. Often these students can't attend internships that take them away from home for long periods, which means that talented students fall through the cracks because they cannot take advantage of programs that offer potentially life-changing benefits.

In response, the CISL team and MSIs professors came up with the idea of transforming some SIParCS positions into externships. In the 2014 prototype of this model, students spent only four weeks of the 11-week program in Boulder. During the first three weeks at NCAR, the externs learned new technology and skills they would need to succeed with their projects. They then returned home for seven weeks, working at their home institutions with a team of remote and local mentors. During the last week of the externship, the students returned to present their final project to their peers and NCAR leadership.

For a student like Justin Moore, who attends Salish Kootenai College, a tribal college in Montana, the externship proved life-changing. After the initial training in Boulder, he returned to his family, job, and academics. His project entailed building and administering a small cluster of Linux machines that, from a software point of view, are as complex as running a supercomputer. In addition to learning practical skills, his experience led to a new job: Moore now administers the college's recently purchased computer cluster, a job that puts Moore solidly in the IT field.

With the first year of externships deemed a success by CISL and the students, externships will likely be offered again in 2015.

Many of the contributors to the Workshop on Diversity in the Computational Geosciences at NCAR. DCG provided a forum and ample time for vigorous discussion and brainstorming.

CISL's 2014 diversity efforts also included a summer workshop on "Diversity in the Computational Geosciences." The workshop was created as a way to develop and sustain a robust national community dedicated to broadening participation in the geosciences. A workshop report summarizing the shared vision, knowledge, and experiences of the participants will be shared with the National Science Foundation, and help define the research, curricula, and best practices needed to increase diversity within the geosciences.

Other 2014 highlights include participation by 10 students from four institutions – Universidad del Turabo in Puerto Rico, Salish Kootenai College, and two historically black universities, Elizabeth City State University and Prairie View A&M University – in UCAR's Software Engineering Assembly (SEA) conference. A technical conference to update software engineers on HPC practices, this meeting fostered collaboration between participants, and offered hands-on computing tutorials for students. The students also had the chance to have lunch and learn from NCAR professionals working in their future industry.

"By working directly with MSIs students and faculty, the team is making inroads on addressing the diversity issue for HPC and meeting the needs of the computational community that CISL and NCAR serve – a win-win for all in terms of interest, time, and energy," Loft said.

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