Sky

The sea, land, ice, life, and people of Earth are all connected by the atmosphere. Climate and weather are the result of atmospheric conditions, which are in a constant state of flux. Atmospheric variables—including air density, temperature, moisture content, wind, chemical composition, and aerosol content, to name a few—combine to determine weather and climate. The interplay among all the components of the climate system makes forecasting future weather and climate no easy task. It's no coincidence that many of the world's leading researchers in climate and atmospheric science are experts in chaos theory.

NSF funds atmospheric research at all levels—from single-investigator projects to major centers devoted to research and education. NSF-funded "sky" research spans the entire atmosphere and beyond, from the troposphere (lower atmosphere) to the Sun (upper atmosphere and Sun-Earth processes). One of NSF's major investments in atmospheric research is the National Center for Atmospheric Research (NCAR). Located in Boulder, Colorado, NCAR houses a number of important research activities in atmospheric science, including the Community Climate System Model (CCSM) and the high-resolution Weather Research and Forecasting (WRF) Model. The CCSM is the foremost U.S. academic global climate model and an important contributor to the findings presented in the reports of the Intergovernmental Panel on Climate Change (IPCC). WRF is used with the global CCSM

Aerial view of the National Center for Atmospheric Research (NCAR) Mesa Laboratory. NCAR provides the university research and teaching community with tools such as aircraft and radar to observe the atmosphere and with the technology and assistance to interpret and use these observations, including supercomputer access, computer models, and user support. *Credit: © University Corporation for Atmospheric Research*

Top image credit: © 2009 JupiterImages Corporation to simulate and predict climate change at regional and finer scales. With its collection of advanced tools and techniques—including models, radar, weather-balloon observations, and satellite data—NCAR climate researchers are working to understand the impacts of global and regional climate variability and change.[14]

Observing the Sun

The Sun is the predominant source of heat and energy in the climate system and, therefore, is an important factor in modeling Earth's past, present, and future climate. The Sun's radiation is not constant; an 11-year oscillation of sunspot activity is one source of variation. Though slight compared to the total irradiance from the Sun, the intensity of oscillations caused by sunspots and other solar phenomena must be taken into consideration by climate scientists, who need to know precisely how much energy Earth's climate system receives.

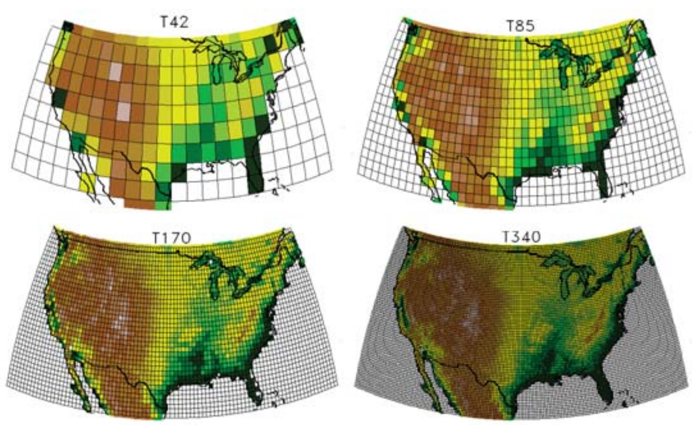
Kitt Peak National Observatory's McMath-Pierce solar facility, the largest solar telescope in the world. *Credit: NOAO/AURA/NSF*

National Solar Observatory

The mission of the National Solar Observatory (NSO) is to advance knowledge of the Sun, both as an astronomical object and as the dominant external influence on Earth, by providing observational opportunities to the research community.[15] NSO has observing facilities atop Kitt Peak, Arizona, and Sacramento Peak, New Mexico. These facilities offer the world's largest collection of optical and infrared solar telescopes and auxiliary instrumentation for observing different features of the Sun, as well as a coordinated worldwide network of six telescopes specifically designed to study solar oscillations (the Global Oscillations Network Group).[16]

Modeling

Climate researchers develop climate models to simulate the interactions of the many factors that influence Earth's atmosphere. These can include inputs from Earth's oceans, ecosystems, landmasses, snow, and ice. The individual pieces of the climate system are highly complex and interrelated, and must be modeled simultaneously. Using complex mathematical descriptions of real-world phenomena, climate simulation allows scientists to test hypotheses, make predictions, and assess environmental mitigation strategies.[17] Models are essential tools for climate scientists, because it is not possible to recreate the atmosphere and its interactions with Earth's systems in a laboratory setting.



This illustration shows how the amount of detail in climate models has increased in recent years, largely because of the calculation power provided by newer supercomputers. The image in the upper left (T42) represents the resolution of the 1990s, with grid boxes measuring roughly 200 by 300 kilometers. Enhancements in computing power will help scientists explore the use of higher resolutions, such as T170 (lower left) and T340 (lower right). Better resolution allows for more realistic topography, which improves the accuracy of regional climate projections. *Credit: Illustration courtesy Warren Washington, NCAR; © University Corporation for Atmospheric Research*

As researchers learn more about the complexity of the climate system, they seek to incorporate this complexity into climate models. To do so requires increasingly powerful supercomputing capabilities. Since the 1950s, when the first

14 NCAR Climate Research Web site: www.ncar.ucar.edu/research/climate.

15 National Solar Observatory Web site: www.nso.edu.

16 NSF-Supported Research Infrastructure: Enabling Discovery, Innovation, and Learning, 2008.

17 NCAR Modeling Web site: www.ncar.ucar.edu/tools/models.

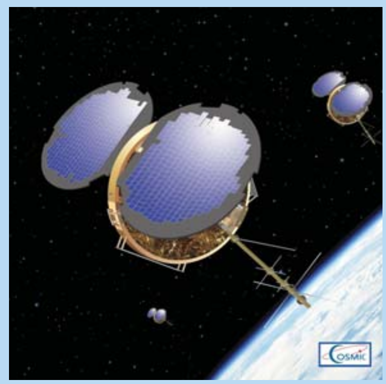
vacuum-tube computers became available, researchers have used the latest computing technology to boost the power of climate modeling. Today's models are staggeringly complex, simulating natural fluctuations and cycles in climate that occur hourly (large frontal systems), monthly (changes in the jet stream), or even on timescales of decades or centuries (ocean circulation, glacial patterns).[18]

As climate models have matured, their spatial resolution has improved. This dramatically increases computational demand. Increased computational complexity can result in better overall model accuracy, but it requires increasingly intricate software and significantly greater computational resources. The software—the algorithms and data structures for analysis, visualization, and prediction—must keep up with the increasing complexity of the physical concepts, which presents a significant challenge to the computer scientists and engineers who design the models.

Climate modelers can check the fidelity of their models' predictions of the future climate by testing them against the record of Earth's climatic past, gleaned from ice and sediment cores, and from tree ring data and other proxy sources of data. (See the *Ice* and *Land* sections for more on these data sources.) Modelers also test their models by simulating the annual cycle of seasonal variations and by comparing their predictions to the actual climate on a year-by-year basis.[19]

Constellation Observing System for Meteorology, Ionosphere, and Climate

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) is a constellation of six satellites in low-Earth orbits. COSMIC, a joint project between Taiwan's National Space Organization and the U.S. Government, takes advantage of the military's sophisticated global positioning system (GPS) satellites, which emit radio wave signals that GPS receivers use to determine positions on Earth, to examine Earth's atmosphere. The COSMIC satellites' GPS receivers detect delays in the propagation of GPS signals when the signals pass through the atmosphere to reach the satellites. Temperature, humidity, and, in the ionosphere, electron density can be obtained from these measurements. COSMIC provides 2,000 vertical profiles of the atmosphere per day, distributed nearly uniformly over the globe. These data are being used for weather research and prediction, and climate research and monitoring, and are providing unprecedented information about Earth's atmosphere in a monitoring system that is as revolutionary as it is straightforward.



In this artist's illustration, six microsatellites are entering low-Earth orbit to form COSMIC, the Constellation Observing System for Meteorology, Ionosphere, and Climate. COSMIC is providing a major boost in the quality and quantity of data needed to improve climate modeling. *Credit: Courtesy Orbital Sciences Corporation*

Community Climate System Model

The Community Climate System Model (CCSM) is one of the world's premier general-circulation climate models. CCSM is unique among comprehensive climate models because it belongs to the entire community of climate scientists rather than to a single institution. Hundreds of specialists at various institutions around the globe collaborate on improvements to CCSM. NCAR makes the model's underlying computer code freely available on the Web. As a result, scientists throughout the world can use CCSM for their climate experiments.[20]

Funded by NSF in partnership with the Department of Energy, CCSM will evolve and adapt to answer the questions of the research community and incorporate the complex processes needed for

18 Community Climate System Model Brochure: www.ucar.edu/communications/CCSM/history.html.

19 Climate FAQ: Climate Model Shortcomings: www.cgd.ucar.edu/research/faqs/models.html.

20 CCSM Brochure Web site (Overview): www.ucar.edu/communications/CCSM/overview.html.

The Community Climate System Model (CCSM) simulates global cloud cover (shown in white) and precipitation (in orange). Composed of four separate models simultaneously simulating Earth's atmosphere, ocean, land surface, and sea ice, and one central coupler component, the CCSM allows researchers to conduct fundamental research into Earth's past, present, and future climate states. *Credit: © University Corporation for Atmospheric Research*

next-generation modeling. CCSM users have the ultimate goal of incorporating the interaction between global climate and all of Earth's natural and human processes, capturing even subtle feedback loops. A future model, for example, might be able to estimate the health and geographic range of northern-latitude forests in times of higher temperatures, and monitor the ability of those altered forests to absorb carbon dioxide from the atmosphere.[21] Predicting the frequency and intensity of extreme weather events, such as hurricanes and severe local storms, in a warming world is also a priority goal for climate models.

Bluefire

On April 24, 2008, NCAR took delivery of a Power 575 Hydro-Cluster, the first in a highly energy-efficient class of supercomputers to be shipped anywhere in the world. Bluefire houses a microprocessor with a clock speed of 4.7 gigahertz. The system consists of 4,064 processors, 12 terabytes of memory, and 150 terabytes of disk storage. With a peak speed of more than 76 teraflops (76 trillion floating-point operations per second), Bluefire is expected to rank among the 25 most powerful supercomputers in the world and will more than triple NCAR's sustained computing capacity. Bluefire is being put to use improving climate and weather simulations, studying solar processes, and refining oceanic and atmospheric circulation models.[22]

NCAR's new IBM supercomputer—Bluefire—has a peak speed of more than 76 teraflops (76 trillion floating-point operations per second). When fully operational, it is expected to rank among the world's 25 most powerful supercomputers and will more than triple NCAR's sustained computing capacity. *Credit: Brian Bevirt, National Center for Atmospheric Research*

Researchers hope to use CCSM for credible prediction of global climate as well as the climate of specific regions. Useful regional climate predictions will help policymakers tackle such issues as where certain crops can be grown and how much sea ice will exist in the Arctic Ocean. CCSM predictions can also help business leaders anticipate future conditions, such as changing energy demands for home heating and cooling or modifications in crop production schedules due to changing growing seasons.

A near-term, high-priority goal for the CCSM, and for many global-scale climate models, is to develop the capability to predict future climate and its impacts on a 10- to 20-year timescale, with a spatial scale that can be useful to people making decisions about the future. For climate models to reach this goal, more information, observational infrastructure, and computational resources will be needed.

The following section describes some of the critical frontiers of atmospheric research that pertain to climate modeling.

21 CCSM Brochure Web site (Future): www.ucar.edu/communications/CCSM/future.html.

22 NCAR press release: www.ucar.edu/news/releases/2008/bluefire.jsp.

Frontiers of Atmospheric Research

NSF funds many investigators who seek to improve our understanding of Earth's atmosphere—its physics, chemistry, and dynamics. NSF also funds studies to understand the natural global cycles of gases and particles in the atmosphere. In exploring these areas, researchers will provide invaluable information for climate model development and testing.

Aerosols

Determining the composition of the atmosphere is vital to climate research. The molecules present in the atmosphere, the reactions they undergo, and their effects on the amount of energy in the climate system are central to NSF's atmospheric research portfolio, including the role anthropogenic pollutants play in the chemical breakdown of stratospheric ozone.

In recent years, researchers have paid increasing attention to the role of aerosols in the physical and chemical makeup of the atmosphere. Aerosols are fine particles or droplets suspended in the atmosphere; they can be emitted by natural systems or by human activities, such as the burning of fuels. Larger than molecules, aerosols can either scatter or absorb sunlight, depending on their size and physical properties. Aerosols also participate in chemical reactions in the atmosphere and can serve as seed particles for the formation of clouds.[23]

Photograph of South Asian brown cloud pollution hanging over the Nepalese town of Phaplu (bottom panel), on March 25, 2001. The photo was taken from a flight altitude of about 3 kilometers, approximately 30 kilometers south of Mount Everest (seen in the top panel). Both photographs were taken from the same location—one looking north (top) and the other looking south (bottom). The brown cloud pollution is primarily caused by the presence of anthropogenic aerosols—particles such as soot suspended in the atmosphere. *Credit: V. Ramanathan*

For these reasons, climate modelers are eager to know more about aerosols—how they affect the energy that enters and leaves the atmosphere, and how they influence the overall chemical content of the atmosphere. Researchers are especially interested in fully understanding how aerosols from air pollution affect Earth's climate, including the properties and distribution patterns of increasing aerosol production from the rise of industrial and transportation activities in developing countries.

Atmospheric brown clouds (ABCs)—composed of a mix of chemicals and aerosols—are a special focus of NSF-supported researchers. These visible brown plumes of pollution prevalent in Southeast Asia result from the burning of fuels, tailpipe exhaust, factory emissions, and other human activities.[24] Researchers have found strong evidence that ABCs from Asian pollution are intensifying winter storms over the Pacific Ocean.[25]

Clouds

Colorado State University's Center for Multiscale Modeling of Atmospheric Processes (CMMAP), a recently established NSF Science and Technology Center, focuses on atmospheric phenomena that are as familiar to us as they are elusive to climate modelers: clouds. Clouds are hard to depict in models because they change shape and move on a variety of time and space scales. Clouds exist in horizontal and vertical scales ranging from a few hundred meters to a few kilometers.[26]

Clouds are extremely important in climate modeling, because they reflect sunlight and absorb heat radiated from the ground below. According to the Fourth Assessment of the IPCC, "cloud feedbacks remain the largest source of uncertainty" in climate models.[27] CMMAP seeks to improve the representation of

23 NSF Highlight 16735: Enhancing Studies of Aerosol-Cloud Interactions.

24 NSF press release 07-087: "Brown Cloud" Particulate Pollution Amplifies Global Warming: www.nsf.gov/news/news_summ.jsp?cntn_id=109712.

25 NSF Highlight 16232: Intensification of Pacific Storm Track Linked to Asian Pollution.

26 Strategic and Implementation Plan: Center for Multiscale Mapping of Atmospheric Processes: http://cmmap.colostate.edu/research/docs/CMMAP_SPlan_v2c.pdf.

27 IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.*

Clouds reflect sunlight and absorb heat from the ground below, and are a major source of uncertainty in climate models. Researchers are working on models that better account for the behavior of clouds. *Credit: © University Corporation for Atmospheric Research*

clouds in climate models. This approach, called the "multiscale modeling framework" (MMF), could serve as an example for modeling other complex climate variables. The MMF approach allows researchers to embed their cloud model, which deals with the relatively small spatial scale of clouds, into a broader climate model that deals with larger scales. With this "model-within-a-model" approach, the simulated physical processes occurring on different scales can interact with one another, increasing the sophistication and accuracy of the combined model. The model-within-a-model approach is a promising template for the incorporation of other small-scale phenomena in global-scale climate models.

Storms

Warmer sea surface temperatures are likely to increase the strength of storms forming over Earth's oceans. At present, hurricanes cannot be resolved in climate models, and the complex relationships between climate and hurricane frequency, intensity, and location are not well understood. With further improvements in global system models, researchers may one day be able to link aspects of hurricane behavior to anthropogenic climate change.[28] In addition, high-powered computers, such as the University of Texas TeraGrid Ranger system, will be able to model storm behavior more accurately, thereby helping coastal communities along the Gulf Coast plan their responses to hurricanes.[29]

In addition to hurricanes, NSF-funded researchers—using climate models to study the large-scale meteorological conditions that foster the formation of severe weather in the United States—have found that, as a result of climate change, we can expect to see an increase in the number of days when the conditions are present for the formation of severe thunderstorms.[30]

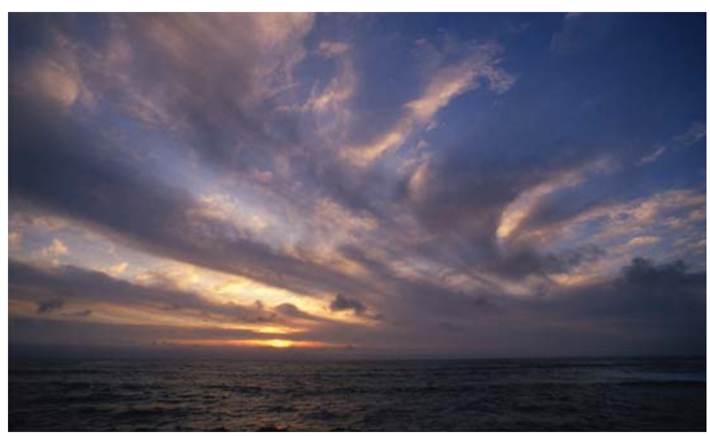
Climate models may one day enable scientists to predict the large-scale meteorological conditions that support the formation of severe thunderstorms. *Credit: © University Corporation for Atmospheric Research*

Earth System Interactions

The physical and chemical interactions between the atmosphere and each of the other climate system pieces are important areas of continued research.

Oceans

Perhaps no other Earth system component has more opportunity to influence the atmosphere than the ocean, which covers 71 percent of Earth's surface. The sea serves as a "sink" for carbon dioxide by dissolving a portion of the gas at the air-water interface. The ocean is also home to phytoplankton and other biological species that incorporate carbon in their tissue, taking it with them to the seafloor when they die.



The ocean has a profound effect on weather and climate. *Credit: © 2009 JupiterImages Corporation*

28 National Science Board Task Force on Hurricane Science and Engineering, *Hurricane Warning: The Critical Need for a National Hurricane Research Initiative*, NSB-06-115, 2007, p. 14.

29 NSF Highlight 16882: New Computer Model Helps Coastlines Prepare for Storm Surges.

30 NSF Highlight 15879: Will There Be an Increase in Severe Thunderstorms Due to Climate Change?

The exchange of water between ocean and atmosphere, along with the exchange of energy, drives the weather and climate worldwide. The ocean is a major source of aerosol precursors—the chemical starting points for the formation of airborne particles or droplets that enter the atmosphere at the air-water interface. This complicated give-and-take between sky and sea is vital to climate modelers, who need to know how to account for the ocean in their calculations. (See the *Sea* section for more on the ocean's role in climate.)

High-Performance Instrumented Airborne Platform for Environmental Research

The best way to access remote areas of the atmosphere is with an aircraft. The NSF-funded High-Performance Instrumented Airborne Platform for Environmental Research (HIAPER)—a medium-altitude, long-duration jet—has become the premier plane for scientific discovery. The modified Gulfstream V jet can reach an altitude of 15,500 meters (51,000 feet) and can cruise for 11,265 kilometers (7,000 miles). It is equipped with advanced instrumentation for environmental research, including instruments to sample the chemical and aerosol composition of the atmosphere. Managed by NCAR through a cooperative agreement from NSF, HIAPER began operational science missions in 2006. HIAPER has already been involved in several missions that have furthered our understanding of the dynamic composition of the atmosphere, including a survey of particle formation in the upper troposphere.[31] HIAPER was also instrumental in a large-scale field project called PACDEX (Pacific Dust Experiment) to study the pollution plumes that originate in Asia and spread over the Pacific Ocean.[32] The HIAPER Pole-to-Pole Observations (HIPPO) study, begun in January 2009, is expected to improve our understanding of the carbon cycle and greenhouse gas distributions through cross-sectional concentration measurements in pole-to-pole flight paths during different seasons in a two-year-period.[33]

HIAPER (High-Performance Instrumented Airborne Platform for Environmental Research) aircraft in flight. HIAPER, modified Gulfstream V jet, can fly at an altitude of 51,000 feet and has a range of 7,000 miles. The aircraft's range enables scientists to survey remote ocean regions in a single flight to learn more about interactions between the oceans and the atmosphere. *Credit: © University Corporation for Atmospheric Research*

Snow and Ice

Another important Earth system component is what researchers refer to as the "cryosphere"—the regions of Earth covered in snow and ice, especially the polar regions. Bright white ice is an excellent solar reflector, sending 75–95 percent of the Sun's rays back into space. The fraction of reflected solar radiation is called "albedo." By contrast, land and open water reflect less than 30 percent of the sunlight that falls on them.[34] (See the *Ice* section for more on albedo.)

Sunlight that is not reflected back into space is absorbed by the surface, which warms as a result. Thus, it is important for climate modelers to know how much ice covers Earth and where it's located, including polar ice, the winter snow that covers much of the Northern Hemisphere, and the year-round snow and ice accumulated in the mountainous glaciers of the world.[35] Because ice is susceptible to positive feedback (melting ice exposes heat-absorbing ground or open sea, increasing surface warming, which in turn causes more ice to melt), researchers must accurately capture the effects of snow and ice in their climate models. (See the *Ice* section for more on the climate effects of Earth's ice and snow.)

31 NSF Highlight 12713: New NSF-Sponsored Research Aircraft Studies Atmospheric Particle Formation.

32 NSF press release 07-042: Scientists Track Impact of Asian Dust and Pollution on Clouds, Climate Change: www.nsf.gov/news/news_summ.jsp?cntn_id=108742.

33 NCAR Earth Observing Laboratory Field Project Web site: www.eol.ucar.edu/deployment/field-deployments/field-projects/hippo_global_1

34 www.ncar.ucar.edu/research/earth_system/cryosphere.php

35 NSF Highlight 15790: Improving Climate Model Predictions Through a Surprising Link to Snow Cover Simulations.

Life and Land

Without life on Earth, the composition of this planet's atmosphere would be radically different. The amount of vegetation covering land surfaces is directly tied to the amount of carbon the land can "fix" or remove from the atmosphere. Microorganisms living in the soil of a particular region can also have a significant cumulative effect on the amount of carbon and other chemical compounds given off by the land. Vegetation influences the amount of solar energy absorbed. For example, dark forests absorb more sunlight than dried prairie grasses.

Plants also influence the cycling of water between land and atmosphere. In terms of land use, the conversion of forest to agricultural fields can have a significant effect on how that patch of land cycles carbon, heat, and water with the atmosphere. In the past, climate models have tended to oversimplify the effects of land cover and use; future climate models will need to account for these effects to improve climate predictions. (See the *Land* and *Life* sections for more on the interactions of these systems with the atmosphere.)

Observational Networks

Atmospheric science is, at its core, an observational science. While much of the day-to-day work of atmospheric scientists is performed on a computer, the input values they use must come from the real world. Accurate, continuous measurements of atmospheric conditions from strategic locations lead to improved climate models. Modelers need to know land cover changes in a given region, such as changes in ice or vegetation cover. Ocean-observing equipment can help modelers keep track of ocean currents and trends in temperature, salinity, and other parameters that are tied to climate conditions. (See the *Sea* section.) Observational satellites are of vital importance to modelers, as they monitor everything from ice sheet mass in Greenland and Antarctica to large-scale trends in land usage in the tropics.

Conclusion

While we've come a tremendous way in our understanding of the changes in Earth's atmosphere in the 50 years since Charles David Keeling, under the direction of Roger Revelle, began recording carbon dioxide levels on Mauna Loa, much work remains for scientists to understand and predict the atmospheric processes that are responsible for global and regional climate. In the research highlights below, individual NSF-funded research projects in "sky" research are described. These projects vary in size and scope, but all have contributed to advancing human knowledge about the atmosphere and to training the next generation of researchers who will continue this important work.

Enhancing Studies of Aerosol-Cloud Interactions

Heavy traffic jams a California freeway. *Credit: © University Corporation for Atmospheric Research*

Recent studies have suggested that exposure to air pollution generated by transportation sources is linked to increased health risks in populations living near roadways. The factors responsible for increased health risks remain unclear but are likely to include elevated particulate matter concentrations. In this study, Colorado State University researchers deployed an Aerodyne Research, Inc., Aerosol Mass Spectrometer (AMS), acquired with support from an NSF Major Research Instrumentation Grant, to measure near-roadway particulate matter on the grounds of an elementary school located immediately adjacent to US-95 in Las Vegas, Nevada, in January 2008. The AMS measures, with high-time resolution, the mass concentrations of particles smaller than 1 micron in diameter, a size class strongly linked to adverse health effects. This technology, in combination with measurements of pollutant gases and meteorological variables, offers an unprecedented look at the short-term variations in airborne particulate loadings and composition, and new ways to link these to pollutant sources. Excursions in concentrations of particles rich in organic carbon were associated with increases in traffic during the morning rush hour, but unexpectedly large transient increases in this particle type were also observed in the late evening and early morning hours. **Highlight ID: 16735 GEO/ATM**

Intensification of Pacific Storm Track Linked to Asian Pollution

A thick, gray blanket of haze hangs over eastern China in this image from Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua satellite on February 19, 2004. The haze pools in the gullies and valleys of the mountain ranges along the left edge of the scene; in many places, it completely hides the coastal plain from view. Unfortunately for the residents of the region, such events are not rare, especially in winter, when people need to burn additional coal and wood. In this case, numerous fires burning in southeastern China may be contributing to the haze as well. *Credit: Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC*

A thick, gray blanket of haze hangs over eastern China in this image from Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua satellite on February 19, 2004. The haze pools in the gullies and valleys of the mountain ranges along the left edge of the scene; in many places, it completely hides the coastal plain from view. Unfortunately for the residents of the region, such events are not rare, especially in winter, when people need to burn additional coal and wood. In this case, numerous fires burning in southeastern China may be contributing to the haze as well.

Renyi Zhang of Texas A&M University has discovered an increasing trend in deep convective clouds over the Pacific Ocean that is likely due to increased pollution coming from the Asian continent. In this NSF-sponsored project, Zhang and colleagues used data from the International Satellite Cloud Climatology Project to analyze two decades' worth of Pacific Ocean cloud statistics. They found a considerable increase in the amount of deep convective clouds over the North Pacific, especially in the winter months.

Pollution increases the aerosols in the atmosphere. Previous studies have shown that additional aerosols lead to smaller cloud droplets, which delay precipitation events and allow clouds to become more invigorated. To be certain that the increased intensification that the researchers were seeing was due to pollution, they had to rule out natural effects, such as sea surface temperature, monsoons, and El Niño events. It was determined that none of these effects could explain the observed change in cloud cover. To further study the hypothesis, Zhang used a special version of the Weather Research and Forecasting computer model tailored to incorporate the effects of pollution on clouds. He found that the observed trend in deep convective clouds could be reproduced in model simulations that account for the influence of the Asian pollution outflow. **Highlight ID: 16232 GEO/ATM**

New Computer Model Helps Coastlines Prepare for Storm Surges

NSF-funded researchers are developing a model to create storm surge flood risk maps along the U.S. Gulf Coast. *Credit: © 2009 JupiterImages Corporation*

Recent events in the Gulf of Mexico and around the world have demonstrated the vulnerability of coastal populations and infrastructure to storm surges. In response, researchers from the University of Texas at Austin, using the TeraGrid Ranger computing system, are developing the Advanced Circulation Storm Surge Model. The model has been used in its design and planning mode before the hurricane season, in forecasting mode as storms approach land, and in hindcasting mode after the event. The researchers are developing a new computationally intensive model of the Gulf of Mexico that includes highly refined details of the Texas coast. This new model will be used to perform hundreds of hurricane scenarios for the State of Texas, to develop flood risk maps and study potential inundation in high-risk areas, such as the Houston-Galveston corridor and the Brownsville region. **Highlight ID: 16882 OD/OCI**

Will Climate Change Cause an Increase in Severe Thunderstorms?

A severe thunderstorm cumulonimbus cloud moves across the plains east of Denver, Colorado, on June 10, 2004. The dark blue or blue-green area is heavy rain and large hail falling in the background. *Credit: © University Corporation for Atmospheric Research*

Robert Trapp of Purdue University and colleagues have recently used global and high-resolution regional climate models to study the large-scale meteorological conditions that foster severe weather formation in the United States. The researchers determined that, as a result of climate change, there is likely to be an increase during the late 21st century in the number of days in which severe thunderstorm conditions occur.

Current climate models cannot simulate phenomena as small as thunderstorms, but they can simulate the larger scale distributions of temperature, moisture, and winds that influence severe convective storms. The researchers found that in a scenario with increased temperatures from greenhouse emissions, there was an increase in one factor for severe thunderstorms (convective available potential energy) and a decrease in the other factor (wind shear). It was determined that the increase in potential energy more than made up for the decrease in wind shear, leading to more days in which meteorological conditions would support the formation of severe thunderstorms. The largest future increases are projected to be during the summer months, especially in the southern and eastern United States.

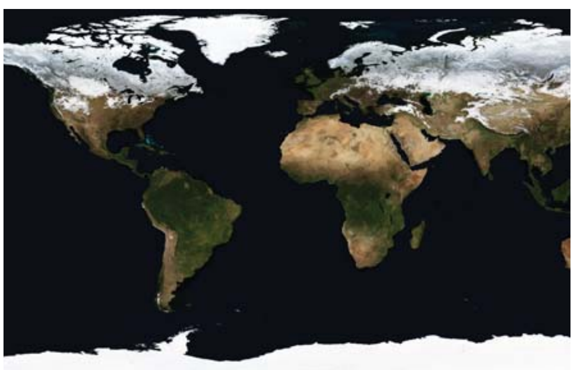
Insurance industry planners will have to take trends in the frequency of damaging severe weather into account because of the potential impacts of severe weather on built structures, automobiles, and cropland. **Highlight ID: 15879 GEO/ATM**

New NSF-Sponsored Research Aircraft Studies Atmospheric Particle Formation

HIAPER takes to the skies for its first science mission on March 2, 2006. *Credit: NCAR*

The NSF-sponsored HIAPER (High-Performance Instrumented Airborne Platform for Environmental Research) sampled particle formation in the upper troposphere and lower stratosphere on one of its first science missions. Researchers are very interested in this region because it has a high number concentration of new particles with diameters from 4 to 8 nanometers, and their subsequent growth to cloud condensation nuclei has important implications for cloud formation. The scientists found that elevated numbers of new particle formation events were observed near tropopause folding, where the mixing of stratospheric and tropospheric air masses occurs. They also observed enhanced new particle formation shortly after sunrise. These events continued even after sunset without the presence of sunlight. The sunrise and sunset experiments allowed the researchers to calculate aerosol nucleation and grow rates. The estimated nucleation and growth rates suggest that an additional species may be involved in particle formation in the upper troposphere. In addition, wintertime measurements with HIAPER showed that new particle formation was higher in the tropics than at the middle latitudes. **Highlight ID: 12713 GEO/ATM**

Improving Climate Model Predictions Through a Surprising Link to Snow Cover Simulation

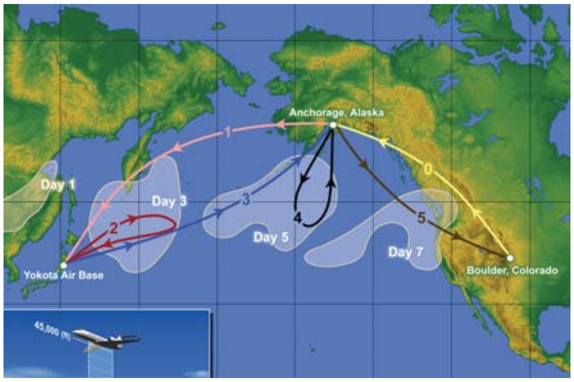


An image of global snow cover for the month of January 2004. *Credit: NASA images by Reto Stöckli*

Snow cover on land during the winter months may be a more significant factor in climate modeling than previously thought. Faculty Early Career Development (CAREER) Program grant recipient Alex Hall of UCLA and colleagues discovered an unexpected link between snow-albedo feedback and climate model predictions of summer climate change in the continental United States. Albedo refers to the amount of solar radiation reflected away from Earth's surface; in this case, from snow cover. Hall, in an NSF-funded project, found that various climate models handle snow albedo differently, causing major differences in the simulation of snowpack. In models with strong snow-albedo feedback, the winter and early spring snowpack is significantly reduced, which leads to water shortages. In turn, these water deficits persist in the modeled soil moisture and allow for more evapotranspiration and warmer temperatures. Hall has determined that by incorporating a more realistic snow-albedo feedback into the climate models, the prediction of U.S. climate could be substantially improved on the decadal to centennial timescale.

Before this work, snow-albedo feedback was not considered a significant factor affecting the sensitivity of climate models. Rather, attention has been on moist-convective processes and cloud parameterizations. This new work will force climate modelers to address the snow-albedo problem, which will likely result in new measurements of snow albedo, and a new interest in efforts to model snow cover and snow albedo. Current projections from global climate models are of limited use to policymakers and businesses. Regional climate change modeling in particular is in need of dramatic improvements, and improving climate change predictions on a regional scale will lead to much better data for decisionmaking than are currently available. **Highlight ID: 15790 GEO/ATM**

Following the Asian-Pacific Pollution Plume



This illustration shows a hypothetical plume and possible series of flight patterns during the PACDEX (Pacific Dust Experiment) field project. When a major plume of dust and pollutants begins blowing off Asia, the G-V would fly from Boulder, Colorado, to Anchorage, Alaska, where it would refuel then fly on to Yokota Air Base, Japan. It would then conduct a series of flights for about a week in and around the plume as the plume moves over the ocean to North America. *Credit: Steve Deyo, © University Corporation for Atmospheric Research*

Scientists are looking at the transport of aerosols, such as dust and soot, which regularly travel in a plume from Eurasia across the Pacific Ocean and into North America. This Eurasian-Pacific-North American dust plume is one of the most widespread pollution events on the planet. To study this phenomenon, National Center for Atmospheric Research (NCAR) deployed the NSF/NCAR Gulfstream V (G-V) in support of the Pacific Dust Experiment (PACDEX) in April and May 2007.

Until recently, scientists lacked an airborne platform capable of taking in situ samples throughout the plume's evolution across the Pacific Ocean. The G-V fills this observational gap and opens new doors for observing this remarkable natural/human-made plume as it passes through the Pacific Ocean's extratropical cloud systems. PACDEX scientists were not only able to observe these systems close up, they also had an opportunity to study the evolution of aerosols' physical and chemical characteristics from the lower to the upper troposphere while examining vertical and horizontal gradients in cloud condensation and ice nuclei across the Pacific, and investigating cloud size spectra and liquid and ice water content.

PACDEX data are opening new frontiers of science through the observation of human impacts on the mixed-phase and ice-phase cirrus cloud systems. As well as monitoring the Eurasian-Pacific-North American dust plume's characteristics, this pilot experiment was designed to further test and take full advantage of the unique capabilities of the G-V. PACDEX showcased the sophisticated research infrastructure available to the U.S. science community. The G-V is the most advanced airborne platform in the world, and NCAR's logistical, technical, and data support services allow the U.S. scientific community to mount complex observational campaigns that provide unprecedented insight into complex atmospheric systems. **Highlight ID: 15901 GEO/ATM**

Human Activities Are Boosting Ocean Temperatures in Areas Where Hurricanes Form, New Study Finds

Rising ocean temperatures in key hurricane breeding grounds of the Atlantic and Pacific Oceans are due primarily to human-caused increases in greenhouse gas concentrations, according to a study published in September 2006. Using 22 different computer models of the climate system, a team of scientists from the Lawrence Livermore National Laboratory, the National Center for Atmospheric Research (NCAR), and eight other research centers showed that the warming sea surface temperatures (SSTs) of the tropical Atlantic and Pacific Oceans over the past century are linked to human activities.

Previous efforts to understand the causes of changes in SSTs have focused on temperature changes averaged over very large ocean areas, such as the entire Atlantic or Pacific basin. The new research specifically targets SST changes in much smaller hurricane formation regions. For the period 1906–2005, the researchers found an 84 percent probability that human-induced factors—primarily an increase in greenhouse gas emissions—accounted for most of the observed rise in SSTs in the Atlantic and Pacific hurricane formation regions.

Hurricanes are complex phenomena that are influenced by a variety of physical factors, such as SSTs, wind shear, water vapor, and atmospheric stability. The increasing SSTs in the Atlantic and Pacific hurricane formation regions are not the sole determinant of hurricane intensity, but they are likely to be one of the most significant influences. **Highlight ID: 14135 GEO/ATM**

Expect a Warmer, Wetter World This Century, Computer Models Agree

A cumulonimbus, or thunderstorm, cloud passes over the plains east of Denver, Colorado. Thunderstorms form as the moisture in updrafts—rapidly rising warm air—condenses into raindrops or hailstones, which begin to fall when the updrafts no longer have the energy to carry the heavy precipitation. If an updraft is extremely intense, the rain may be held in the cloud for an hour or more. *Credit: © University Corporation for Atmospheric Research*

Recent episodes of deadly heat in the United States and Europe, long dry spells across the U.S. West, and heavy rainfall and snowfall across much of North America and Eurasia hint at longer term changes to come, according to a new study based on several of the world's most advanced climate models. Much of the world will face an enhanced risk of heat waves, intense precipitation, and other weather extremes, conclude scientists from the National Center for Atmospheric Research (NCAR), Texas Tech University, and Australia's Bureau of Meteorology Research Centre.

Many previous studies have looked at how average temperature or rainfall might change in the next century as greenhouse gases increase. However, the new research looks more specifically at weather extremes, such as heat waves and intense rains, because these extremes cause the most damage to society and ecosystems. This study is one of the first analyses to draw on extensive and sophisticated computer modeling recently carried out for the Intergovernmental Panel on Climate Change. The team based its work on simulations from nine different climate models for the periods 1980–1999 and 2080–2099. The simulations were created on supercomputers at research centers in France, Japan, Russia, and the United States. Each model simulated the 2080–2099 interval three times, varying the extent to which greenhouse gases accumulate in the atmosphere. These three scenarios were used to account for uncertainty about how fast society will act to reduce emissions of carbon dioxide and other greenhouse gases over the coming decades. For all three greenhouse gas scenarios, the models agreed that, by 2080–2099,

- The number of extremely warm nights and the length of heat waves will increase significantly over nearly all land areas around the globe. During heat waves, very warm nights are often associated with fatalities, because people and buildings have less chance to cool down overnight.
- Most areas above about 40 degrees north latitude will see a significant jump in the number of days with heavy precipitation. This includes the northern tier of U.S. States, Canada, and most of Europe.
- Dry spells could lengthen significantly across the western United States, southern Europe, eastern Brazil, and several other areas. Dry spells are one of several factors in producing and intensifying droughts.

The effects were least severe for the lowest emission scenario. The research was supported by NSF, which is NCAR's primary sponsor, as well as by the U.S. Department of Energy and the Environmental Protection Agency. **Highlight ID: 14121 GEO/ATM**

The Effects of Climate Change on Ozone Distribution

Scientists are increasingly turning their attention to the study of the possible effects of a CO_2-warmed world. In work sponsored by NSF, researchers at the University of Washington and the California Institute of Technology used computer models to simulate circulation in the mid-levels of the atmosphere that is important for ozone concentrations. The models indicate that this circulation intensifies when the temperature of the lower levels of the atmosphere increases, as is the case when the carbon dioxide level is doubled in the computer models. As a result of this stronger circulation, there is an increase in total ozone in the high latitudes of both hemispheres of Earth and a decrease in the ozone levels in the tropics. This is an important result to be considered in the modeling of ozone recovery. **Highlight ID: 13434 GEO/ATM**

Fossil Fuel Burning Interrupts Natural Carbon Cycle

Carbon has always been present in the atmosphere, but in natural amounts it can be absorbed by plants during photosynthesis and returned to the atmosphere by decomposition. Carbon is also absorbed by the ocean, where it rides the ocean conveyor belt for centuries before returning to the atmosphere. The burning of fossil fuels has interrupted the natural balance of these systems. Researchers have recently developed a computer simulation of the global carbon cycle using a specialized version of the Community Climate System Model (CCSM). The models show that excess carbon in the atmosphere leads to warmer temperatures. The increased temperatures dry out land and hinder growth of plants in tropical areas, reducing photosynthesis rates. They also warm ocean surface temperatures and slow the conveyor belt, making it harder for carbon to mix downward into the ocean. These changes result in a positive feedback between the carbon and climate systems, so that climate warming acts to increase the airborne fraction of anthropogenic carbon dioxide and amplify the climate change. **Highlight ID: 12620 GEO/ATM**

Future Heat Waves: More Severe, More Frequent, Longer Lasting

An aerial view of Chicago. The Chicago heat wave of 1995 resulted in an estimated 739 deaths. *Credit: © 2009 JupiterImages Corporation*

Heat waves in North America and Europe will become more intense, more frequent, and longer lasting in the 21st century, according to a study by scientists at National Center for Atmospheric Research (NCAR). Model results showed that an increase in heat-absorbing greenhouse gases intensifies an unusual atmospheric circulation pattern already observed during heat waves in Europe and North America. As the pattern becomes more pronounced, severe heat waves occur in the Mediterranean region and the southern and western United States. Other parts of Europe also become more susceptible to severe heat waves. These results are highly significant, because heat waves can kill more people in a shorter time than almost any other climate event. The Chicago heat wave in 1995 resulted in an estimated 739 deaths, and approximately 15,000 people are believed to have died in the 2003 Paris heat wave.

The scientists compared present (1961–1990) and future (2080–2099) decades to determine how greenhouse gases and sulfate aerosols might affect climate in Europe and the United States. They assumed little in the way of policy intervention to slow the buildup of greenhouse gases. During the Paris and Chicago heat waves, changes in atmospheric pressure produced clear skies and prolonged hot conditions at the surface. In the model, similar atmospheric pressure changes are enhanced during heat waves in both regions as carbon dioxide accumulates in the atmosphere.

The model showed heat waves that were longer and more frequent. In parts of the United States and Europe, minimum nighttime temperatures increased by as much as 3 degrees Celsius (5.4 degrees Fahrenheit). The implications are serious: In the Chicago heat wave, health experts reported that the most severe health impacts resulted from the lack of cooling relief several nights in a row. **Highlight ID: 11252 GEO/ATM**

Urban Trace-Gas Emissions Study: Interactions Among Canopy Processes, Anthropogenic Emissions, and Social Institutions in the Salt Lake Valley, Utah

An interdisciplinary team of investigators will study the multiple and interacting influences of urban land cover on air quality and greenhouse gas emissions in the Salt Lake Valley. The goal is to significantly contribute to our understanding of the complexity of urban airshed processes and provide a framework for evaluating the social, physical, chemical, and biological factors that influence the urban atmosphere. The Salt Lake Valley is a good model system for studying these issues because of excellent historical records, an extensive urban forest relative to the surrounding desert ecosystem, and a characteristic rapid rate of urban growth. Decisionmakers from the city, county, and State governments have agreed to participate in this project by attending workshops, providing input into model development, and discussing policy implications of project results. A systems dynamics model will be developed with a user-friendly interface, so that decisionmakers can use the model as a tool to explore the factors that strongly influence local air quality and greenhouse gas emissions. The model will also be used to evaluate the impact of future scenarios of urban growth. The social science team will provide questionnaires to decisionmakers at the beginning and end of the project to evaluate the effectiveness of the partnership between university researchers and decisionmakers.

The majority of greenhouse gases and other atmospheric pollutants originate in cities, so we must improve our understanding of key aspects of the complexity of the urban airshed. The investigators will focus on complex factors affecting emissions of carbon dioxide (CO_2), water vapor, and volatile organic compounds (VOCs) in the Salt Lake Valley through atmospheric measurements, traffic monitoring, modeling, remote sensing, and compilation of energy use statistics. Water vapor and CO_2 are important greenhouse gases that affect local, regional, and global climate. VOCs are precursors to the formation of urban smog. All these trace gases are emitted from human activities and by vegetation in the urban environment. Interdisciplinary collaboration among atmospheric scientists, social scientists, urban planners, engineers, and ecologists is required to measure the concentrations and emissions of these gases, trace their origins, and evaluate the implications for effective management of the urban airshed. By applying scientific measurement techniques to a quantitative model and collaborating with local policymakers, this project will evaluate feasible and effective ways to reduce greenhouse gas emissions, maintain high air quality standards, and improve the quality of life of urban residents. **Highlight ID: 1346 GEO/ATM**

Individual-Particle Investigations of East Asian Aerosols From the Aerosol Characterization Experiment

To fully understand and model the effects of pollution on climate, researchers must learn more about what, exactly, is contained in the pollution. James Anderson and colleagues collected samples of atmospheric aerosols during the Aerosol Characterization Experiment (ACE-Asia) in spring 2001. The objective of this major international field project was to characterize aerosols in the Northwest Pacific region and to understand their impact on the radiative budget in the region. The researchers collected aerosols from both air- and ground-based collection sites, then analyzed the samples using automated scanning electron microscopy and manual transmission electron microscopy. The analysis provided detailed information about particle composition, size distribution, shapes, and state of mixing. Information on shapes and mixing state is very difficult to obtain by any other method, yet it is crucially important to correctly determine the role of aerosols in the regional climate.

Perhaps the most important finding is the variety of the East Asian pollution particles, even from samples not mixed with urban pollution. The dust mineralogy and size and shape distributions have a variability that is probably due to the pollution originating in different regions and having different transport histories. Aggregation of mineral particles is common, and the variable degree of aggregation affects both size and shape distributions. A very wide range of shape distributions means that simplifying assumptions in lieu of observations used in modeling optical properties are not valid. Once the dust mixes with urban pollution, several additional consequences ensue. Perhaps the most important consequence for climate change is the common aggregation of black carbon with mineral dust, as this causes the aggregate to absorb light (most aerosol particles only scatter sunlight). The investigators also observed a number of other complex particle interactions that must be taken into account to adequately understand the pollution's interaction with sunlight. **Highlight ID: 1361 GEO/ATM**

Climate Change Is Affecting Earth's Outermost Atmosphere

Illustration of the thermosphere. New research shows that the outermost layer of the atmosphere will lose 3 percent of its density over the coming decade, a sign of the far-reaching impacts of greenhouse gas emissions. As the density declines, orbiting satellites experience less drag. *Credit: © University Corporation for Atmospheric Research*

Carbon dioxide (CO_2) emissions from the burning of fossil fuels will produce a 3 percent reduction in the density of Earth's outermost atmosphere by 2017, according to a team of scientists from the National Center for Atmospheric Research (NCAR) and Pennsylvania State University. The study showed that climate change will affect the upper as well as the lower atmosphere; it confirms recent satellite observations showing that the thermosphere (the highest layer of the atmosphere) is becoming less dense. Lower density in the thermosphere reduces the drag on satellites in low-Earth orbit, allowing them to stay airborne longer. Forecasts of upper level air density could help NASA and other agencies plan the fuel needs and timing of satellite launches more precisely, potentially saving millions of dollars.

Carbon dioxide cools the thermosphere but warms the atmosphere near Earth's surface (the troposphere). This paradox occurs because the atmosphere thins with height. Near Earth's surface, CO_2 absorbs radiation escaping Earth, but before the gas molecules can radiate the energy to space, collisions with other molecules in the dense lower atmosphere force the CO_2 molecule to release energy as heat, thus warming the air. In the much thinner thermosphere, a CO_2 molecule absorbs energy when it collides with an oxygen molecule, but there is ample time for it to radiate energy to space before another collision occurs. The result is a cooling effect. As it cools, the thermosphere settles, so that the density at a given height is reduced. Also affecting the thermosphere is the 11-year cycle of solar activity. During the active phase of the cycle, ultraviolet light and energetic particles from the Sun increase, producing a warming and expansion of the upper atmosphere. When solar activity wanes, the thermosphere settles and cools.

To analyze recent solar cycles and peer into the future, the researchers used a computer model of the upper atmosphere that incorporates the solar cycle, as well as a gradual increase of CO_2 due to human activities. The team used a prediction that calls for a stronger than usual solar cycle over the next decade. The model showed a decrease in thermospheric density from 1970 to 2000 of 1.7 percent per decade, or about 5 percent overall, which agrees with observations. The team found that the decrease was about three to four times more rapid during solar minimum than solar maximum. **Highlight ID: 14119**

Identifying Clouds Using Statistical Tools

Scientists from the University of California-Berkeley, and Pennsylvania State University are collaborating with the Jet Propulsion Laboratory at NASA to create new technology for detecting and modeling cloud formation. Understanding weather patterns via cloud formation and movement is one of the key features necessary in climate modeling. Cloud monitoring via satellite technology is underdeveloped, but has the potential to provide more accurate information that could lead to greater predictability in climate modeling.

The research performed through this project aims to improve detection of clouds from space, specifically in the Arctic, through multiangle imaging technology housed in NASA's Earth Observing System Terra satellite. Initial findings suggest at least a 20 percent improvement in accuracy for satellite imaging. If successful, the technology will greatly improve meteorological precision and lead to improved software and modeling techniques. **Highlight ID: 12359 MPS/DMS**

Why Is This Cloud Raining on Me?

A team of multidisciplinary scientists wants to know more about cumulus clouds, the simplest and "puffiest" clouds that float across the sky. To do so, they are developing new visualization and analysis techniques to gain insight into the factors that control precipitation development in cumulus clouds found in trade winds. These clouds are present over much of the globe; they affect heat and moisture budgets; and they have an impact on the amount of radiation that enters and leaves Earth's atmosphere. They are poorly represented in global climate models, and this research should improve their portion of the models. Because cumulus clouds are relatively simple clouds that contain no ice, they can be used to investigate long-standing, fundamental questions about precipitation development by the warm rain processes that are relevant to other types of clouds. This knowledge could inform precipitation-flood-drought forecasts and benefit agriculture. **Highlight ID: 15937 CISE/IIS**

Project Atmospheric Brown Clouds Advances U.S. Leadership in Climate Research and Education

V. Ramanathan of Project Atmospheric Brown Clouds with several autonomous unmanned aerial vehicles. *Credit: Scripps Institution of Oceanography, UC San Diego*

Atmospheric brown clouds (ABCs) are caused by air pollution emissions containing aerosol particulates. Project ABC is a concerted effort among an international group of distinguished atmospheric scientists and researchers, governments in Asia, and research institutions in Asia, Europe, and the United States to address the causes and impacts of ABCs, which are a major environmental challenge facing the Asia-Pacific region. The project is guided by a science team led by V. Ramanathan of the Scripps Institution of Oceanography and a United Nations Environmental Programme steering committee. Unlike issues such as greenhouse gases and global warming, the effects on climate from pollution aerosols are universally accepted throughout Asia. Project ABC provides high visibility for the United States in its leadership role on climate research and education in the South Asia and Asia-Pacific region, which is home to more than half of the world's population.

Project ABC aims to develop the physical infrastructure, human resources, and networks of experts and institutions in the South Asia and Asia-Pacific region. Central to its mission is the development of surface observatories and ABC training schools. Over the past 4 years, 14 climate observatories have been established in the Maldives (2), Nepal (2), India (2), Pakistan (1), Thailand (1), China (3), Korea (1), Japan (1), and the United States (1). Local scientists and technicians maintain the stations and carry out measurements using instruments deployed at those sites for radiation, aerosol species, gas-phase species, precipitation chemistry, and meteorology. The first training school was held in October 2004 in Thailand and a second in December 2006 in the Maldives. **Highlight ID: 13675 OD/OISE**

In Search of the North American Monsoon

A group of undergraduate and graduate students in the Department of Earth and Environmental Science (EES) of New Mexico Institute of Mining and Technology (New Mexico Tech) spent nearly 3 weeks in Sonora, Mexico, as part of a large international field campaign to study the North American Monsoon (NAM). The NAM is an annual regional atmospheric phenomenon that controls hydrological and ecological conditions during the summer season in the southwestern U.S. and northwestern Mexico. Given its wide effect, ecohydrological studies of the NAM require coordinated research efforts between U.S. and Mexican scientists.

New Mexico Tech's EES Department is playing a key role in these binational studies through several projects sponsored by NSF and the National Oceanographic and Atmospheric Administration. The efforts have been carried out in collaboration with scientists from the Universidad de Sonora, Instituto Tecnológico de Sonora, University of Arizona, University of New Mexico, and the National Center for Atmospheric Research. In 2007, 21 students and researchers from the United States and Mexico participated in the Sonora Field Campaign, engaging in scientific and cultural exchanges.

The students helped plan, organize, and carry out a series of ecohydrological experiments in a remote, mountainous region in northern Sonora. Predicting the NAM should prove very useful to communities affected by its weather patterns. **Highlight ID: 15269 OD/OISE**