NCAR Strategic Plan

28 August 2009

I. Introduction

This NCAR strategic plan outlines seven institutional imperatives that describe our fundamental ongoing responsibilities as a national center. Each imperative is followed by a prioritized set of supporting actions that NCAR will undertake. Our plan also lays out a set of frontiers—areas where NCAR intends to build out from and across existing programs and research activities—listed in order of priority. Together, the imperatives and frontiers explain our highest-priority ongoing efforts and our aspirations for program development and enhancement. This is a five-year plan, but it often focuses on the next two to three years and also includes some activities that extend beyond the five-year horizon.

This plan is not a comprehensive overview of the many valued activities conducted within NCAR and in partnership with our community. Rather, it is intended as a concise, high-level explanation of institutional direction and priorities for growth. More detailed descriptions of the full sweep of NCAR activities can be found in the NCAR Annual Report and the plans of NCAR's laboratories, divisions, and institutes.

Many stakeholders, including members of the university science community and program officers of the U.S. National Science Foundation and other federal agencies, contributed to this document's development. Wide involvement in NCAR planning is essential because NCAR's work is collaborative; the activities described herein will be carried out in conjunction with numerous partners in the broader university and scientific community.

The NCAR Mission

To understand the behavior of the atmosphere and related physical, biological, and social systems

To support, enhance. and extend the capabilities of the university community and the broader scientific community, nationally and internationally

To foster the transfer of knowledge and technology for the betterment of life on Earth

NCAR and its Mission: NCAR is a federally funded research and development center (FFRDC) devoted to research, service, and education in the atmospheric and related sciences. We conduct scientific research, operate observational and computational facilities for the science community, develop and transfer technology and information products to interested users, and provide opportunities for educational and professional development to post-secondary students and early career scientists. Our primary sponsor is the National Science Foundation (NSF), with important additional support provided by other U.S. government agencies. As an FFRDC, NCAR has a strategic partnership with NSF, and we fully embrace NSF's mission and overarching goals:

helping the United States to uphold a position of world leadership in science and technology, promoting the transfer of new knowledge to society, and contributing to excellence in science and technology education.

Partnerships and Collaboration: NCAR is a crossroads for scientific interaction and collaboration. We work closely with universities, environmental research and assessment programs, government laboratories, and other international and national research institutions to define grand challenge problems in the atmospheric, solar, and related sciences; and we collaborate with these partners to organize and support communities of leading experts in sustained, long-term projects that address such problems. We maintain strong ties to innovative researchers and other centers of excellence, nationally and internationally, and include our partners in decision making and direction setting for our institution. Successful implementation of this plan depends on close and ongoing engagement with a wide variety of scientific partners.

NCAR is also a venue for the interaction of science and society. Our partnerships and interactions with decision makers in business and industry; nongovernmental organizations; and local, national, and international governmental bodies and agencies are steadily increasing. We consider policy questions and societal issues as we develop research plans. We investigate decision making processes and develop decision-support mechanisms to help ensure efficient and effective applications of science to societal needs. We embrace both research and operational goals in model development. We reach out to diverse groups interested in the atmospheric and Earth system sciences, conduct our work in an open and transparent manner, and proactively inform the public about our programs and results. We see active engagement with stakeholders who can use and benefit from our work as a fundamental responsibility.

NCAR and the Academic Community: NCAR has a special relationship with the university community, which manages NCAR through the nonprofit University Corporation for Atmospheric Research (UCAR) on behalf of NSF. The UCAR Board of Trustees and UCAR President's Advisory Committee on University Relations, elected by representatives of UCAR member universities, provide fiduciary, legal, and program oversight for NCAR and all other UCAR programs. University representatives are part of the NCAR Advisory Council and the advisory panels for all NCAR laboratories, divisions, and institutes. Collaborations among NCAR staff and university colleagues are integral to our institutional success; the strength, variety, and frequency of our university interactions provide metrics of our programmatic health.

NCAR–University Interactions in 2008: A Snapshot

- 73 North American universities are members of UCAR, which manages NCAR
- 23 universities and colleges are academic affiliates of UCAR
- 77 academic representatives currently serve on NCAR advisory committees/panels
- 702 university scientists are registered users of the NCAR Weather Research and Forecasting model
- 79 NCAR staff served on thesis committees at 34 universities, 42 NCAR staff were graduate advisors at 33 universities, and NCAR scientists held 72 teaching appointments at 30 universities
- 70 universities and colleges around the world use data from the NCAR Mauna Loa Solar Observatory
- 22 U.S. universities are deeply involved in development of the NCAR-led Community Climate System Model
- NCAR submitted 205 collaborative proposals with 86 different universities for non-NSF funding
- Approximately 400 papers were coauthored by academic and NCAR scientists
- Approximately 600 academic scientists participated in NCAR-supported field campaigns
- 644 academic scientists used NCAR computational facilities

II. NCAR and the Changing Context of Atmospheric Science

The next five years will present significant opportunities and challenges for NCAR and the broader atmospheric and related sciences. Even in the few years since the last NCAR strategic plan, we have witnessed significant advances in our understanding of fundamental atmospheric processes and how the atmosphere interacts with and is influenced by other components of the Earth system. Notable strides have also been made toward understanding the solar processes that affect the Earth's atmosphere and environment in space. The knowledge gained through these efforts has been incorporated in ever-improving research and operational models, thereby yielding further insights and providing better predictions of weather (including catastrophic events), climate variability and change, and space weather. This progress is being driven, in part, by new technologies, including sophisticated remote and in situ instruments and increasingly powerful computers and information systems.

Yet our understanding and ability to predict the Earth and Sun systems remain insufficient for societal needs. Rapidly changing environmental conditions and growing societal need for relevant information and services are placing new demands on the atmospheric and related sciences. For example, human-induced global climate change has been largely accepted as real, but information about temperature changes are not at a sufficiently fine scale for planning regional adaptation and mitigation. Increasingly sophisticated yet remarkably vulnerable societies need greater detail, accuracy, and lead time in weather and space weather forecasts. Air quality remains a major problem, and we are witnessing food and water shortages in many areas. Further scientific progress, active engagement with a range of stakeholders, consideration of societal needs in research planning, and more effective transfer of applications and information to users are needed to effectively address these issues.

- Improved understanding and documentation of many basic processes is needed to better explain relationships and feedbacks among components of the Earth and Sun systems and to develop more accurate predictive models.

- We need weather, climate, and chemistry models that can provide accurate and reliable predictions of regional climate change and air quality, including the statistics of extreme events and high-impact weather. Initializing and validating the high-resolution models needed for this task requires significant advances in observations and data assimilation.

- In order to more accurately predict phenomena like hurricanes and possible changes in their intensity and frequency, models must resolve these phenomena, the critical forcing elements, and the associated planetary-scale circulations in which they are embedded.

- Improvements in modeling and observations are needed to better understand the likelihood of abrupt climate change; the rate and magnitude of sea-level rise; changes in the water cycle; changes in ecosystems; and the effects of climate change, agricultural practices, and other stresses on uptake and release of carbon from the biosphere and oceans.

- Equally imposing difficulties must be surmounted in order to understand the nature and impacts of the solar outputs that connect the Earth and Sun systems.

Atmospheric scientists are crossing disciplinary boundaries to respond to these challenges. Collaborations with oceanographers, biologists, demographers, and economists are necessary to understand and model the causes and impacts of weather and climate change, while work with software and hardware engineers is required for improved use of advanced computers and development of new observing systems. Closer cooperation with social and communication scientists can help to more effectively identify information needs, increase the salience of the natural sciences to decision making, and improve the outcome of decisions through better communication approaches and methodologies. Atmospheric science continues to cross organizational and national boundaries as well. National and international coordination of research is becoming increasingly important, not only because the atmosphere is a global commons but because many problems require scientific and engineering expertise beyond that resident in any single institution, nation, or discipline.

Results from UCAR's Most Recent Survey of the Community: UCAR's most recent survey of the atmospheric science community, conducted in 2009, was sent to more than 15,000 people, with 2,215 responses (about 14%).

- 69% suggested increased emphasis on interdisciplinary research for UCAR and NCAR.
- 68% reported interactions with NCAR.
  - 14% reported interaction with NCAR weather researchers.
  - 11% reported interaction with NCAR climate researchers.
- The top five areas where additional NCAR services were suggested were data streams and data sets, community models, education materials, community workshops, and observational facilities.

All of these factors have influenced our planning, leading to a strategy that balances and integrates theory, modeling, and observation. It emphasizes fundamental research on the processes that are central to the operation of the Earth and Sun systems; leadership in the development and provision of observing, supercomputing, and modeling facilities; aggressive pursuit of key integrative and collaborative scientific thrusts; a close, synergistic relationship with the university community; extensive national and international collaboration; and development of the human capital needed to achieve these aims. While core disciplines necessarily remain an emphasis, NCAR's programs have become increasingly interdisciplinary in order to address the challenges of studying the atmosphere, terrestrial environment, and Sun as interrelated systems.

Our long-term goal is to build on improvements in scientific understanding, software engineering, and computational technology to develop a next-generation Earth System Model that provides a more complete representation of the Earth system. Such a model would enable analysis of processes across multiple scales and examination of the relationships and feedbacks among multiple environmental stresses. Its development will require more collaboration among weather and climate scientists; new approaches for coupling oceanic, land surface, chemical, biogeochemical and physical processes; and creative methods for including human activities and influences. This long-term objective shapes and guides many of the activities that are described in this document, even though full realization is probably more than a decade away.

III. Structure of This Plan: Imperatives and Frontiers for NCAR

This plan is organized around a set of imperatives and frontiers for NCAR. The imperatives are the activities that NCAR must carry out to fulfill our role as a national center for the atmospheric and related sciences. They are based on our mission and our role in the atmospheric sciences community as it has evolved over nearly 50 years. All of the imperatives are top priorities, and we would maintain some level of effort in each even in the face of budget stress. Section IV of this document describes each imperative, followed by a set of action items, or specific activities for that imperative, in rough priority order. It is important to recognize that the action items are all deemed very important (and taken together they represent a subset of NCAR's overall suite of activities).

NCAR Imperatives

- Promote innovation and creativity within our institution and across the community of atmospheric, solar, and related sciences
- Provide capabilities for more accurate prediction and attribution of changes in climate, severe weather, air quality, and solar output, and the impacts of such changes on ecosystems and human well-being
- Work with collaborators to advance world-leading numerical models of the atmosphere and Earth system, make them widely available, and support their use by the scientific community
- Develop and provide state-of-the-art supercomputing and data services that will drive the advancement of the atmospheric and related sciences
- Develop and provide state-of-the-art observational facilities that meet the needs of NSF, NCAR, and the atmospheric and related sciences community
- Develop and transfer scientific applications, technology, and information products that address societal needs
- Attract a diverse group of university students and early career scientists and engineers to the atmospheric sciences and provide them with exciting opportunities for educational and professional development

The frontiers are areas where we have identified opportunities to build out from and across existing efforts. The frontiers stress challenges associated with significant emerging societal needs. NCAR and the atmospheric sciences community can play a significant enabling role in advancing these frontiers by creating new partnerships; working to cross disciplines; and by providing an improved foundation to address issues associated with water, ecosystems, renewable energy and to connect to diverse stakeholders. Frontiers are extensions of NCAR work that require increased support to be fully and rapidly implemented. The five frontiers in the plan were derived from a much longer list of potential extensions suggested by NCAR scientists, divisions, institutes, and laboratories. They are in priority order. Progress in frontier areas is dependent on continued strength in the imperatives. Unlike with imperatives, budget stress could result in deferral of frontier activities.

NCAR Frontiers (*in priority order*)

- Advance modeling and analysis focused on informing climate change adaptation and mitigation
- Conduct and enable studies of water resource availability, vulnerability, and adaptation planning
- Develop and support new community tools for integrating Earth and Sun system measurements with models
- Promote new grid-based computing technologies for interacting with universities and the broader science and education community
- Develop methods to more accurately assess and predict wind and cloud cover in support of renewable energy industries. Understand the impacts of biofuels and other renewable energy technologies on water resources and regional climate

Prioritizing the frontiers and the action items under imperatives involved multiple iterations between the NCAR strategic planning council and NCAR senior managers. All suggested activities and frontiers had to meet thresholds of feasibility, affordability, and appropriateness to NCAR's role as a national center. The suggestions that met those criteria were then evaluated according to

- scientific quality and excitement
- broader impact and relevance to stakeholder needs
- ambitiousness and vision

The priority rankings that resulted from this process are better thought of as a rough guide than a rigid template. Actual year-by-year funding decisions will be influenced by opportunities for cooperation and leverage, availability of funds vs. projected costs, and other factors. A lower-priority, lower-cost item might be funded in a given year if sufficient funds are not available for a more expensive, higher-priority item. Nevertheless, the order of action items and frontiers provides a good indicator of where NCAR would invest additional funding.

IV. NCAR Imperatives

Promote innovation and creativity within our institution and across the community of atmospheric, solar, and related sciences

As a national center that provides service and leadership for the scientific community, NCAR must be a venue where new ideas, methods, tools, and practices are developed, gathered, evaluated, and shared. NCAR should serve as a hub for community interactions, collective definition of grand challenges, and development and implementation of collaborative research activities to address such challenges. To fulfill this role, NCAR has to maintain a world-class scientific workforce, a high standard of excellence, strong collaborations, and a broad spectrum of fundamental research that leads to new understandings, and more-focused programmatic research (such as described in the imperatives that follow). Programs that encourage innovation and creativity contribute to intellectual and programmatic renewal at NCAR and in the community and help build the foundations for continuing scientific advancement. To support this imperative, NCAR will

- Conduct discovery-oriented research across the atmospheric, solar, and related sciences to identify emerging issues, develop new approaches, and guide the direction or redirection of ongoing research programs

- Develop and support collaborative research efforts that combine ecological, hydrological, biogeochemical, and social science expertise with core atmospheric disciplines to address challenging and multifaceted Earth system science problems

- Build an expanded scientific visitor program with the flexibility to entrain a broad community of scholars and reward NCAR staff for spending time in other research organizations to encourage exchange of information and development of new perspectives

- Work with universities, the broader science community, and public- and private-sector decision makers to identify grand challenge problems of societal and scientific interest, in order to define new approaches and methods for research

- Enhance supercomputing, observational, and modeling facilities by evaluating new technologies; experimenting with advanced computational architectures; and developing prototype instruments, models, and model components

- Provide regular opportunities for staff to pursue high-risk, potentially path-breaking research projects

Provide capabilities for more accurate prediction and attribution of changes in climate, severe weather, air quality, and solar output, and the impacts of such changes on ecosystems and human well-being

Climate change, weather extremes, atmospheric pollution, and space weather have significant societal, environmental, and economic costs. More accurate prediction can help reduce these costs by providing advance warning of dangerous conditions. But the development of effective long-term strategies to minimize damages is hampered by incomplete ability to attribute observed changes in the atmosphere and Earth system to specific causes and mechanisms. For instance, the precise mix of factors driving regional climate variability is not fully understood. There are also many unanswered questions about the relationships among atmospheric change and ecological, biological, and societal processes. Improved understanding of such relationships would, for example, enable us to better anticipate how continued climate change will affect water availability, agriculture, and urban development in the western United States or to project the rate of loss of biodiversity from the combination of climate change, degraded air quality, and land use change. Enhancing our ability to analyze and determine the causes of changes and their impacts will help ensure that mitigation and adaptation strategies are focused on the right problems.

NCAR, with its university partners, is well suited to address the twin challenges of prediction and attribution because of our broad strength in process studies, observational research, model development, and simulation, as well as our long experience in collaborative interdisciplinary research. NCAR's deep experience in modeling complex processes provides a strong foundation for accurately quantifying the uncertainty associated with predictions – an important component of making them more useful for decision making and informing policy. Over the next three to five years, we will

- Produce experimental high-resolution climate forecasts for the next few decades, with companion measures of uncertainty, and work with collaborators to use these for investigating regional-scale climate impacts

- Conduct research and develop models to improve the accuracy and utility of forecasts of high-impact weather, focused on hurricane landfall and intensity, severe thunderstorms, and other extreme events

- Use models and observations to more accurately identify the natural and anthropogenic processes driving atmospheric changes as well as related societal and environmental vulnerabilities, impacts, and feedbacks

- Develop new techniques for predicting changes in air quality and their impacts on ecosystems and human health

- Analyze and predict the Sun's variable magnetic, radiative, and particulate outputs and their impacts on the terrestrial environment

- Collect critical measurements needed to improve our understanding of physical processes and test and improve models and their predictions of the atmosphere and the Sun

- Develop a comprehensive model of interactive processes throughout the Earth's atmosphere-ionosphere-magnetosphere systems, analyze how these are affected by solar variability, and begin prediction of space weather

Over the next five to ten years, we expect to move from independent predictions of climate, weather, and air quality to more unified environmental predictions that include aspects of all three. Fundamental research conducted at universities, NCAR, and other scientific institutions will significantly improve our understanding of basic atmospheric, oceanic, biological, hydrological, solar, and ecological processes. New modeling systems will permit integrated analysis of the relationship among changes in atmospheric composition, climate, and weather. We also expect significant advances in understanding how such changes affect ocean acidity, plant and animal species, ecosystems, human health, and communities. This should enable the attribution of observed impacts to specific causes and lead to more detailed, accurate, and useful prediction of potential future impacts, thus underpinning development of effective adaptation and mitigation strategies.

Work with collaborators to advance world-leading numerical models of the atmosphere and Earth system, make them widely available, and support their use by the scientific community

NCAR has a proud and unique tradition of collaboration with scientists from universities, national laboratories, and other research organizations to create, maintain, and distribute "community" climate and weather models that integrate the best available expertise across institutions. This effort extends from continuous basic theoretical and observational research, which underpins model development and evaluation, to provision of user support services. NCAR emphasizes ongoing advancement and redefinition of the atmospheric model components, integration and maintenance of complete models, and user support, while partners often lead in the development of additional model components such as sea ice and oceans. Scientists all over the world rely on these openly available tools to perform their research. In return, they contribute to model evaluation and development. During the past 30 years, community modeling has become one of the most important services provided by NCAR to university researchers and other interested users, and it will continue to be one of our top priorities. Over the next three to five years, NCAR will work with its partners to

- Improve the Community Climate System Model (CCSM) and the Weather Research and Forecasting (WRF) model

    - Develop and release CCSM version 4, with improved representation of the carbon cycle, the nitrogen cycle, and atmospheric chemistry

  - Develop and release Advanced Research WRF version 4, with improved data assimilation and microphysical and boundary-layer processes and exchanges
  - Continue development of WRF and CCSM variations, such as WRF-Chem, WRF-Fire, and the Whole Atmosphere Community Climate Model (WACCM)

- Develop and release new community modeling systems that incorporate new atmospheric components, offer state-of-the-art representation of a greater number of Earth system processes, and select and involve full testing of appropriate discretizations, grid refinement, and data assimilation approaches

- Continue research on data assimilation methods and parameterization, evaluate the impact of these new techniques on model performance, and continue enhancing the data assimilation capabilities of the NCAR community models

- Build innovative, extensible, and maintainable software design into the initial definition of Earth System Models. Determine a set of best practices for developing and modifying scientific model software, including requirement specifications, design reviews, and procedures for software testing and validation. Establish organizational incentives to follow these best practices

- Develop new software capabilities and infrastructure, including advanced software for massive parallelization, as well as new computational methods and experimental modeling platforms to advance numerical modeling and basic algorithmic and computational fluids research across the atmospheric and related sciences

Over the next decade, NCAR will move towards unified atmospheric and Earth system modeling. We will continue the integration of chemical, upper atmosphere, climate, and weather modeling, with particular attention to land surface modeling and dynamical processes work across our weather and climate groups. We plan to push ahead rapidly with use and evaluation of a first-generation combination of WRF with CCSM, the Nested Regional Climate Model (NRCM), described in more detail in the climate frontier section below. We will enhance our efforts in integrated assessment modeling (IAM), focusing both on improving capabilities and better integrating IAM approaches and experimentation with larger-scale Earth system modeling. Over the longer term, we plan to create a new, unified atmospheric modeling system capable of accurate prediction on time scales from hours to decades that is useful for both weather and climate prediction. This system will provide the basis for an advanced community Earth System Model that will include representation of oceans, sea and land ice, land cover, the upper atmosphere, and a large number of biogeochemical and ecological processes. We foresee extensive collaborations with existing and new partners in these efforts.

Develop and provide state-of-the-art supercomputing and data services that will drive the advancement of the atmospheric and related sciences

NCAR plays a critical national role in the development and provision of effective, end-to-end cyberinfrastructure (CI) for the atmospheric and Earth sciences community. NCAR's robust, innovative, and accessible supercomputing and data services have made customized high-end resources available to thousands of scientists and students, supported the creation and ongoing improvement of world-class atmospheric models, and enabled numerous cutting-edge simulations.

This track record of leadership, service, and success will continue. We will marshal the necessary facilities, equipment, software, and numerical and intellectual capabilities to meet the ever-expanding scientific goals of the geosciences community. In particular, we anticipate a 20-fold increase in the atmospheric community's demand for cyber-resources by 2012—requiring a capability comparable to the NSF "Track-2" or "petascale" centers. To be effective, this Track-2 –scale supercomputer must also be connected to a balanced and customized set of data systems, including petabyte-scale high-performance file systems shared with advanced data analysis and visualization resources, all backed up by a hundred-petabyte mass storage system. The entire facility must be connected, via high-performance networking, to the nation's other leading CI facilities, particularly those centers operated by NSF and the Department of Energy. The power, space, and cooling requirements of this facility will certainly exceed the capabilities of the NCAR Mesa Laboratory. *Constructing and beginning operation by 2012 of a new supercomputing facility capable of housing Track-2–scale systems is, therefore, NCAR's top priority.* Over the next three to five years, NCAR will

- With our Wyoming partners, construct the NCAR/University of Wyoming Supercomputing Center in Cheyenne, Wyoming

- Acquire and begin operating a suite of Track-2–scale supercomputers, networks, and data storage systems that are customized to support the requirements of the atmospheric and related sciences community

- Develop and support the software infrastructure specific to the simulation, analysis, and forecasting needs of the atmospheric and related sciences community

- Curate and develop research data sets, enable information extraction, and make the data and information openly and easily available to users

- Develop, maintain, and provide numerical analysis, visualization, archive, and access tools

- Develop, maintain, and provide robust and portable observational cyberinfrastructure to support field campaign operations, acquisition of data from instruments and observing platforms, and near-real-time analysis

Looking further ahead, higher wide-area-network bandwidth, more powerful computers, and specialized software are creating a grid that promises to provide simplified access to distributed high-performance computing resources. A grid strategy offers several potential benefits. By working together, geographically dispersed partners can scale up processing cycles to meet increasingly large scientific challenges. In addition, complementary expertise and resources can be combined across centers to tackle the complex and interdisciplinary challenges in computational science that are difficult or impossible for one center to address in isolation. These challenges include many computational problems in the geosciences, such as climate and earthquake modeling. Furthermore, the grid is part of a cluster of technologies forming a trend in high-end computing toward “cloud computing”: system virtualization, center automation, service-oriented architectures, and distributed workflows. Keeping up with and even leading the evolution of these ideas is essential to the long-term health of the laboratory.

Develop and provide state-of-the-art observational facilities that meet the needs of NSF, NCAR, and the atmospheric and related sciences community

Observational science is central to NCAR, and helping to define and conduct field campaigns and observational experiments is one of the most important services NCAR provides to the broader scientific community. To fulfill this imperative, NCAR must maintain a robust and reliable set of deployable observing facilities (aircraft and ground-based) and seek opportunities to develop and upgrade observational technology and instruments. NCAR also maintains and operates stationary observing facilities such as those at Mauna Loa; participates in the definition, design, and development of satellite-based and balloon-based instrumentation; and provides access to extensive archives of observational data sets. All of these activities are dependent on NCAR’s proven ability to attract and retain an experienced cadre of engineers, technicians, scientists, and logistics experts who provide world-class support for planning, development, and implementation. Over the next three to five years, NCAR will

- Ensure that the atmospheric observing facilities required for anticipated community research remain in ready-to-deploy status and operate these systems in support of those research programs

- Complete development and begin operation of all initial instruments on the NSF/NCAR G-V high-altitude research aircraft

- Distribute and manage observational data sets from new and archived experiments and meet the challenge posed by the increasing size and complexity of observational data sets by developing suitable systems and procedures for archival and access

- Enhance the Mauna Loa Solar Observatory through upgrade of existing instruments and addition of new instruments

- Develop life-cycle plans for major facilities and instruments, considering anticipated changes in technology and observational needs, in order to formulate a long-range strategy for replacement and upgrades

- Develop specific plans for a future airborne weather radar system (to replace or upgrade the ELDORA system) and for ground-based profiling of wind, moisture, and temperature (to replace, complement, or upgrade the Integrated Sounding System)

- Advance ground-based radar systems, with a near term focus on collaborating with CSU/CHILL to develop and deploy an integrated and networked multi-facility Doppler weather radar system

- Conduct a small set of exploratory development projects (often in partnership with others) selected for their potential to provide new observational capabilities

- Advance observational capabilities for atmospheric chemistry research, including developing and deploying time-of-flight mass spectrometry systems for analyzing organic trace gases and aerosols

If the observing systems that NCAR operates for the community are to remain at the state of the art, NCAR must also pursue long-term development projects with time scales of a decade or more. One such project is the Coronal Solar Magnetism Observatory (COSMO), which will provide unprecedented insights into coronal structure, heating, and dynamics, as well as the activity responsible for space weather, through synoptic observations of coronal magnetic fields. The centerpiece of COSMO will be a meter-class coronagraph with instruments to measure the coronal magnetic field using the polarization of forbidden infrared emission lines. Supporting instruments will provide context, and the suite will eventually replace the Mauna Loa Solar Observatory, operated by NCAR for over 40 years.

Two other prominent efforts in the early planning stages are the next-generation airborne radar that will replace the ELDORA system and the next-generation system for wind profiling (see planning efforts described in the actions above). NCAR also has developed proposals for a remote-sensing suite of airborne instruments (the Community Airborne Platform Remote-Sensing Interdisciplinary Suite, or CAPRIS) and for a "virtual operations center" (VOC). CAPRIS will include development of several lidars and short-wavelength radar for airborne use, and the VOC will integrate advanced networking and communications capabilities with analysis and visualization tools for remote access and interaction with researchers and students during field experiments. Finally, we see many opportunities for continued participation in the development of space-borne instrumentation for observations of the Sun and Earth system.

These major efforts, along with continued development of smaller component instruments for community use, represent the long-term vision for observational capabilities.

Develop and transfer scientific applications, technology, and information products that address societal needs

It is central to NCAR’s mission to transition research results into information, science-based applied technologies, and decision systems that protect life and property and benefit society. Conducting directed research that is relevant to societal needs, providing scientific information to support public and private sector decision making, and contributing to national and international scientific assessments are important responsibilities. We collaborate with university partners, other research organizations, and the private sector to carry out these activities. In addition, many governmental and private sector organizations (domestic and international) provide funding to create applications that are tailored to their needs. Over the next three to five years, NCAR will

- Define and undertake climate simulations that contribute to scientific assessments of climate change, including the Intergovernmental Panel on Climate Change Fifth Assessment Report and U.S. national assessments expected under the U.S. Global Change Research Program

- Develop decision-support systems in partnership with universities and other research organizations to assist the renewable energy, water, national security, agricultural, health, manufacturing, and transportation sectors

- Develop, test, and transfer to operational agencies state-of-the-art numerical techniques for atmospheric, climatic, and space weather modeling, and support the research community by providing repositories of tested code, tutorials, and help desks

- Integrate atmospheric and social sciences to assess and improve the utility of weather products and services and provide information on the societal impacts of weather and climate

- Develop and transfer advanced observational systems to the research and operational communities in collaboration with our university partners

Looking farther ahead, we will begin to apply integrated assessment modeling techniques traditionally used for climate studies to weather-scale problems and needs. Additionally we will begin to experiment with "interactive" science and technology transfer systems in which a decision maker or planner will be able to enter cyberspace, specify certain parameters that define the problem they are addressing, and get a nearly instant response consisting of explicit decision information, guidelines for developing a tailored decision system, or further references relevant to their inquiry.

Attract a diverse group of university students and early career scientists and engineers to the atmospheric sciences and provide them with exciting opportunities for educational and professional development

A steady flow of talented new participants into the atmospheric and related sciences is essential for scientific progress on many of the most compelling problems facing society. NCAR is committed to fostering graduate and postgraduate research and education, providing opportunities for undergraduate participation in NCAR research, and promoting students' interest in the atmospheric and related sciences. As a national laboratory active in research, modeling, and observational activities, we can provide unique hands-on educational experiences and many opportunities for students, advisors, and early career scientists to collaborate with a wide variety of scientists and engineers. Over the next three to five years, NCAR will

- Increase the number of postdoctoral appointments at NCAR
- Increase the size of NCAR's graduate fellowship program, which supports joint work among graduate students, their university advisors, and NCAR researchers
- Conduct educational activities/programs that integrate research and education in each NCAR laboratory, including work-study and summer programs for undergraduates in engineering, applied mathematics, and computer sciences that supplement the educational experiences they receive at universities
- Continue aggressive outreach to qualified candidates for educational programs, with particular attention to attracting candidates from diverse backgrounds and disciplines
- Bring science and engineering to students by providing Web-based access to near-real-time information about field campaigns and experiments and deploying NSF and NCAR observational facilities at or near universities and colleges
- Increase the involvement of NCAR scientists and engineers in teaching, supervising students, and other educational activities in the university community, and engage this community in increasing diversity
- Maintain a variety of early career employment options that provide entry points and pathways to different aspects of atmospheric and related research at NCAR and in the broader community

V. Program Frontiers for NCAR

NCAR divisions, institutes, and laboratories have identified many opportunities where building out from existing programs and integrating expertise across disciplines could accelerate scientific progress and provide new information to address societal needs. The following frontiers, *ranked in priority order,* are particularly compelling near-term opportunities for program enhancement.

Frontier #1: Advance modeling and analysis focused on informing climate change adaptation and mitigation

Over the next one to five years, governments, corporations, foundations, advocacy groups, consulting firms, and science labs will be involved in many overlapping decision processes on adaptation and mitigation. We have two near-term opportunities for constructive engagement that build on our strengths in modeling and simulation and include cooperation with universities and other collaborators with complementary expertise.

The first is to use our newly developed Nested Regional Climate Model (NRCM) to provide very-high-resolution (4 km) predictions of climate change over the next 50 years for the United States and possibly other regions, to support consistent local, regional, and national adaptation planning. (An atmospheric resolution of about 150 km was considered high resolution until recently.) Such simulations would help a wide variety of users with assessing vulnerability and potential impacts and developing strategies to respond. The model holds great promise for investigating the relationship of climate change to hurricanes. It also offers many possibilities for exciting collaborations with the hydrological, ecological, and human health communities, especially if additional atmospheric chemistry is incorporated. Specific actions would include

- Produce very-high-resolution (4 km) regional-scale predictions of climate change and impacts with NRCM, including detailed characterizations of prediction uncertainty
- Develop new partnerships focused on analysis of climate impacts on human health, ecosystems, and water resources
- Partner regionally with scientists and involve stakeholders end to end in creating regional assessments of vulnerability and adaptation options

Our second opportunity is to further develop and apply the Integrated Population-Economy-Technology-Science (iPETS) model to evaluate alternative climate change response strategies. This effort can provide fundamental insights about the coupling of human and natural systems. It can also provide useful information for national-scale decision makers on mitigation and adaptation through integrated analysis of the atmospheric, environmental, and economic consequences of different policy, economic, and technological choices. The use of this medium-scale tool could also inform and be informed by analyses using CCSM. NCAR's computing resources would enable a large number of experimental simulations on a very rapid timescale and would facilitate exploration of couplings to CCSM. We plan to

- Add and refine components of the iPETS model, including improved representation of spatial land use change, emissions, and mitigation of non-CO_2 greenhouse gases, and more detailed representation of key energy technologies

- Design and execute new simulations to evaluate different mitigation strategies and emissions pathways

- Explore new ways of linking integrated assessment models to Earth system models and incorporate impacts and adaptation into integrated assessment models

Frontier #2: Conduct and enable studies of water resource availability, vulnerability and adaptation planning

Water and water resources in many areas of the world are particularly sensitive to climate change. The water-limited regions such as the southwestern United States are a case in point. These regions are also experiencing rapid population growth and consequent competing demands for those limited water resources. As a result, water managers, western governors, and the general public are keenly interested in how the water cycle will change as the climate warms and what they might do to cope with such change. We see two topics as particularly important: (1) the potential that the mountain snowpack (the main water reservoir for the western United States) will decrease under climate change, changing the seasonal patterns of runoff and river flow; and (2) the threat of increasing drought under climate change and consequent societal vulnerability and response. To investigate these issues, we plan to

- Determine the principal controls (large-scale dynamics, moisture sources, orography, convective processes, etc.) on precipitation character (seasonality, frequency, intensity, and phase) in western North America and how these will respond to a changing climate

- Diagnose, in models and observations, the partitioning of precipitation among runoff, evapotranspiration, and groundwater recharge across western North America and define how this partitioning will change in response to climate change and landscape disturbance (e.g. forest dieback, shrubland succession, fire, urbanization)

- Improve model physics parameterizations (convection, microphysics, land surface, snow processes, planetary boundary layer) to enable credible climate model simulations of the water cycle over western North America

- Improve characterization of uncertainty in climate model simulations, through statistical and dynamical downscaling and multi-model ensemble processing (as in the North American Regional Climate Change Assessment Program, or NARCCAP) for the western North American water cycle

- Work with partners to examine the impact of climate change on groundwater storage (such as in the Ogallala Aquifer).

- Improve the characterization and parameterization of the impact of the water cycle on biogeochemical cycles through the BEACHON project

- Determine the leading drivers of societal vulnerability and adaptive capacity to changes in water availability in western North America and determine how state-of-the-art model scenarios can best inform decisions about water resources

- Develop modeling scenarios to explore how changes in population size and location, economic development, land use, and infrastructure impact water resource management, and how these processes are influenced by climate change

The resulting improvements to climate models and the inclusion of societal vulnerability and adaptation in model development and applications will benefit many other parts of the world, especially those with comparable vulnerabilities.

Frontier #3: Develop and support new community tools for integrating Earth and Sun system measurements with models

Effectively synthesizing multi-scale Earth and Sun system model output with measurements is at the core of much NCAR science. Observations are used to develop theories, confront model results, and, through assimilation techniques, adjust those results. Remote sensing from space now provides essential global-scale information on the atmosphere, and novel sensor networks are being developed that will provide new unique and dense observations, supplementing traditional observations. Model representation of difficult-to-observe processes can be improved by examining the mismatch between models and corresponding forecasts based on assimilation of observational data, particularly satellite observations and spectrally resolved images of the Sun and its magnetic field.

There is an emerging opportunity for NCAR to serve the community by developing and supporting numerical tools and strategies for integrating measurements and models. This process relies on new, flexible methods of data assimilation in which heterogeneous sets of physical measurements can be combined with geophysical models to both yield better predictions and detect model biases. This activity has two distinct benefits: models can augment the often-sparse coverage of observations, and high-resolution observations can diagnose strengths and weaknesses of a physical model and its supporting parameterizations. This frontier will also support new instrument design by providing a framework in which the community can assess the ability of novel observations to improve prediction or elucidate imperfectly understood physical processes. We plan to

- Confront climate models, solar simulation models, and their components with observations via data assimilation and extensive diagnostic analysis. Extend data assimilation procedures to the upper atmosphere (such as the regions covered by WACCM), and to geospace modeling

- Develop and distribute tools that promote the integration of remote sensing data with models via data assimilation, and map science questions onto measurement and instrument requirements

- Develop a prototype system for chemical weather analysis and prediction by combining remote sensing and other observations with data assimilation and a prediction system

- Exploit the capabilities of NSF aircraft and other airborne observing systems in model and satellite validation and provide tools for comparing measurements with corresponding model representations

- Develop ensemble data assimilation methods to address sets of bounded observations such as atmospheric concentrations or Doppler radar reflectivity

- Develop and test assimilation approaches for initialization of decadal-scale and longer climate predictions

- With the university community, continue to assemble observations of the carbon and nitrogen cycles for the evaluation and improvement of biogeochemical models through testing against observational constraints

Frontier #4: Promote new grid-based computing technologies for interacting with universities and the broader science and education community

NCAR's research, service, and educational activities involve extensive partnerships with individuals and institutions all over the world. Reliable and easy-to-use cyberinfrastructure (CI) is increasingly important to sustaining these collaborative endeavors. Continued advances in advanced grid-based technologies hold significant promise for accelerating scientific progress by making high-performance computing and analysis tools widely and easily available; permitting remote access to and use of scientific instruments; and greatly easing the flow of, access to, and storage of data and information. NCAR is deeply involved in supporting high-performance CI services and tools, observing systems, and atmospheric and related science and education. We are thus very well positioned for a leadership role in the development of advanced grids for scientific research and education. Our near-term objectives are to

- Develop next-generation science gateway infrastructure and other grid-based technologies to enhance the development of virtual organizations for research and education in the atmospheric and related sciences

- Continue as a resource partner in the TeraGrid, at least through April 2011, and participate in the proposed TeraGrid data replication service, if funded, as an archive resource partner through September 2013

- Help define, implement, and improve the next-generation research grid through participation in the NSF eXtreme Digital (XD) Program
- Investigate and evaluate methods for remote examination and analysis of very large or heterogeneous data sets
- Explore future grid environments that will allow NCAR and other sites (e.g., universities) to see and be seen through NSF's XD infrastructure
- Apply the urgent-computing paradigm to weather forecasting applications in a production grid environment
- Improve the effectiveness and availability of tools for computation, data analysis, workflow, and visualization and of services for researchers and students
- Develop and deploy a virtual operations center that increases the connectivity of field experiments to researchers, students, and high-end data analysis and modeling facilities

Frontier #5: Develop methods to more accurately assess and predict wind and cloud cover in support of renewable energy industries. Understand the impacts of biofuels and other renewable energy technologies on water resources and regional climate

Shifting the nation's energy portfolio toward renewable energy sources, such as wind, solar power, and biofuels, is a national priority. Atmospheric science has a role in developing these resources: important meteorological and climatic factors influence the amount of energy available from these sources, and renewable energy developments themselves can have climate and environmental impacts.

There are a number of atmospheric research frontiers of particular relevance. Improved understanding of the atmospheric boundary layer and the interaction of flow regimes with variable topography is crucial for developing wind resources. There is now widespread recognition that poor characterization of the atmospheric conditions in which wind turbines operate is hindering the development of their energy-generation potential: wind farms are under-producing by 15-20%, and turbines that are designed for a 20-year lifetime are failing in less than five years. The efficiency of future power grids can be substantially improved by using accurate and detailed short-term weather predictions to control renewable power generation systems. New sensors and weather prediction systems are needed for future grids that may include energy storage components. Finally, in the area of biofuels, cultivating new crops for scaled up production could significantly change land-use patterns, which, in turn, could negatively impact soil erosion, water resources, and regional climate. NCAR has significant expertise in all of these areas. We plan to

- Work with collaborators to develop weather and climate research programs focused on infrastructure planning and management, such as boundary layer studies and characterization of land use interactions with regional climate

- Develop partnerships with the National Renewable Energy Laboratory and utilities that are investing in wind power system to develop, evaluate, and improve sensor technology, observational systems, and short-term wind prediction models

- Investigate the potential value of improved short-term and seasonal weather prediction for determining energy demands, management of energy supply, pricing and markets, system operations and regulatory compliance, and minimization of economic risk

End of NCAR Strategic Plan