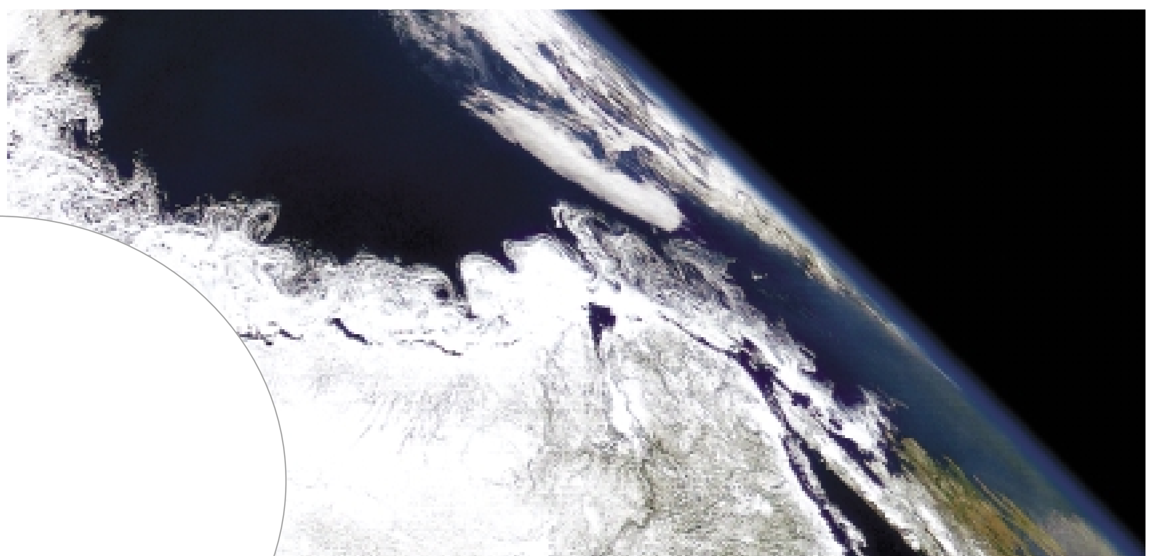
NCAR

NCAR as an Integrator

A Vision for the Atmospheric Sciences and Geosciences
National Center for Atmospheric Research
October 2001



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PREFACE

At the turn of a new millennium and under new leadership, the National Center for Atmospheric Research is pleased to present this plan for its future activities in research, facilities, educational programs, and outreach to meet the evolving needs of the scientific community. The plan draws on new modalities that foster communication, collaboration, and creativity and enhances NCAR's historic support of the community. The plan propels NCAR into a new era as a vital integrator of people, ideas, and tools.

The new initiatives and continuing core activities of the center described here will not be possible without the indispensable contributions of the scientific community that NCAR was founded to support. The ambitious agenda that follows relies on that collective energy, which nurtures and sustains all of our combined efforts—building the human capital for the geosciences, supporting an ambitious scientific agenda, serving to better integrate research and education, capitalizing on the information technology revolution, and enabling sound science to be brought to bear in service to society.

INTRODUCTION

The National Center for Atmospheric Research (NCAR) is a uniquely important institution in many ways. As a federally funded research and development center of the National Science Foundation (NSF), it plays a key role in helping to shape the scientific agenda for the only agency of the U.S. government that has basic research at the core of its mission. As a well-endowed center with a university governance system, a broad portfolio of fundamental and applied research, and a focus on the geosciences, it has an important responsibility to both *lead* and *support* the nation's researchers in the interdisciplinary study of the atmosphere and related systems.

At the turn of the millennium, NCAR celebrated 40 years of scientific and technological achievement as the nation's premier center for research into the atmospheric and related sciences. In 2000, NCAR also appointed its first new director in over a decade. These institutional milestones were accompanied by the largest single increase in the NSF budget in its 50-year history, a new presidential administration, and a growing international concern about a variety of global environmental issues including global climate change. Advances in technology, exemplified by the explosion of the Internet as a tool for communication, education, and the dissemination of scientific knowledge, are fundamentally changing the way our research is done. Science is becoming increasingly interdisciplinary in nature, and the fundamental importance of improving our understanding of the natural environment—and humanity's relationship with that environment—is obvious to all.

How should NCAR respond to these challenges and opportunities? Change is always accompanied by challenge. New directions and opportunities emerge as the impacts of change are felt. We must decide what to continue, what to phase out, and in what new enterprises to engage.

Over the past year, using a grassroots approach, we have reviewed and discussed options, opportunities, initiatives, and plans for future directions throughout the institution. We have evaluated our strengths and resources. This document is the result. It lays out an ambitious agenda that extends the concept of NCAR as a center supporting the broad university research community to fulfill the vision articulated by NCAR's founders in 1959 (see box).

Four compelling reasons to establish NCAR

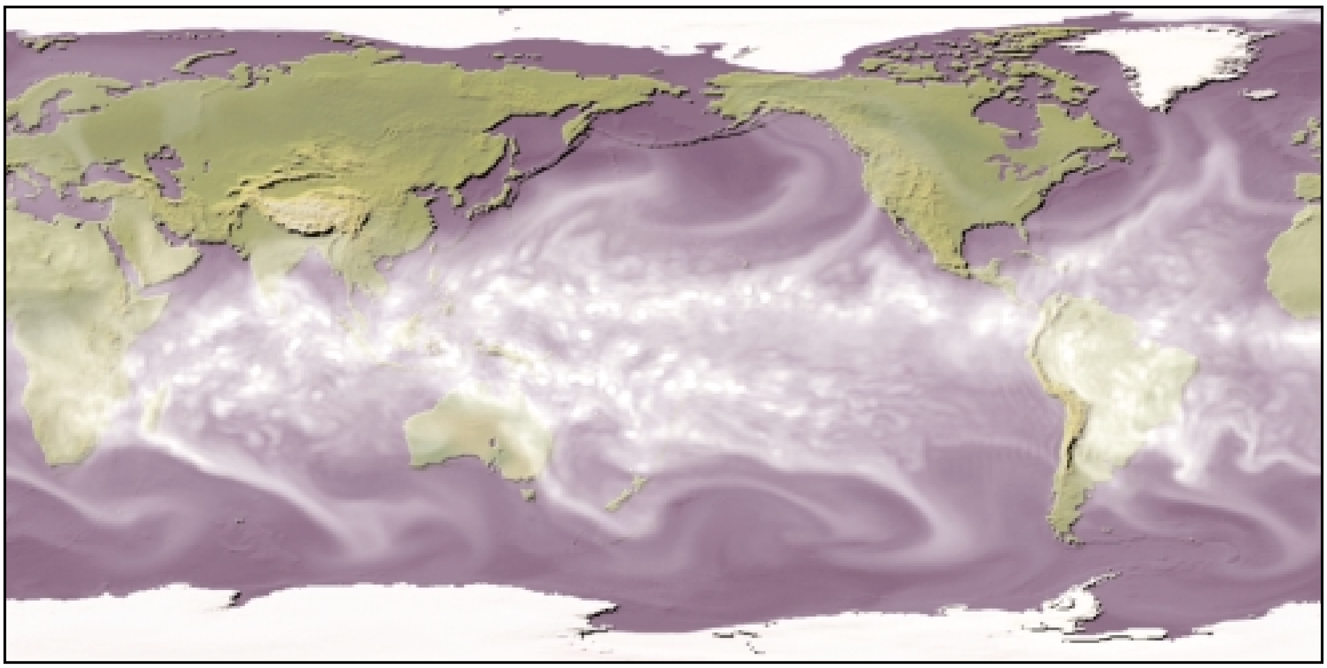
1. **The need to mount an attack on the fundamental atmospheric problems on a scale commensurate with their global nature and importance;**
2. **The fact that the extent of such an attack requires facilities and technological assistance beyond those that can properly be made available at individual universities;**
3. **The fact that the difficulties of the problems are such that they require the best talents from various disciplines to be applied to them in a coordinated fashion, on a scale not feasible in a university department; and**
4. **The fact that such an institute offers the possibility of preserving the natural alliance of research and education without unbalancing the university programs.**

— from the summary of the "Blue Book," *Preliminary Plans for a National Institute for Atmospheric Research*, February 1959, prepared by the University Committee on Atmospheric Research

In thinking deeply about the challenges for NCAR's future, we have come to the conclusion that our continued success depends critically on our ability to integrate new capabilities and approaches in the context of the fundamental strengths of our institution.

We therefore envision NCAR as an "integrator"—a center for the broad geosciences community that brings together the ideas, the people, and the tools to address scientific questions of critical importance to society. It is the breadth and depth of NCAR's disciplinary work that enables us to fulfill this vision. Without broad disciplinary strength, it will be impossible to successfully attack difficult problems that require interdisciplinary expertise.

Figure 1. High-resolution output from the NCAR Community Climate System Model—see also http://www.scd.ucar.edu/vets/vg/Climategallery.html. Future such models will integrate other aspects of the Earth system (e.g., land use/land cover, ecosystem dynamics, carbon and water cycles, etc.) to develop a more comprehensive Earth System Model.



1.0 Background and Context

1.1 Founding Principles and Heritage

The National Center for Atmospheric Research was founded over 40 years ago to fill four compelling needs spelled out by the science community at that time. This raison d'être remains as relevant today as it was at NCAR's inception, a testimonial both to the vision of the founders and to the fundamental validity of the center's activities as they have evolved.

For all of its 40 years, NCAR has been the product of a partnership with the universities, which govern the center, and NSF, which sponsors it. This three-node structure continues to be a unique and successful model of management and partnership.

Over these 40 years, NCAR, under the management of the University Corporation for Atmospheric Research (UCAR), has made fundamental scientific and infrastructural contributions. These have included the basic scientific underpinnings for weather forecast models; modern understanding of the coupled ocean/atmosphere climate system, including the El Niño/Southern Oscillation and other dynamical perturbations; delineation of the detailed chemistry of the stratosphere and troposphere; discovery of extrasolar planets; studies of solar magnetism, helioseismicity, and coronal mass ejections; understanding of the microphysics of clouds; and quantitative analysis of the socioeconomic impacts of severe weather. NCAR has also supported the universities by providing advanced observing facilities for use in many field studies around the world, increasingly powerful supercomputing capabilities and related software, a variety of community models, and valuable research data sets that describe the Earth and the Sun. UCAR and NCAR's educational and technology transfer activities have brought many of the results of this basic research into the private and public sectors.

At the start of a new millennium, under new leadership, with new environmental challenges facing us, and with new technologies at our disposal, it is time to build on this heritage, rearticulate our vision and values, and reexamine our strategic priorities. The strategic plan below builds on the strong record of achievement of the past 40 years, providing a road map for the institution in the challenging years ahead. As with any such plan, it must both articulate our guiding principles and leave the institution flexible enough to evolve with changing national priorities, developing technologies, unforeseen opportunities, and new scientific insights.

1.2 National and Global Context

This is a new era for scientific discovery. Since NCAR's inception, the global population has doubled, carbon dioxide concentration has increased from 315 to 370 parts per million, and the mean global temperature has risen by roughly one-half of a degree Celsius. An ozone hole appears every spring over Antarctica and another may be developing over the Arctic. Air and water pollution problems are ubiquitous and global in scale.

NCAR's strategic plans fit into the broader national and international context that is evolving to address these global-scale problems. They involve participation and leadership in major international programs and reflect scientific priorities that transcend national boundaries. They flow from recently articulated statements of national priorities and initiatives, in documents such as the Board on Atmospheric Sciences and Climate (BASC) report *The Atmospheric Sciences Entering the Twenty-First Century* and NSF's *Geosciences beyond 2000*. A list of national reports relevant to this strategic plan is provided in the Appendices.

> **Improvements in atmospheric observations, further understanding of atmospheric processes, and advances in technology will continue to enhance the accuracy and resolution of atmospheric analysis and prediction. As a consequence, society will enjoy greater confidence in atmospheric information and forecasts and will be able to act more decisively and effectively.**
>
> *The Atmospheric Sciences Entering the Twenty-first Century,* BASC.

NCAR has been an active contributor to these broad national priority-setting activities, and our own plan echoes their ambitious interdisciplinary goals. We will continue to provide leadership both in shaping the research agenda and in solving the global and environmental problems that the agenda addresses. To do this, we must partner with our traditional colleagues in academia and government as well as with a host of new players in the industry and policy arenas.

The BASC report clearly sets the mandate to the atmospheric sciences community:

> to focus on the observing and modeling infrastructure, on research tasks with the greatest promise, and on mechanisms to ensure that federal investments in atmospheric research and operations are effective and produce results significant to the nation in the early decades of the twenty-first century.

Perhaps the most compelling recommendation of the BASC report as it affects NCAR's strategies is the call to initiate new studies of emerging scientific issues, including climate, weather, and health; water resources; and rapidly increasing emissions to the atmosphere. These issues, individually and in combination, present challenges and opportunities to NCAR and the community to contribute our expertise, developed with society's support, to address these critical societal problems.

Even more sweeping challenges have been put forward by the NSF Geosciences Directorate in *Geosciences beyond 2000*:

> Today we are profoundly aware that society has the ability to alter and/or exploit the planet's physical, chemical, biological, and geological environments on all scales—local, regional, and even global. Human impacts on the atmospheric composition, the global ocean, the climate system, the water cycle, the landscape, the solid Earth, and the diversity of life itself will almost certainly grow in the next century as the global population increases and economies expand and technologies emerge. At the same time, because of our increasingly complex social and technological infrastructure, we are more vulnerable than ever to natural hazards, biological variations, and anthropogenic influences. Viewed more positively, because of our more comprehensive understanding of the planet's environment, we are offered new and unforeseen opportunities to improve the standards and quality of life.

***Geosciences beyond 2000,* NSF.**

Objectives:

- **Fostering discovery and understanding of the factors that define and influence the Earth's environmental and planetary processes.**
- **Expanding understanding and predictability of the complex, interactive processes that (i) determine variability in the past, present, and future states of planet Earth; (ii) control the origin and current status of the forms of life on the planet; and (iii) affect the interdependencies of society and planetary processes.**
- **Providing the resulting scientific information in forms useful to society.**

To address these important needs, NCAR strategies must be positioned within the national political context. The center needs to consider the level of resources the nation might allocate to address these lofty and ambitious goals. In 2000, NSF seemed to be on course to achieve its planned budget doubling over five years as Congress increased funding at a rate unparalleled in NSF history. However, the future rate of NSF growth is considerably less certain. The nation's priorities may not always coincide with those of the atmospheric sciences or, specifically, of NCAR. Yet our vision and our strategy must be focused on accomplishment. To a degree, NCAR and the community can help shape federal priorities through effective advocacy of our cause. Our strategy emphasizes that avenue. It is unlikely, however, that the available resources will be fully adequate to support the bold strategy identified in this plan without redirecting existing resources so that investments commensurate with the magnitude of the challenges can be undertaken. Thus the strategy must be sufficiently compelling and flexible to be undertaken at any future funding level.

1.3 Internal Context

Within NCAR, there is a healthy tension between the ongoing research and service of the core program and the emerging new challenges and initiatives. Our current strategic plan strikes out in exciting new directions. However, it represents both an evolution and a maturation of goals and plans as articulated in past planning documents and can be seen as the current manifestation of the principles of the founders, as quoted in the introduction to this plan.

The timing of this plan finds the national center particularly ready for strategic change. NCAR has experienced nearly a decade of subinflationary growth in the core program, apart from programmatic increases in a few specific areas. As a result, the breadth of the core program has often been maintained at the expense of depth. This has been a conscious strategy, since it is this very breadth that allows NCAR to respond to emerging national priorities and the attendant opportunities. In any future budgetary environment, careful management will be needed to optimize NCAR's productivity in alignment with the strategic mission of the center to address the most important scientific challenges.

Despite these budgetary stringencies, NCAR remains a center of excellence, with a continuous outstanding record of contribution and achievement. NCAR scientists contribute to significant advances in the atmospheric and related sciences through over 400 annual publications and participation on national and international planning and program panels. Their work has been recognized with numerous national awards and prizes. NCAR supports literally hundreds of university and agency researchers with high-end computing and observational tools and services.

NCAR programs are making tremendous strides in diverse areas, including the detection of extrasolar planetary systems; the first long-term global satellite measurements of atmospheric carbon monoxide; plans for the acquisition of a uniquely outfitted jet aircraft for high-altitude research; an imminent, dramatic increase in supercomputing capability; development of coupled models of Earth's climate; design of next-generation weather research and prediction models; and creation of aviation weather products that contribute to increased safety for pilots and passengers. In addition, there has been an increased emphasis on the impacts of atmospheric phenomena on society—and vice versa—and on science education and outreach.

1.4 Societal Context

The strategic plan for NCAR is based in part on our analysis of societal needs of the next half-century. In the next few decades, the pace of environmental change will continue to quicken, and scientific understanding will become ever more important as society faces the multifaceted challenges of global environmental change. With a global population in 2070 of nine billion, the effects of a technological society on the environment, and of the enviroment on society, will be far more pervasive, complex, and substantial than today. The global mean temperature may rise another 1–2°C (1.8–3.6°F), leading to uncertain but significant changes in weather patterns and storms. Sea level may rise 9 to 88 mm (0.35 to 3.5 inches), with profound effects on low-lying coastal areas. The healing of the ozone hole permitted by gradually decreasing chlorofluorocarbons may well be offset by colder polar stratospheric temperatures and, consequently, more polar stratospheric clouds. Unpredictable phenomena, akin to the unforeseen development of the ozone hole in the 1970s and 1980s, are almost certain to occur.

What does all this imply for the future of science and society? In an optimistic view, our scientific understanding of the Earth system and the human relationship with it will be much greater, and our ability to predict variability and change will be much more advanced than it is today. Science will be used by decision makers to minimize the negative impacts of humanity on the Earth, while providing the basis for all people to live healthy, safe, and fulfilling lives. Rigorous environmental science will be used routinely in the public and private sectors, including agriculture, energy, water, transportation, health, and emergency management.

However, enormous challenges stand in the way of attaining this optimistic vision of a future guided by human knowledge. These include intellectual challenges in all the scientific disciplines, in mathematics, and in observational and computational technologies. They also include fundamental challenges for human-resource development and education. Knowledge and technologies are advancing so rapidly that it is difficult for people to keep up with the rate of change and effectively exploit the progress. The integration of scientific and technological advances and their application to societal needs are perhaps the greatest of all grand challenges.

NCAR, working with researchers in the mathematical, computer, life, and social sciences, has an essential role to play in achieving the vision. We will have to respond to these challenges in an aggressive and effective manner. Our community bears the awesome responsibility of educating and informing the populace about the issues involved in global change, without shrinking from the needed debates on uncertainty and complexity. We must also reach out to all sectors of society to assemble a diverse human resource pool and to ensure that interdisciplinary science is used as a tool to effect responsible planetary stewardship.

Many new partnerships will be needed to make certain that the appropriate mix of advances in modeling, observational systems, information technologies, and the social sciences is brought to bear on the most critical problems. The universities, UCAR/NCAR, and NSF must be the intellectual leaders of this effort, working with our counterparts in industry, government, and the international community. We must ensure that the intellectual and human resources and the observational and computational capabilities are adequate to identify and solve the most critical problems. And we must guarantee that intellectual successes in understanding are translated quickly and effectively to meet the needs of society.

NCAR today is—without question—more relevant and needed than ever. NCAR's intellectual evolution over the first four decades has set the stage for critically important contributions well into the 21st century. The world has seemingly grown smaller through astonishing advances in telecommunications, but we have, at the same time, a vastly greater appreciation of the complexity and interrelatedness of the physical and human spheres that form the coupled Earth system. NSF now uses new terms such as "planetary metabolism" and "planetary ecology" to capture the need to think in a more integrated sense about humanity's relationship with the natural world.

NCAR must—and will—meet these challenges by stretching its "intellectual envelope," by contributing to the development of a diverse work force capable of generating and using new scientific knowledge about the Earth system, and by nourishing existing and new partnerships with universities and other public and private institutions to study the large and complex research and policy issues related to global change.

2.0 Mission, Vision, Values, and Goals

2.1 The NCAR Mission

The mission of NCAR and its governing body, UCAR, has been validated over many years through extensive interactions with NSF and the university community.

> **NCAR's Mission**
>
> **to support, enhance, and extend the capabilities of the university community, nationally and internationally; to understand the behavior of the atmospheric and related systems and the global environment; and to foster the transfer of knowledge and technology for the betterment of life on Earth.**

In addressing this mission, and as affirmed by repeated NSF reviews, NCAR contributes strongly to all three of the overarching goals in NSF's own strategic plan: 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.

2.2 A Vision for NCAR

Our vision of NCAR in the next decade is of an institution that will attack all aspects of its mission with an ambitious, effective, and aggressive scientific program of large scope and import:

- with world-class scientific and technical staff, bringing true diversity in people, backgrounds, and ideas to the table, and able to integrate seamlessly across disciplines, tools, and techniques to gain ever-greater basic scientific understanding of the environment and the human relationship with that environment;

- with unparalleled observational and computational infrastructure dedicated to these studies and made broadly available for university researchers;

- with a long-term commitment to work on the most complex and important scientific topics;

- with an expanded commitment to integrating research and education at all academic levels, kindergarten through adulthood, for both individual learners and learning communities; and

- with a leadership role in defining what the information technology revolution means for the geosciences.

NCAR is committed to rigorous fundamental research in a broad range of basic areas: geophysical turbulence, cloud droplet formation, atmospheric chemistry, solar and space physics, computer and computational science, geophysical statistics, and many others.

NCAR is committed to maintaining a broad program of research, with appropriate balance across the areas of disciplinary and interdisciplinary research, instrument development and deployment, experimentation, advanced facility provision, theory, modeling, and data analysis and interpretation.

> **A Vision for NCAR's Future**
>
> **With a world-class, diverse work force, NCAR is a renowned center for basic and applied research in the atmospheric and related sciences. With its superb facilities, expertise, and ability to integrate across disciplines, tools, and ideas, NCAR leads and supports the university community in developing critically needed understanding of the Earth system and the human relationship with that system. Working with other academic institutions, public and private partners, and innovative information technology, NCAR maintains a comprehensive knowledge-generation and knowledge-dissemination environment for the geosciences. NCAR's work serves to inform public decision making with sound science—at local, regional, and global levels—and supports rich, inquiry-based teaching and learning across the full educational spectrum.**

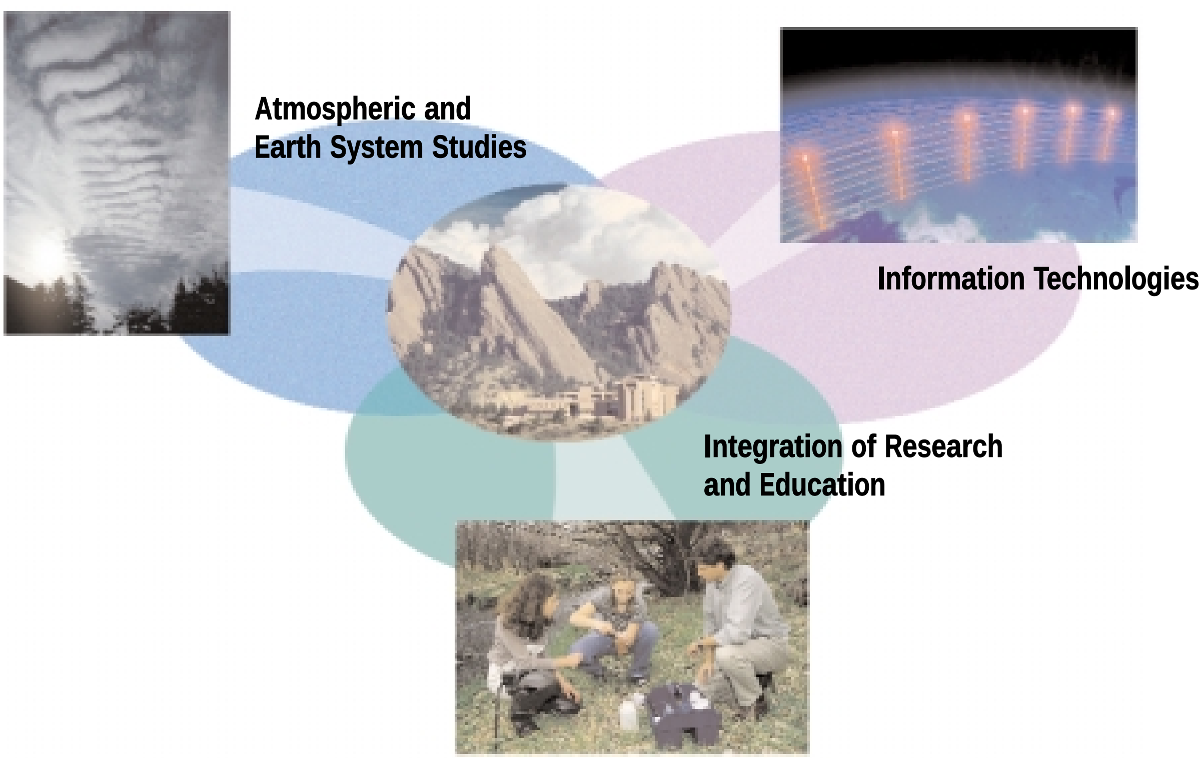
NCAR will also focus on research applications by building and maintaining critically needed decision-support systems—such as in the fields of aviation safety and natural hazard mitigation—based on fundamental geophysical understanding and observation.

Finally, NCAR will continue in its traditional role as the leader of community-developed and community-owned models of the Earth system. Such sophisticated models will provide us with the world's best theoretical understanding of coupled environmental systems, incorporating the relevant physical, chemical, biological, and human processes.

In developing the NCAR strategic plan, we have articulated a "willed vision" of NCAR in the next decade:

- with increased leadership in national and international science planning and implementation, playing a more proactive role in setting the research agenda to address the urgent problems facing our nation and the world;
- becoming a "virtual center" in support of the broad Earth system sciences and geosciences—not just our core meteorological community;
- able to take on an increasing number of major interdisciplinary challenges, without moving away from its key disciplinary strengths;
- able to contribute in major ways to research-enriched education at all scholastic levels and through public outreach;
- closely coupled to—and driving —the information technology revolution for the geosciences;
- moving toward a more comprehensive Earth systems approach to integrative studies, including the human dimensions, and with an emphasis on bringing sound science to bear on societal decision making;
- building new partnerships with other academic institutions, government, and private sector organizations—an NCAR that rapidly transfers technology developed at government expense to other government programs and the private sector;
- as a place where individual professional growth and career development are encouraged, nurtured, and celebrated—where building upon diversity of people and ideas is not just a slogan but a firm institutional commitment.

Figure 2. NCAR as an integrator



2.3 NCAR Values and Guiding Principles

To accomplish this vision, NCAR must develop its strategy within the context of a set of values and guiding principles that inform the selection of activities and that are consistent with the responsibilities of NSF's national center.

Values

- **We value creativity and excellence in science and all aspects of our work.**
- **We value activities that address societal needs.**
- **We value our employees and strive to support diversity of ideas and backgrounds, to foster professional development, and to recognize accomplishment.**
- **We value activities that support and lead the geoscience community.**
- **We value activities that contribute to science education.**
- **We value innovation and renewal of our program in light of new scientific and technological developments.**

Several key principles drive the strategic plan.

2.3.1 Creativity and Excellence

A commitment to creativity and excellence in all aspects of our work is fundamental to our strategy. Our commitment to maintain and extend our reputation for excellence in scientific research is our first and primary guiding principle.

2.3.2 Valuing Our People

We are committed to the optimal development of our human capital. Without capable, intelligent, dedicated, and effective personnel, NCAR cannot fulfill its vision. As highly technological as research has become, it remains dependent on the understandings and insights of the human mind.The pursuit of science rests as much on our ability to entrain the right people, enable them to work with each other, and incorporate their diverse insights as it does on our engineering the right tools or acquiring the largest and fastest computers. Therefore we prize individual professional growth.

As a mature institution, we must ensure that our scientific staff exhibits a demographic balance that guarantees future vitality and that this group reflects the diversity inherent in our society. In particular, NCAR must ensure that expertise is passed on to the younger generation of scientists and engineers and that sufficient numbers of highly qualified early-career scientists are brought into the program. After ten years of subinflationary funding and low staff attrition, a demographic imbalance favoring the senior ranks has become a significant problem within many job categories. To address this problem, NCAR and UCAR have established a multiyear program of hiring at the Scientist I level. In the first year of this program, the center has hired ten early-career scientists. Through a sustained commitment, we intend to promote the demographic health of the institution.

Excellence and dedication will always remain hallmarks of NCAR's staff. We recognize that effective mentoring and professional development are critical in recruiting, training, and retaining this outstanding staff. NCAR will commit itself to a continuous program of professional training for all staff, to optimize productivity and to enable each staff member to enjoy productive pathways to professional growth.

2.3.3 Broadening the Intellectual Envelope

As is true across all of science, many if not most of the difficult and challenging scientific problems in the geosciences have emerged at the intersections among the traditional disciplines—disciplines that were identified in the early part of the last century. Yet it is also true to say that these interdisciplinary or transdisciplinary problems cannot be addressed effectively without deep wells of disciplinary expertise. It is therefore clear that many scientific challenges will only be addressed by effectively harnessing teams of disciplinary experts, able to work together on tough interdisciplinary problems.

Interdisciplinary work is difficult and demanding in many ways. Institutional barriers, such as divisional structures, must not be allowed to stand in the way of effective teamwork, yet these very structures also play a key role in sustaining the required core disciplinary expertise. Our response to this classic conundrum is to recognize that NCAR must retain its successful divisional (disciplinary) structure while finding ever-more-flexible ways to ensure that cross-divisional and interinstitutional work is facilitated—and that individuals working in large teams get support and recognition for the significant work they undertake. A cultural change may be needed to make this happen. Our strategy will emphasize interdisciplinary work and will prototype organizational structures to facilitate these efforts.

As we broaden our intellectual scope to address interdisciplinary challenges, it will be necessary to also extend the range of NCAR's core expertise to include other aspects of the Earth system. Future Earth system models will need to incorporate not just atmospheric and ocean dynamics but also the biosphere itself, including ecosystem dynamics and, ultimately, human structures. Our strategy will point, for example, to the role of biology in coupled Earth system model developments.

2.3.4 Redefining Partnerships

NCAR is not simply a research laboratory. We represent a crossroads for scientific thought and collaboration. We are citizens of many communities: the universities whom we both serve and galvanize, the national laboratories and agencies whose initiatives we support and help foster, and international environmental research bodies.

In this new era, our partnerships must broaden to encompass new roles and new alliances—in business and industry and in local, national, and international policy arenas. We will expand our technologies and expertise to embrace both research and operational goals in model development. We will develop decision-support mechanisms to ensure the appropriate allocation of resources toward society's highest priorities.

As part of our strategy, we will emphasize the development of nontraditional partnerships and will reach out to the private sector, to governmental bodies and agencies, to like-minded institutions, to nongovernmental organizations, and to other nations to build the needed collaborative capacity and capability.

2.3.5 Preserving Breadth and Balance

Part of NCAR's heritage and strength has been our determination to maintain a broad and well-balanced program of disciplinary and interdisciplinary research. Our scientific breadth is not only our strongest asset but also a necessary and enabling prerequisite for an effective attack on challenging new scientific problems. As an institution with a complex and successful program, we will preserve our traditional strengths while moving aggressively in exciting new research directions.

NCAR, in close consultation with the university community, continuously reevaluates the balance of activities to ensure that our fundamental (and collective) capability to do leading-edge research remains at the highest possible state of readiness. Our strategy will include mechanisms to continuously review our scientific portfolio in the light of changing requirements and needs.

2.3.6 Mining the Information Technology Revolution

The information technology revolution will affect the fundamental ways that research is conducted. Virtual centers and collaboratories will become our new workplaces. We must develop new tools such as data portals, digital libraries, and three-dimensional visualizations to elucidate our understanding.

New technologies in observational systems also present new opportunities. Remote sensing, miniaturization, and nanotechnologies all hold great potential to increase productivity and provide new insights into our investigations of the Earth system. Advances in these areas will come about as the result of collaborations and partnerships with other institutions as well as through our own activities.

2.3.7 Integrating Research and Education

More effective education in science, mathematics, engineering, and technology—at all academic levels—is clearly of supreme importance for the nation. Many studies have shown the great value of inquiry-based education, where research and education are integrated to enable learners and communities of learners to (in NSF's words) "share the joy of discovery." NCAR has

a major responsibility to participate in research-enriched education from kindergarten through adulthood. The intrinsic interest and importance of our subject matter lend themselves well to inquiry-based learning. We can provide materials ranging from new visualizations to curriculum modules supporting Earth system science education. In January 2001, we hosted a multi-institutional workshop[1] to develop specific plans for greater involvement of NCAR in education and outreach. Recently, UCAR established a permanent corporation-wide Education and Outreach (E&O) office to coordinate these efforts.

As society becomes more complex and the interdependence of all the Earth system's components becomes more apparent, we recognize the need to educate and inform policy and decision makers, as well as the public, about how human actions affect that system. We can do this through the creation of new knowledge systems and educational products that result from our scientific discoveries.

A separate strategic plan for education and outreach across all of UCAR has been developed under the leadership of the new E&O office (see Appendices). NCAR played a role in developing this plan and will participate fully in its implementation. The E&O strategic plan is an integral part of NCAR's strategy.

2.3.8 Improving Connections to Society

NCAR has an established record of leadership and collaborative research on understanding and predicting the Earth system. This includes research on prediction of weather and climate from local to global scales and from short-term forecasts to long-term scenarios. The prospects for greatly improved weather forecasts and climate simulations are excellent.

The deployment of new technologies for observing the Earth system from spacecraft, airborne systems, and in-situ platforms is accelerating at an unprecedented pace, yielding an increasingly comprehensive

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[1] *http://www.ucar.edu/governance/meetings/feb01/ppts/ucar/sld022.htm*

description of changes in every component of the Earth system. Improved computational capabilities for high-performance simulation—along with storage and analysis of huge data sets—are yielding important new insights into the relative roles of natural and human factors that influence weather and climate systems across time and space.

NCAR will continue to conduct the fundamental and integrated research necessary to improve forecasts of weather and projections of global change. The anticipated improvements in prediction will also enable an increased understanding of societal vulnerability to weather and climate extremes. An improved qualitative and quantitative analysis of societal vulnerability and resilience to trends and extremes in weather and climate can have significant economic, environmental, and societal benefits to the United States and the world.

Recognizing society's need for access to sound science to make important decisions at the local, regional, and global levels, NCAR's strategy includes a firm commitment to bring forward the fruits of its research to the public and private sectors effectively. Paraphrasing the words of Walter Orr Roberts, the founding director of NCAR, we believe that good science exists to serve society.

NCAR will work to develop new collaborations and partnerships with the private sector as well as with other academic institutions and both governmental and nongovernmental organizations. To this end, the NCAR director will establish a new external advisory council comprising influential leaders from all these sectors and charged with improving the dialog and helping develop more concrete plans for new alliances.

2.4 NCAR as an Integrator: Meaning and Implications

The NCAR program priorities for the next five years are consistent with those of the past yet are informed by the ambitious mission, vision, and values outlined above. The overarching theme of this strategy is to consider NCAR as an integrator. There are several types of integration implied by this phrase:

- the integration of knowledge and information across disciplines to create interdisciplinary synthesis and thereby develop new knowledge,
- the integration of research and education,
- the integration of different tools and methods to attack new problems,
- the integration of different points of view, ways of thinking, and experiences to create teams capable of attacking difficult interdisciplinary problems,
- the integration of scientific understanding with societal needs to create useful, societally relevant applications.

Figure 3 illustrates the elements that contribute to NCAR's roles as an integrator. With our mission, vision, values, priority areas, and unique disciplinary strengths, we can address a whole series of complex problem areas for which interdisciplinary or integrative work is a prerequisite. Our approach is to employ disciplinary and integrative research capabilities side by side.

The exciting scientific initiatives described below are possible because of the combination of our longstanding commitment to depth and breadth of disciplinary work and our strengths in integrative research.

Overarching Goal

Integration of people, ideas, and tools for accelerated scientific progress in the geosciences

Priority Areas

- **Interdisciplinary science initiatives**
- **Integrating models**
- **Advancing tools and methods**
- **New facility initiatives**
- **Applying the benefits of the IT revolution across research and education**
- **Integrating research and education**

2.5 The Process of Defining Programmatic Goals

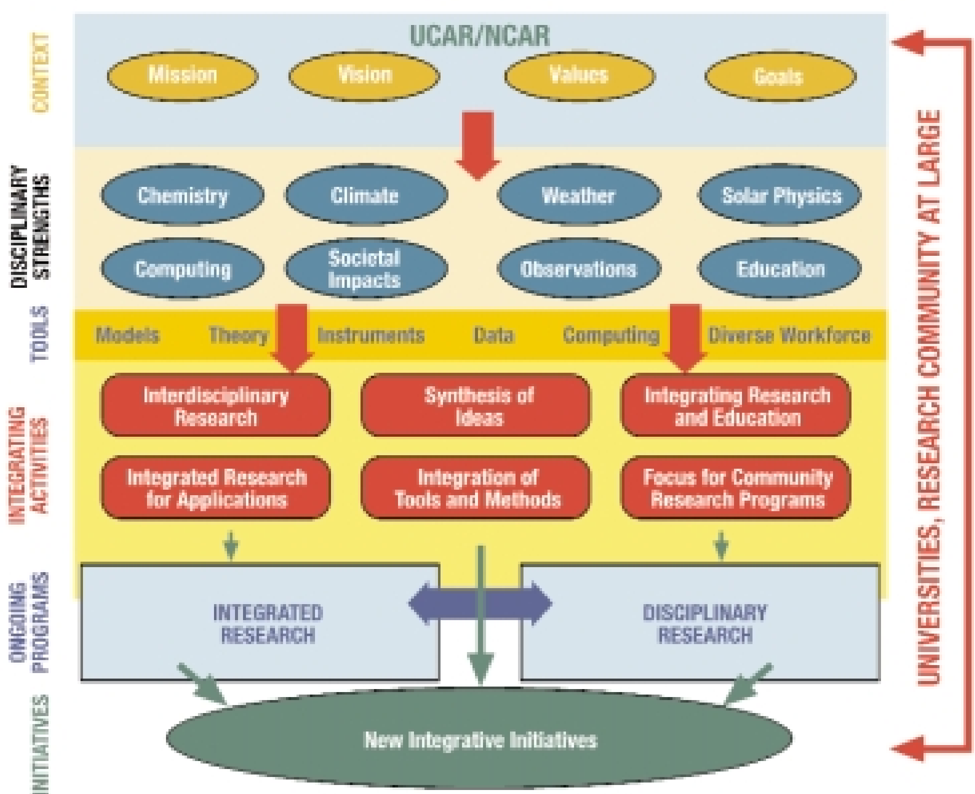
In fleshing out programmatic goals and objectives for this plan, we consulted heavily with NCAR's scientific staff and with many members of the university community. What follows is, therefore, the result of a grassroots effort to define and refine NCAR's scientific future. NCAR scientists self-organized to develop scientific initiatives that address the mission, vision, and values described above. In a process that lasted ten months and involved many scientists from within NCAR and the university community, an exciting set of research initiatives was developed and published on the Web. Working papers described key scientific questions, defined an approach to their resolution, and identified potential teams of NCAR and university partners.

The working papers were reviewed by the NCAR Scientist Assembly, NCAR and UCAR senior management (the President's Council), UCAR program directors and NCAR division directors (the UCAR Management Committee), the UCAR Board of Trustees, and the UCAR University Relations Committee. In a two-day retreat held at NSF headquarters in October 2000, elements of the plan were also reviewed by NSF program officers.

The overall process was led by Robert Harriss, NCAR associate director for strategic planning, in conjunction with a steering committee comprising all NCAR division directors, the director of the UCAR E&O office, and the director of the Unidata program.

Two supplemental plans serve as integral components of the overall strategy. These are the UCAR Education and Outreach Strategic Plan[2] and the Strategic Plan for High Performance Simulation.[3] These documents are summarized in Appendix 7.2 and 7.3 respectively.

Figure 3. Schematic illustrating NCAR's strategic integration



[2] *http://www.ucar.edu/educ_outreach/stratplan.html*
[3] *http://www.ncar.ucar.edu/Director/plan.pdf*

3.0 The University-NCAR Alliance

The unique and symbiotic alliance between NCAR and the universities has provided the basis for the successes of the center over the past four decades. Our strategy seeks not only to sustain and nurture this relationship but also to expand it in ways that will enable fundamentally new approaches to today's scientific and educational challenges.

The need for a strengthened university-NCAR partnership is clear. Issues such as global climate variability and change, stratospheric ozone depletion, local and regional air pollution, and societal vulnerability to severe natural hazards (e.g., floods, heat waves, tornadoes, hurricanes, solar storms) have put the atmospheric and related sciences at the center of national and world affairs. The U.S. research community has the responsibility to: (1) develop a sophisticated understanding of the processes at work, (2) train the next generation of researchers to confront an array of challenging interdisciplinary problems, and (3) build needed diagnostic and predictive capacities to inform societal decision making at all levels. The combination of collaborative research teams with NCAR-managed facilities will be needed to meet this responsibility.

The atmospheric science community is remarkably well prepared to conduct a fundamental research program at the forefront of global change science. The prescient action by university researchers to form NCAR more than 40 years ago anticipated the future demands of large-scale, complex environmental problem solving. The university-NCAR alliance now stands as a uniquely effective and economical approach to conducting fundamental research and informing policy in an arena where extensive collaboration involving people, tools, and ideas is essential. NCAR has provided a platform for scientists to shape collaborative approaches to problems that were clearly too large for the resources available to any single institution.

The successful university-NCAR alliance must continually respond to evolving needs of the scientific agenda. Leaders in the atmospheric sciences have long recognized that state-of-the-art community facilities best evolve and prosper under the stewardship of a critical mass of outstanding scientists. NCAR is recognized as a world-class laboratory for research, education, and outreach populated by a diverse mix of resident and visiting scientists. NCAR's role as a catalyst for sharing ideas equals or exceeds its role as a home for community facilities.

This strategic plan seeks to build on existing strengths in order to nurture and enhance the university-NCAR alliance. In the following sections we briefly summarize the current community resources supported by NCAR and the large number of collaborative activities in research and education that serve the atmospheric sciences. We then outline a suite of new initiatives that focus on shaping a stronger alliance through new modes of collaboration, revolutionary technologies, and, most importantly, attracting a talented and diverse work force to the atmospheric sciences.

3.1 Community Resources

NCAR's mission has always included the mandate to provide the broad research community with observational instruments and platforms as well as computational resources. In recent years, this suite has broadened to include solar observing telescopes, community models, and Web-based data and information services.

As described in Section 4.3, NCAR plans to extend these community resources even further by acquiring new computing systems, providing a high-altitude jet for the observational community, and investing in Web technologies to make our data services and models more accessible to the community of users.

Community facilities are made available through a number of mechanisms. Allocation panels composed of university and other laboratory researchers weigh and evaluate all requests for use of major NSF-supported facilities such as the aircraft, supercomputing resources, and large (facility-class) instruments.

Open planning meetings to develop facilities, such as the instrumentation for the new high-altitude jet, bring together scientific, technological, and engineering expertise to ensure that future developments provide the capabilities needed in the field. Community groups also help shape the future direction of facilities through workshops and standing working groups, such as those that determine the development of the Community Climate System Model.

3.2 Traditional Partnerships—Research and Education Collaborations

Research collaborations among NCAR staff and university colleagues are integral to our success as an institution, and the strength, variety, and frequency of our interactions with the university community provide metrics of the health of our programs. NCAR fosters and strongly supports these interactions through many approaches devised over the course of 40 years. Yet, there is room to improve both the number and character of the NCAR-university interactions. Some ideas for new mechanisms for collaboration are outlined in Section 3.3.

NCAR's visitor programs provide unique opportunities for interaction[s] among scientists from around the globe. NCAR routinely hosts university collaborators, co-PIs on grants, and others, including young scientists and world leaders in climate, chemistry, solar physics, meteorology, turbulence, and societal impacts. Visitor programs provide opportunities for research collaboration within and across disciplines. They also add specialized expertise beyond the capabilities of the center and are characterized by their flexibility, quantity, and quality. These interactions generally begin at the individual scientist level.

Visits can last anywhere from a few days to a year or longer and produce results in the form of joint publications, model improvements, and improved scientific understanding.

NCAR also hosts numerous and extensive scientific meetings. The center initiates and coordinates a large array of conferences, workshops, and colloquia on scientific and technical topics. Specialized conferences, such as the annual Climate System Modeling Workshop and the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) Workshop, are held for specific segments of the research community. Advances in understanding, discussions of future directions, and technical problems and solutions can be shared through invited talks, poster sessions, and demonstrations.

Educational collaborations have expanded greatly at NCAR over the past decade. These build on NCAR's traditional services at the graduate and postgraduate levels, which have been a mainstay of the center since its inception. Such activities include NCAR scientists' serving on thesis committees and acting as advisors. Teaching arrangements, both formal and informal, have also been traditional mechanisms of university interaction. Along with sabbaticals, these activities place NCAR scientific staff in the universities to collaborate, share their expertise with faculty and students, and assist in the preparation of textbooks and other curricular materials.

In the 1990s, NCAR broadened its participation to include K–12 and undergraduate education, through Project LEARN in 1992 and Significant Opportunities in Atmospheric Research and Science (SOARS) in 1996, both of which integrate research into science education. These activities have expanded to the point that UCAR established an Education and Outreach office in 2000, with which NCAR is heavily involved.

3.3 Enhancing the Alliance

Strengthening the university-NCAR alliance is a centerpiece of our strategic planning, focusing on three proposed enhancements. First, we will increase support for direct face-to-face professional collaborations on research, education, and outreach at NCAR and on campuses across the nation and world. Second, we will place special emphasis on increasing the diversity of the work force in the atmospheric sciences through active recruitment and support of members of underrepresented groups in both university and NCAR programs. Third, we will use the information technology revolution to create a "virtual NCAR"—a shared information space that dissolves the distance between NCAR and its university partners.

3.3.1 Enhancing University Interactions

A Professional Development Initiative for Early-Career Faculty

NCAR proposes to significantly enhance direct interactions with young scientists by providing financial support for early-career faculty and their graduate students to participate in NCAR's research initiatives and in planning and use of facilities. We will also increase exchange visits between NCAR and university campuses. Through these measures, we will build

awareness of community resources such as community models, observing sensors and platforms, and collaborative activities beyond university campuses. More importantly, we will directly involve early-career faculty in the design and implementation of emerging strategic research initiatives at NCAR through a widely advertised, competitive small-grants program. While all of the current NCAR strategic initiatives involve partners from universities or national laboratories, these participants tend to be well-established scientists whose grants allow them to participate in the early stages of a new research program. The NCAR small-grants program will bring next-generation scientists, with their new ideas and approaches, more actively into the early stages of large-scale, long-term projects.

A Bi-directional Sabbatical Initiative

We propose to increase the exchange and visitor programs that bring university scientists to NCAR and NCAR scientists to the universities by encouraging sabbatical exchange visits and providing additional funding for senior visiting fellows in the NCAR Advanced Study Program.

A Graduate Student Initiative

We plan to increase substantially our support for graduate students at NCAR, building on the successful Advanced Study Program and High Altitude Observatory Newkirk Fellowships. We will also host groups of graduate students from individual universities on a more systematic basis. These visits will have as explicit goals the development of leadership, promoting an awareness of community resources, and fostering research opportunities. A detailed plan for NCAR's graduate fellowship program will be developed in close partnership with the universities.

An Undergraduate Leadership Workshop Initiative

NCAR is committed to augmenting its provision of research experiences for undergraduates, primarily during the summer months. We also propose to offer an annual summer leadership conference for undergraduate students selected for participation by university departments. Costs will be shared by the respective universities and NCAR.

3.3.2 Enhancing Diversity in the Geosciences

An increasing share of the future work force in America will consist of women, (currently) underrepresented minorities, and persons with disabilities. If the atmospheric sciences are to attract the best people and to prosper in coming decades, we must tap the talents of all segments of our population. The Significant Opportunities in Atmospheric Research and Science (SOARS) program has demonstrated resounding success in recruiting undergraduate students from underrepresented groups into a multiyear research experience at UCAR, NCAR, national laboratories, and universities. Many of the SOARS students are now planning or beginning careers in the atmospheric and related sciences. To maintain quality, SOARS must remain a relatively small program of 20 to 25 students at a time. NCAR is committed to providing financial support for new initiatives that will expand the talent pool to include more women, underrepresented minorities, and persons with disabilities. These efforts will be carefully crafted in conjunction with the UCAR Office of Education and Outreach. Proposed activities include collaborations with a tribal college and with universities and colleges along the Texas-Mexico border. Additional efforts will establish pipelines with other institutions serving underrepresented students, leading to their increased participation in geoscience research.

3.3.3 Enhancing University Access through Information Technology

The tremendous growth in the volume and scope of services available on the World Wide Web has resulted in a revolution in the ways research and education in the atmospheric sciences are conducted. The explosion in network communication is irreversible, and NCAR is moving aggressively to take advantage of it. A "virtual NCAR" will greatly enhance access to data and information from community models and field campaigns, and it will stimulate teleconferencing and collaboratory tools for research, teaching, and community interaction.

The Community Data Portal Initiative

One important enhancement will greatly improve university access to the wealth of data resources under NCAR's stewardship. The Community Data Portal will provide pinpoint, seamless entry for individuals and allow them to personalize their information searches as well as contribute data holdings from their own research. NCAR will work closely with the UCAR Office of Programs' Unidata program to bring significantly enhanced data access, manipulation, and display tools to the broad university community. We anticipate that new "access grid" technologies will provide important underpinnings for this work.

Collaboration Infrastructure

NCAR will work closely with the university community in joint sponsorship of information technology infrastructure that promotes effective and efficient communication and collaboration. Current efforts include the development of common modeling frameworks for Earth system models, state-of-the-art data mining and data assimilation systems, NCAR graphics and command language systems, server support for Unidata, maintenance of research collaboratory infrastructures (e.g., the Space Physics and Aeronomy Research Collaboratory), archiving and curation of important data sets (e.g., the NCEP-NCAR reanalysis), and the development of advanced Web tools and services to enhance quality of user services (e.g, the Web 100 project that seeks to significantly improve network throughput via the optimization of TCP/IP dynamic protocols).

Through these and other means, NCAR commits itself to support the university community with an aggressive suite of programs that utilize the fruits of the information technology revolution.

4.0 Building on NCAR's Strengths

4.1 Importance of the Core Program

NCAR's nine existing divisions and two interdivisional programs serve specific functions and particular segments of the university community. Four of the divisions have distinct scientific emphases (ACD, CGD, HAO, MMM), two provide observational and computational facilities for the university community (ATD and SCD, respectively), one develops research applications (RAP), one focuses on environmental and societal impacts of weather and climate (ESIG), and one supports postdoctoral and interdivisional programs (ASP). Table 1 provides a summary of the divisions and interdivisional programs and their respective functions.

All of the current NCAR divisions are successful and highly valued by the university community, as demonstrated in numerous reviews of accomplishments and service. Each division obtains input from its own external, university-based advisory committee, and each has developed a strategic plan based on an analysis of its highest priorities.

NCAR also supports a number of interdivisional efforts, including the Geophysical Turbulence Program and the Geophysical Statistics Program. The Advanced Study Program has been a catalyst (and sometimes home) for these interdivisional programs.

A complete summary of the recent accomplishments of NCAR's divisions can be found in the Annual Scientific Reports at http://www.ncar.ucar.edu/ASR01.

4.2 Core Program Research Strategy

NCAR's ability to maintain a vital core program rests on continued support for the high-priority efforts in the divisions and programs, defined in close consultation with the university community.

Table 1: NCAR Divisions and Programs

Division	Acronym	Functional Area
Advanced Study Program	ASP	Postdoctoral and graduate fellowships; fostering of new research areas
Atmospheric Chemistry Division	ACD	Tropospheric and stratospheric chemistry and dynamics
Atmospheric Technology Division	ATD	Observational facilities, instrument development and deployment
Climate and Global Dynamics Division	CGD	Climate system science
Environmental and Societal Impacts Group	ESIG	Socioeconomic and enrironmental impacts of weather and climate, assessment science
High Altitude Observatory	HAO	Solar, space, planetary, and upper-atmospheric physics
Mesoscale and Microscale Meteorology Division	MMM	Weather systems, with emphases on precipitation forecasting and small-scale processes in weather and climate
Research Applications Program	RAP	Decision-support systems, operational products and applications
Scientific Computing Division	SCD	Supercomputing, communication, and data services
Program	**Acronym**	**Functional Area**
Geophysical Statistics Program	GSP	Postdoctoral program involving the mathematical and statistical sciences
Geophysical Turbulence Program	GTP	Fundamental studies of turbulence

Divisional programs should and will evolve in time; high-priority areas should be supported fully, and low-priority areas should be phased out. Our strategy includes a willingness to revisit organizational boundaries as called for by scientific priorities. Flexibility in organizational design is essential and has been a valuable attribute of NCAR from the beginning. For example, the current nine divisions have grown from an original three, and the current number is not immutable. The history of NCAR has shown how productive science and community support can be facilitated by changes in the organization.

In addition to the carefully developed and articulated priorities of the divisional programs, NCAR's strategy includes a commitment to continue leadership in important national initiatives. Table 2 lists several important national efforts and summarizes NCAR's continuing involvement. NCAR scientists are very active in international programs such as the International Geosphere-Biosphere Program, the International Weather Research Program, the International Association of Geomagnetism and Aeronomy, and many others.

4.2.1 Atmospheric Chemistry Division

ACD's mission is to understand the composition of the atmosphere, the processes that modify and control atmospheric composition, and how these factors may change in time due to natural and human influences. ACD also provides relevant, reliable, and timely information on atmospheric chemistry to government and society and acts as an intellectual resource to the wider atmospheric sciences community through the development of new capabilities and methodologies and the conduct of complex field experiments. The division is organized around three main research themes: tropospheric chemistry, middle-atmosphere chemistry, and biosphere-chemistry-climate interactions.

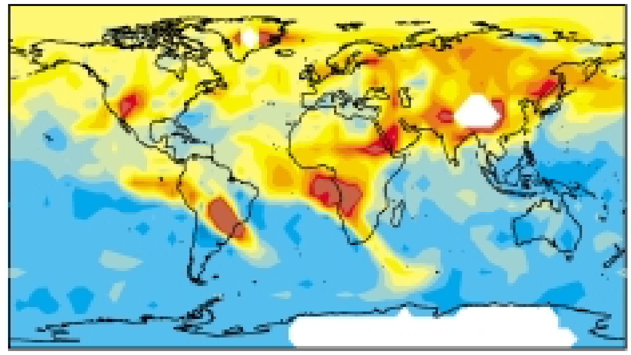


Figure 4. Satellite measurements of global carbon monoxide from MOPITT (Measurements of Pollution in the Troposphere) are being assimilated into the MOZART model. Here, CO at 700 mb for 3 August 2000 shows high values over South America and Africa, a result of biomass burning. Such assimilations allow atmospheric chemists to extend their studies to quantities not directly measured and to transport away from sources.

ACD research covers a broad range of instrumental, experimental, and theoretical goals. Basic laboratory studies include gas-phase and heterogeneous processes involving gas chromatography and mass spectroscopy from whole air or in-situ samples and measurements of two important radical species: hydroxyl and hydroperoxy radicals. These are complemented by the measurement of spectrally resolved actinic fluxes.

Global, regional, and process models advance our understanding of chemical processes and transport. The Model for Ozone and Related Chemical Tracers (MOZART) is a comprehensive global chemical transport model used to study the formation and fate of chemical compounds in the troposphere. It is used to simulate the distributions of key constituents and aerosols, quantify global budgets, and predict changes

Table 2: Summary of National Programs within Which NCAR Has a Leading Role

National Program	Acronym	NCAR Role
National Space Weather Program	NSWP	NCAR supports the NSWP through the development of models, maintenance of facilities, etc.
U.S. Global Change Research Program	USGCRP	NCAR supports the USGCRP though a large range of scientific and leadership activities across many divisions.
U.S. Weather Research Program	USWRP	Scientific leadership; NCAR houses the Office of the USWRP Chief Scientist and adjusts internal program to support overall goals and objectives of the USWRP.

in the distribution of chemical compounds in response to natural and anthropogenic perturbations. A regional-scale chemistry transport model, HANK, is being used to simulate and interpret measurements from major tropospheric campaigns.

Future research themes within ACD include:

- *Megacity Impacts on Regional and Global Environments (MIRAGE)*, an investigation of the impact of pollution from megacities on regional and global scales. We envision one or more intensive field campaigns to track and study the chemical and physical evolution of megacity emissions far from their source regions, where their influence on background processes will be more easily observed. These observational activities will be supported by simulations from global, regional, and process models to assist in campaign preparation, deployment, and post-mission interpretation.

- *Organic Carbon Initiative*, aimed at studying many facets of the organic carbon cycle in the atmosphere, including the emission, oxidation, conversion, and deposition processes that regulate the magnitude and makeup of organic carbon in tropospheric air masses. A spectrum of activities is planned, ranging from laboratory studies of targeted organic species and small field studies with specific observational goals to large field campaigns where the complete life cycle of organic carbon in the atmosphere will be studied in key natural and anthropogenic environments.

4.2.2 Climate and Global Dynamics Division

CGD's research goals are to work toward a comprehensive understanding of climate system components and the interactions among them, to represent this understanding in models of the coupled climate system, and to provide a basis for prediction of weather and climate using these models to investigate important scientific and societal questions. There are two broad emphases: understanding and predicting the Earth system, and climate variability. An integrating activity is the Community Climate System Model (CCSM), which involves many CGD scientists and software engineers, together with other NCAR staff, university researchers, and scientists from a variety of national laboratories. Improvements to the CCSM component models are ongoing.

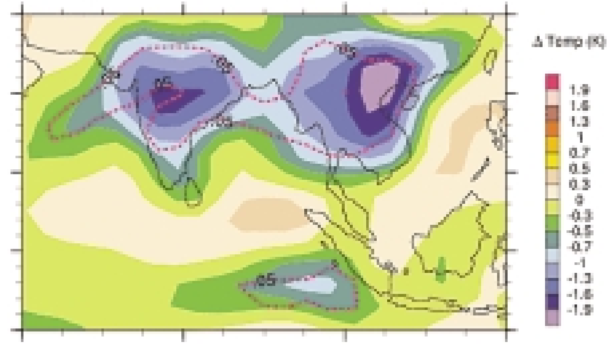


Figure 5. Recent simulations by researchers from NCAR and the Scripps Institutions of Oceanography show that the presence of absorbing aerosols over the Indian Ocean region leads to a cooling of the land and ocean surface, not a warming as suggested by other recent investigations.

CGD acquires, evaluates, and restructures data sets as part of its work in climate analysis and diagnostics. A wide variety of empirical studies have been undertaken on El Niño/Southern Oscillation, the North Atlantic Oscillation, the Tropical Biennial Oscillation, and temperature anomalies in the midlatitude oceans. Diagnostic studies have been conducted on tropical Atlantic variability, atmospheric response to long-term trends in sea ice, and mechanisms of midlatitude climate variability.

CGD scientists have also been involved in a variety of studies on predictability, including how predictability error-growth affects an ensemble of predictions and the impacts of different methods for generating initial states in an ensemble on the ensemble properties.

CGD will expand its activities in evaluating and analyzing major community data sets, particularly the multidecadal reanalysis from the European Centre for Medium-Range Weather Forecasting. CGD will expand its investigation of seasonal-to-interannual climate prediction using the new CCSM-2 and will participate heavily in the new Data Assimilation Initiative, including scientists involved in CCSM.

4.2.3 Environmental and Societal Impacts Group

ESIG research contributes to an improved understanding of how social capacity and technological capabilities influence the infusion of new scientific knowledge into decision making processes at all levels of society. The research focus is on integrating findings and applications that will facilitate better use of weather and climate information in decision making on crucial societal issues.

ESIG is a multidisciplinary group of social and biophysical scientists linking advances in the understanding of social-system dynamics and public policy to fundamental weather and climate science. ESIG uses a wide range of ideas and tools, including quantitative and qualitative approaches such as economic modeling, policy and institutional analysis, forecasting by analogy, statistical analysis, deterministic modeling of the atmosphere, biophysical modeling of ecosystem responses to weather and climate variability, and remote sensing/geospatial information systems.

ESIG's recent scientific studies have included systems that are intensively managed by the private sector (such as agriculture) and publicly managed systems (such as fisheries, water resources, and public lands). Some of ESIG's research has addressed how institutional processes and investments in infrastructure influence the ability to be resilient and flexible in responding to climate variability. Other research has focused on identifying and quantifying basic relationships between climatic variables and the productivity of selected natural resource systems. This multidisciplinary work involves collaboration among ESIG, other NCAR divisions, the university community, and the international policy and resource management communities.

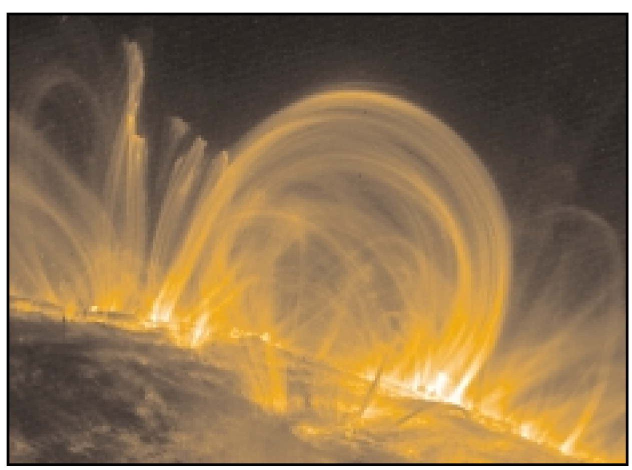
In planning for the future, ESIG proposes to lead efforts in climate impact assessment, with a particular focus on revealing and coping with uncertainties and exploring the intersection of climate variability with the health sciences. ESIG will also be an active participant in the NCAR Biogeosciences Initiative, the information technology initiatives, and education, training, and outreach. ESIG will work closely with public- and private-sector partners to explore new models and methods for bringing new ideas and technologies into societal applications that promote a transition to a more sustainable future. ESIG's first priority will be continuing action on reducing impacts of well-known threats to human well-being, such as droughts, floods, and severe weather. An additional focus is the longer-term development of new knowledge and strategies that will reduce vulnerability and enhance resilience of communities and regions in the uncertain future ahead.

4.2.4 High Altitude Observatory

HAO takes a multifaceted approach to attaining its research goals, bringing together instrumental, observational, interpretive, computational, and theoretical studies as components of a unified undertaking to better understand the Sun and solar forcing of the terrestrial atmosphere.

The observatory's program is founded upon four long-standing, cornerstone research areas: the solar dynamo and internal solar dynamics; the measurement and analysis of magnetic fields in the solar atmosphere; the physics of the solar corona, solar wind, and space weather; and observations and modeling of the thermospheric, ionospheric, and mesospheric regions of the Earth's upper atmosphere. These major research themes are complemented by studies of Sun-like phenomena in stars other than the Sun and the comparative study of planetary atmospheres. Through projects in astroseismology and the detection of extrasolar planets, HAO scientists learn more about the Sun and

Loops of ionized material emitting near 1 million degrees Kelvin are shown in this image obtained at a wavelength of 171 Angstroms from the TRACE spacecraft during November 1998. The loops, which trace magnetic lines of force, were "lit up" shortly after a solar flare released its energy from twisted magnetic fields that arose from the evolution of a magnetically active region at the Sun's surface.



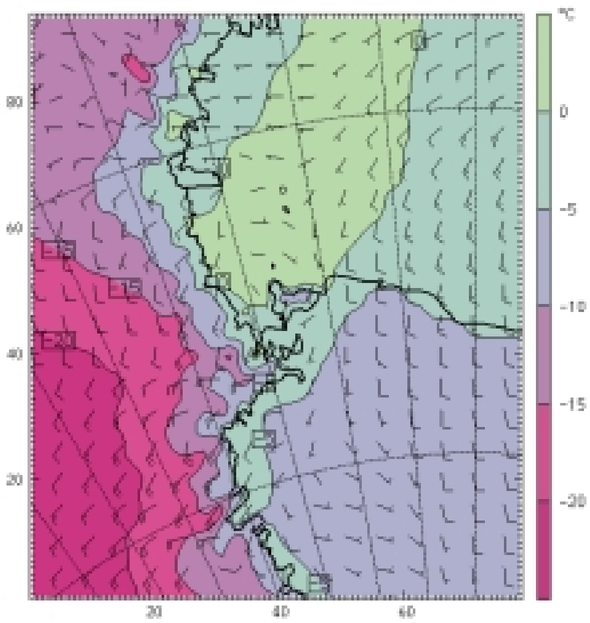
Earth by studying them within the wider astrophysical contexts of stars and planets in general.

Through this integrated program of research, HAO seeks a physical understanding of the origins of the Sun's magnetic field, the role of that magnetic field in producing solar activity and its attendant radiative and particulate variability, the interaction of these variable outputs with the Earth's upper atmosphere, and the possible implications of such interactions for the lower atmosphere and climate.

4.2.5 Mesoscale and Microscale Meteorology Division

MMM addresses the most important and fundamental scientific themes in mesoscale and microscale meteorology, with emphases on understanding and forecasting weather and on evaluating the influence of small- and medium-scale processes on larger-scale phenomena. Researchers engaged in mesoscale and microscale meteorology are poised to make major progress in forecasts of precipitation and accurate depiction of these processes in models of climate and weather. This progress is made possible by recent advances in observing systems, computers, and theoretical understanding.

Figure 6. Beginning in the austral summer of 2000, NCAR has provided twice-daily forecasts for Antarctica through a special polar version of the MM5. The outlooks support field projects, polar research, and flights to and from the continent, including the emergency rescue of ailing physician Ronald Shemenski last April. Factors behind the success of the Polar MM5 include its accurate depiction of Anarctica's rugged topography and its high resolution, which was increased to 3.3 kilometers (2.1 miles) in 2001 in the vicinity of McMurdo Sound. Below is a sample 6-hour forecast of temperature and winds at a resolution of 10 km (6.2 mi).



MMM is unique because of the breadth of its expertise and its ability to focus this expertise on important problems that require an integrated, interdisciplinary approach. Along with its continued major role in mesoscale and microscale meteorology, MMM will address several objectives of the U.S. Weather Research Program and the Global Change Research Program. The two main research themes of the division—both in accord with key USWRP and GCRP goals—are prediction of precipitating weather systems and cloud and surface processes parameterizations.

Prediction of precipitating weather systems: The main goal of this research is to advance the understanding and prediction of significant precipitation events in order to reduce forecast errors toward the limits of predictability. Accurate prediction of precipitation is one of the major objectives of the USWRP, and the division's research agenda is intentionally aligned with this national program. To improve the ability to forecast precipitation a few hours to a few days out, our plans include theoretical studies of the predictability of precipitation in synoptic-scale systems; observational and modeling studies of the initiation, organization, and decay of precipitating convection; analysis of observations and simulation of precipitation over mountainous terrain; fundamental study of the precipitation process using multiparameter radar observations and other field data; further development and operational deployment of a next-generation forecast model with advanced data-assimilation capabilities; and evaluation of advanced observing systems to improve the two- to five-day forecast.

Parameterization of cloud and surface processes: The main goals in this area are to quantify the large-scale effects of mesoscale and microscale processes, and to develop the physics needed to account for these effects in large-scale models. Until this is done, predictions from large-scale models—including both weather and climate forecasts—will be of limited accuracy. The emphasis within MMM is on understanding how the atmosphere, land and ocean surface, and hydrological processes interact, and how these processes can be quantified. Our plans in this area include further development of a global nonhydrostatic model to be used in cloud-resolving-model studies of the multiscale organization of convection and its role in determining the climatic equilibrium; application of the foregoing to study tropical atmosphere-ocean interactions and to improve cloud-parameterization schemes for large-scale models; investigations of the stratus-topped boundary layer through field experiments and large-eddy simulations; exploration of new ways to remotely sense the atmosphere, especially with respect to water vapor in the planetary boundary layer; development of improved bulk formulae for subgrid turbulent fluxes of heat, momentum, and chemical species over heterogeneous terrain using field data and large-eddy simulations; and cooperative and interdisciplinary investigations coupling small-scale dynamics with chemistry, aerosols, and cloud physics.

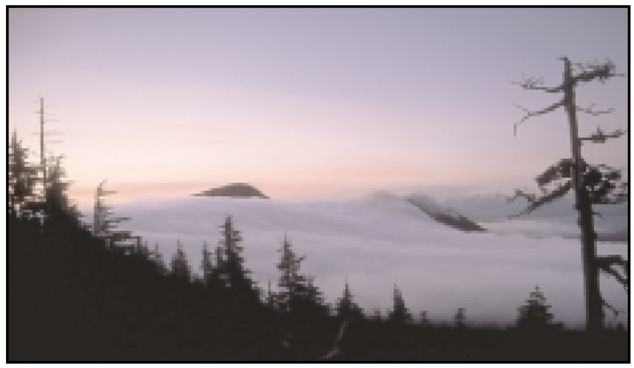
4.2.6 Geophysical Turbulence Program

GTP is an interdisciplinary program, bringing together participants from almost all NCAR divisions and programs with interests in turbulence. GTP objectives are to coordinate and communicate the diverse turbulence research activities at NCAR and to maintain links to the broad external community interested in fundamental and applied turbulence. The program holds an annual workshop that involves the external community, maintains an active visitor program, and hosts a seminar series, all of which promote links within NCAR and with the university community. GTP research includes studies of subgrid-scale turbulence to improve large-eddy simulations, entrainment at the tops of stratocumulus layers, the effects of turbulence on nonlinear processes in chemical reactions and in cloud microphysics, the scaling properties of convection using direct numerical simulation, and magnetohydrodynamic turbulence as it influences solar processes such as the heating of the solar corona.

4.2.7 Geophysical Statistics Program

GSP pursues the innovative development and application of statistical methodology to address problems in the Earth sciences. A complementary activity is to generalize specific problems in the geophysical sciences to broad-based statistical research. Major research areas include the extension of statistical methodology to spatial and space-time processes; the application of modern regression and model selection to the analysis of geophysical data; deriving a statistical basis for forecasting, including the assimilation of observational data into numerical models; and modeling complicated physical processes through the use of dynamical systems and nonlinear time series. In addition, GSP provides expertise to researchers at NCAR in the application of traditional statistical ideas.

The program is the result of recognition by the NSF Directorate for Mathematical and Physical Sciences of the importance and societal relevance of global climate change and the value of modern statistical techniques to the geophysical sciences. GSP is an effort to integrate these techniques with current atmospheric and oceanographic research.



4.3 Core Facility Support to the Community

4.3.1 Scientific Computing Division

SCD is a premier scientific computing facility serving a disciplinary community of over 1,100 university, UCAR, and NCAR scientists and other researchers around the world. SCD provides high-end computing, world-renowned archival storage and retrieval services, discipline-specific research data sets, and enterprise networking capabilities. Building upon a heritage of over 30 years of service and innovation, SCD has successfully managed the transition for its users from a vector-parallel to a massively parallel computing environment. SCD currently provides the 20th-most-powerful supercomputing environment in the world and is poised to enhance this capability several fold.

SCD manages two separate computing facilities—a specialized multiagency facility known as the Climate Simulation Laboratory and dedicated to long-running simulations of the Earth's climate, and a community facility for UCAR's university constituents and NCAR researchers.

New components have been added and existing services enhanced in recent years to better support research. Specifically, SCD has increased available computing cycles threefold, enhanced data analysis and data distribution services, provided next-generation visualization capabilities, and developed collaborative environments. More emphasis has been placed on training, outreach, and consulting support, and on collaboration with the modeling community through conversion support, model design, utilities, and frameworks—all designed to enhance the exploitation of the new architectures.

SCD is increasingly using Web technology to provide a more approachable and a more responsive infrastructure. Through the Web, SCD is providing researchers with easy access to the information and services they need, when they need them. Using a personalized Web portal, users will submit jobs and check on their status, manage their mass-storage holdings, view their accumulated charges, and access news, data, and information relevant to their research.

SCD's road map for the next several years is articulated in a new strategic plan. Much of the plan focuses on advancing the areas where SCD has demonstrated strong intellectual leadership. New to SCD is a focus on using this leadership as a transformational engine for NCAR and its community through convergence of elements of the information technology revolution, such as collaborative environments and connection to NSF's TeraGrid of distributed computing and data services.

SCD is committed to playing a central role in defining and realizing the benefits of the information technology revolution for NCAR and the community it serves.

4.3.2 Atmospheric Technology Division

ATD serves the geosciences research community by developing and operating advanced observing systems. These systems allow NSF-funded researchers to gather unique and specialized data covering a wide range of research topics, from surface emissions to upper-atmosphere dynamics and from local severe weather to global aerosol distributions. Researchers often use ATD systems to complement data from their own instruments. ATD systems serve as reference and intercomparison tools for operational systems such as national radar and profiler networks, state mesonets, and satellites. ATD systems and ATD engineering and fabrication services support development and testing of new instruments from universities and other laboratories.

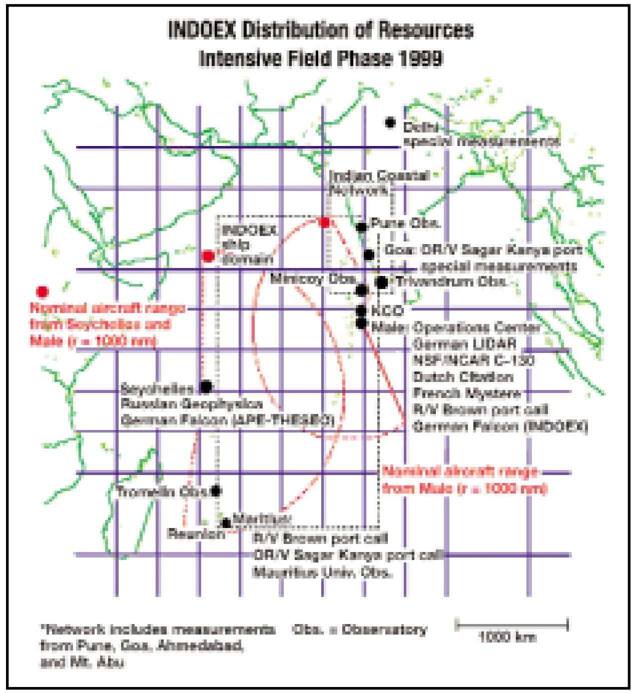


Figure 7. INDOEX field resources

ATD continuously upgrades and replaces systems under a three-tiered set of priorities: systems with the highest impact for the broad geoscientific community over a decade and more, substantial new developments that will advance observational capabilities for major scientific activities over the next three to five years, and system upgrades and new technology infusions that will enhance observational support for a wide range of research over the next year or two.

ATD expects to lead the development of a new airborne platform, the High-Performance Instrumented Airborne Platform for Environmental Research (HIAPER), that will represent a major improvement in NSF's geoscientific observational capacity for the next several decades. This new aircraft will provide a combination of altitude, range, endurance, and payload unavailable in any current aircraft of the U.S. national research fleet.

ATD has several new instruments planned to support strong NCAR research initiatives in water and precipitation processes and in biogeosciences, including a new high-resolution scanning water vapor lidar, a new isotope-discriminating carbon dioxide lidar jointly developed with ACD, and an advanced multifunctional sonde. ATD also expects to perform substantial technological upgrades to existing systems, including new radar signal processing and display systems, new chemical sampling systems for tethered balloons (again joint with ACD), and new high-resolution wind profilers.

4.3.3 Solar and Upper Atmosphere Facilities

HAO operates facilities in support of the worldwide solar physics, space physics, and space weather communities, supplying both data and laboratory calibration capabilities to a diverse group of users.

HAO's observational facilities are centered at the Mauna Loa Solar Observatory, located on the island of Hawaii. The instruments at this observatory provide daily observations of the Sun's photosphere, chromosphere, and corona, exploiting capabilities that are not available elsewhere and that greatly enhance the usefulness of observations from space and from large ground-based telescopes. The Precision Solar Photometric Telescope delivers images of the photosphere and chromosphere with unprecedented photometric accuracy. The Mark-IV K-coronameter takes images of the solar corona close to the solar limb, including at heights that are too low for other coronagraph systems. The Chromospheric Helium I Imaging Photometer observes structure in the solar chromosphere and low corona at a three-minute cadence, faster than any observations elsewhere. Daily summary data from Mauna Loa are vailable on the Internet, and particular data sets are supplied to community users on request. During FY 2001, HAO filled such requests from more than 40 users at a similar number of institutions, in addition providing direct access to Internet-available data.

The NCAR Vacuum Tunnel Facility is a combination optical testing facility and clean room for testing and calibrating spaceborne coronagraph instruments. This facility has been used to calibrate instruments such as the Solar Maximum Mission Coronagraph/Polarimeter and the Spartan 201 White-Light Coronagraph. After recent refurbishment it was used in 2001 to test the breadboard COR-1 coronagraph for NASA's Solar-Terrestrial Relations Observatory mission. Further improvement of the facility is planned, chiefly to facilitate operations in the clean room.

In the near future, HAO plans to open a new facility for upper-atmospheric observations near Platteville, Colorado. It will combine instrumentation to measure upper-atmospheric winds with modest support for community experiments on related topics. The observational activities will involve close coordination with other optical- and radar-based measurement systems worldwide and will play an important role in synoptic studies of high-altitude atmospheric processes.

4.3.4 Community Models as Facilities

NCAR serves the broad community through the development and ongoing support of numerical models that simulate the physical Sun-Earth system. The continued development of these community models is an integral part of our strategic plan for the future.

CCSM: From the beginning, the Community Climate System Model (CCSM) has involved a significant part of the climate community in its development and application. There is community governance of all its activities. Model development takes place at NCAR and at many collaborating institutions, and data from major experiments are shared with all users and analyzed at a variety of institutions. Improvements to the model are being made in collaboration with several national laboratories. Future directions are discussed and decided in a community process. An annual CCSM workshop allows hundreds of scientists (260 participants in 2001) to gather, discuss their work, and plan future activities. Working groups meet during the year to discuss progress on model development and future plans. All model components and major model data sets are made available on the Web. Collaborators are allocated computer time through a community-based governance process, and NCAR supports several liaison personnel to facilitate interactions with these scientists. The success of the CCSM can, in part, be attributed to the contributions from these outside collaborators. Many of the components to be used in CCSM-2 were developed collaboratively with other institutions. We expect the CCSM will continue to be used as a facility by scientists from across the United States and, indeed, from around the world.

WACCM: The Whole Atmosphere Community Climate Model (WACCM) is the next step in the evolution of Earth system models at NCAR. The development of WACCM is an interdivisional collaboration that brings together upper-atmospheric modeling in HAO and middle-atmospheric modeling in ACD with tropospheric modeling in CGD, using the CCSM as a common numerical framework. A comprehensive numerical model that spans from the Earth's surface to the thermosphere, WACCM reflects the importance of coupling between atmospheric regions. The initial model incorporated the physical and chemical processes required to investigate coupling between atmospheric regions from the surface to 140 kilometers. The model will eventually extend upward to about 500 km. WACCM is envisaged as a flexible model environment whose domain and component modules can be configured according to the specific problem under study. Its expanded capabilities will be mirrored by an expanded community of developers and users.

Chemistry Models: ACD has a long tradition in the development of community models to serve a variety of needs. Process models that focus on a particular facet of a problem are developed and distributed. The Master Mechanism (MM) model is a highly detailed description of atmospheric chemistry designed to simulate the complexity of hydrocarbon oxidation processes. Thus, a single hydrocarbon oxidation such as isoprene can result in a self-generated chemical scheme involving hundreds if not thousands of distinct species and reactions. This model can be used for fundamental research or as a valuable teaching aid. The Tropospheric Ultraviolet and Visible radiation model (TUV) simulates the propagation, absorption, and scattering of shortwave radiation in the atmosphere. It can be used to calculate photolysis and erythemal rates and is valuable as both a teaching and research tool. Results from TUV contribute to scientific assessments of the impacts of ozone depletion and to health assessments of the risks of skin cancers.

On a larger scale, regional and global models capable of simulating a range of atmospheric processes and suitable for studies of the evolution of the real atmosphere are also developed in the division. In collaboration with MMM, an off-line regional chemical transport model (HANK) has been developed. ACD is playing an active role in the implementation of on-line chemistry within the Weather Research and Forecast (WRF) model framework. ACD has been instrumental in the development of several global models, including the 2-D model Simulation of Chemistry, Radiation, and Transport of Environmentally Important Species (SOCRATES), developed to study stratospheric processes and the interactions among chemical, physical, and dynamical processes and the Model for Ozone and Related Chemical Tracers (MOZART), which aims to describe the chemistry of the troposphere and stratosphere. This work is further extended by the WACCM activities (see above). In the future, these activities will be extended to on-line simulations of tropospheric chemistry within the CCSM framework.

4.3.5 Community Data Sets

NCAR provides access to numerous discrete data sets. For example, in response to community requests for easier access to NCAR climate model data, data products from NCAR's CCSM have been available on line since 1998. The on-line data products are considerably more refined than the raw history data output directly from the CCSM and have proven to be very popular with climate change researchers, both in the United States and internationally. SCD collects and maintains a large archive of both historical and global observations and of analysis research data. This computer-accessible archive represents an irreplaceable store of research data sets used by major national and international atmospheric and oceanic research projects. The data are made available to scientists around the world using various distribution media (e.g. Web, tape, CD-ROM). The number of on-line users accessing the archives has grown to over 880 scientists and researchers around the world, requesting more than 15 terabytes of data each year. A majority (61%) of these users are from the university community.

Another important data set, available on the Web and on CD-ROM, is the NCEP-NCAR reanalysis of 53 years of global data. This quality research data set, which was produced by NOAA's National Centers for Environmental Prediction and NCAR, will be useful to researchers for many years. Plans are being formulated to do the next U.S. global reanalysis with a 2005 state-of-the-art system. In addition, ATD maintains an extensive library of radar and aircraft data sets.

Our vision is to make data and information services uniformly available to all elements of the UCAR community via transparent, wide-area access, independent of how and where the data are collected and stored. Data intiatives are described in Section 5, below.

4.4 Technology Transfer and the Research Applications Program

RAP is directed toward the successful transfer of NCAR science and technology to federal mission agencies and to the private sector. Currently RAP focuses on mesoscale meteorology, with specific long-standing expertise in aviation weather systems. The RAP mission depends on a strong scientific staff and on close collaboration with other groups inside and outside of NCAR. RAP provides mission agencies with operational products, capabilities, and advice that would not be successfully transferred without the science to back the effort. RAP technology transfer activities represent a unique capability that provides a tangible benefit to NCAR and is in the national interest.

RAP's major activities revolve around short-term forecasting/nowcasting of weather hazards that affect aviation safety and efficiency (including in-flight icing, ground icing, thunderstorms, turbulence, ceiling and visibility, oceanic weather problems, and low-level wind shear), topics related to hydrometeorology (improved techniques for rainfall measurement, nowcasting, and forecasting, coupled hydrologic run-off models, feasibility study of rain enhancement), and development and transfer of advanced forecast systems for decision makers in a variety of weather-sensitive sectors (e.g., ground transportation, defense, government, commercial enterprises). The work involves directed research to increase the accuracy of forecasts and system developments such as improved weather displays, rapid prototyping, and artificial intelligence to automate weather products.

RAP will continue to emphasize the transfer of technology, including leading NCAR's efforts to establish a national wildland fire science and decision-support program.

Weather/climate technology transfer, particularly the demand for tailored and effective decision support tools, is certain to grow in the future. Many sectors of the national economy are vulnerable to perturbations in weather and climate (one current estimate shows $2 trillion of the national economy as weather/climate sensitive). In this context, it will be important to carefully manage NCAR's technology transition efforts. In some cases, commercialization should occur through the newly created for-profit Intelligent Weather Solutions, Inc., which is wholly owned by UCAR.

In our strategic planning, we see technology transition as a *core mission* of the center and not a supplemental or peripheral activity. In fact, we believe that RAP's activities speak directly to NSF Merit Review Criterion #2, which cites societal benefit and impact as important objectives.

To augment and better acknowledge the broad impacts of NCAR's work, we plan to integrate RAP more thoroughly into the center, by cross-strapping elements of our scientific and technical strategy and by supporting interdivisional linkages involving RAP.

RAP is currently funded entirely though extramural grants and contracts. We intend to solidify the needed interdivisional interactions involving RAP by providing targeted core funds in areas pertaining to our strategic plan.

4.5 Educational Contributions

4.5.1 Advanced Study Program

The objectives of ASP are to provide career opportunities for outstanding recent Ph.D. graduates in atmospheric and related science, to foster and publicize emerging scientific areas, to help organize new scientific initiatives, to support interactions with universities, and to promote continuing education at NCAR. The principal program components are the postdoctoral and graduate fellowship programs, the summer colloquium, and the visitor program. The Geophysical Turbulence Program (see Section 4.2.7) is housed and supported within ASP.

ASP postdoctoral fellows are selected annually and hold an appointment of approximately two years. At any one time, there are between 20 and 25 postdocs. Their presence ensures that NCAR will have constant contact with young minds with new ideas and approaches from university departments. ASP objectives are to develop their independence, broaden their scientific perspectives, and develop lasting collaborations with these scientists at the start of their careers. NCAR also benefits from their original research contributions, which often help forge new scientific directions for the institution. The postdocs benefit from opportunities to work with NCAR scientists and from freedom to develop their own career directions. The ASP fellowship program has contributed to the careers of many scientists who now hold prominent positions at NCAR and in the community.

ASP also holds an annual colloquium that surveys an emerging or rapidly developing area of research. Often there is no appropriate textbook or review document for the topics covered, so the reports from the colloquia serve as unique resources. The colloquia are designed for graduate students, but postdocs and NCAR scientists also attend.

ASP will continue these core efforts but will also broaden its activities to more profoundly influence the institution and contribute to intellectual and professional development. ASP will recruit and host senior colleagues from various disciplines, who will reside for a time within ASP as "senior NCAR fellows" and who will act as advisors to and codevelopers of strategic thrusts. The program will also coordinate visits of early-career scientists participating in the Early-Career Faculty Professional Development Initiative. ASP will coordinate the recruitment and mentoring of early-career scientists and will extend its role in mentoring to all postdoctoral scholars, not just those within the ASP program. ASP will augment its graduate fellowship program, which declined in scope during the 1990s due to budgetary constraints. ASP will provide logistical support to the Early-Career Scientist Assembly and the NCAR Scientist Assembly. Finally, ASP will develop a series of colloquia on emerging scientific areas, by inviting teams of key players to NCAR for intensive dialog. Through these and other means, ASP will act as a catalyst for the development of new ideas and scientific expertise at NCAR.

Table 3: Recent ASP Colloquia

Year	Title
1997	A Systems Approach to El Niño
1998	Hurricanes at Landfall
1999	Ice Formation in the Atmosphere
2000	Dynamics of Decadal to Centennial Climate Variability
2001	The Tropical Atmosphere and Oceans

4.5.2 Education and Outreach Programs

Over several decades, various education and outreach programs have been developed by dedicated staff within UCAR, NCAR, and UOP. These programs have been designed to disseminate information about the geosciences to students in K–12, undergraduate, and graduate schools, to postdoctorates, and to the general public.

Educational tours and exhibits are the hallmark of public outreach at NCAR's Mesa Laboratory, reaching tens of thousands of people every year and receiving core support on an ongoing basis.

NCAR scientists have contributed strongly to professional training within UOP's COMET program (Cooperative Program for Operational Meteorology, Education and Training) and are now working closely with the new Digital Library for Earth System Education (DLESE). Project LEARN used NCAR expertise and personnel extensively to reach many middle- and high-school teachers, providing both curricular materials and workshop support. The SOARS program (Significant Opportunities in Atmospheric Research and Science), involving NCAR, UCAR, and UOP, is nationally regarded for its innovative, long-term, multi-faceted mentoring at the undergraduate level to increase the diversity of the geosciences community. These specific programs, with unique missions and audiences, have significantly contributed to educational resources, training opportunities, and tools available to support the academic community from the middle-school level through professional training.

NCAR and UCAR also house a number of innovative science education Web sites, such as the award-winning *Windows to the Universe* site. Such Web sites provide high-quality, extensively reviewed science material for informal science education over the Internet.

While these education and outreach programs will continue, NCAR and UCAR management has recognized the importance of building a more significant infrastructure to support leveraged efforts. This recognition has led to the recent establishment of the Office of Education and Outreach and the development of its strategic plan (see Appendices).

4.6 Capital Infrastructure

4.6.1 Physical Plant

The national center has been well endowed by the federal government during its 40 years of existence. NSF provided the spectacular Mesa Laboratory in the 1960s and continues to support the physical plant through both direct funding and the allocation of overhead charges. In the recent past, NSF provided special funding of $12 million for a comprehensive refurbishment of the Mesa Laboratory.

Through tax-exempt bonds issued by the county of Boulder, UCAR has financed major building purchases and renovations, most notably the purchase of the Foothills campus, as space needs have grown. Sponsoring agencies pay off the bond through overhead charges for debt service, depreciation, and interest based on actual space usage of each UCAR entity. This creative financing by UCAR has enabled NCAR and NSF to economically provide the space and facilities necessary to support the center's programs.

Coincident with this strategic plan, UCAR and NCAR are planning a major addition to the Foothills campus. UCAR already has over 30,000 square feet of space under lease and needs significantly more space. By calculating space now being leased, current needs, and planned growth over the foreseeable future, we envision constructing a building of 80,000 to 100,000 square feet. Low bond interest rates and refinancing of the existing bonds could allow us to provide additional space without a significant increase in cost.

4.6.2 Major Equipment

UCAR has provided over $20 million in bond funds to purchase equipment for NCAR programs. This technique allows us to amortize the cost of special-purpose equipment over its useful lifetime at a reasonable cost, due to the tax-exempt rates. Programs reimburse the cost, through annual depreciation and interest charges to their programs.

As of 2001, NSF has provided over $20 million through its Major Research Equipment fund for the acquisition, modification, and instrumentation of a high-altitude jet aircraft. While this amount is significant, it is only about one-fourth of the total projected cost of the aircraft. NCAR and the UCAR contracts office are proceeding with the definition of requirements, engineering plans, and preliminary negotiations for the purchase of the system. Upon receipt of the necessary funds, procurement will proceed immediately.

In 2001, SCD began acquisition of an Advanced Research Computing System. ARCS will bring NCAR into the sustained teraflop computing range by 2005, a more than tenfold increase over the 2000 level of approximately 74 gigaflops.

5.0 New Directions for NCAR

Building on our disciplinary strengths, much of our strategy speaks to the synergy between and among the NCAR divisions—a critical component of NCAR's role as an integrator.

The following paragraphs are brief, integrated summaries of specific interdisciplinary scientific thrusts developed by NCAR staff and their university collaborators. They also describe how the proposed new initiatives build on and integrate with existing core research programs. More detailed descriptions of each of the proposed research initiatives can be found at http://www.ncar.ucar.edu/stratplan.

5.1 Integrating Interdisciplinary Scientific Initiatives

At all scales, atmospheric and other environmental research issues are no longer the purview of single disciplines. Examples of this abound. Chemical transport studies require the integration of atmospheric dynamics, radiative transfer, and atmospheric chemistry. Precipitation studies require expertise drawn from experimental and theoretical hydrology, cloud physics, ecosystem dynamics, and large-scale atmospheric circulation. Socioeconomic studies of severe weather require an integration of qualitative social science and quantitative numerical modeling. Predictive space weather models require detailed knowledge of solar physics and magnetospheric and ionospheric processes, as well as the dynamical coupling between the upper and lower atmospheres.

To make progress in such areas, NCAR must assemble disciplinary expertise from across organizational boundaries. We must adjust our merit review and promotion policies to recognize the value of teamwork in the arena of tough interdisciplinary research.

5.1.1 Investigating Chemistry-Climate Connections

NCAR and its university collaborators conduct a suite of investigations of planetary metabolism across scales from cities to major ecosystems to the entire global atmosphere. A primary challenge is to understand the impacts of human activities on the chemistry of the atmosphere. Understanding the chemistry-climate connection is also a rapidly emerging priority. The NCAR program is closely allied to the International Global Atmospheric Chemistry project of the International Geosphere-Biosphere Program.

Field campaigns will continue to be the primary method of understanding and characterizing emissions of gases and aerosols from various environments. NCAR is an active participant in the Large-Scale Atmosphere-Biosphere Experiment in Amazonia (LBA) and in the Aerosol Characterization Experiment—Asia (ACE-Asia). The international LBA campaign will make significant progress in characterizing controls of the chemistry of the atmosphere over regions of intact and disturbed tropical rainforest. ACE-Asia is the first major investigation of a massive aerosol plume that periodically covers vast areas of western Asia, the North Pacific Ocean, and beyond. The results of these field campaigns are important to improving the characterization of processes in the NCAR Model of Ozone and Related Chemical Tracers (MOZART) and in the Community Climate System Model (CCSM).

The NCAR chemistry-climate research program addresses issues on an enormous range of scales in time and space, from the atmospheres of cities to the distant Sun. The dynamics and chemistry of the global atmosphere are made very complex by cross-scale interactions that link the exchanges of gases and particles among humanity and nature from the boundary layer to the outer reaches of our planetary atmosphere.

5.1.2 A Biogeosciences Initiative

An NCAR Biogeosciences Initiative will engage a large number of scientists from the United States and beyond in an exploration of the role of biological processes in the dynamics, chemistry, and evolution of the climate system on time scales from days to millennia. This effort will be especially important to developing next-generation land surface and ocean components of the CCSM, and for evolving towards an Earth System Model. An array of simplified inverse and

Courtesy U.S. Forest Service Research

prognostic land and ocean models, together with remote-sensing data and atmospheric tracers, will be used to identify key uncertainties in fluxes of gases and aerosols that influence the radiative balance of the climate system. The CCSM Biogeochemistry Working Group will conduct a "Flying Leap Experiment" where fossil-fuel carbon emissions will be specified and carbon will be actively advected through the Earth system; the atmospheric concentration of carbon will be determined as a residual of the integrated, global biogeochemical interactions. The Biogeosciences Initiative will also encompass a variety of modeling and field studies that investigate major feedback processes between the climate system and the biosphere. For example, the role of fire as a biogeochemical feedback and as an agent of land cover change that influences heat, water, and momentum exchanges will be explored in a series of regional investigations. An integrated program of field and modeling studies will address the fundamental issue of pattern and scale of vegetation cover and land use as a control on biogeochemical cycles of trace gases, aerosols, heat, water, and momentum. Studies of the human role in modifying land cover and biogeochemical cycles will include a special focus on the driving force of urbanization and megacities in global atmospheric change.

NCAR will be an active participant in the development and implementation of a major North American Carbon Cycle Experiment.This program will reveal uncertainties in our capability to measure net carbon exchange between the landscape and the atmosphere and will provide a legacy of observations and infrastructure to enable U.S. estimates of CO_2 sources and sinks in subsequent years.

The NCAR Biogeosciences Initiative will contribute heavily to the evolutionary development of a community Earth System Model. A management council with representatives from all the participating NCAR organizational units will facilitate and coordinate interactions between the observational and modeling components of the program. This activity will also build on and expand university involvement in the CCSM Biogeochemistry Working Group.

5.1.3 Advancing the Science of Weather and Climate Impact Assessment

Weather and climate affect every human being, and human activities affect the climate system. In turn, ecosystems are sometimes altered by the interacting impacts of atmospheric processes and human activities. These multiple interactions have significant social, economic, and political implications. NCAR's environmental, societal, and applications research, education programs, and outreach activities link fundamental advances in the atmospheric sciences to human needs and strategies for a sustainable future. This mission is closely tied to NSF's strategic goal to "promote the discovery, integration, dissemination, and employment of new knowledge in service to society."

There are four fundamental outcomes to which NCAR aspires in promoting the employment of new knowledge in service to society. (1) NCAR work on natural and anthropogenic hazards should enhance the protection of health and property; (2) NCAR research results should contribute to improved strategies for management of natural resources and the environment; (3) NCAR should promote the use of state-of-the-art weather and climate information in decision making and policy formulation; (4) NCAR should foster the integration of usable knowledge and action through education and outreach.

NCAR and its university partners conduct original research on a broad array of policy-relevant issues involving interactions among weather and climate dynamics, society, and natural systems. Fundamental discoveries are also the basis for a rich array of technology transfer activities and applications that have enhanced the safety and efficiency of civil aviation and improved capabilities for precision forecasting of weather at local sites. These efforts enhance the usability of information from the atmospheric and related sciences. NCAR's environmental, societal, and applications programs have a history of bridging gaps

between disciplines and between researchers and users of weather and climate information.

A central theme of NCAR's future applications research will be understanding the characteristics and impacts of uncertainties surrounding societal vulnerability to the impacts of extreme weather and climate events. Revealing uncertainties allows both the researcher and decision maker to anticipate needs for information and technology that support taking preventive action and reducing impacts of weather and climate variability. This initiative also builds on a strong record in building decision support models and software that provide precision weather and climate information to help solve important management and operational issues in the areas of transportation, national security, natural resource management, and natural disaster prevention and mitigation. New areas of investigation will include applications of precision weather and seasonal forecasts to energy sector operations, agricultural production systems, and national security planning. Most of these research and development activities will be highly collaborative, involving NCAR and university scientists working with government agencies and/or private sector clients. The tools and methods include highly automated decision support systems, remotely sensed data and Geographic Information Systems, and high-performance simulation and knowledge management capabilities.

An NCAR Climate Assessment Strategic Initiative identifies five areas of assessment science that will greatly benefit from improved characterization of uncertainty. These are: (1) emissions scenarios, (2) climate projections and scenarios, (3) impacts models (e.g., agriculture and ecosystem models), (4) the environmental data sets these models use (e.g., climate observations, soils), and (5) uncertainties involved in decision making. The research will focus on implications of these uncertainties for modeling and assessing impacts of climate extremes. NCAR also proposes to coordinate an interdisciplinary program on human health impacts of climate extremes that would bring together university, government, nongovernment, and private sector researchers.

NCAR and its university partners have been heavily involved in assessing potential impacts of long-term climate variability and change. Past activities have included participation in the Intergovernmental Panel on Climate Change assessments and in the U.S. National Assessment of Climate Variability and Change. The importance of characterizing uncertainty in all aspects of climate assessment work is becoming more obvious as assessment science develops. The enhanced research on weather and climate impacts briefly described here will be a significant contribution to the design and implementation of future national and international assessments.

5.1.4 Understanding Sun-Earth Connections and Planetary Atmospheres

A Solar Magnetism Initiative: The NCAR research program takes an integrated approach to understanding the Sun-Earth system. Variable solar radiative and particulate outputs have consequences for the dynamics and composition of the Earth's atmosphere. Extreme solar variability produces space weather events on short time scales, and longer-term solar cycles influence climate system dynamics and chemistry.

NCAR scientists, in collaboration with the national and international solar physics community, seek to understand the physical processes operating within the Sun on time scales of seconds to millennia to produce its variable output of radiation and particulate matter. The origin of solar variability can be traced to the solar magnetic field and its dynamical interactions with the turbulent solar plasma. An integrated understanding of origins of variability in solar radiation and particulate fluxes will contribute significantly to better space weather predictions and climate models. The major themes that focus NCAR research in solar-terrestrial physics are (1) understanding the magnetic Sun and its intrinsic variability, and (2) the coupled Earth system and its response to the variable Sun.

A deeper understanding of the Sun's magnetic activity cycle is a prerequisite to realizing the goals of the interagency National Space Weather Program and the NSF-sponsored Earth system modeling activities. The solar magnetic field strongly influences the variability of solar outputs. A community Solar Magnetism Initiative is planned that will include the development of a near-infrared spectropolarimeter to measure magnetic fields in the solar corona. An integrative modeling program will perform theoretical studies of fundamental processes, including global numerical simulations, to analyze observations of the solar atmosphere and carry out a synthesis between data and theory. This research will elucidate the nature of the dynamo action at the interface between the nearly rigid solar core and the solar convection zone that is dominated by differential rotation and large-scale convection. This understanding will provide a basis for characterizing the physical manifestations of the generated magnetic fields after emergence into the solar atmosphere and their impacts on solar emissions of particulate and energy fluxes.

A Comparative Planetary Atmospheres Initiative: The comparative study of the atmospheres of planets, both within and outside the solar system, is an exciting field that can stimulate productive interactions between terrestrial and planetary atmospheric researchers. NCAR will place increased research emphasis on two areas: comparative planetary upper atmospheres and the study of the dynamics of extrasolar planetary systems.

This initiative builds on previous research investigating the upper atmospheres of Earth, Mars, and Venus that included studies of comparative photochemistry, magnetosphere-ionosphere interactions, and studies of exospheric escape of planetary atmospheric constituents. Important goals for the expanded program are to quantitatively observe and model the Earth's mesospheric and thermospheric winds and temperatures, to gain a comprehensive understanding of the influences of solar wind on the upper atmospheres of solar system planets, and to explore the composition, structure, and history of formation of the atmospheres of extrasolar planets. NCAR and its university collaborators are well positioned to pursue these scientific issues. Observational and modeling studies associated with the Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) satellite mission will provide the basis for significant advances in understanding upper-atmospheric thermal tides, planetary tides, and fundamentals of nightglow emissions. NCAR scientists have been heavily involved in the discovery of extrasolar planets using both radial velocity and transit photometry techniques. These studies will be expanded by observations from ground-based facilities and by connections with new space-based instruments such as NASA's recently selected Kepler mission. The aeronomy community associated with NCAR also has considerable experience with adapting general circulation models to the atmospheres of the Earth, Mars, Venus, and Jupiter—and understands many of the issues that must be confronted when adapting models to new regimes of composition, surface gravity, solar irradiation, and rotation.

5.1.5 The Water Cycle across Scales

The Earth's hydrologic cycle has an enormous impact on human activity and on economic prosperity, especially through precipitation. However, understanding the complex interactions among the various processes that drive the hydrologic cycle remains a major scientific challenge. Part of this uncertainty is due to poor measurements of the distribution of water vapor in the atmosphere and inadequate information on the accompanying sources and sinks. Basic issues stem from the chaotic, nonlinear properties of fluid motion, especially during transitions among the three phases of water.

While the hydrologic cycle is a product of multiscale interactions among cloud microphysics, radiation, convection, and boundary layer and surface hydrology, none of these processes is dominant. All of these processes involve a subgrid-scale component. Thus, the dynamical interactions embodied in the attendant parameterizations are not well understood and are poorly represented in large-scale models. The fact that weather prediction models, even the most advanced ones, have great difficulty in estimating precipitation underscores this point. The absence of precipitation can be just as important as its presence, and extremes in either can have major consequences for society and the environment.

A first phase of this research initiative seeks to understand how water vapor, precipitation, and land-surface hydrology interact across scales to define the hydrological cycle up to the continental scale, and thus improve large-scale prediction models. This goal is consistent with the Global Energy and Water Cycle Experiment (GEWEX), which aims to improve regional and global models of the hydrologic cycle. A key area of research will be to better understand and measure how the components of the water cycle work together as a coupled system. The overall objective here is to define activities that bridge the gap between studies of small- and large-scale processes and address how small-scale processes should be parameterized in large-scale models. The project focus is broadly on multiscale water-cycle processes and their parameterization. Proposed research activities are built around four tasks: diagnostic analysis of precipitation on a continental scale; cloud-system simulation; water vapor, convective initiation and triggering; and land-surface hydrologic processes.

A second phase in the Water Cycle Initiative will be the utilization of atmospheric parameters derived from space-based Global Positioning System observations. This research builds on the remarkable success of the GPS/MET pathfinder satellite experiment, which demonstrated the potential for deriving unique global observational data related to water vapor and temperature from the refraction of GPS signals transiting the atmospheric column. In the coming decade, UCAR will provide scientific leadership in the design, implementation, and operation of a constellation of GPS satellites called COSMIC (Constellation Observing System Meteorology, Ionosphere, and Climate). This international experiment will provide a unique set of global observations related to atmospheric water vapor and temperature that has the potential to dramatically improve weather forecasting and analysis. NCAR scientists will be engaged in all aspects of data assimilation and model enhancement and evaluation, and will assess the societal value of the enhanced observational and forecasting capabilities resulting from the COSMIC observations.

5.1.6 Advancing Weather and Climate Research and Prediction

Fundamental research in mesoscale and microscale meteorology is focused on making major progress on improving forecasts of precipitation and improving next-generation models of weather and climate. For prediction of precipitating weather systems, the main goal is to advance the understanding and prediction of significant precipitation events in order to substantially reduce forecast errors to the limits of predictability. NCAR and its university collaborators will put special emphasis on the development of a high-resolution forecast model—the Weather Research and Forecasting (WRF) model—and on data assimilation systems needed to initialize both weather and climate models. A new initiative on generalization of the WRF software framework will allow the model to be run efficiently across a variety of platforms. This effort is especially important to making WRF available to the university community as a successor to the widely used Penn State/NCAR mesoscale model (MM5). Information on the WRF project can be found at http://wrf-model.org.

An integrated initiative focused on the atmospheric and near-surface water cycle across scales in continental North America during the warm season will address several challenging problems by (1) aiming to improve the prediction of convective precipitation in the 1- to 12-hour interval, where a critical gap exists between observations and the skill of models; and (2) providing a comprehensive and interdisciplinary approach to improving the treatment of the water cycle in models across scales, from cloud-resolving to global. A suite of field campaigns is in progress or being planned that will characterize and quantify the fundamental cloud and surface processes related to heat, water, and momentum fluxes and transformations.

The development of the CCSM is the centerpiece of a collaborative process involving NCAR, university scientists, and staff at national laboratories. The CCSM is aimed at understanding and predicting the climate system. Complementary efforts using simplified models are also necessary for focused studies of crucial processes like the role of aerosols in the energy balance of the climate system. A CCSM-2 is imminent that will produce improved simulations of the mean climate and climate variability and will have reduced deep-ocean drifts. The CCSM-2 will be used to perform an extended, multicentury simulation of the recent-past equilibrium climate. CCSM-2 will be an important resource for future assessments of national and global impacts of climate variability and change.

The next quantum step in global modeling will be the development of an Earth System Model that incorporates a comprehensive suite of interactive feedback processes that modulate variability in the behavior of the Earth system. This effort addresses Earth system science's loftiest goal—a fully integrated, long-term prediction capability. NCAR and its university partners are now taking first steps toward this important goal.

5.1.7 Fundamental Issues in Geophysical Turbulence

There are four areas where the NCAR Geophysical Turbulence Program (GTP) will join with worldwide efforts to advance fundamental theory and methods: (1) reactive interactions that influence atmospheric chemistry, aerosols, and cloud physics; (2) anisotropic turbulence at interfaces; (3) quasi-geostrophic turbulence (QG); and (4) turbulence associated with magnetic fields. GTP treats the disciplinary boundaries between turbulence and fluid dynamics as porous and reaches well beyond what might be characterized as classical turbulence studies. New fast-response, high-resolution lidar and radar measurements of turbulent structures taken by NCAR scientists and their university collaborators provide a rich opportunity for comparing theory and observations. Advances in computational capabilities allow for significant sophistication in the modeling and visualization of turbulent phenomena.

Research on the role of turbulence in reactive interactions will be applied to improve the characterization of cloud turbulence in chemistry-droplet reactions, growth and interactions of cloud particles, and turbulent transport of heat by convection in the outermost layers of the Sun. For example, anisotropic flows are ubiquitous on the Sun due to the presence of rotation, stratification, or a mean magnetic field. GTP scientists will investigate departures from isotropy through studies of helical flows and the bi-dimensionalization of flows, such as in the domain of weak magnetohydrodynamic turbulence. Research on QG will relate to the sources and sinks of QG turbulence and the implications for the subgrid-scale parameterization of dynamics and transport in the large scales. Compressible magnetoconvection and the dynamics of flux tubes, plumes, and sunspots, coronal mass ejections, and heating of the solar corona are areas reliant on fundamental advances in the study of turbulence and magnetic fields.

5.2 Integrating Models

The unique challenge of the geosciences is to address—as a whole—the many interlocking processes in the atmosphere, oceans, land surfaces, ice sheets, and biota that together determine the behavior of the planet. This holistic set of processes requires an Earth systems approach to global and even regional and local problems, combining many specialties in a way that is not required in other scientific pursuits.

5.2.1 A First-Generation Earth System Model

NCAR has made a long-term commitment to develop the first generation of an Earth System Model (ESM). Such efforts will require the integration of current capabilities, such as the Community Climate System Model (CCSM), the Weather Research and Forecast model (WRF), and models of the biosphere and ecosystem. This grand challenge will tax our computational and observational facilities and will involve extensive teaming with university and other colleagues.

5.2.2 A Whole Atmosphere Community Climate Model

An important new initiative that will contribute to major improvements in modeling and prediction of planetary dynamics and metabolism is the development of a Whole Atmosphere Community Climate Model. WACCM will allow study of the atmosphere from the surface to 140 km and eventually to 500 km. WACCM will be developed to easily plug into the CCSM coupler and serve as an alternative atmosphere module in CCSM-2. Ultimately it could serve as a major component of the ESM.

5.2.3 Weather Research and Forecasting Model

The WRF model is a next-generation mesoscale forecast model and assimilation system that will advance both the understanding and prediction of important mesoscale precipitation systems. WRF is expected to set a new standard for the integration of research and operational forecast models and to promote closer ties between the research and operational forecasting communities.

The model will be a multiagency effort with significant community input through development teams and working groups. It will incorporate advanced numerics and data assimilation techniques, a multiple relocatable nesting capability, and improved physics, particularly for treatment of convection and mesoscale precipitation. It will also incorporate a new software framework that provides a modular, flexible, single-source code for use across diverse computing architectures. It is intended for a wide range of applications, from idealized research to operational forecasting, with priority emphasis on horizontal grids of 1 to 10 km.

5.3 Advancing Tools and Methods

5.3.1 Data Assimilation Initiative

While NCAR's program has always combined the three thrusts of theory, observation, and modeling, these components are increasingly becoming unified in a way that was never possible before. It is clear, for example, that numerical prediction codes can be greatly improved through sophisticated data assimilation techniques. Also, community models and their key parameterizations require extensive validation through iterative comparison with new and archival data sets. Similarly, observing campaigns (for example, the recent ACE-Asia campaign) can be greatly enhanced through the use of preparatory scenario modeling and advanced visualization techniques. However, practical impediments exist to the seamless application of such techniques, including file format inhomogeneities, data access barriers, and computer time limitations (e.g., to enable full 4-D variational data assimilation). NCAR must work to provide the infrastructure and expertise to enable effective integrations of theory, modeling, and data.

Improved data assimilation systems will be crucial to the incorporation of data from new observing systems, optimal analysis of observations, understanding of the observational requirements for accurate forecasts, and design of optimal strategies for obtaining targeted observations. NCAR is committed to supporting the development of a community data assimilation system together with a suite of supporting components, including observational operators, minimization software, and background and observational error covariances. The focus of this initiative will be fundamental advances in data assimilation that will support new methods for WRF, CCSM, ESM, and other agency and community forecasting and prediction efforts. Specifically, this initiative will provide improved quantitative understanding through the added value of assimilating data into weather and climate models from new observing tools like Doppler radars, GPS systems operating in space and on the ground, and many other in situ and space-based systems.

5.3.2 Remote Sensing Initiative

During the next decade, new spaceborne Earth observing systems will provide a revolutionary and comprehensive description of the Earth system. In fact, almost every aspect of the Earth system accessible to modern observational science will be monitored in some fashion. For example, satellite systems will monitor the distribution of atmospheric pollutants and will observe the planetary-scale carbon and water cycles in substantial detail. NASA is planning a suite of satellites in the Living with a Star program that will provide extensive measurements of the upper atmosphere, magnetosphere, and solar environment. There will be a veritable explosion of data on the Earth system and the Sun-Earth relationship. The new data will provide both an opportunity and a challenge for NCAR.

It is essential that NCAR position itself to be able to fully interpret such data sets and help provide the improved quantitative understanding of the basic processes responsible for controlling the Earth system. In order to be able to fully respond to this opportunity, NCAR needs to build upon its current base of expertise in remote sensing as well as its capabilities in data handling. We do not need to start from scratch. NCAR and UCAR have participated in important ways in satellite observations through such programs as the High-Resolution Dynamics Limb Sounder (HIRDLS), Measurements of Pollution in the Troposphere (MOPITT), GPS/MET, TIMED, Solar-B, and the planned COSMIC missions. We need, however, to further develop our experimental remote-sensing capabilities in order to provide broadly based in-house expertise. NCAR will need to develop and validate new inversion schemes and data assimilation techniques, and to understand instrument limitations. This understanding can only be gained through experience and direct participation in engineering efforts. As with all other aspects of the strategic plan, NCAR's role in remote-sensing research will be one of partnership with the university community.

5.3.3 A Geographic Information Systems Initiative

The integration of our scientific models and data products across disciplinary boundaries will be facilitated by our ability to speak the same language as other important communities. In many areas of the social sciences, including aspects of urban planning, demographic studies, and natural resource management, as well as for many educational purposes, Geographic Information Systems (GIS) have become a lingua franca. GIS tools are designed to enable detailed spatial analysis of multivariate information coded by two- or even three-dimensional location. GIS tools have broad acceptance in many disciplines. NCAR will need to develop capabilities to be fully interoperable with data sets and model products based on GIS techniques.

Our approach will be to first develop a modest in-house capability to translate from traditional atmospheric science data formats and manipulation tools to those available in the GIS community. This will involve the development of a small technical center for GIS at NCAR. In a subsequent step, we will fully integrate GIS capabilities into our Knowledge Environment for the Geosciences (see Section 5.5.1).

5.4 Proposed Community Facilities

The core facility plans discussed in Section 4.3 are either already under way or largely incremental in nature. We also need to develop community-owned and -operated facilities that are more revolutionary and provide infrastructure for next-generation capabilities. Our ambitions in this regard focus on two areas: supercomputing for the Earth System Model era and an atmosphere observing system.

5.4.1 Supercomputing for the Earth System Model Era

The demands of the CCSM- and WRF-class models for access to supercomputing cycles are already outstripping available resources, even taking into account the NSF centers in the Partnerships for Advanced Computational Infrastructure and Terascale programs. It is a straightforward calculation to demonstrate that dedicated terascale (and soon even petascale) computing, delivering trillions and soon thousands of trillions of calculations per second, is needed for today's large-scope geoscience models. These national climate assessment requirements point to the application of models that: (1) couple land use, land cover, sea ice, surface hydrology, atmospheric and ocean circulation, (2) provide the needed temporal and spatial resolution for regional decision support and for predicting severe weather impacts, (3) can be run efficiently and quickly (in terms of wall clock time) for validation and development purposes, and (4) can be run in ensemble batches for probabilistic work. Such specifications naturally lead to terascale computational requirements.

If we are already demonstrably in need of dedicated terascale resources, the next generation of models, in the Earth System Model era, will require even more computational capability. Our assessment is that we are currently not on a path that will provide the needed infrastructure for geoscience modeling in the next decade. This assessment is in accord with recent National Science Board and National Academy reports.

NCAR must play a role in providing the leadership needed to resolve this critical impediment to progress. Accordingly, we will propose a "Geoscience Computing Initiative for the ESM Era" to NSF and other agencies, working in collaboration with other leading institutions here and abroad. This initiative will quantify the computing requirements and develop the strategic road maps to provide the needed computational capability for the future. One explicit objective will be to raise the profile of supercomputing needs for the geosciences within the national information technology agenda.

We believe that a greatly augmented NCAR supercomputing capability, coupled with a "virtual machine room" approach involving other supercomputing centers and strong partnerships with industry, will lead us toward the needed petascale computing environment.

5.4.2 An Atmosphere Observing System

We believe that now is the time to prepare a more integrated and comprehensive next-generation observing system for the atmosphere, involving networks of ground-based systems coupled with extensive modern information technology. Such an Atmosphere Observing System (AOS) could be an integrated research effort of international scope designed as a distributed, multipurpose instrument array, each element of which would be identical and would have the ability to characterize the physical and chemical

state of the entire vertical atmospheric column from 0 to 300 km. Parameters to be monitored would include winds, waves, tides, temperatures, pollutants, aerosols, and constituent densities such as ozone, nitrogen oxides, odd nitrogen, carbon, water, nitrogen fluxes, and sensible heat fluxes. Our preliminary vision is of an AOS array that could be deployed at approximately 50 to 100 sites around the world as a partnership among NSF, other U.S. agencies, U.S. universities, and governments and research institutions internationally. The ground-based array would be complemented by approximately five GPS-equipped transportable (trailer-based) atmospheric sounding laboratories, able to map the detailed atmospheric fingerprint of, for example, carbon fluxes within an urban area. The architecture of the AOS would be tailored to provide for near-real-time operation and include a GCM-based data assimilation package and extensive educational products for public use.

5.5 Applying the Benefits of the Information Technology Revolution across Research and Education

Integrating the information revolution into research poses unprecedented challenges and opportunities for NCAR. As a national center with a long history of bringing supercomputing capabilities to the atmospheric and geosciences, we have unparalleled experience in networking, visualization, data archiving and curation, and high-performance computing across a large range of platforms and architectures.

In the words of the director of NSF's Computer and Information Sciences Directorate, we now must "define what the digital revolution means for the geosciences." To that end, we have developed a multifaceted agenda to build an IT-enriched environment for the geosciences community. During 2000 and early 2001, under SCD leadership, NCAR produced a nested set of proposals that together define NCAR's strategy for using the IT revolution in service of our atmospheric sciences community.

5.5.1 A Knowledge Environment for the Geosciences

NCAR will lead a team involving many universities to build a "Knowledge Environment for the Geosciences" (NCAR-KEG). The KEG will combine and coordinate attributes from high-performance computing, networking, data mining, visualization, collaboration tools, and collaboratory technologies.

The KEG will not only facilitate leading-edge geoscience research but will also be a platform for fundamental IT breakthroughs, advancing methodologies and tools for large-scale collaborative research, knowledge evolution, and distributed information environments. It will organize research products into a searchable, shared, group resource and thus become a knowledge-based problem-solving environment for the geosciences.

The initial design for the KEG has been worked out in collaboration with ten research-university partners and involves three interacting layers: a knowledge portal, a knowledge framework, and a sources and repository layer.

The repository layer will comprise observational data, a linked hierarchy of Earth system models, results from model experiments, and other sources of information. The knowledge portal will provide user access to the KEG by means ranging from an individual browser to distributed and collaborative group interaction software systems. The complement of tools in the portal will range from conventional packages for data analysis and software development to innovative systems for collaboration among physically separated groups and access to massive distributed databases. Finally, the knowledge framework is a set of layered services that support activities and elements in the repository. The framework is the middleware to support large-scale distributed and collaborative research activities, such as knowledge encapsulation, discovery, recording, and sharing. Each element in the architecture is designed to be highly distributed and scalable. The system will enable scientists, students, and members of the public to access and manipulate data of all types, in order to create, share, explore, and discover new knowledge relating to the geosciences.

5.5.2 Enhanced Capabilities for Data Management and Sharing

NCAR will tackle the enormous growth in observational and modeling data products through several initiatives that address systematic aspects of data management and make data readily available to the university community and other interested parties. This initiative will consist of innovative database management designs customized for highly interdisciplinary and integrated data sets. The development of a world-class presence on the Internet for accessing both data and information will be central to the design of a new NCAR portal.

5.5.3 A Common Modeling Infrastructure for Earth System Science

NCAR is leading a highly experienced, multi-institutional team to build and maintain an Earth System Model Framework designed to provide a common infrastructure for geoscience models. This initiative represents a major step toward full implementation of our strategic plan for end-to-end high-performance simulation (http://www.ncar.ucar.edu/Director/plan.pdf). In collaboration with major modeling centers at NOAA, NASA, and DOE and with several universities, this NCAR-led initiative involves the extensive use of software engineering precepts to develop software utilities, benchmarks, libraries, and frameworks for generic use across the full spectrum of geoscientific modeling. The work will enable vastly improved interoperability, parallelization, and portability across and within geoscience-based models, enabling more efficient substitution of university-developed physical parameterization schemes within large community models. This work will be done in partnership with many of the institutions and agencies involved in climate, weather, and space weather modeling.

5.5.4 A World-Class Web Presence for NCAR

NCAR is committed to a greatly improved Web interface (as part of our move to become more of a virtual center). NCAR will work closely with other programs within UCAR (the Digital Library for Earth System Education, Unidata, the Cooperative Program for Operational Meteorology, Education and Training, and the UCAR Office of Education and Outreach) and with the university community to accomplish this effort. Our world-class Web system, involving both portal and collaboratory technologies, will be designed to bring NCAR's data, models, and other resources to the scientific community and to the public in new and exciting ways.

A pilot effort has been undertaken, called the Community Data Portal (http://www.ncar.ucar.edu/stratplan/communitydata.html). This project has already demonstrated how NCAR's data holdings can be made available to external users with flexible, interactive graphical user interfaces. Our strategy will also make use of UCAR's *Windows to the Universe* Web site (http://www.windows.ucar.edu), which now reaches more than four million users annually. *Windows to the Universe* will be extended to incorporate more of NCAR's Earth systems science content, enabling improved outreach to the public and to the K–12 educational community.

Our Web strategy acknowledges that our contact with the external world is increasingly virtual. Our electronic presence must reflect the excitement and depth of our science as well as our core institutional values. We will provide and maintain a world-class Web interface both for scientific research and for education and outreach.

5.6 Integrating Research and Education

Together, NCAR and its sister activities in the UCAR Office of Programs can enrich formal and informal education for all ages by bringing the unique opportunities and expertise of a national research center to the service of students and educators. NCAR has a major role to play in augmenting national capabilities in inquiry-based teaching and learning.

We consider the effective use of our scientific, computational, and observational facilities to serve education and outreach a core component of NCAR's mission, not merely a peripheral or volunteer effort. NCAR embraces the new UCAR Strategic Plan for Education and Outreach and will work toward its full implementation. Our personnel policies must also reflect this commitment to education and outreach.

5.7 Criteria for Selection of New Initiatives

The new initiatives listed in this document are not all at the same state of readiness, and a series of decisions will be needed to determine which are ready and deserving of support. Also, there are obviously missing, but important, scientific areas that were not fully developed during the recent initiative process but will be defined in the future. The following seven criteria will be used to determine which scientific initiatives receive funding and at what level.

- *Scientific Excellence:* This criterion for basic scientific merit must be met for a positive decision on funding and is identical in intent to NSF Merit Review Criterion #1.

- *Broader Impacts of the Initiative:* Projects that have a demonstrably broad impact beyond a specific, narrow disciplinary topic will be favored. For example, a significant impact on the geosciences, on allied research fields (e.g., mathematics, computer sciences), on society, or on the private sector would be favorably considered. This criterion is identical in intent to NSF Merit Review Criterion #2.

- *Uniqueness:* Projects for which NCAR has unique strengths and capabilities will be favored.

- *Appropriateness:* Projects must fit NCAR's mission and objectives. For example, all selected projects must serve the university community well.

- *Staff Commitment:* Initiatives that have strong support from NCAR's scientific staff will be favored.

- *Timeliness:* Initiatives that are timely or urgent will be favored.

- *Opportunity:* The new initiatives are intended to be path-breaking and nonincremental in nature. Initiatives that provide—or are responsive to—particular opportunities will be favored.

Table 4 summarizes the organization of the initiatives according to their broad themes.

Table 4: Summary of Research Initiatives by Theme

Integrating Interdisciplinary Scientific Initiatives	*Investigating Chemistry-Climate Connections*	*A Biogeosciences Initiative*	*Advancing the Science of Weather and Climate Impact Assessment*	*Understanding Sun-Earth Connections and Planetary Atmospheres*	*The Water Cycle across Scales*	*Advancing Weather and Climate Research and Prediction*	*Fundamental Issues in Geo-Turbulence*
Integrating Models	*A First-Generation Earth System Model*	*A Whole Atmosphere Community Climate Model*	*Weather Research and Forecasting Model*				
Advancing Tools and Methods	*Data Assimilation Initiative*	*Remote Sensing Initiative*	*Geographic Information Systems Initiative*				
Proposed Community Facilities	*Super-computing for the ESM Era*	*An Atmosphere Observing System*					
Applying the Benefits of the IT Revolution across Research and Education	*A Knowledge Environment for the Geosciences*	*Enhanced Capabilities for Data Management and Sharing*	*A Common Modeling Infrastructure for Earth System Science*	*A World-Class Web Presence for NCAR*			
Integrating Research and Education	*Undergraduate Leadership Program*	*Professional Development Workshops for Educators*	*Enhanced Public Exhibits*	*Education and Outreach at NCAR on line*			
Enhancing University Interactions	*Professional Development for Early-Career Faculty*	*Bi-Directional Sabbaticals*	*Graduate Student Initiative*	*Undergraduate Leadership Workshop*			

6.0 Implementation: Next Steps

The strategic agenda outlined above is an ambitious one, reflecting both the importance of the scientific challenges and the significance of NCAR as a large and well-endowed institution, which simultaneously serves and leads the university community. Our implementation plan (outlined briefly here) will recognize the scope of the challenge and must proceed in a realistic fashion.

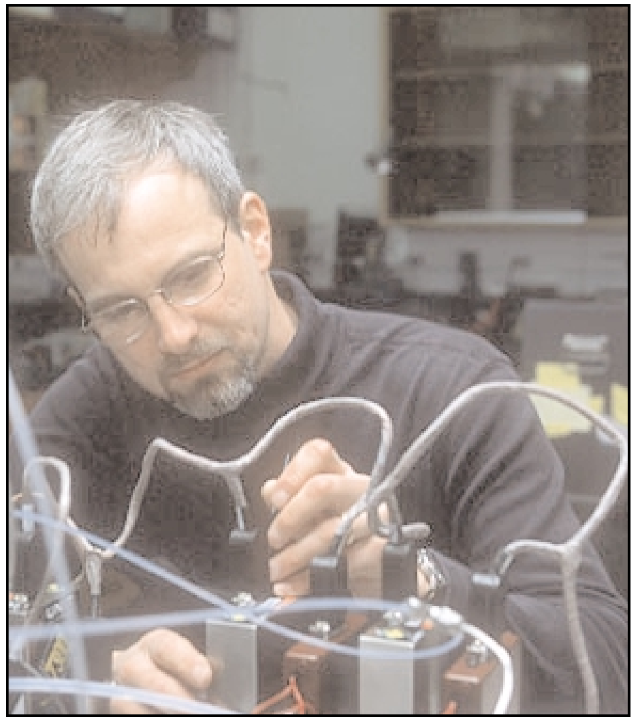
There are several pitfalls to avoid. We cannot spread ourselves too thin by taking on each and every challenge. We must also plan for success, avoiding underinvestment in high-priority areas—a clear recipe for failure. We must preserve flexibility in planning and implementation and recognize that strategic planning must be continuously re-evaluated in the light of a changing environment.

6.1 Core Program Needs

A healthy, broad, and balanced core program is a necessary condition for successful implementation of this strategy. For the same reasons that we support a doubling of the NSF budget, we believe that funding of the core program at NCAR must grow to accommodate the requirements of our strategic plan without distorting our program and while enhancing interactions with and support of our university constituency. NCAR therefore rededicates itself to the highest possible standards of excellence in basic research in the atmospheric and related sciences and explicitly recognizes the need to preserve and augment core scientific capabilities.

6.2 Mentoring and Professional Development

Consistent with the institutional values described above, our approach to implementation recognizes that *people are our most important resource*. NCAR will foster professional development for all staff on a sustained basis. To this end, we have already instituted a number of professional development and mentoring programs in conjunction with UCAR, and are working on more such programs.



We have initiated formal reviews of the status and function of various professional tracks and are also reviewing leave and remuneration policies to determine what steps may be needed to improve our corporate personnel policies.

We recognize that effective internal communication is tremendously important for staff morale and efficiency. Various communication mechanisms will be used to ensure that all NCAR staff stay both informed and involved in institutional debates. These mechanisms include the NCAR Scientist Assembly, the Early-Career Scientist Forum, regular town meetings held by the NCAR director and UCAR president, regular "all-hands" divisional meetings with the NCAR director, newsletters, etc.

We are committed to a supportive and nurturing workplace environment designed to sustain and augment NCAR's reputation for excellence.

6.3 Scientist Hiring Strategy

One of the consequences of a decade of subinflationary funding and a fairly low professional staff turnover has been a skewing of the demographic curve in favor of the senior ranks. For the ladder scientist track, for example, there were 30 Scientists I (entry level) in 1993 and only 9 in 2000. The number of senior scientists increased from 41 to 55 over the same period.

We believe that a forward-looking personnel strategy must include a conscious effort to ensure sustained demographic balance and diversity at NCAR. As a consequence, we have initiated a multiyear program of hiring early-career scientists. In the fall of 2001, ten new Scientists I were appointed, after a rigorous international search coordinated through the Advanced Study Program. We expect to recruit approximately four new Scientists I each year until the demographic balance is restored.

The Scientist I hiring program is being conducted in a manner that guarantees that the most highly qualified and creative young individuals are recruited. The program has the explicit goal of increasing the diversity of both people and ideas at the center and has already shown signs of success in this regard. This hiring program is being complemented by a formal review of the Project Scientist and Associate Scientist tracks at NCAR. Recommendations from this review will become available in late 2001.

The NCAR Appointments Review Group examines nominations annually for Scientist III and Senior Scientist appointments. The criteria for these reviews will be explicitly modified to reflect the goals and objectives of this strategic plan, without lowering the highest possible standards for scientific accomplishment that have stood NCAR in good stead for many years.

6.4 Capital and Facility Infrastructure

This strategic plan has implications for capital and facility infrastructure at NCAR. A new building for UCAR will eliminate the need for leased space within the corporation and will allow an ultramodern suite of experimental laboratories to be designed and built in support of the objectives of this plan. We anticipate that the new building will also relieve congestion at the Mesa Laboratory.

Additional capital equipment and instrumentation will also be needed. The implementation plan will call for new instrument development and deployment, and for large facilities, such as supercomputers, radars, lidars, telescopes, and aircraft.

6.5 Opportunity Funds

As mentioned above, *flexibility* will be a critically important attribute of our approach to implementation. In order to achieve this, after a decade of subinflationary growth at NCAR, we must allocate a greater portion of core funds (ideally from future increases) to an opportunity fund at the institutional level. A larger opportunity fund will also provide both flexibility and seed funding for new ventures.

6.6 Continuity of Strategic Planning

This strategic plan is not an end point but the beginning of a process that will *continuously reevaluate* NCAR's programs in a strategic light. This constant reevaluation will best position NCAR to lead and support the university community and inform the national research agenda.

The grassroots approach to the development of strategic scientific initiatives is a vital one that empowers NCAR scientists to envision a future and develop a common plan for how to get there. We must continue this process of institutional reflection and reexamination.

Several mechanisms will allow the momentum of this strategic planning effort to continue. One of these is the ASP-sponsored summer colloquium mentioned above. Another is the series of Director's Roundtables—which will be intensive internal workshops on emergent areas. We will continue to use the Web to communicate future plans and position papers that speak to what NCAR's intellectual agenda should be—or should become.

6.7 NCAR within UCAR

NCAR is a major part of the UCAR family of programs. The collaborative relationships among the NCAR divisions and programs in UOP are already very close and productive. However, there are a multitude of opportunities in those interfaces that need to be fully explored as we move forward in the context of this strategic plan. NCAR is committed to intensive internal discussions within UCAR to optimize communication and collaboration.

6.8 Closing Comments

This strategic plan represents a clear statement of intent for NCAR to assume critical new responsibilities to further fundamental understanding of the Earth system. The unprecedented environmental changes we face pose daunting scientific challenges. But the rewards will also be of unprecedented scope—not only in terms of the sustainability of our planet's resource base but also of the health, safety, and economic and military security of our citizenry.

Much work remains to be done to develop aggressive yet realistic and flexible implementation. This detailed implementation planning work will be conducted in partnership with NSF via the annual program planning process.

The future is indeed challenging but, as we have tried to emphasize in this document, we believe that NCAR is supremely qualified to take on these important scientific challenges by virtue of its heritage and its long-standing mission of service to the university community.

We also believe that the unique relationship among NCAR, UCAR, the university community, and NSF, along with the other mission agencies, provides us with a successful, "battle-hardened" model of management that will enable the planning to be carried forward in harmony with NSF strategic objectives and those of our university partners.

UCAR is a university-governed and university-serving organization, with NCAR as its major engine of basic and applied research. Our strategic plan is not just NCAR's and UCAR's but really belongs to the university community and is therefore intended to be an expression of the broad community's aspirations. We invite full participation, review, comment, criticism, and suggestions from our university colleagues. Our strategic planning Web site (http://www.ncar.ucar.edu/stratplan) is designed to collate all such inputs.

In conclusion, we are truly excited by these strategic goals and stand ready to work towards their accomplishment in full partnership with NSF, the university community, and our other sponsors and friends.

7.0 Appendices

7.1 Strategy Documents

A. National

NSF GPRA Strategic Plan, 2001–2006

NSF Geosciences Strategic Plan, 2000: *NSF Geosciences beyond 2000: Understanding and Predicting Earth's Environment and Habitability*

National Research Council, 2001: *Astronomy and Astrophysics in the New Millenium*

National Research Council, 2000: *Environmental Science and Engineering for the 21st Century*

National Research Council, 1999: *Our Common Journey: A Transition toward Sustainability*

National Research Council, 1999: *Global Environmental Change: Research Pathways for the Next Decade*

Board on Atmospheric Sciences and Climate, 1998: *The Atmospheric Sciences Entering the Twenty-first Century*

NSF Strategic Plan, 1995: *NSF in a Changing World*

B. Institutional

University Corporation for Atmospheric Research, 2001: *Education and Outreach Strategic Plan*

National Center for Atmospheric Research, 2000: *Strategic Plan for High Performance Simulation: Towards a Robust, Agile, and Comprehensive Information Infrastructure for the Geosciences*

University Corporation for Atmospheric Research, 1997: *NCAR and UCAR at the Millennium, NSF Cooperative Agreement Proposal for 1998–2003*

University Corporation for Atmospheric Research, 1996: *UCAR 2001: A Mid-Course Assessment*

University Corporation for Atmospheric Research, 1992: *UCAR 2001, a Strategic Outlook*

7.2 Education and Outreach Strategic Plan

We consider the recent *UCAR Education and Outreach Strategic Plan: Serving UCAR, NCAR, and UOP* to be an integral component of the NCAR strategic plan. The major goals of the education and outreach plan are to:

- create the institutional infrastructure and funding portfolio that will allow UCAR to have an effective education and outreach program;
- develop, deliver, and promote education resources for students and professionals to enhance scientific literacy;
- develop and support inspiring programs about the atmospheric and related sciences that allow citizens to make educated decisions; and
- promote the involvement of diverse and historically underrepresented populations in the geosciences.

NCAR commits itself to the implementation of the objectives of the education and outreach strategic plan and recognizes that resources will be needed (space, facilities, funds, personnel) to carry forward this ambitious new program. NCAR will work to establish a culture that encourages, supports, and recognizes effective work carried out by NCAR staff in the area of education and outreach.

The full plan can be accessed at http://www.ucar.edu/educ_outreach/stratplan.html.

7.3 High-Performance Simulation Strategic Plan

We consider our recently developed *Strategic Plan for High Performance Simulation: Towards a Robust, Agile, and Comprehensive Information Infrastructure for the Geosciences* to be an integral component of this plan. The six themes of the HPS plan are

- provision of high-performance computing capability;
- use of modern software engineering practices;
- development of advanced data services, tools, acquisition, and display;
- acknowledgement of management challenges for multidisciplinary teams;
- augmentation of the role of computer science at NCAR; and
- collaboration with geographically dispersed teams.

Implementation of the high performance simulation plan is a high priority for NCAR as reflected in the discussion in Section 5.5, above.

The full plan can be accessed at http://www.ncar.ucar.edu/Director/plan.pdf.