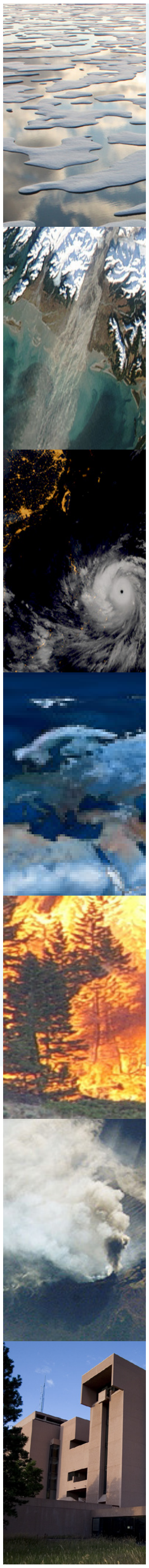
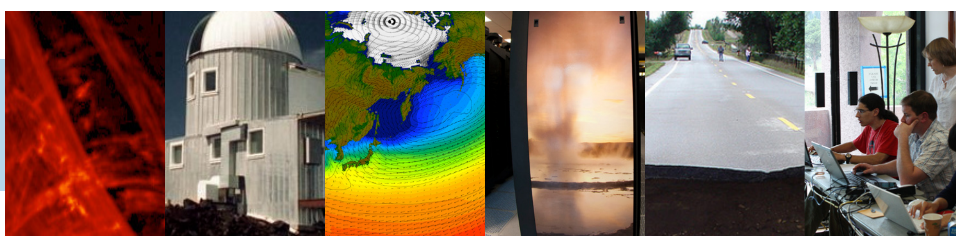


National Center for Atmospheric Research

2014 - 2019 Strategic Plan



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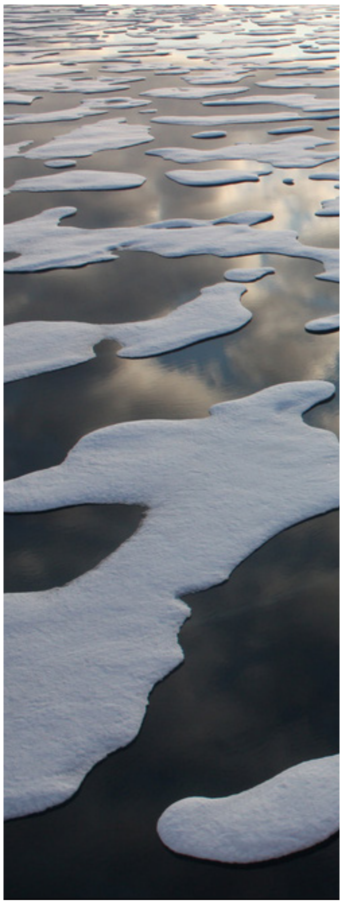


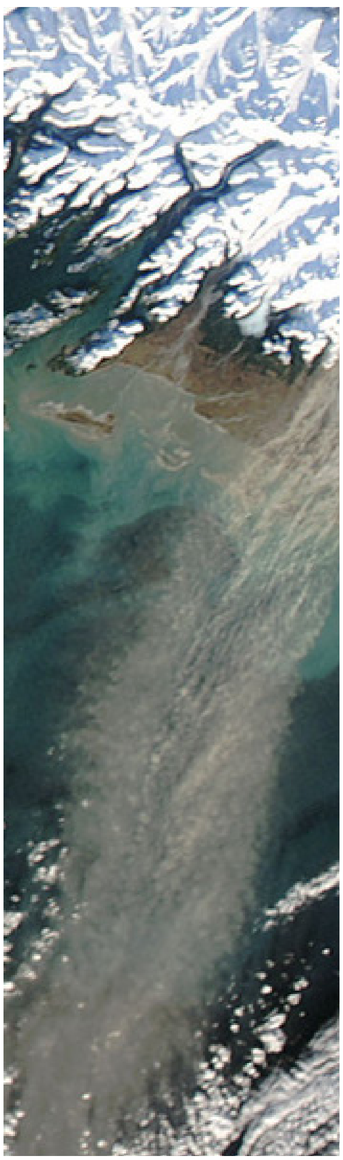
Contents

Introduction

The National Center for Atmospheric Research (NCAR) is a national institution and resource dedicated to the study of the atmosphere, the Earth system, and the Sun. Our primary responsibility is to the broad goals and objectives of our sponsor, the U.S. National Science Foundation (NSF 2014). As an NSF Federally Funded Research and Development Center (FFRDC), we share NSF's overarching goals of helping the United States 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.

The NCAR Vision

A world-class research center leading, promoting and facilitating innovation in the atmospheric and related Earth and Sun systems sciences



This strategic plan will steer NCAR's direction over the next five years. It outlines the execution of an innovative, compelling and ambitious research program, the aggressive pursuit of which will require the sustained, long-term commitments appropriate for a national center. In support of the broader community, the plan also emphasizes leadership in the development and operation of observational, computational and modeling facilities. Our people – world-class scientists, engineers, technicians, support staff, and administrators – will achieve the objectives of this plan by continuing to work in close, synergistic relationships with the academic community. This strategic plan will thus guide NCAR priorities, focus energy and resources, and ensure that employees and other stakeholders are working toward common goals consistent with the missions of NCAR and NSF.

The NCAR Mission

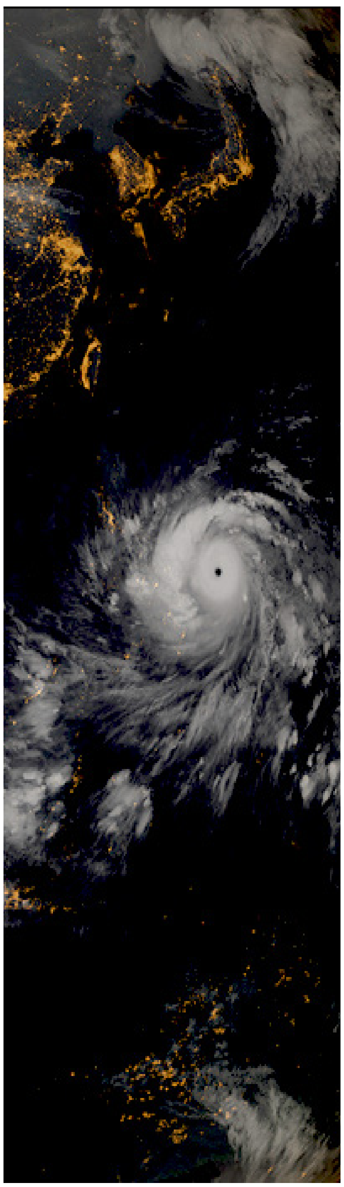
- To understand the behavior of the atmosphere and related Earth and geospace systems
- To support, enhance, and extend the capabilities of the university community and the broader scientific community, nationally and internationally
- To foster the transfer of knowledge and technology for the betterment of life on Earth

An eminent research program is necessary in order for NCAR to accomplish this mission. Moreover, only through superlative research can NCAR meet emergent scientific challenges and posses the agility to adapt to the changing needs of the community.

NCAR staff, members of the university and broader scientific community, and program officers of the NSF and other federal agencies contributed to the development of this plan. Wide involvement in NCAR planning is essential because of the collaborative nature of our work and because NCAR can only be fully successful through a close and ongoing engagement with a wide variety of partners.

The Role of NCAR

The atmospheric and related sciences are of critical importance to society, especially with rapidly changing environmental conditions and growing needs for relevant information and services. The hazards of long-term atmospheric and climate changes, air pollution episodes, sudden extreme weather, space storms, and secondary impacts such as drought, storm surges and wildfires take a significant toll in terms of human life and economic loss. During 1993-2013, the United States suffered 137 weather and climate disasters, with each costing more than $1 billion, adjusted to 2012 values (NatCatSERVICE 2013). Poor air quality is estimated to contribute to more than 3 million premature deaths per year worldwide. Global greenhouse gas emissions are increasing at an unprecedented rate, the Earth's atmosphere and oceans are warming, and the impacts of climate change on communities and ecosystems are becoming more extensive. Ice melt in the Arctic and Greenland is outpacing the forecasts of today's best models, and forecasts of the probabilities of changes in temperature, precipitation, and water availability are not yet at the fine spatial scale for effective use in regional adaptation and mitigation planning. Skill in predicting space weather is currently not yet adequate for safeguarding radio communications, satellite-based navigation systems, and the electrical power grid. Many important aspects of the interactions of societal change and environmental change remain poorly characterized.



Continued advancement in the atmospheric and related sciences, improvement in predictive capabilities, and more effective application of these advances to societal needs are more important than ever. NCAR has an exceptional record of leadership, scientific achievement and effective translation of scientific advances into useful knowledge for a nation that is highly impacted by atmospheric events that are sometimes catastrophic. Weather, space weather, air quality, and climate change research are historical strengths of NCAR, and must remain so over the next five years and beyond. NCAR plays an important role in bringing relevant and objective information to national and international decisions on mitigation, adaptation, resiliency and sustainability. NCAR must also continue to embrace a leadership role and actively engage with community leaders, research agencies, professional organizations, policy makers and others to convey significant research findings and emphasize the importance of investment in research and major facility development.

NCAR is recognized for its unique and innovative approaches to collaborative science and service to the broader scientific community. Joining colleagues at universities and laboratories from around the world, NCAR scientists have decoded the workings of the Sun, deciphered the processes that produce variations in weather and climate of significance to society, created comprehensive community models that reproduce and project the behavior of the atmosphere and other parts of the Earth system, built transformative observing instruments and platforms, and supported powerful computers, networks and systems to assimilate, archive and visualize data. Such ambitious and long-term projects can only be carried out at a vibrant national center with a global reach. In fact, NCAR is so unique that no other atmospheric research center in the world provides the range and quality of freely available facilities, tools and services to the broader research community than it does.

Yet, despite its ability to tap into vast university expertise, it is an imperative for NCAR to possess the broad range and depth of scientific expertise and world-class observational science and computational facilities required to mount an end-to-end attack on some of today's most significant environmental problems and interrelated sustainability and resilience issues. NCAR prides itself on sustaining research and facilities for the long haul, which is required to tackle difficult and important research challenges and develop solutions and highly valued services to the NSF community. Through its close ties to the university community, other national and international research centers and laboratories, federal and state agencies, businesses, and non-governmental organizations, NCAR will continue to serve as a crossroads for the exchange of ideas, think big and develop strategic partnerships in order to enhance synergies and bring the best minds to the table for large-scale, sustained and highly collaborative research efforts. Moreover, NCAR will continue to emphasize active engagement with the stakeholders and consumers of its science.

The Path Forward

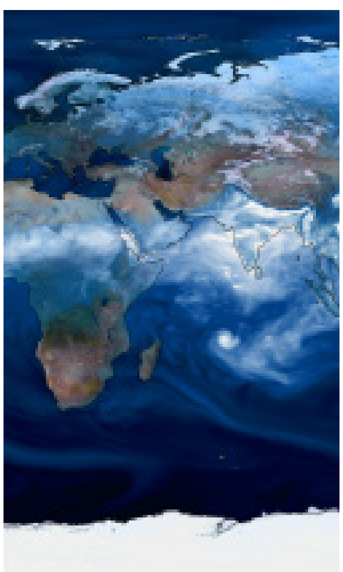
With exceptional assets in observational, computing and community model facilities, NCAR and its university and other research partners are extraordinarily well positioned to address the most-pressing problems in Sun-Earth system science. This strategic plan focuses on two grand challenges.

Grand Challenge 1

Improved understanding and prediction of atmospheric, chemical and space weather hazards and their impacts on ecosystems, people and society

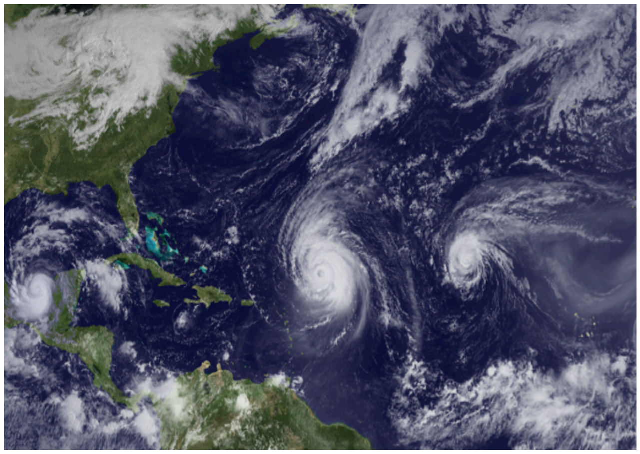
Grand Challenge 2

Improved understanding, prediction and projection of the consequences of natural and anthropogenic climate variability and change at regional and global scales



The former grand challenge includes determining the relevant processes responsible for hazards, investigating the global context of destructive weather and unhealthy air quality events, working with operational agencies to enhance observational data and models for space-weather forecasting, and strengthening partnerships with researchers in the applied sciences and health communities to determine the societal and ecosystem impacts of hazards. The latter grand challenge includes the impacts of climate change on the water cycle, water availability, weather extremes, and the health and functioning of marine and terrestrial ecosystems, the potential for abrupt changes in climate, and understanding the limits and options society has to respond to climate change. These challenges are not new, but they are being continually reshaped by the broadening realization of their societal significance.

At the heart of these challenges is our ability to observe and understand the complex Sun-Earth system, including forcing from human systems. This knowledge must be encapsulated in dynamical models that provide increasingly skillful capabilities for predictions of weather, climate, atmospheric chemistry, space weather, and associated impacts on socio-ecological systems. A potential tension exists, however, between different directions for progress in modeling. Specifically, should resources be allocated and research efforts be extended to increase model resolution, ensemble size, or model complexity? The answer to this question should be problem-driven. Predicting high-impact weather events, such as severe storms and tropical cyclones, will require significant increases in model resolution to capture important convective-scale forcing, as well as the assimilation of new data sources. Moreover, stakeholders are demanding estimates of the uncertainty in predictions, which require ensemble-forecasting techniques. On the other hand, climate applications with great societal relevance, such as climate change impacts on water resources and sea-level rise, require substantial progress to accurately represent the complex interactions of the earth system (e.g., ice-sheet dynamics and land-surface hydrology). Significant progress will be achieved through the advancement of the Weather Research and Forecasting (WRF) Model and the Community Earth System Model (CESM), the continued development and community support of which will remain a research and service priority for NCAR.



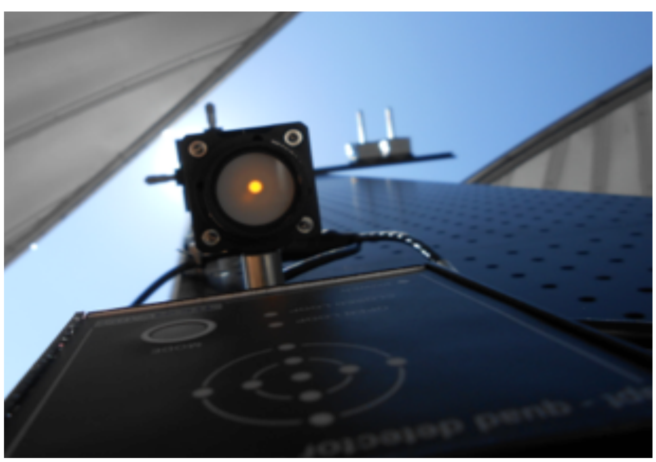
Global multi-scale simulation and prediction systems will provide the opportunity to address better important weather-climate interactions that occur across a wide range of scales. Using seamless variations in resolution, for instance, the local impact of global trends in climate can be assessed with less ambiguity, as well as the upscale influences of smaller scale processes, such as the role of tropical convection in regulating global circulations. Such multi-scale simulation capabilities will be of great benefit to, for example, tropical-cyclone forecasting, for which both global-scale steering influences as well as convective-scale distributions of latent heating are critical factors in controlling the cyclone track and intensity. The development of multi-scale simulation systems will also enhance the prediction and warning of hazardous weather systems by allowing observational information at all scales to be effectively synthesized by advanced data-assimilation systems.

Historically, regional weather prediction models and global climate models have evolved on separate paths of development. However, with increasing computing power and advancing modeling technology, weather models are moving toward global coverage, while enhanced resolution climate models are beginning to resolve mesoscale processes. This trend toward multi-scale simulation capabilities emphasizes that the traditional distinctions between "weather" and "climate" models are becoming increasingly blurred, and there is great synergistic benefit in developing unified modeling approaches for both physical processes and model dynamics. The large-scale climate, for instance, determines the environment for microscale and mesoscale processes that govern weather, and these small-scale processes likely have significant impacts on the evolution of the large-scale circulation. The accurate representation of this continuum of variability in numerical models is, consequently, a challenging but essential goal. Fundamental barriers to advancing weather and climate prediction on time scales from days to decades, as well as long-standing systematic errors in prediction models, are partly attributable to our limited understanding of and capability for simulating the complex, multi-scale interactions intrinsic to atmospheric, oceanic, and cryospheric fluid motions. For weather prediction, moreover, there is the opportunity to benefit from the advances in climate modeling that reduce systematic errors due to mean-state drift, leading to more accurate medium-range weather and air quality forecasts. In turn, global climate and chemistry modeling can benefit from the experience of weather modelers in designing parameterizations for model physics that more accurately capture mesoscale weather systems, thus enhancing understanding of multi-scale interactions in the coupled system.

A cornerstone of the NCAR strategy over the next decade will be the pursuit of a more unified modeling approach to support global models that run efficiently and accurately at a variety of horizontal resolutions, as well as developing global models with limited-area, higher-resolution grids for both regional downscaling and upscaling of information from local events. Both the global CESM and the Model for Prediction Across Scales (MPAS) are moving in this direction, and their utilization of variable-mesh grids offers an improvement over current methodologies in regional modeling that employ boundary forcing from lower-resolution global models. These next-generation community-supported modeling systems will also necessitate the development of "scalable" physical parameterizations and numerical algorithms (NRC 2012), as well as new techniques for modeling and coupling socio-ecological systems, human activities and decision-making with the biophysical components of the Earth system. They will form the basis for prediction systems that produce representative probabilistic forecasts from minutes to decades and provide societally relevant information across multiple spatial scales. Additionally, the development of predictive systems that more effectively address societal needs will necessarily involve decision makers and other users of predictive information in the definition and design of simulation experiments and related research projects. A strategic focus on the development and application of multi-scale simulation and prediction systems, necessary to address both of the grand challenges above, will also provide important opportunities for much stronger collaboration between the weather and climate modeling communities, both within NCAR and in the broader community.

The planetary boundary layer (PBL) is the lowest part of the atmosphere and its behavior is directly influenced by its contact with the Earth's surface. The development of comprehensive, multi-scale modeling capabilities is critical to advancing predictions of the structure and evolution of the PBL, especially over complex and heterogeneous terrain. This is key to improving near-surface weather forecasts for a range of applications, including renewable energy, aviation, air quality, water resources, homeland security, fire weather, surface transportation, and agriculture.

Observations are the foundation of science and are essential to fundamental discovery. Moreover, NCAR is the steward of some of the most unique and sought after observing systems. The effective utilization of existing data from completed field campaigns, as well as the development and deployment of new observing systems, will be critical components of NCAR's success. This includes observing systems targeted at important under-sampled phenomena, such as hurricanes and other severe storms over ocean areas. New observations are also needed to better understand and predict solar storms, from their origins in magnetic complexes on the Sun to their impacts in near-Earth geospace and on the Earth. In addition, new observations are necessary to increase scientific knowledge about complex, poorly understood interactions between biophysical and human systems, as well as social and behavioral processes of human systems at multiple scales. In the context of the NCAR grand challenges, observations are essential to evaluate models and to attain the requisite process understanding to develop improved models. A particular strength of NCAR is that cutting-



Observations are the basic foundation upon which science is built, and supporting community observational science is an important responsibility of NCAR. This includes defining observational challenges and developing new capabilities. One proposed new facility is the Coronal Solar Magnetism Observatory (COSMO) – a suite of complementary ground-based instruments designed to study magnetic fields and plasma conditions in the solar corona. These observations are critical to improving predictions of space weather events, which can damage communication systems, global positioning systems, power transmission grids and harm humans in space. The Airborne Phased Array Radar (APAR) is a proposed addition to the NSF Lower Atmospheric Observing Facilities suite of community accessible observing systems. APAR will provide the capability to estimate dynamical and microphysical characteristics of clouds and precipitation, which are critical to improving predictions of severe weather and regional climate. In particular, APAR will provide important observations of phenomena over remote and data sparse regions, including tropical convection, tropical cyclones, oceanic fronts, atmospheric rivers of enhanced moisture over the oceans, and orographic precipitation over mountainous terrain.

edge observational and modeling facilities reside side-by-side, with routine interaction between scientists and engineers pursuing research challenges from both perspectives. A closer integration of data assimilation techniques and statistics with model development and verification is also needed not only to generate initial conditions but to facilitate analysis of sensitivity and uncertainty, as well as to assess the benefit of new observations.

New multi-scale simulation systems will push the modeling scale and complexity beyond the limits of current software engineering, data analytics and computer science capabilities. Achieving good performance, scalability, and fault tolerance on petascale to exascale (10^{15} to 10^{18} floating point operations per second) computers will necessitate new algorithms and revision of existing model designs. The next-generation computers will also require the development of radically new approaches to testing and optimizing software and new model validation strategies. The resultant large increase in model output will require new approaches for data storage and analysis.

The growing number of datasets that are impractical to deal with because they are too large in one or more of three dimensions – volume, velocity, and variety – is a critical issue for the atmospheric and Earth science community. Volume, which is the amount of storage space required by a dataset, is the most obvious aspect of the Big Data challenge. NCAR tape archive holdings recently passed 30 petabytes, consisting of 180 million files, and are growing at over 13 petabytes per year. Transferring data of this magnitude to remote sites is impractical; even accessing large parts of it are daunting. Velocity refers to problems that require very high rates at which the data must be produced, received, or processed. Variety refers to the burgeoning diversity within or between datasets, while bringing them together is increasingly important to solve complex, interdisciplinary problems. These interlinked Big Data problems are rapidly outstripping the capabilities of current tools and workflow practices, and threaten to become a significant barrier to scientific progress.

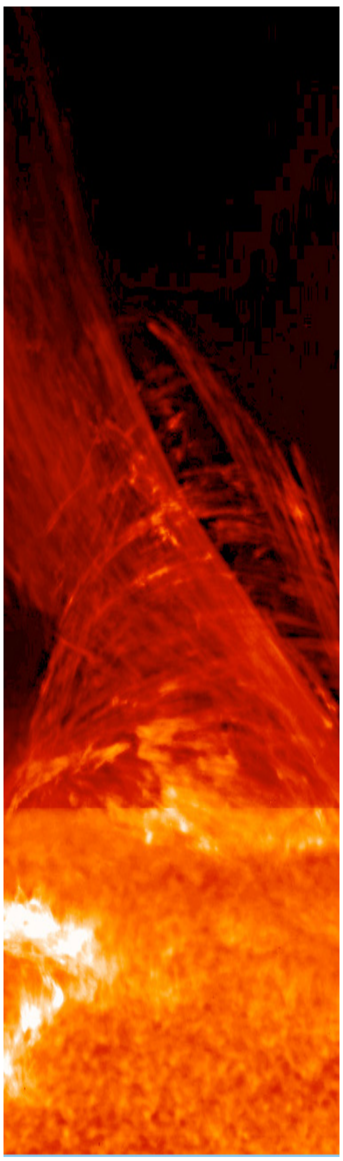
Developing new capabilities for extracting useful information from "Big Data" – large, diverse, distributed and heterogeneous data sets – will be integral to meeting the Grand Challenges. Datasets that are impractical to deal with because they are either too large or too complex are a growing problem for the atmospheric and Sun-Earth science community, as they are rapidly outstripping the capabilities of current analysis tools and workflow practices and threaten to become a significant barrier to scientific progress in our fields. Bringing together large numbers of disparate observational and model datasets, and enhancing data publication and discovery by promoting data publication as a first-class scientific activity, will be critical to conducting novel scientific research, including the development, validation and application of the next-generation multi-scale simulation systems. Addressing this challenge will require close collaboration with external agencies and data archives to standardize metadata and promote transparent data discovery, access, analysis, legacy, preservation and stewardship. Thus, NCAR will work toward an integrated, next-generation portfolio of "Big Data" services. Our data delivery environment will need to be developed in collaboration with those created by our research peers to ensure that our services can be externally federated and provide the research community with even greater assets and stewardship.

NCAR Imperatives

The Path Forward will be organized within the framework of six "imperatives". These are ongoing efforts and activities that can only be carried out at a national research center, and so are essential to the NCAR mission. In addition, they form the foundation for our attack on the two grand challenges articulated in the previous section. Despite budget pressures, NCAR will strive to maintain these imperatives over the next five years, while strategically evolving their key components in the directions necessary to tackle the grand challenge problems. By their nature, the imperatives are roughly equal in importance.

- NCAR Imperative 1 Conduct innovative fundamental research to advance the atmospheric and related sciences;
- NCAR Imperative 2 Develop, maintain and deploy advanced observational facilities and services;
- NCAR Imperative 3 Develop, deliver and support a suite of advanced community models;
- NCAR Imperative 4 Develop and sustain advanced computing and data system services;
- NCAR Imperative 5 Develop and transfer science to meet societal needs;
- NCAR Imperative 6 Educate and entrain a talented and diverse group of students and early career professionals.

NCAR Imperative 1: Conduct innovative fundamental research to advance the atmospheric and related sciences



NCAR is deeply engaged in the identification of new scientific frontiers and the development, evaluation, and dissemination of new approaches, methods, and tools. These activities are important for accelerating scientific progress, and often lead to efficiencies within the research enterprise that optimize the impact of constrained resources. NCAR fosters a culture of experimentation and encourages cross-disciplinary discovery through sustained interaction of our staff and scientists with the broader research community to explore emerging issues and relevant opportunities. Being engaged at the intersection of exciting scientific opportunities and important societal needs, we value and support regular interactions with a wide range of non-scientific audiences. We are facilitating connections between the scientific community and public and private sector decision-makers who benefit from new scientific insights by increasing the involvement of stakeholders in the definition of scientific problems and in the planning and evaluation of our scientific efforts.

There are many unanswered scientific questions about the processes and interactions that determine weather, climate, atmospheric chemistry, space weather and their predictability. For example, projecting changes in weather and climate over the coming decades depends on understanding the components of the land-atmosphere-ocean-cryosphere-human system and their multi-scale interactions, particularly those that regulate the cycling of water and carbon. Similarly, quantifying the role of solar variability in space and Earth climate requires investigations that span the entire system from the Sun's interior to the Earth's surface, along with the feedbacks that occur within the Earth's atmosphere-ionosphere-magnetosphere system. Connecting research on the atmospheric chemistry-climate processes to research on climate impacts on human health are other examples of complex problems being addressed. Progress on all of these fronts requires integrative approaches involving a mix of theory, observations and models, and an understanding of the coupling between human and natural systems. Our priorities are to:

- Create an environment that enables creative exploration across the scope of NCAR science, including discovery-oriented research into key components of the Sun-Earth-human system in order to understand fundamental processes and mechanisms

- Develop process-level understanding, including the nature of couplings and feedbacks among the different components of the Sun-Earth-human system, and integrate this knowledge to better predict the behavior of the coupled system

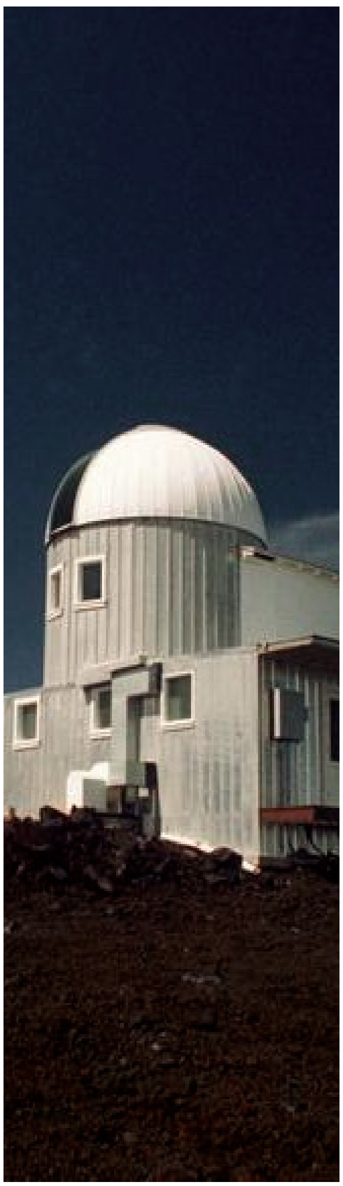
- Determine the inherent predictability limits and explicitly quantify the uncertainty of predictions of the Sun-Earth system for weather, climate, air quality and space weather applications

- Pursue strong interdisciplinary projects and partnerships that join, in essential ways, the core atmospheric disciplines with the ecological, hydrological, biogeochemical, health, and social science communities

In these pursuits, NCAR must continue to overcome barriers between basic research, use-inspired research, and the application of this research by the operational community and decision makers for the benefit of society at large.

NCAR Imperative 2: Develop, maintain and deploy advanced observational facilities and services

Observations are of fundamental importance for the study of the Sun-Earth system and, as such, are an essential foundation for the atmospheric and related sciences. Providing world-class airborne, ground-based and space-based observational facilities and services that are not otherwise available to the atmospheric and space physics communities is one of NCAR's central responsibilities. NCAR's record in meeting this obligation is stellar, especially the extensive and unique airborne facilities that are available to the NSF community. In close collaboration with NSF and scientists at universities and other research organizations, we define observational challenges and opportunities, develop new capabilities, and advance the observational science frontiers.



The NSF Lower Atmospheric Observing Facilities (LAOF) support observational surface-to-stratosphere weather and climate research, and NCAR develops and maintains a portfolio of airborne and ground-based LAOF for NSF. These observational facilities include two instrumented research aircraft (the C-130 heavy-lift turboprop aircraft, and the high-altitude and long-range GV jet), a large ground-based mobile S-band radar (SPOL-Ka), the airborne HIAPER Cloud Radar, lidars, in-situ and remote sounding systems, a tower flux network, and many associated instruments. These platforms and instruments are used to provide key measurements for studying and parameterizing fundamental atmospheric processes, and for initialization and verification of large-scale weather and climate models. Another NSF facility, The Mauna Loa Solar Observatory (MLSO) located on the Big Island of Hawaii, supports study of the solar atmosphere. It includes a new state-of-the-art K-coronagraph, a full-disk multi-wavelength irradiance monitor, and the Coronal Multi-channel Polarimeter (CoMP) instrument, which provides unique daily observations of coronal magnetism.

Maintaining excellent observational facilities, services and support depends on maintaining both strong observational science efforts at NCAR and robust links to the broader observational science community. This results in two positive impacts: (a) ensuring that NCAR's facilities are state-of-the art and thus address current and future observational needs; and (b) providing opportunities for collaboration in areas such as instrument development, calibration and inter-comparison, data management, field organization and deployment, and analysis of observations. Moreover, as described in the Path Forward section of this plan, the development and deployment of new observing systems, and the effective utilization of existing observational data, will be a critical component of a more unified modeling strategy. This includes observing systems targeted at important under-sampled phenomena and the targeted use of observations for model improvements and validation. Our priorities are to:

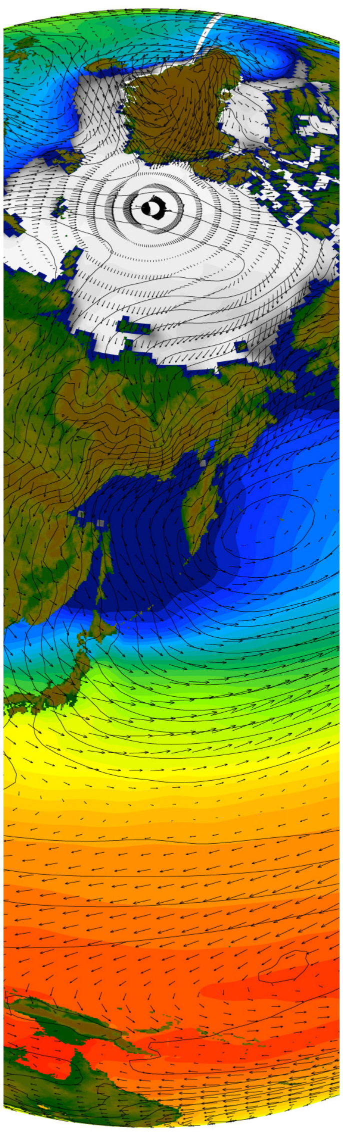
- Ensure the NSF-supported science community has access to world-class instruments by refining, maintaining, and operating existing facilities, conducting NSF-approved campaigns, developing new instruments and algorithms, and performing critical process research in support of observational and modeling science

- Advance community efforts and partnerships to build major next-generation facilities to enable significant advances in observations of atmospheric, chemical and space weather hazards, including the Airborne Phased Array Radar (APAR, on the C-130), the Coronal Solar Magnetic Observatory (COSMO), and a new atmospheric chemistry community initiative to coordinate and support atmospheric chemistry observations (the Atmospheric Chemistry Center for Observational Research and Data – ACCORD)

- Further develop methodologies to acquire, improve, restructure and manage observational datasets, evaluate their strengths and weaknesses for use in diagnostic studies and model evaluations, and distribute them in a timely and long-term sustainable manner to the broader research community

NCAR will continue to collaborate with the NSF and the broader scientific community to meet observational research needs by operating the extant suite of NCAR observational facilities and contributing to the development of new ground-, airborne- and space-based community observing systems. NCAR remains committed to occasional targeted rapid response LAOF deployments for high impact events that supplement large coordinated field campaigns. New collaborative development efforts may include observing systems that facilitate the exploration of under-sampled atmospheric regions, networks of small inexpensive sensors to enable comprehensive global measurements of atmospheric constituents, a global ground-based network of solar telescopes to provide continuous space-weather diagnostics in near real-time, and an airborne instrument suite to study turbulent mixing, surface fluxes, and cloud processes to facilitate new insight into severe weather systems.

NCAR Imperative 3: Develop, deliver and support a suite of advanced community models



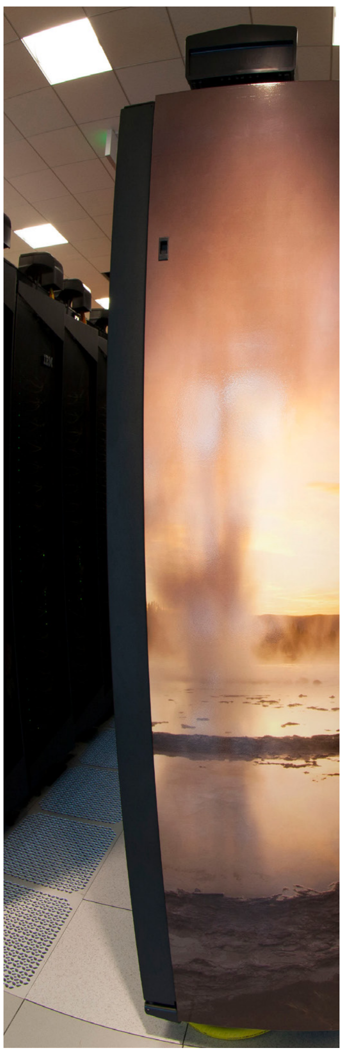
One of NCAR's outstanding accomplishments over the last several decades is the collaborative development and advancement of a series of community models. These models – which include the Community Climate System Model (CCSM), the Weather Research and Forecast model (WRF), the Whole Atmosphere Community Climate Model (WACCM), and, more recently, the Community Earth System Model (CESM) and the Model for Prediction Across Scales (MPAS) – are the products of sustained cooperation between scientists from universities, other national laboratories and research organizations, and NCAR scientists, software engineers, and technical staff. The models cover the broad range of NCAR science including climate, weather, atmospheric chemistry, and space weather, and are widely used in both research and operations. Excellent software engineering practices are particularly critical for community models because their effectiveness depends on innovative, extensible and maintainable software that enables effective collaboration and can take advantage of new computational capabilities and algorithms. Our efforts build upon core theoretical and observational research and include the development of new techniques for initializing, constraining and validating models using a wide range of observational data sources. To tackle the Grand Challenges, a major focus for NCAR will be the pursuit of a more unified modeling strategy, including global models capable of both regional downscaling and upscaling of information from local events. Model software and simulations will continue to be openly available to all interested parties free of charge. Stewardship of community models remains one of the most important services provided by NCAR to university researchers and other interested users. Our priorities are to:

- Accelerate advances in community models by incorporating improvements from community research results and by enhancing capabilities to couple models of components of the Sun-Earth system
- Develop and provide new multi-scale community modeling systems for weather-climate predictions and projections, spanning time scales from minutes to decades, with companion measures of uncertainty
- Adapt community models to emerging exascale supercomputing architectures, and apply them to a wide range of pressing problems in Sun-Earth system science
- Continue a structured process for community involvement and expand community access to NCAR models through open-source software along with an infrastructure that supports effective utilization of the models and their results; develop and provide advanced community tools for model testing and evaluation, including approaches and methods reflecting end-user purposes; and conduct modeling tutorials and workshops to entrain the next generation of scientists into their development and application

The move toward a more unified approach to atmospheric and Earth system modeling is already underway, with the integration of chemical, upper atmosphere, climate, and weather modeling, and new high performance atmospheric dynamical cores that allow regional enhancement of resolution and better representations of motions at the meso- and cloud-scales. Current models that simulate the solar drivers of space weather and climate will be evaluated for developing Sun-Earth community models. Physical parameterizations that function across a range of scales and resolutions are fundamental to further progress.

NCAR Imperative 4: Develop and sustain advanced computing and data system services

High Performance Computing (HPC) is one of the foundational elements of NCAR's scientific research and applications. NCAR is a key component of the research computation infrastructure of the United States through its provision of important supercomputing systems and services specifically tailored for the atmospheric, geospace and related sciences community. The recently completed NCAR-Wyoming Supercomputing Center (NWSC) is one of the world's most advanced and efficient HPC facilities. NWSC uniquely positions NCAR to enhance research with advanced computing, data storage and analysis capabilities designed with the specific workflows of the atmospheric sciences in mind. It is important, furthermore, to recognize that supercomputing is not our only critical cyberinfrastructure: NCAR also provides high performance networking infrastructure to the research community, as well as computing infrastructure for acquisition, quality control, and distribution of real-time data from field campaigns and observational sites. NCAR, indeed, maintains a large repository of Sun-Earth science data, from both observations and model simulations. To address the multi-disciplinary Grand Challenge research problems, NCAR will need to achieve significant improvements in data publication and discovery. It will do this by promoting data publication as an important activity with a view toward seamlessly connecting disparate data sets residing in many different repositories. Our priorities are to:



- Sustain and enhance unique supercomputing services that are tailored to the atmospheric, geospace and related science community by preparing for the next upgrade of NWSC computing and data systems into the trans-petascale regime to enable increasingly data-centric science

- Provide needed local, regional, national, and international networks in support of NCAR's mission to advance science, technology, and education, and maintain operational reliability, integrity, scalability and adaptability of NCAR's networking functionality

- Develop, maintain, and operate atmospheric and geospace science-specific data services, gateways, portals, product distribution, and data analysis, visualization, and assimilation tools, including robust and portable cyberinfrastructure to support field campaigns, and provide near-real-time analysis

- Move forward with improved efficiencies in Big Data capabilities by accelerating the data-centric science workflows, reducing the need to move and reformat data, advancing parallelization of systems used for assimilation, extraction, exploration, and visualization, and reducing the data footprint by adopting statistical, data compression, and data mining methods that meet the needs of the atmospheric and related science community

Looking ahead, NCAR will prepare for the exascale computing regime through continued testing and evaluation of – and adaptation to – rapidly evolving technologies in order to take advantage of new opportunities and minimize disruption of scientific productivity.

NCAR Imperative 5: Develop and transfer science to meet societal needs

In addition to serving as the nation's premier agency for promoting fundamental scientific research, NSF also intends its programs "to foster and encourage the translation of new knowledge generated through basic research into processes, products, and methodologies with significant economic or societal impact." NCAR is a leader in collaborative research, development and technology transfer, expanding the reach of our science to address important problems that impact society. We consider active engagement with stakeholders who can benefit from our work to be a fundamental responsibility. The potential scope of our contribution is broad – from basic information about anthropogenic climate change to supporting such areas as renewable energy, water resources, transportation, agriculture, human health, urban planning and space operations. Much of this work is collaborative with universities, the University Corporation for Atmospheric Research (UCAR) Community Programs, other research organizations and the private sector. Our priorities are to:

- Develop and implement advanced methods and techniques to observe, analyze and predict weather, air quality, climate and the hydrologic cycle in support of decision making at local, regional and national levels, including provision of the requisite scientific information, datasets, analysis tools, training materials and capacity building

- Transfer to the community state-of-the-art numerical models, data assimilation procedures, numerical and diagnostic techniques, and user-centric verification methods for atmospheric, climate, hydrological and space weather forecasts

- Integrate information from the physical and social sciences on the impacts, risks and vulnerabilities associated with climate variability and change, terrestrial physical and chemical weather, and space weather to improve the communication of risk and uncertainty to a diverse population

- Further our close research and educational partnership with the university community by maintaining robust visitor programs, and continuing to garner perspectives from our advisory committees, working groups, and external field campaign investigators

Societal vulnerability to extreme weather and climate change is expected to increase. Thus, there is a growing need for more precise and timely environmental information and better access to that information. We will respond to this challenge through advances in integrating physical and social sciences to generate and deliver new knowledge and information on critical impacts of weather and climate, including uncertainty estimates. We foresee expanded opportunities for stakeholder engagement and extended collaborations with existing and new partners across multiple sectors to ensure that our activities are relevant and usable.

NCAR Imperative 6: Educate and entrain a talented and diverse group of students and early career professionals

We recognize that the vivacity of our center is closely linked with the vitality of the atmospheric and related sciences community as a whole. The strength and success of NCAR and our entire community depends on the skills of those involved. A steady flow of new and diverse talent with new ideas and competencies is essential for scientific progress, not only at NCAR but also throughout our community. NCAR regards leadership in attracting, motivating and training the next generation of scientists and engineers as one of our fundamental responsibilities. We are committed to fostering graduate and postgraduate research and education, and to providing opportunities for undergraduate participation in NCAR research and promoting students' interest in our field. We offer a variety of early career employment opportunities that provide entry points and multiple pathways to different aspects of atmospheric and related research within our center and in the broader community. As a national center active in research, modeling and observational activities we provide unique hands-on educational experiences and opportunities for students, advisors and early career scientists to collaborate with a wide variety of scientists and engineers.

NCAR also supports formal and informal education programs to showcase exciting developments and opportunities in science. We support ongoing education and flexible working conditions for our staff. We maintain strong visitor programs that enable early career scientists and engineers to spend time at NCAR and encourage NCAR scientists and engineers to visit universities and other institutions. Our priorities are to:

- Sustain a strong Advanced Study Program (ASP) Postdoctoral Fellowship program and other postdoctoral opportunities

- Work with UCAR member universities and other academic institutions to identify opportunities for increasing the educational benefits of NCAR science

- Increase opportunities for NCAR researchers to engage in teaching, student research training and other educational activities in response to university requests, to collaborate with graduate students and their university advisors, and to maintain strong engagement with UCAR educational programs

- Continue and enhance our programs to involve students from traditionally underrepresented groups in all aspects of NCAR's science and engineering, and aggressively pursue a diverse range of candidates for all visitor programs and employment opportunities

As technology makes remote teaching and collaboration more productive, NCAR will adopt methods to enable a virtual presence in university classrooms and give students improved interactive access to field campaigns and to NCAR observational facilities. We will increase our visibility in the rapidly evolving "digital commons" to share our knowledge and passion for the atmospheric and geospace sciences and establish an earlier and deeper relationship with students. As science evolves, new societal needs and challenges will be identified, and the problems addressed by NCAR and our community will change. Our workforce will also need to change and evolve. Thus, we will thus be proactive in supporting innovative science education and sustaining a wide range of opportunities for continuing education and flexible career development.

Summary: Scientific Challenges and Societal Needs

The next five years will present significant opportunities and challenges for NCAR and its partners in the atmospheric, geospace and related sciences. Despite impressive gains in knowledge, our understanding and predictive capabilities remain insufficient for many societal needs. The reality of human-induced climate change is established, but the current generation of weather and climate modeling systems is inadequate to provide the accurate and reliable predictions of regional changes in climate and high impact weather required for adaptation and mitigation strategies. Major challenges are also associated with the need to understand the likelihood of abrupt climate change, the magnitude of sea level rise, and shifts and changes in the intensity of the water cycle. An increasingly sophisticated and technological society remains vulnerable to atmospheric and space weather hazards, air quality remains a major health issue, and we are witnessing the global stresses of food and water shortages.

This strategic plan lays out a vision for NCAR to help tackle these challenges by focusing on the development, application and analysis of next generation numerical models. By 2019, NCAR will have developed significantly improved versions of its community modeling systems, including weather and Earth system models with global grids that utilize variable mesh layouts, and a convergence of atmospheric parameterizations that will be used across spatial scales. The models will provide improved predictions of weather hazards, such as hurricane intensities and paths, and improved predictions and projections of climate variability and climate change from global to regional scales. NCAR will also focus on the development and deployment of new observing systems, such as COSMO, APAR and ACCORD, and it will move forward with new capabilities for extracting useful information from "Big Data". Ultimately, NCAR will only be successful in addressing these challenges through its commitment to retain and develop a workforce of world-class scientists, engineers and support staff, and by continuing to work synergistically with the broader academic community. This includes relations with university researchers coming to NCAR as both short- and long-term visitors, serving on NCAR advisory committees and working groups, and working as principal investigators on field campaigns. In so doing, NCAR will continue to embrace a leadership role in delivering objective information in support of national and international decisions on mitigation, adaptation, resiliency and sustainability, and it will continue to actively engage with the stakeholders and the consumers of its science.

About NCAR

NCAR's research activities include the study of the atmosphere, the Earth system, the Sun and solar-terrestrial physics, and the coupling of the atmosphere with oceans, biosphere, cryosphere and human activities. Our technical staff includes experts in meteorology, climate, atmospheric chemistry, solar and space physics, mathematics, statistics, turbulence, hydrology, ecology, social sciences, health science, computer science, and software, mechanical, electrical and optical engineering. NCAR is a Federally Funded Research and Development Center, whose sponsor is the U.S. National Science Foundation. We also receive important support from other U.S. government agencies and international and private sector sponsors.

We are a crossroads for scientific collaboration and the interaction of science and society. More than 6,500 participants attended over 120 workshops and colloquia at NCAR during 2012. We host over 800 scientific visitors annually, and about one third of those visit for longer than two months. We work closely with universities, environmental research and assessment programs, and other national and international research institutions to define scientific grand challenges and carry out sustained, long-term research projects. We interact regularly with decision makers in nongovernmental organizations, business, and local, national, and international government agencies to ensure that our research plans are informed by societal needs. We include our partners in decision making and direction setting for our institution.

NCAR has a special relationship with the U.S. university community. NCAR was created more than 50 years ago to provide advanced facilities and research capabilities beyond the scale of individual university departments. Provision of services and facilities to university scientists, support for university education, and collaboration with university researchers remain central to our mission today. During 2012, academic and NCAR scientists coauthored 471 peer-reviewed papers, and NCAR worked with 109 different universities to submit 215 collaborative proposals to agencies other than NSF. One hundred and four North American universities and colleges are members of the nonprofit UCAR, which manages our center on behalf of the NSF. The UCAR Board of Trustees, elected by members, provides governance oversight for NCAR and all other UCAR programs. In addition, 97 university representatives are currently serving on advisory panels for NCAR and its laboratories, divisions, and programs.

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