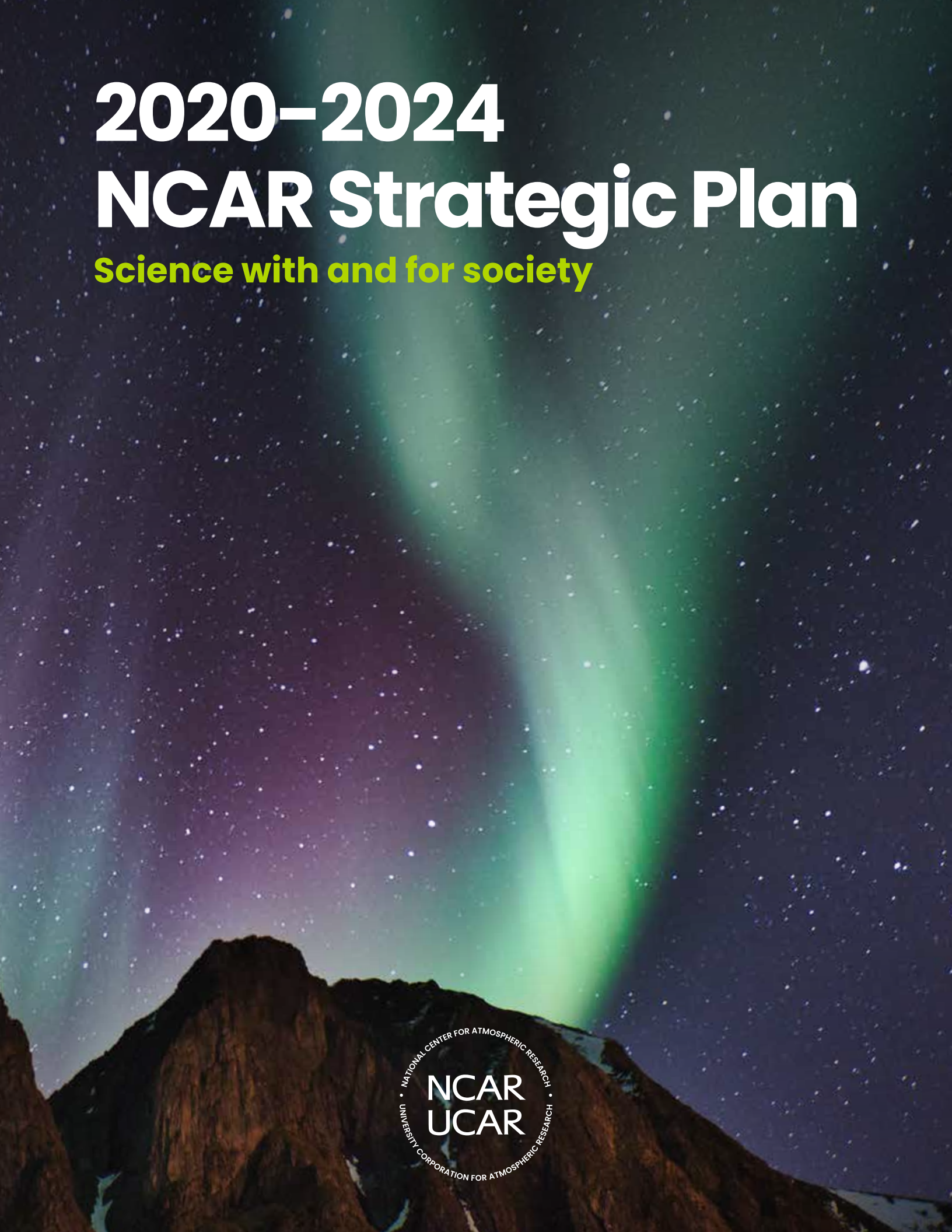

2020–2024 NCAR Strategic Plan

Science with and for society

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NCAR
UCAR
UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

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Image by: Scott Landolt

About NCAR

The National Center for Atmospheric Research is a federally funded research and development center established by the National Science Foundation in 1960. NCAR supports NSF's mission[1] "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" by expanding knowledge in science, engineering, and learning, and by advancing the capabilities of the United States to meet current and future challenges. Since its inception, NCAR has been managed by the University Corporation for Atmospheric Research (UCAR), a nonprofit consortium of 120 North American colleges and universities focused on research and training in atmospheric and related Earth system science. NCAR's headquarters are in Boulder, Colorado, with additional facilities in Colorado, Wyoming, and Hawaii, and collaborations across the U.S. and worldwide.

NCAR provides the university community with advanced facilities and research capabilities beyond the scale of any individual institution. We are dedicated to working with our community colleagues to advance the frontiers of Earth system science and technology, expand community capabilities for research and training, and respond to the scientific and societal challenges of our time. NCAR's priorities are defined by the priorities of the academic and broader community, which includes NCAR, through a deliberative and convening process. That process includes advisory panels for each lab and program and for NCAR as a whole, as well as workshops and targeted meetings convened with and for the broad community to gather diverse perspectives.

NCAR's special relationship with the university community is amplified by UCAR through its 120 Member Institutions. To understand societal needs and provide maximum benefit to the U.S., NCAR also collaborates with local, regional, national, and international researchers, practitioners, and decision makers in the government, private, and nonprofit sectors. NCAR's leadership and service extends to all academic institutions engaged in elements of Earth system science, with particular attention to capacity building and inclusion of underrepresented groups.

ncar.ucar.edu

Image by: Eliott Faust

About this plan

This strategic plan encompasses activities conducted with core funds from NSF as well as activities made possible by complementary support from other government agencies, the private sector, and nonprofit organizations. The plan was written with and for our community. To develop strategic priorities that are guided by the community's current and anticipated future needs, NCAR senior leadership and a Strategic Planning Steering Committee composed of staff from across the NCAR laboratories and programs developed initial concepts for the strategic plan by gathering and synthesizing extensive input from UCAR Member Institutions, the broader research community, and NCAR's scientific, technical, administrative, and support staff. As development and drafting of the plan proceeded, we listened to and incorporated multiple rounds of feedback from these groups as well as the NCAR Advisory Panel, the UCAR Board of Trustees and senior leadership, NSF, and other advisory groups and reviewers. We thank everyone who contributed to this plan.

Implementation plan

This strategic plan will provide the guiding principles and goals for a five-year NCAR Implementation Plan. That plan will include more technical and managerial specifics on the activities outlined below, including evaluation of progress toward specific goals. The implementation plan will be developed in close collaboration with NCAR's laboratories and programs, NSF, and the university and broader community.

Other related plans

As a guide to NCAR's high-level strategy for the next five years, this strategic plan is closely aligned with the NSF Strategic Plan. It will also work in concert with the UCAR Strategic Plan 2019-2028,[2] which addresses UCAR provision of management and operations, communications, and other services to NCAR. Other relevant NCAR and UCAR plans include the NCAR Education & Outreach Strategic Plan[3] and UCAR's Diversity, Equity, and Inclusion Strategic Plan,[4] Technology Transfer Strategic Plan,[5] and a workforce management plan that is currently in development.

Cooling the new Airborne InfraRed Spectrometer with liquid nitrogen on the NSF/NCAR HIAPER Gulfstream V for the Eclipse 2019 observing campaign over the South Pacific Ocean.

Image by: Simmi SInha

Definitions of terminology

actionable science
provides sound knowledge, information, or technology that is useful either to the scientific community by supporting research or education, or to society by enabling decision making. Actionable science can be fundamental or applied, and can create benefits over the short or long term.

co-development
brings people with multiple kinds of expertise together to form collaborative teams that jointly design and implement scientific or technological efforts.

community
the collection of individuals and organizations, including NCAR, in the academic, government, private, and nonprofit sectors that are interested in Earth system science and technology. NCAR convenes, supports, and collaborates with other community members, with a particular focus on academic community members engaged in research and education in atmospheric and related Earth system science.

constituencies
organized groups and individuals who are affected by or make decisions about Earth system–related risks and opportunities.

convergent research
research that is driven by and addresses a specific, complex, compelling problem, which may arise from deep scientific questions or pressing societal needs. It uses deep integration across disciplines to form novel frameworks and catalyze scientific discovery and innovation.

Earth system science
science of the atmosphere; connected components of geoscience including the land, ocean, ice and fresh water, geospace, and Sun; and their interactions with ecosystems, people, and the built environment.

geospace
the region of space beginning with Earth's upper atmosphere, ionosphere, and magnetosphere, and the scientific field that includes research into these domains and into the solar and heliospheric regions responsible for Sun-Earth connections.

interdisciplinary research
research by teams or individuals that integrates data, techniques, perspectives, concepts, and/or theories from two or more bodies of specialized knowledge to advance fundamental understanding or to solve problems beyond the scope of a single discipline.

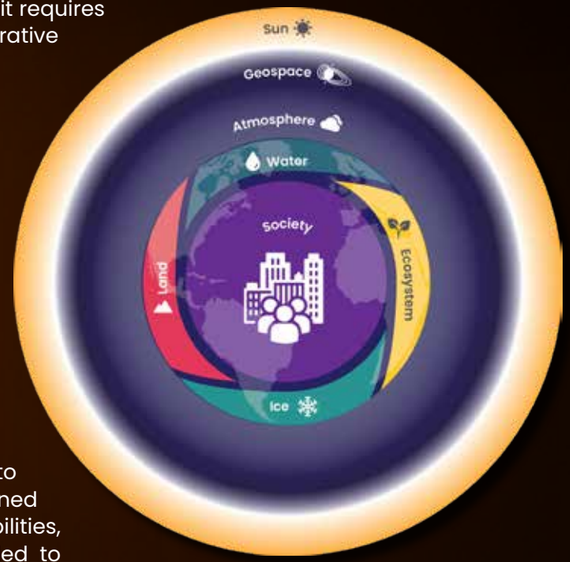
partners
members of the community and constituencies with whom we collaborate in specific, explicit ways over time to actualize strategic goals.

Science with and for society

Our ever-changing physical environment presents society with enormous challenges and opportunities. For example, high-impact atmospheric and geospace events threaten human lives and can devastate infrastructure; climate variability and change strongly influence water and food supplies, ecosystems, and political stability; and chemicals emitted by human activity and wildfires contribute to poor air quality that affects human health and livelihoods. Advancing scientific understanding of the atmosphere and its complex interactions with other components of the Earth system is now more crucial than ever, holding the potential to save lives, contribute to economic prosperity, and ensure a sustainable and secure future for the planet.

To realize these benefits, researchers, educators, and decision makers need science that generates sound and useful information about Earth system behavior, variability, and change. Creating actionable Earth system science requires deliberate leadership in advancing fundamental scientific and technological innovation. It requires development of novel predictive capabilities and research infrastructure that accelerate scientific discovery. It requires organization and empowerment of the intellect and creativity of a diverse, inclusive, and engaged network of people working toward common goals. In sum, it requires a strong, dynamic national center with an integrative focus, convening power, and community reach.

The National Center for Atmospheric Research is exceptionally well qualified to play a pivotal role in addressing these scientific, technological, and societal challenges. NCAR's well-recognized expertise[6] on the atmosphere and its interactions with the Earth and Sun is both broad and deep. By design, NCAR is woven into the fabric of the community, and it exists to tackle fundamental problems and facilitate research not otherwise possible by the academic community. This unique combination of expertise and community focus enables us to develop and support large-scale research infrastructure for our community and to address complex research topics requiring sustained effort. Through this distinguishing set of capabilities, NCAR builds the collaborative frameworks needed to advance scientific and technological frontiers, enable today's experts, and cultivate tomorrow's scientific leaders.



Components of the Earth system

Soon after the center opened its doors in 1960, NCAR leadership and staff began summarizing our purpose as ***science in service to society***, words often heard in the broad community as well. In a time of dramatic environmental change, we are inspired by urgent scientific and societal needs to chart a path forward for NCAR within the Earth science community, and to renew our purpose going forward as ***science with and for society***.

1

Renewing our vision & mission

NCAR's demonstrated history of success[7] as a federally funded research and development center sponsored by the National Science Foundation is based on the mandate articulated in our foundational document[8]. That mandate inspired early articulations of our core principles: to advance the progress of science, support the university and broader research community, and benefit society. This pioneering guidance continues to provide a framework for NCAR's activities, adapted to today's needs and opportunities.

Guidance from the community is central to NCAR's planning process, ensuring that we evolve to address changing capabilities, articulate new strategic directions, and respond to emphases emerging from community dialogue. Recent years have seen considerable advancement in our community's ability to observe, model, and analyze the atmosphere and its interactions with other components of the Earth system. Our community is also increasing its focus on integrated science and technology, interdisciplinarity, and research that addresses societal challenges. In the face of today's environmental challenges, enhancing human well-being and securing a sustainable society requires decision making that is informed by sound Earth system science. Thus, as we view 2020-2024 and beyond, community and societal needs impel NCAR to use our strengths in atmospheric science and technology to build capacity in community Earth system science that is actionable.

Our vision:

Accelerated progress toward a thriving and sustainable society, empowered by the fundamental science and resulting applications made possible by NCAR's leadership and collaboration within the academic and broader community.

Our 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.

To advance this vision and mission, NCAR will continue its roles as:

- **A national and international leader** in atmospheric and Earth system science and technology that develops and expands community capabilities.
- **A vibrant intellectual hub** that convenes diverse people to develop transformative ideas and address significant gaps in knowledge and technology.
- **A catalyst of innovation** in Earth system science and technology and in their use for societal benefit.
- **A core member of the Earth system science community** that partners with and supports scientific and technological advancement in the academic, government, private, and nonprofit sectors.
- **A trusted source** of knowledge, research facilities, and technologies for enabling discovery and innovation and enhancing societal well-being.
- **A vital collaborative provider of training and mentoring** for the current and next generation of Earth system scientists.

We do so by addressing challenging scientific and technological problems of national importance that fill critical gaps in knowledge and that require long-term focus and integration across areas of expertise. This includes applying our intellectual capabilities to develop, operate, and support the use of state-of-the-art facilities for observation, numerical modeling, computation, and data analysis that advance knowledge frontiers and enhance development of diverse human talent in the university and broader community.

Image by: Rebecca Hornbrook

Participants in WE-CAN, the Western Wildfire Experiment for Cloud Chemistry, Aerosol Absorption and Nitrogen, bring the multiagency field campaign's logo to life during a team meeting.

2

Affirming our values & principles

Our values and principles reflect the staff and community input that informed the development of this strategic plan. They will guide how we make decisions, prioritize activities, and develop and manage our workforce going forward.

- Scientific and technological excellence at the forefront of atmospheric and Earth system science.
- Support of community goals through effective management and strategic investment of resources.
- Scientific integrity and ethical conduct, including fairness and respect for others.
- Diversity, equity, and inclusion in our research, workforce, and community activities.
- Connectivity to societal benefits, informed and enabled through strategic partnerships with expertise beyond geoscience and engagement with relevant constituencies.
- Organizational agility to lead our community in tackling critical, emerging science, balanced with organizational continuity to address strategic, long-term scientific problems and community needs.

3

Fundamental research that enables actionable Earth system science discovery

3.1 Enhancing and building on our core strengths

During the five years covered by NCAR's 2014-2019 Strategic Plan,[9] NCAR's science focused primarily on improving understanding, prediction, and projections of the future state of the atmosphere and related components of the Earth system. At the same time, the 2014-2019 plan recognized the critical importance of understanding and predicting environmental and societal impacts of atmospheric conditions and pursuing integrative and interdisciplinary research. As we look beyond 2019, the importance of these areas will continue to grow, and new areas are emerging.

Over the next five years, NCAR will continue to strategically advance our expertise and community research facilities, providing the essential foundation for advancing scientific and technological frontiers and enabling science in the United States and worldwide. In order to do so, we will evolve our core strengths to:

- **Emphasize long-term, team-oriented science and technology** with community reach and significant transformative potential.
- **Maintain, develop, and deploy state-of-the-art instrumentation** in support of the university community at the Mauna Loa Solar Observatory and across the extensive airborne and surface-based assets of the NSF Lower Atmosphere Observing Facilities and other NCAR observational assets.
- **Develop and apply community models** with improved scientific capabilities, flexibility of use, inter-model compatibility, and strategies for community support.
- **Provide the robust, state-of-the-art high performance computational resources and expertise** required to accelerate research by a community with diverse and cutting-edge computing needs.
- **Adopt co-development and systems engineering approaches** that integrate physical science, mathematics, computer and data science, and engineering expertise in ways that effectively harness the data and computational revolutions to transform science discovery.

NCAR remains committed to scientific and technological creativity and to fundamental research that addresses critical gaps in understanding of the climate and Sun-Earth systems, meso- and microscale meteorology, atmospheric composition,

NCAR global simulation of precipitable water.

Investigating the potential of artificial intelligence

NCAR scientists are experimenting with a range of ways that artificial intelligence might be used to enable discovery in Earth system science. For example, AI techniques akin to those used in image recognition technologies have shown promise in improving forecasts for two extreme weather phenomena that are challenging to predict: the severity of hailstorms and the rapid intensification of hurricanes. AI also has the potential to reduce the computing resources needed to represent fine-scale processes that typically require vast amounts of computing, such as detailed cloud microphysics, in Earth system models. While the potential of these and other applications for machine learning in Earth system science are exciting, the results from early research vary in their quality and interpretability. As a result, NCAR has developed a strategy to work with the community to develop and apply best practices in artificial intelligence. NCAR's next supercomputer, housed at the NCAR-Wyoming Supercomputing Center, will also be designed with capabilities that better support machine learning applications.

and related processes. Thus, we will continue to evolve our strategic goals to keep NCAR and our community at the forefront of science, technology, and societal relevance. This evolution requires skillfully integrating across disciplines to examine the Earth system holistically and to conduct convergent research that addresses complex research problems inspired by societal needs.

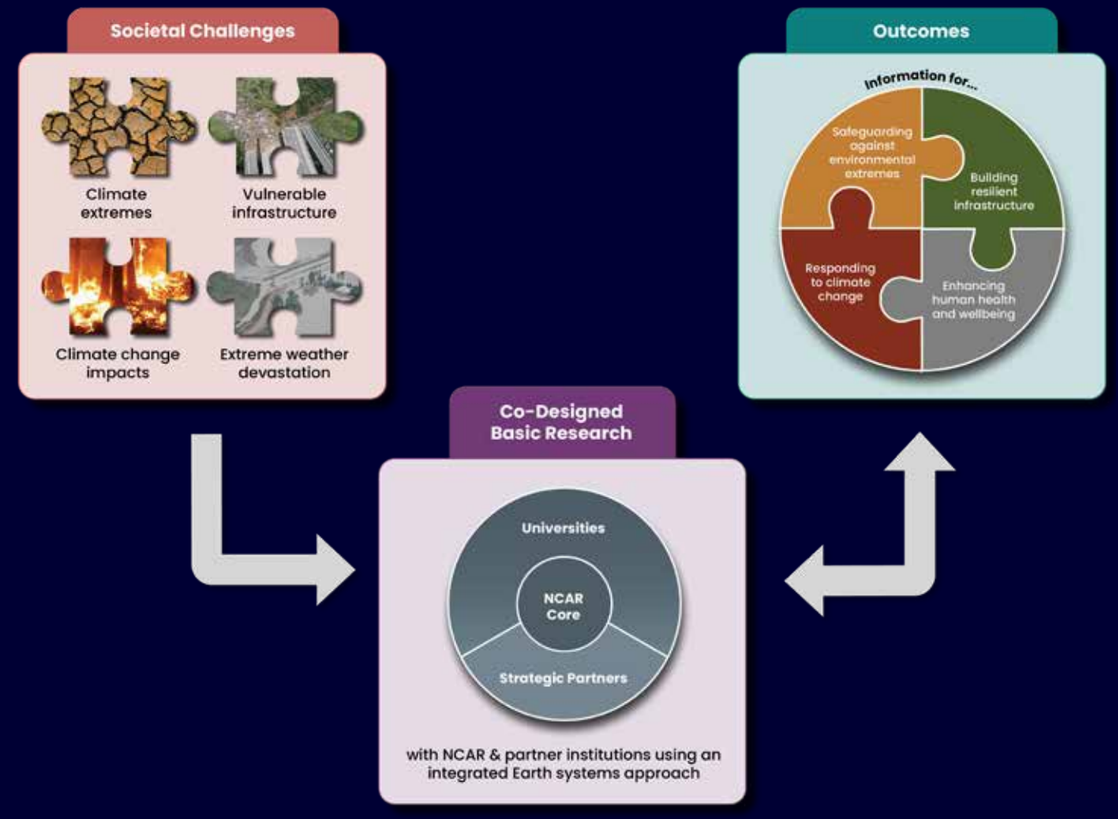
The most compelling scientific and technical problems for NCAR are those that resolve fundamental gaps in knowledge or capabilities, including gaps between disciplines, gaps in integrating facilities, and gaps that hinder societal benefit. We will define and prioritize these problems through community engagement activities at NCAR and elsewhere, using mechanisms that range from external advisory bodies at the lab, program, and organization level to community workshops. Strategic prioritization may also in some cases require us to rebalance NCAR's activities.

3.2 Promoting community Earth system science

Positioning our community to remain vibrant, relevant, and effective requires that we approach the atmosphere from a more interdisciplinary Earth system perspective, across a range of space and time scales. At the global scale, the interactions of the atmosphere with the land, ocean, ice, and freshwater, as well as the Sun and geospace, must be considered holistically, throughout the depth of the atmosphere. On the regional scale – for example in the Arctic or the Amazon – the atmosphere and ecosystem, including water in all its states, form a delicate system, with behavioral changes on time scales from days to multiple decades, that must be better understood. At the local scale – for example in studies of megacities – interactions across boundary layer dynamics, atmospheric chemistry, and the built environment form a complex system that requires new paradigms of research and technology. And all of these systems fundamentally affect and are affected by humans.

Addressing these topics requires a comprehensive Earth system approach. Thus, NCAR will enhance our scientific and technological collaborations with universities and other organizations to:

- Evolve our science to place greater emphasis on understanding interactions within the Earth system, on global to local scales. This includes developing process-level understanding of couplings and feedbacks among system components from laboratory studies, field experiments, and sensitivity analyses.
- Improve observational and modeling capabilities and develop new techniques for integrating across them to build understanding about Earth system behaviors and predictability.
- Ensure the advances we make in data science and computational capabilities, as described in section 3.1, effectively enable Earth system science discovery.



The roles of strategic partnerships and co-designed basic research in achieving societally relevant outcomes

3.3 Advancing actionable science

The science developed by NCAR and our community collaborators in support of the NSF mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" has made a dramatic impact on some of society's most pressing environmental challenges. As these increasingly interconnected challenges intensify, NCAR must play a more vital role in advancing fundamental understanding of the Earth system in ways that enhance societal outcomes. Our academic community members are indispensable

collaborators in the process of actionable scientific research, both because their expertise in Earth system science extends our own and because use-inspired research is highly motivating for the next generation of scientists and engineers.

Depending on the problem, our activities will include:

- Developing new information and tools that derive from fundamental research, and making them broadly available for use by others in solving a diverse set of practical problems.
- Leveraging NCAR and community expertise in societally relevant and convergent research to elucidate constituents' information needs and to incorporate those into fundamental atmospheric and Earth system research and technology.
- Collaborating with experts in social sciences, engineering, and other fields, strategically selected based on research aims.
- Partnering with mission-driven government agencies, nonprofit organizations, and other constituencies to understand and address key scientific and technological gaps for decision making, especially on the regional and local scales where many decisions are made.

Spotlighting wildfires

In 2018, wildfires burned 8.7 million acres, caused an estimated $24 billion in damage, and killed dozens of people in the United States. Scientists from NCAR and their university colleagues were able to fly instruments through smoke plumes from some of those fires as part of WE-CAN, the NSF-funded Western Wildfire Experiment for Cloud Chemistry, Aerosol Absorption, and Nitrogen campaign, to better understand how wildfire plumes are chemically processed and how they affect local and regional air quality, visibility, climate, and weather.

NCAR scientists also work on modeling wildfires, both in the short term to help emergency responders battle blazes in real time, and also in the long term to understand how climate change may change global wildfire patterns.

Over the next five years, NCAR will connect to societal needs more intentionally by pursuing fundamental research and technological innovation with our community that is motivated by four interconnected societal drivers:

- Enhanced human health and well-being,
- Protection and provision of critical infrastructure,
- Protection of lives and property from high-impact environmental conditions, and
- Scientifically sound responses to climate change.

These drivers were selected because they are national and international societal priorities that pose broad intellectual and technical challenges linked to NCAR's mission, expertise, and core capabilities. To enhance integrated science and technology in relation to each societal driver, we identify more specific research goals below.

3.3.a Research to support air quality management and water, energy, and food availability

People need clean air and sufficient water, energy, and food to survive and thrive in the face of drought, air pollution, and other stressors, all of which are amplified by socioeconomic changes. Ensuring sustainable provision of these resources to support human health and well-being requires convergent Earth system science information on time scales from days to decades. To help address these societal needs, NCAR will:

- ***Improve capabilities to understand and predict regional air quality by***
  - Capturing more comprehensive observations to understand reactive and formative processes for key chemical species in a changing background environment.
  - Developing enhanced, variable-resolution chemical modeling and data assimilation capabilities.
  - Quantifying the impacts of emission sources, atmospheric chemistry, and regional and global transport.
- ***Expand understanding of the interconnections of weather and climate with water, food, and energy systems by***
  - Extending observations of the land surface and subsurface, water cycle, and land-atmosphere interactions across a spectrum of land uses.
  - Improving models to more accurately represent interactions of the boundary layer with land, vegetation, and urban areas as well as hydrology, water management, and agriculture processes.
  - Further developing capabilities to optimize weather-dependent renewable energy production on time scales from minutes and days to decades.

3.3.b Research to reduce damage and disruption to critical infrastructure from weather and space weather hazards

Modern civilization relies on critical infrastructure systems such as energy, transportation, communication, water, and health and emergency services, all of which are highly susceptible to weather and space weather hazards. To mitigate these threats to safety, commerce, and well-being, decision makers require information about potential impacts from individual events as well as longer-term risks. To help address these societal needs, NCAR will:

- ***Build capacity to predict space weather impacts on communications, navigation, satellite function, and the electric power grid by***
  - Improving observations and modeling of solar magnetic eruptions.
  - Embracing a whole-geospace model of the coupled responses to solar and geomagnetic variability and forcing from the lower atmosphere.
- ***Improve capabilities to understand and predict impacts to critical infrastructure from weather hazards by***
  - Deploying novel observations and advancing models and data assimilation techniques focused on the urban boundary layer and surrounding environment.
  - Partnering with experts in infrastructure management and urban planning to develop techniques for evaluating near- and long-term risks that incorporate knowledge about infrastructure sensitivities along with scientifically sound future scenarios of events.

3.3.c Research to advance predictive science and technology for weather and water risks

Each year, weather and flooding cause devastating damage, disruption, and loss of life in the U.S. and around the world. Timely, relevant information about potential future Earth system conditions can help public officials, members of the public, and other decision makers understand imminent risks and take protective actions to mitigate this harm. To help address these societal needs, NCAR will:

- ***Investigate the predictability of high-impact weather and hydrological conditions and probe the underlying causes of prediction errors by***
    - Conducting field programs and analysis targeted at understanding the processes with the largest uncertainties by deploying innovative observations and data assimilation techniques to quantify model error and improve physical parameterizations.
    - Designing and conducting hierarchical numerical simulations to understand the roles and interactions of different processes, including physics, dynamics, and initialization, in intrinsic and practical predictability.
- ***Discover and incorporate diverse constituencies' needs for decision making into predictability and prediction research by***
    - Building new understanding of how evolving forecasts and other risk information interact with risk perception, decision making, vulnerabilities, and societal outcomes.
    - Developing new capabilities for predicting and communicating hazardous conditions, impacts, and associated uncertainties.
    - Integrating this understanding and capability into the design of prediction strategies and systems.

3.3.d Research to advance development and analysis of climate change mitigation, intervention, and adaptation strategies

Given the risks posed by climate change, NCAR must improve and use its Earth system science knowledge and capabilities to provide scientifically sound and timely information on the likely effects of proposed climate mitigation and intervention strategies. We must also provide relevant information to policy makers as they consider ways to help people adapt to ongoing and future climatic changes. To help address these societal needs, NCAR will:

- ***Expand capabilities for assessing and predicting societally relevant climate variability and change on time scales ranging from seasonal to interannual to centennial by***
    - Enhancing the flexibility of modeling systems to enable integration with observations and initialized Earth system prediction for the purpose of investigating model physics and biases, bridging weather and climate, and understanding evolution toward future climate states.
    - Improving the physical representation of processes and feedbacks in Earth system models, and extending those processes to encompass key societally relevant variables.
    - Integrating climate-related information needs into Earth system modeling and co-developing information channels to provide the best-available climate science information to constituencies.
- ***Contribute relevant information to policy and decision makers on possible pathways to limit global warming to 1.5° or 2°C by***
    - Advancing understanding of how the Earth's climate system responds to various natural and human-generated influences, including improving estimation of climate sensitivity and the risks of tipping points and unintended consequences.
    - Combining models and observations to assess the performance of natural Earth system carbon sinks.
    - Identifying climate mitigation strategies and developing comprehensive modeling assessments of their efficacy and associated uncertainties.

3.4 Addressing the challenges ahead

Pursuit of the research goals discussed above will require integration across NCAR's unique capabilities and those of our partners to solve the most significant and pressing Earth system science problems of the 21st century. We will continue to pursue a combination of scientist-inspired and use-inspired research and technology development.

Central to this is the ingenuity of NCAR's scientists, engineers, managers, and other staff. We will also leverage our decades of experience in combining multiple areas of expertise and in collaborating within the community to extend the reach of NCAR science. We must selectively build on relevant existing partnerships and adopt new ways to creatively partner with the expertise of diverse community members and constituencies. To address all of these challenges, new talent and forms of expertise will be needed; thus, we must ensure that education and training are an integral part of each scientific and technological activity.

Global modeling at storm scales

To understand how global-scale atmospheric features affect local weather, NCAR scientists have run MPAS, the Model for Prediction Across Scales, at a resolution of just 3.75 kilometers, which is more than 25 times finer than scales traditionally used in global models. The results provide a detailed view of Earth that brings once-blurry storms into startling focus. The more explicit rendering of clouds, precipitation, and other fine-scale processes will also facilitate the use of high-resolution observations from space as well as ground-based and airborne measurements to assess the model's performance. The combination of high-resolution global model runs and data from observations will allow scientists to study how global atmospheric features may affect the predictability of local weather, especially high-impact weather events.

4

Positioning NCAR for success

This section identifies strategies that NCAR will pursue to ensure that our activities are effectively directed toward realizing our mission and vision and our community's goals. Given UCAR's responsibility for managing NCAR on behalf of NSF, these strategies will be pursued in concert with the supporting functions within UCAR.

Healthy investments in Earth system research will be required for the community to bring about transformative solutions addressing our most challenging scientific problems with societal reach. NCAR, however, must also be prepared to undertake activities within resource constraints, which necessitates creative solutions ranging from strategic prioritization to pursuing funding opportunities to more efficient management processes. Decisions about prioritization will be made in consultation with NSF and with broad community input.

Image by: Simmi SInha

4.1 Enable discovery, innovation, and novel scientific and technological solutions to challenging research problems

Addressing the challenges outlined above will require that we continue to create intellectual space for creative, curiosity-driven research. Work on complex problems that is guided by community interests and societal needs also requires expanded mechanisms for collaboration. NCAR will:

- Further embrace a culture that values intellectual freedom and creativity, supports calculated risk taking, and applies critical thinking and learning when evaluating our activities and their outcomes.
- Create physical spaces, invest in information and communication technology, and adopt best practices in talent/human capital management that support the collaborative needs of NCAR staff and our community.

4.2 Align research infrastructure and facilities with research goals

Development and support of computing, observing, modeling, and data facilities for community benefit remains an essential element of NCAR's mission. Thus, it is imperative that NCAR continue to invest in these facilities to effectively meet the community's current and future needs and enable the goals of this strategic plan. NCAR will:

- Extend observational capabilities by:
  - Developing an advanced airborne radar (APAR) along with an integrated ground-based remote sensing and in situ system (LOTOS) to observe and deduce boundary layer, cloud, and precipitation processes, with emphasis on those that are poorly represented in models and thus limit practical predictability and the use of models for scientific discovery.
  - Developing new observation capabilities to complement process and modeling studies, such as instruments with greater sampling accuracies and more efficient operations for airborne campaigns, to better quantify the effects of organic species on ozone and secondary aerosol production and loss.
  - Developing a next-generation solar synoptic observatory (COSMO) to observe the magnetic fields and plasma conditions of the solar corona.
- Develop, support, and evolve our community modeling systems by engineering for a hierarchy of computational environments, up to the exascale regime. Along with continuing to serve critical ongoing community science needs,[10] we will increasingly focus on unified modeling frameworks to enhance efficiency and enable exploration of scientific frontiers in Earth system science. These include:
  - System for Integrated Modeling of the Atmosphere (SIMA), as the atmospheric component of the Community Earth System Model (CESM).
  - Community Terrestrial Systems Model (CTSM), for hydrology, ecosystems, land-atmosphere coupling, and human systems.
  - Multi-Scale Infrastructure for Chemistry and Aerosols (MUSICA), for studying air quality and chemistry-climate interactions.
  - A whole geospace model extending from the Sun to Earth's surface, for studying solar-terrestrial coupling.
- Advance our community data assimilation tools to improve model initialization capabilities, identify model biases, and inform process representation in models, to enhance understanding of Earth system predictability and advance predictive capabilities.
- Develop a community data science initiative that incorporates artificial intelligence, efficient workflows, and access to large and interoperable datasets to enable researchers to effectively and

Convergence of modeling and computing for Earth system science

Peering deeper into storms

NCAR scientists and engineers are working on the next generation of tools to better observe the many aspects of the Earth system. For example, NCAR is collaborating with its university partners to develop an advanced airborne weather radar to be flown on the NSF/NCAR C-130 research aircraft. The Airborne Phased Array Radar (APAR) will sample weather systems in striking detail and allow scientists to measure the type and size of "hydrometeors," including rain, snow, hail, graupel, and other types of precipitation, in unprecedented precision. APAR's wavelength allows measurements of storm dynamics and microphysics deeper inside storms, while the aircraft stays at a safer distance. These new observations will improve our knowledge of cloud processes and dynamics, addressing shortcomings in hazard predictability and process representation in models across weather and climate time scales.

collaboratively analyze and synthesize the diverse data necessary to accelerate scientific discovery and communication of useful information.

- Ensure that our data holdings remain a vital national and global scientific asset by implementing standardized scientific data management practices and discovery technologies across the organization.
- Balance use of NCAR and community computational and storage resources to maximize scientific discoveries and fulfill community needs in Earth system modeling.
- Co-develop hardware and software, implementing a multipronged approach that includes, for example, machine learning, accelerators, mixed precision, and new algorithms.
- Scale the science conducted at the NCAR-Wyoming Supercomputing Center to the exascale regime by evaluating and adopting new and more effective technologies quickly as they become available for high performance computing systems, cloud computing, and storage infrastructure.

Co-developing interdisciplinary research with our community

In 2019, NCAR and NSF launched a new program to further build the center's capacity to conduct integrative, societally relevant Earth system science research in partnership with the community. The inaugural cohort of the Early Career Innovator Program brought nine faculty members and their graduate students to NCAR to collaborate with scientists and engineers on climate change and natural hazards in U.S. coastal regions. The Innovator Program will strengthen and invigorate the culture of convergent research at NCAR, while establishing a growing network of early-career social science faculty and students with strong connections to NCAR and, by extension, with its partners in Earth system science.

4.3 Foster a diverse and inclusive workforce to maximize our scientific and technological capabilities

NCAR's workforce must be diverse, innovative, and agile in response to emerging scientific and technological capabilities, community priorities, and societal needs. NCAR will continue to build a more inclusive and equitable culture that values the knowledge, background, experience, and talents of diverse staff, visitors, and collaborators. We will continue to grow our expertise in strategic areas by recruiting exceptional staff and supporting mentoring, training, and professional development across all job categories and career levels. Because many potential staff who are early in their career and/or from underrepresented groups express deep interest in societally relevant work, our goals for actionable science and for diversity and inclusion are synergistic. NCAR will:

- Expand mechanisms to reward excellence and recognize contributions to strategic goals.
- Cultivate effective leadership to promote NCAR's values and principles at all levels in the organization.
- Develop succession management plans, along with training initiatives and flexibility in career paths to ensure continuity of critical knowledge and skills.
- Pursue strategic hiring initiatives that augment expertise in areas critical to advancing community research goals and increase workforce diversity.
- Implement additional practices outlined in the UCAR Diversity, Equity, and Inclusion Strategic Plan that foster an equitable and inclusive workplace.
- Explore novel strategies to increase personnel flow-through at NCAR to promote diverse representation and new perspectives, and to cultivate long-term relationships with early career scientists.

4.4 Build strategic partnerships aligned with science and technology goals

Delivering on the research goals in section 3 requires that we strengthen strategically aligned partnerships. To address fundamental gaps in knowledge and capabilities, we will continue to build research and development partnerships aligned with our mission and community roles. To evolve our core strengths and advance actionable and community-engaged Earth system science, we will give particular attention to partners with expertise and ties to communities of practice in disciplines beyond atmospheric science. We will expand the societal relevance of our research by collaborating with key constituencies to integrate their perspectives into NCAR's science and technology. We will also continue to seek appropriate opportunities to transfer NCAR technologies to mission agencies, decision makers, and others.

Engaging and convening the academic community

NCAR has deep ties to the college and university community within and beyond the UCAR Member Institutions. We will continue to collaborate with this academic community to advance research, technology, education, and training. We will continue to serve as a community convener through a variety of forums, identifying mutually determined needs and prioritizing the maintenance and development of tools and services according to those needs. NCAR will:

- Expand research collaborations with minority serving institutions to advance diversity, inclusion, and capacity building and collaborative and integrative science.
- Increase emphasis on, and support for, visits by NCAR staff to colleges and universities to interact with faculty and students and collaborate in training, teaching, and/or mentoring.
- Build upon and make strategic use of visitor programs and initiatives such as the Early Career Faculty Innovator Program to extend and strengthen NCAR's expertise by enhancing bridges to disciplines that are essential for convergent and actionable science, such as ecology, health, engineering, and social and human dimensions.
- Explore the potential for NCAR to help catalyze development of Earth system science, technology, and training hubs at the regional level, focusing on collaborative approaches to scientific and societal challenges of mutual interest. The hubs would be resourced, led, and managed by local academic and other public or private partners. NCAR would focus on co-developing research and education activities aligned with the goals of this plan and amplifying benefit to the broad community.

Engaging government agencies, nonprofit organizations, and the private sector

NCAR's partnerships with organizations outside the academic community provide important capabilities that enhance our mission and create critical connections with societal needs. We will sustain those existing partnerships that effectively further our strategic goals and support NCAR's core, and build new relationships with both funding and collaborative partners as necessary. In these endeavors, the UCAR Community Programs will be an important partner for

NCAR where appropriate. NCAR will:

- Strengthen strategic relationships with business and industry; with local, national, and international governmental bodies and agencies; and with nongovernmental organizations in order to address gaps in scientific and technical knowledge and capabilities.
- Proactively identify societal decision-making needs that may benefit from NCAR's capabilities and inform NCAR's work, convene relevant members of the community and constituencies to co-develop societally beneficial research priorities, and co-design projects to advance science and technology that contributes to positive societal outcomes.

4.5 Develop and deploy novel education and public engagement strategies

The NCAR Education & Outreach Strategic Plan[11] articulates a vision and pathway for NCAR to strengthen its partnerships with the university community in entraining and preparing a highly skilled and diverse workforce. It also emphasizes NCAR's role in inspiring, engaging, and informing the public. NCAR E&O will restructure as a center of excellence to better integrate education activities into scientific and technological research across the national center. NCAR will also strengthen its education research capabilities to stimulate pedagogical research within the community. To support our organization-wide goals in workforce development and broadening participation, NCAR will:

- In partnership with UCAR's Center for Science Education, prioritize strategic engagements with the broader community that reach diverse audiences through events, exhibits, and online resources.
- Broaden participation of early career scientists from more diverse demographic and disciplinary backgrounds through targeted recruiting and retention within the Advanced Study Program, and by further integrating UCAR's SOARS program with NCAR's focus on developing community capacity in Earth system science and technology.
- Expand NCAR-hosted faculty sabbatical and fellowship opportunities and explore joint appointments, especially with schools that traditionally have participated less in NCAR activities, such as minority serving institutions and smaller schools.

4.6 Foster strategic integration

Achieving the goals outlined in this section and in section 3, above, requires integrated capabilities across areas of expertise, both within NCAR and with other members of the community. This includes integration within atmospheric science, as well as with complementary areas of Earth system science and societal perspectives. To advance integrative scientific and technological development, NCAR will:

- Invest in building greater capacity to conduct integrative work within our workforce and community, through workshops, training, and mentoring.
- Develop and implement processes to encourage, enable, and reward integration at the forefront of science and technology, building on established practices in integrative and team research.
- Organize teams of scientists and engineers across NCAR to pilot specific research and technological innovation on topics of strategic interest and priority.
- Leverage NCAR's experience in integrating social and natural sciences and in developing research applications to create a culture that supports robust convergent and actionable Earth system science, and to develop new frameworks for facilitating such work in the academic and broader community.
- Build a cohort of staff with expertise and skills in collaborative conduct of convergent and societally relevant science and technology, with an emphasis on professional development for staff who express interest in working across traditional research boundaries.

Students in the Undergraduate Leadership Workshop visit the NSF/ NCAR C-130 aircraft during the five-day NCAR immersion program.

5

NCAR's roadmap to 2024

Guided by NSF's mission, this strategic plan leverages the power of the atmospheric and related Earth system science community to set a course toward a more secure and thriving nation, catalyzed by the leadership, service, and community empowerment at the heart of NCAR's mission and a renewed focus on science with and for society. Because our goals include progress on many vexing, persistent scientific challenges, some outcomes will be achievable within five years, while others will require longer, sustained attention. In all cases, NCAR will be focused and deliberate in its conduct and assessment of progress toward the goals in this plan.

Through 2024 and beyond, NCAR will continue to be an indispensable national resource for advancing Earth system science for the benefit of society. NCAR will be known as a strong, dynamic national center with an integrative focus, convening power, and community reach. It will organize and empower the intellect and creativity of a diverse, inclusive, and engaged network of people working toward a thriving and sustainable national and global society.

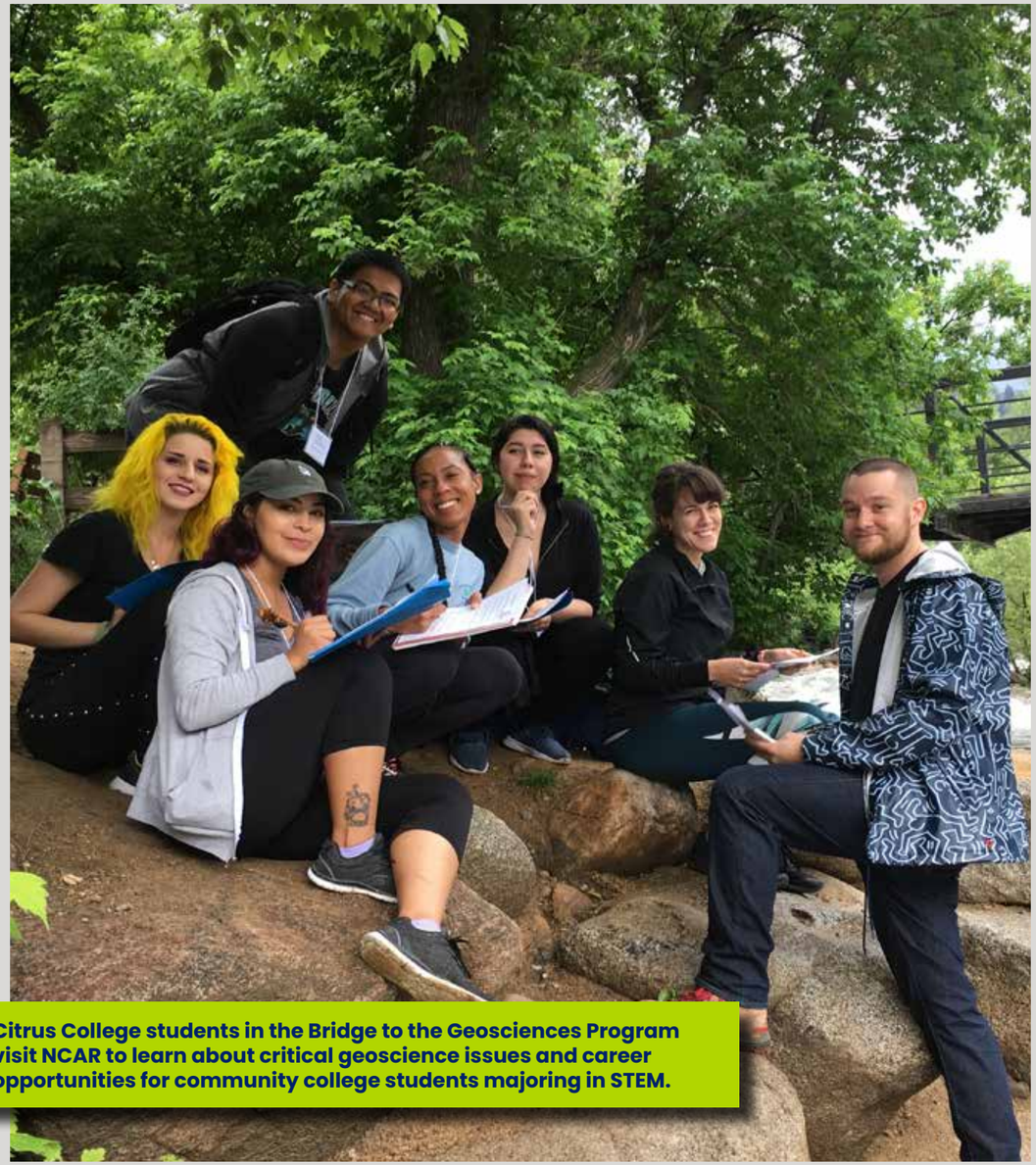
To support our community's scientific goals, NCAR will continue to provide core expertise and state-of-the-art community facilities committed to advancing frontiers in science and technology that extend our understanding of the climate and Sun-Earth systems, meso- and microscale meteorology, atmospheric composition, and related processes.

To advance Earth system science, NCAR will lead and empower science and technology focused on interactions within the Earth system, on global to local scales. This will require building new understanding about Earth system behaviors and predictability from new observational and modeling capabilities as well as research that integrates across NCAR and community expertise. To enable next-generation Earth system science discovery and keep community modeling and data analysis affordable and accessible, NCAR will also develop and apply techniques and approaches that draw on the latest data and computational innovations.

To promote actionable science, NCAR will play a more intentional role in advancing fundamental understanding of the Earth system in ways that enhance societal outcomes. We will engage the expertise of colleagues in the academic and broader community, amplifying our mutual impact to attack urgent societal and environmental problems at the intersection of our core expertise with human and environmental security and well-being. To ensure the usefulness of our work, our strategic partnerships will include diverse constituencies affected by Earth system behavior, variability, and change, and we will integrate these partners' knowledge into our research.

To position our community for success, NCAR will adopt a more diverse, center-wide, integrative approach. We will lead the integration and enhancement of community observational, modeling, and computing and data facilities through co-development among scientists and engineers. We will diversify our science through strategic partnerships, workforce development, and renewed efforts in outreach and inclusion. These efforts include working closely with minority serving institutions to recruit talent and advance the careers of scientists from underrepresented groups. Finally, NCAR will investigate novel collaboration models, such as the Innovators Program and regional hubs, as a means of deeper intellectual engagement with universities and colleges of all sizes and research capabilities in Earth system science. The concept of hubs will require further evaluation, with implementation predicated on their potential to further community objectives.

To map our path and evaluate our progress, NCAR will develop an implementation plan in 2020, along with corresponding evaluation metrics. NCAR will prioritize activities, in close partnership with NSF and the academic community, to operate within budgetary and capacity boundaries and maintain the integrity of our status as an NSF federally funded research and development center. Our comprehensive evaluation processes will be streamlined to assess NCAR's annual progress toward achieving the goals and objectives set by this strategic plan and the more detailed roadmap that will be established by the implementation plan. Our evaluation strategy will build upon our internal review processes and our extensive external, community-based advisory panel system. Evaluation will also include appropriate metrics and other mechanisms to effectively achieve and communicate that assessment.



Citrus College students in the Bridge to the Geosciences Program visit NCAR to learn about critical geoscience issues and career opportunities for community college students majoring in STEM.

This strategic plan embodies a vision of a more integrated, outward-facing NCAR

that maintains an unparalleled mix of curiosity-driven and use-inspired science, including development and technology transfer of the applications that emerge. Solving the most pressing scientific and societal problems of our time requires all the capabilities of the broad community to which we belong, making NCAR's unique combination of expertise, facilities, research, and focus on community empowerment more essential than ever. As we invest in a dynamic work environment and the diverse talent of the current and next generation, the potential for outcomes that improve life on our planet will only grow.

Acronyms used in this plan

APAR	Airborne Phased Array Radar
CAM	Community Atmosphere Model
CAM-Chem	Community Atmosphere Model with Chemistry
CESM	Community Earth System Model
CLM	Community Land Model
COSMO	Coronal Solar Magnetism Observatory
CTSM	Community Terrestrial Systems Model
LOTOS	Lower Tropospheric Observing System
MPAS	Model for Prediction Across Scales
MPAS-A	Model for Prediction Across Scales–Atmosphere
MUSICA	Multi-Scale Infrastructure for Chemistry and Aerosols
NCAR	National Center for Atmospheric Research
NOAH	National Centers for Environmental Prediction/Oregon State University/Air Force/ Hydrology Lab–National Weather Service
NSF	National Science Foundation
SIMA	System for Integrated Modeling of the Atmosphere
UCAR	University Corporation for Atmospheric Research
WACCM	Whole Atmosphere Community Climate Model
WACCM-X	Whole Atmosphere Community Climate Model extended to the thermosphere and ionosphere
WRF	Weather Research and Forecasting Model
WRF-Hydro	Weather Research and Forecasting Hydrological modeling system

Endnotes

[1] nsf.gov/about

[2] bit.ly/ucar-stratplan-2019-2028

[3] http://bit.ly/ncar-eo-stratplan

[4] http://bit.ly/ucar-odei-stratplan-2019

[5] http://bit.ly/ucar-tech-transfer-stratplan-2018

[6] bit.ly/ncar-ucar-honors-awards. Also see “NCAR by the numbers” on the back page of this plan.

[7] bit.ly/annual-reports-ncar

[8] bit.ly/ucar-blue-book

[9] bit.ly/ncar-stratplan-2014-2019

[10] Examples include the atmospheric models CAM, CAM-CHEM, WRF, MPAS-A, WACCM, WACCM-X and land-water-atmosphere models CLM, NOAH and WRF-Hydro (see acronym list, facing page).

[11] bit.ly/ncar-eo-stratplan

30%
of PhDs

earned in atmospheric sciences by historically underrepresented students since 1996 are UCAR SOARS Program alumni. Each year, NCAR staff comprise 85–95% of SOARS mentors, providing protégés with research, writing, computation, and community coaching in this undergraduate-to-graduate-school bridge program.

3,000+

NCAR-Wyoming Supercomputing Center users from 500+ external institutions, running 1,650 projects with more than 3.7 billion core-hours of computation. (FY15-19)

1 Billion

in estimated savings in losses averted since 1980s adoption by airports of the wind shear detection system developed by NCAR and academic partners.

4,800+

new registered users per year of WRF, the NCAR-based Weather Research & Forecasting Model, on average, and 795+ peer-reviewed publications per year citing WRF use, on average.

800+

scientific and technical visits per year to NCAR from 347 institutions in 46 states and 40 countries, on average (78% for more than 7 days). (FY15-19)

~1,250

individual community meeting participants and ~125 community model developers contributed to launch of CESM2 in 2018.

100+

institutions, 75 PIs, 88 graduate students, and 52 undergrads per year participating in 9 field campaigns facilitated by NCAR's Earth Observing Lab, on average. (FY15-19)

14.9 PB

of curated data available to researchers, from solar observations to field campaigns to supercomputer modeling experiments. (Feb 2020)

219

graduate students per year, on average, began or continued work with an NCAR advisor/ committee member on their thesis/dissertation.

7,700+

participants per year in NCAR-hosted workshops/tutorials/ colloquia, on average. (FY15-19

of 4,453 peer-reviewed publications include community co-authors

yielding an institutional H-index of 91.

NCAR by the numbers

Calendar years 2015–2019, inclusive, unless otherwise indicated