SCIENCE IN SERVICE TO SOCIETY

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ADVANCING ACTIONABLE EARTH SYSTEM SCIENCE

Strategic Goals & Priorities

2020-2024

Research Applications Laboratory (RAL)
National Center for Atmospheric Research

NCAR
UCAR
University Corporation for
Atmospheric Research

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1 BACKGROUND

1.1 INTRODUCTION

This working document describes the strategic goals and priorities of the National Center for Atmospheric Research (NCAR) Research Applications Laboratory (RAL). RAL's strategic priorities align with the strategic plans of NCAR (2020-2024), UCAR, and the National Science Foundation (NSF). The plan builds on RAL's demonstrated success in fundamental and use-inspired research and development as well as experience in executing successful processes for technology transfer. It is informed by the experience of its staff and on advice provided by RAL's external Advisory Panel and by colleagues internal and external to NCAR.

This document does not provide a comprehensive description of RAL projects and activities. Much more detailed descriptions of the items addressed here – and of many other RAL research including technology transfer, education, and service activities – can be found on the RAL website (www.ral.ucar.edu) and in the RAL Annual Reports.

1.2 RAL MISSION AND STRUCTURE

NCAR is a Federally Funded Research and Development Center (FFRDC) of the NSF and all parts of NCAR conform to the NSF mission "*To promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense*." In addition to serving as the Nation's premier agency for promoting fundamental research, NSF programs are also intended "*to foster and encourage the translation of new knowledge generated through basic research into processes, products, and methodologies with significant economic or societal impact*."

In conformance with the NSF statements above, the RAL mission closely follows the NCAR mission of actionable Earth system science. RAL's mission is:

- To conduct fundamental and use-inspired research that contributes to the understanding of the Earth system and its interaction with society;
- extend the capabilities of the scientific community; and
- transfer knowledge and technology for the betterment of society.

RAL makes important contributions in each of the three elements listed, although it emphasizes carrying advances from the first two elements into the third as a matter of course. The last bullet of the RAL mission statement closely connects to the Broader Impacts Criterion of NSF and suggests translating research findings into actionable Earth system science for the benefit of society. This mission emphasizes an "end-to-end" research and development approach. This mission statement is often shortened to be "*Science in Service to Society,*" as derived from a statement from NCAR's founder, Walter Orr Roberts.

While NCAR is primarily supported by NSF, RAL receives roughly 90% of its funding from other sources including other Federal agencies, the private sector, and foreign entities. In addition to use-inspired fundamental research, a hallmark of RAL's effort has been building programs directly with the operational agencies, stakeholders, and end users. RAL operates by keeping their requirements in focus to develop and transfer capabilities that are put to practical use. RAL has grown from its origins as a wind-shear research project at NCAR in the early 1980s to its current status as one of the largest of NCAR's seven laboratories. The staff is composed of approximately 180 staff with a diverse set of skills and experience in the physical sciences, social sciences, mathematics, software engineering, geography, information technology, project management, and administration. RAL also contributes heavily to NCAR's education mission through partnering with universities and hosting visiting students and postdoctoral fellows as well as reaching out to general audiences to share our research.

The Laboratory is managed by its Executive Committee, which is composed of the RAL Director (who also serves as an NCAR Associate Director), Deputy Director, RAL Assistant Director for Administration, Program Directors. This management team provides oversight and direction to a strong cadre of midlevel managers endowed with the authority and responsibility for leading scientific projects within RAL. RAL provides in-house training to guide project leaders using best practices within the NCAR environment. The RAL Representative Council represents the staff and provides input and feedback to the Executive Committee.

1.3 Vision and Values

1.3.1 RAL Vision

> RAL seeks its place as a world-class leader in performing collaborative and innovative end-to-end multidisciplinary Earth-system science that extends the capabilities of the scientific community and addresses important problems that impact society.

Achieving this vision requires the desire and capability to work in an interdisciplinary fashion with teammates within the Laboratory, with other units of NCAR and UCAR, with stakeholders, and with a host of colleagues across universities, federal laboratories, international organizations, and the private sector. Ensuring that people, projects, and programs are woven into a diverse, but coherent whole is a primary objective of RAL's management.

1.3.2 Operating Principles and Associated Values

The operating principles that underpin an organization's success and define its fabric and culture often reflect its inherent values. For RAL, these tenets leverage and expand on NCAR's values and principles and include:

- Scientific and technological excellence at the forefront of atmospheric science and its connections to the Earth and human systems.
- Staff passion to perform science in service to society.
- Ethical conduct, including fairness, respect for others, and scientific integrity.

- Connecting to societal benefits, informed and fostered through intentional partnerships having expertise beyond Earth system sciences, and with stakeholders in industry, government, and academia.
- Recognizing the importance of multidisciplinary specialized knowledge and expertise, as well as the ability to see the big picture.
- Creating opportunities for staff to grow professionally and to contribute to the development, application, and transfer of fundamental scientific and technological understanding.
- Creating and maintaining a workplace where openness, transparency, respect and trust are fostered, and in which inclusiveness, diversity of background, and diversity of approach are deeply respected.
- Creating and maintaining a working environment in which people are encouraged to be creative, ask hard questions, and take risks.
- Cultivating an entrepreneurial approach to the development of sponsored research that continually seeks new ways to apply knowledge and expertise to societal needs.
- Building and strengthening connections with sponsors and stakeholders extending from the initial stage of identifying their needs, capabilities, and constraints through the delivery of solutions.

2 SCIENTIFIC RESEARCH GOAL AREAS (2020-2024)

In 2019, RAL undertook an opportunity to think deeply about our current and future strategic goals, objectives, and priorities in support of the newly developed NCAR Strategic Plan. The RAL process included:

- Encouraging staff to participate in the NCAR strategic planning throughout 2019
- Posting a shared document posing a series of questions and inviting staff to contribute their answers to those questions (October 2019)
- Holding a 3-hour mini-retreat for staff to evaluate individually, in small then larger groups, RAL's strengths, weaknesses, opportunities, and threats, and to consider RAL's priorities for the coming five years (November 5, 2019)
- Discussing the outcomes of those first two efforts with RAL's external Advisory Panel and soliciting their input on RAL's strategic priorities and goals (November 14, 2019)
- Integrating the information gleaned by a small group of RAL leaders (November 18, 2019)
- Documenting the results in RAL's Internal Planning Analysis Report (February 2020)
- Soliciting feedback on the draft report from management, staff, and stakeholders (March 2020)
- Finalizing RAL's Strategic Goals and Priorities document in coordination with NCAR's Strategic Implementation Plan and involving the RAL Strategic Development Team (Spring - Summer 2020)

For the purpose of this docuent, we are defining our *goals* to represent our vision of what we would like RAL to achieve in the next five years. The *objectives* express our specific strategies and implementation steps to attain our goals. We then seek to *prioritize* our objectives to build a path toward implementation.

The strategic goals described here are based on several overarching scientific objectives chosen to advance Earth system science and prediction, and prioritized to address society's most pressing weather, water, climate, and air-quality challenges. These goals and objectives are synergistic with, and derive from, the NCAR strategic objectives (Ref. Section 3, NCAR Strategic Plan).

The RAL goals and objectives are configured to be applications-oriented, per RAL's role within NCAR. RAL possesses the expertise and capabilities to provide scientific and technical leadership within NCAR, the Earth System science community, and the world for innumerable research and development topics. RAL will continue partnering with other NCAR laboratories and leverage its capabilities to advance the state-of-the-science, conduct transfer technology, and educate the next generation of researchers in these areas for the betterment of humanity. Our goals relate to defining specific research areas for which RAL is uniquely qualified to lead. These goals include:

1. RAL will play a leadership role in transdisciplinary and convergent Earth system science in service to society, both within NCAR and throughout the research community.
2. RAL will lead the research community in implementing future-facing computational methods and models designed for the computational infrastructure of the future. This will include building and adapting new and existing numerical weather prediction models to develop emerging high-performance computing (HPC) architectures and apply those models across a variety of applications.
3. RAL will leverage big data and modern data discovery and analysis methods, including artificial intelligence and machine learning, and lead in exploiting these technologies for applications in environmental science.
4. RAL will co-lead advancing Earth system modeling through providing leadership on integrated cross-scale land-surface/hydrological modeling, modeling urban thermal and dynamic effects, boundary layer modeling, coupling the mesoscale to microscale models, modeling air pollution transport and dispersion, and advancing methods of modeling across scales. Such advances will be motivated by and applied to applications that are important to society.
5. RAL will collaborate with other NCAR laboratories to provide actionable Earth system science research results to users with needs for environmental information. Through these partnerships, advances in the science can focus on areas that most benefit society.
6. RAL will work with the community to define and advance common scientific goals, to enhance communication and cooperation across the Earth system enterprise, and to educate the next generation on ways to achieve excellence in actionable Earth system science. In addition, RAL will work with our colleagues to design annual symposiums to define "best practices" in actionable Earth System Science.

3 STRATEGIC RESEARCH OBJECTIVES AND PRIORITIES

The RAL strategic objectives draw from and build on the NCAR Strategic Plan (2020-2024). They flesh out the specific ways RAL's scientific goals will be accomplished over the next five years. They identify specific themes to which RAL staff will align with to position ourselves to provide leadership in discovering solutions to crucial Earth System Science challenges. Here we organize the objectives according to how they serve each of the scientific and technical goals and prioritize them in a way that more naturally leads to successful implementation.

3.1 LEADERSHIP IN CONVERGENT, TRANSDISCIPLINARY SCIENCE

NSF defines convergent research as:[1]

> *"Convergent research is a means of solving vexing research problems, in particular, complex problems focusing on societal needs. It entails integrating knowledge, methods, and expertise from different disciplines and forming novel frameworks to catalyze scientific discovery and innovation. Convergence research is related to other forms of research that span disciplines - transdisciplinarity, interdisciplinarity, and multidisciplinarity. It is the closest to transdisciplinary research, which was historically viewed as the pinnacle of evolutionary integration across disciplines. NSF identifies Convergence Research as having two primary characteristics:*
>
> - *Research driven by a specific and compelling problem. Convergence Research is generally inspired by the need to address a specific challenge or opportunity, whether it arises from deep scientific questions or pressing societal needs.*
> - *Deep integration across disciplines. As experts from different disciplines pursue common research challenges, their knowledge, theories, methods, data, research communities and languages become increasingly intermingled or integrated. New frameworks, paradigms or even disciplines can form sustained interactions across multiple communities."*

RAL has been successful in conducting research inspired by real atmospheric and related science problems and leveraging a transdisciplinary approach for several decades. We have achieved such research goals by embedding social science techniques in our use-inspired research. By nature, such research is actionable and often results in capabilities developed that integrate multiple methods and techniques to solve the problem. This approach requires that we listen to the needs of the end user, convene experts from multiple disciplines, employ a systems approach, and work synergistically to produce state-of-the-science solutions. We publish papers that describe both the results of our research as well as our convergent approach to research.

RAL will continue to advance this line of convergent research in areas that require Earth science information. Some specific convergent research areas in which RAL has been working and expects to continue to do so are:

- Renewable energy prediction (wind, solar, and hydro)
- Aviation hazard prediction (turbulence, icing, convection, lightning)

[1] https://www.nsf.gov/od/oia/convergence/index.jsp

- Hydrometeorology prediction (cloud physics, precipitation processes, land surface/hydrological modeling, long-term continental-scale hydromet simulations using convection-permitting models)
- National security hazard prediction (biological and chemical dispersion, urban meteorology)
- Geographical Information Systems (GIS) applied to Earth system problems
- Surface transportation weather (mobile sensor observations, pavement condition, hazard characterization)
- Wildland fire behavior prediction (coupled atmosphere fire behavior modeling, fuel moisture content)
- Verification method and technique development

These are examples of applications where applying a convergent science approach has been the key factor in providing actionable information for decision makers.

3.2 Leadership in Earth System Modeling

RAL will continue to seek, enhance, and develop, and extend atmospheric and land surface models to simulate aspects of the Earth system and advance them as applications to real-world problems. We will build and adapt models to fit future computational architectures seeking solutions that are forward looking and leverage new computing frameworks. This will continue along RAL's approach to developing modeling solutions for specific use-inspired needs and adapting existing community models, where appropriate.

RAL boasts a successful history of customizing community models for specific needs, as evidenced in the trend of extending, such as extending the Weather Research and Forecasting (WRF) model to address specific applications, such as those listed below. Many of these modeling advances can be applied widely in other models as well.

- WRF-Hydro merges the WRF weather model with hydrological systems modeling. WRF-Hydro has become the basis for the U.S. National Water Model, and for the development of a new community-oriented hydrologic modeling development effort in partnership with the USGS.
- WRF-Crop couples the Noah-MP photosynthesis and soil hydrology components with agriculture management models (crop-growth, irrigation, tile drainage), and develops high-resolution continental-scale datasets required by executing WRF-Crop .
- WRF-Solar was developed to optimize prediction of global horizontal and direct normal irradiance for use in predicting generation of solar power.
- WRF-LES (large eddy simulation) has been enhanced and adapted for use in wind energy applications and supporting UAS operations.
- WRF-Fire, originally developed within MMM, has been significantly enhanced to model wildland fire progression and interaction with the atmosphere to provide information for fighting wildland fires.

- WRF-Urban includes a variety of urban-canopy models that capture urban land-surface and urban-canyon turbulence processes as well as the urbanized high-resolution land data assimilation system.
- Cloud Microphysics - The Thompson scheme was the first aerosol-aware cloud physics scheme available in WRF that was critical for improving predictions of supercooled liquid in winter storms as well as the radiative impacts of clouds and aerosols.
- Noah-MP is a land surface model (LSM) using multiple options for key land-atmosphere interaction processes, and widely used in weather and water prediction models.

RAL also has an extensive history developing and testing models on new computing architectures and platforms. RAL has built a new large eddy simulation capability known as Fast-Eddy®, which fully utilizes Graphical Processing Unit (GPU) architecture to provide realistic high-resolution simulations of atmospheric flow faster than real time and saving substantial energy in computing. Fast-Eddy® is continually adding new physics capabilities and could become an all-purpose computing tool that allows next-generation forecasting for a multitude of applications. This new modeling capability has just begun to realize its potential and will continue to advance over the next five years.

3.3 Leadership in Machine Learning

RAL has long been a leader in applying artificial intelligence as part of our systems approach to weather research and prediction. With the design and deployment of the Dynamical Integrated foreCast (DICast®) system in the 1990s, RAL scientists and software engineers pioneered an AI approach to automating the forecasting process. DICast® is still considered the gold standard for weather prediction and has been continuously advanced through the past couple decades. It leverages historical and real-time weather and observations, including Internet of Things (IoT) data, to improve forecasts by applying machine learning. This Big Data approach was innovative and forward-looking, and this technology continues to be applied across many research areas in RAL.

The application of machine learning methods to support our research continues to expand in RAL and this expansion will continue. Machine learning will be applied toward broadening our knowledge of physical processes, accelerate modeling codes, and improve predictive skill through post-processing. Machine learning research is being conducted to improve our understanding of boundary layer turbulence, cloud physics, hurricane intensification, and air quality. The use of machine learning will expand over the next five years.

3.4 Leadership in Applications of Cloud Computing

RAL is increasingly utilizing cloud computing capabilities to conduct our sponsored research and deliver capabilities to our end users where most applicable. In addition, RAL is enhancing community collaborations through containerization of NWP system components and cloud compute platforms. This work leverages and complements previous efforts of the NSF-sponsored Big Weather Web project. A goal of this E&O effort is to expose the undergraduates to NWP systems through the use of software containers running in the cloud. RAL is exploring and utilizing cloud capabilities for:

- Predicting energy output by variable renewable resources (wind and solar installations)
- Improving upon prediction of extreme events, such as tropical cyclones
- Enhancing our knowledge and prediction capabilities of aviation weather hazards
- Enhancing our knowledge and prediction capabilities of bio/chem national security hazards
- Predicting weather conditions on roadways to improve safety for the traveling public
- Providing information on fuel moisture content to improve prediction of wildland fire spread
- Enabling faster, more accurate methods of downscaling model output to finer resolution

These applications, among many more, are transforming how we build systems for societally relevant applications. RAL will continue to seek out and pioneer new advances using these modern computational tools. RAL will continue to track the development of cloud computing and exploit advances as opportunities arise.

3.5 Partnering Across NCAR to Advance Actionable Earth System Science

NCAR's Earth system science research threads are ripe for advancement by leveraging RAL's expertise and capabilities. Other laboratories at NCAR may be making progress in areas where RAL can both contribute and utilize results for specific research and development applications. Thus, strengthening partnerships across NCAR's laboratories is expected to accelerate both research results and their application to societally relevant problems. A few timely examples for enhanced collaborations include:

- Working with CGD and CISL to apply big data and artificial intelligence techniques to climate modeling. These applications can involve emulating model parameterization using real data to both speed and improve results as well as post-processing model output to derive targeted information to inform stakeholders.
- Partnering with CGD and other laboratories to improve sub-seasonal to seasonal (S2S) prediction practices through leveraging artificial intelligence approaches to translate information into actionable science for particular purposes (such as for energy, aviation, or agriculture planning).
- Partnering with CGD and MMM to extend its cross-scale weather and water application capabilities.
- Partnering with MMM to better couple the mesoscale to microscale simulations for specific applications, such as for renewable energy.
- Expanding cross-lab collaborations on the NCAR Water System Program, which was established to conduct research to advance our understanding of hydro-meteorological processes and develop decision support tools for water management practitioners.
- Partnering with HAO to adapt their science advances to actionable space weather predictions for stakeholders.
- Enhancing cross-lab collaborations on the Short-Term Explicit Prediction (STEP) Program. STEP has focused on the improvement of short-term explicit prediction of high-impact

weather associated with severe weather including heavy rain, tornados, downbursts, flash floods, lightning and hail.

- Working closely with ACOM to leverage the best of chemical modeling to better model and predict air quality in order to better control extremes and protect the public from dangerous levels of pollution.
- Partnering with EOL to design and support experiments that inform and lead to solving societally-relevant problems, such as measurements to inform smarter deployment of renewable energy and measurements to improve characterization of UAS sensor and platform performance for data assimilation and impact modeling.
- Partnering with MMM and NCAR's Education and Outreach (E&O) Program on convergent science.

These and other collaborations across NCAR can multiply our impact and provide uses for the many science advances.

3.6 Partnering with the Research Community to Advance Common Goals and Educate the Next Generation

RAL scientists and engineers actively seek opportunities to collaborate with university investigators when developing proposals for a wide range of application areas including short-term weather forecasting, hydrology, water cycle, renewable energy, aviation, and surface transportation. Select R&D is focused on developing and advancing areas such as: connected vehicles, dispersion modeling, weather decision support systems, communication of weather risk, weather data analytics, climate and health science, GIS, climate services, community support for numerical weather prediction, data assimilation, urban meteorology and modeling, agriculture, wildland fire, and machine learning applications. RAL also supports and trains future generations of diverse scientists and engineers, and we will continue expanding our partnerships with the NCAR E&O Program and universities to foster and strengthen their programs for students in the Earth system sciences. RAL will continue to offer opportunities for collaboration through our engagement programs, including:

- RAL Visitor Program
- Developmental Testbed Center (DTC) Visitor Program
- Graduate Student and Post-Doctoral Opportunities, including mentoring Advanced Study Program participants
- Warner Internship for Scientific Enrichment (WISE) Fellowship
- Halaby Fellowship for graduate students interested in aviation weather research
- Workshops and Tutorials (METplus, WRF, WRF-Hydro, etc.)
- BRIGHTE workshop that involves under-represented groups
- NCAR's Actionable Earth System Science Symposium (proposed)

RAL will continue to look beyond NCAR for research topics that coincide with our approaches and expertise in Earth system science. RAL continues to cultivate partners across the community and beyond who might benefit from our approaches. RAL staff use their expertise to provide service to the community through various organizations such as the American

Meteorological Society, American Geophysical Union, and specialized organizations to collaborate with other experts toward the common good.

RAL will continue its role in educating the next generation of scientists and engineers about methods that use science to address society's problems and seek innovative solutions through a convergent science approach. This education focus will include mentoring undergraduate and graduate students, as well as postdoctoral fellows, teaching them how we approach research for applications.

4 IMPLEMENTING THE RESEARCH GOALS AND OBJECTIVES

Achieving the stated research goals and objectives requires ongoing planning and resources. Given that RAL only receives about 10% base funds from NCAR, targeted program development and sponsor maintenance efforts are essential. Here we discuss some of these specific research themes that meet the above-described goals, objectives, and priorities; advance science aligned with research that capitalizes on the skills and passion of RAL staff; and fit within the scope of the actionable Earth system science emphasized in the NCAR Strategic Plan (Ref. Sections 3 and 4).

4.1 ENHANCING HUMAN HEALTH AND WELL-BEING

RAL will continue to target research opportunities that improve human health and well-being. Example target areas where RAL's applied research, targeted systems modeling approach, skill with working with end users, and providing specialized decision support will be applied include:

- Enhancing air quality
- Improving water resource management
- Advancing research that will allow energy systems to advance toward carbon free operations
- Improving food and water security
- Improving urban hazards prediction
- Improving hurricane and tropical cyclone prediction
- Developing predictive capabilities for wildland fire behavior
- Providing actionable scientific information to improve transportation safety (air and ground)
- Providing actionable scientific information on environmental conditions in support of national security
- Enhancing knowledge of the impact of weather and climate on human health
- Providing actionable scientific information on the impacts of weather, climate and air quality on human health and well-being
- Enhancing the weather, water, and climate prediction capabilities of mission agencies and private sector

- Advancing research in environmental health, risks and resilience to extreme heat, spread of disease, and other health impacts.

4.2 Enhancing the Design and Protecting Critical Infrastructure

RAL's applied research will continue to extend the capabilities of the world's energy, transportation, communication, water, and health, and emergency services, all of which are susceptible to weather and climate hazards. Decisions support:

- Advancing applied research in aviation to enhance the safety of air transportation with particular emphasis on supporting the safe integration of emerging modes of autonomous vehicles into the National Airspace
- Providing state-of-the-science water management tools that combine our models of Earth system science to best represent the hydrological cycle
- Developing targeted tools that deliver weather decision support for surface transportation to departments of transportation as well as the traveling public
- Collaborating with HAO to provide actionable information on space weather and its impacts on communications, navigation, satellite function, and the electric power grid
- Designing systems targeted at optimizing the operation of the energy systems of the future that incorporate increasing amounts of renewable energy and storage technology
- Providing best practice methods for understanding, modeling, and delivering decision support for urban infrastructures

4.3 Advancing the Science and Technology of Predicting High-Impact Environmental Conditions

RAL will advance our ongoing applied research to improve the prediction of high impact environmental conditions and provide actionable information to a variety of stakeholders. This will involve modern computational tools, a systems approach to prediction and decision support, and using a convergent science approach to understand the needs of the stakeholders. Some specific contributions will include:

- Testing, validating, and verifying NWP systems plus their pre- and post-processing systems in collaboration with our operational partners
- Advancing Earth system modeling systems in ways to provide actionable decision support to partners, including WRF-Hydro, WRF-Fire, WRF-Solar, WRF-Crop, WRF-Urban, FastEddy®, Noah-MP, CTSM, and more. These advances will leverage both our physics approaches as well as machine learning.
- Transition and enhance capabilities to next generation community Earth System Models.
- Continuing research on boundary layer processes and how they are coupled to both the larger and finer scales
- Advancing the science of short-term explicit prediction, which seeks to improve understanding and prediction of high impact weather by developing advanced short-term local-scale prediction capabilities. The research includes data assimilation, uncertainty

quantification, atmosphere-land modeling and coupling, observation research, and verification

- Continuing research on the coupled relationship between natural and human systems, such as relates to urban meteorology, agriculture, and warning systems

4.4 Advancing Scientifically Sound Climate Mitigation and Adaptation

RAL will leverage its expertise to advance applied research in the area of climate change as well as methods to mitigate and adapt to it. Some specific ways that RAL will contribute include:

- Working with our partners, inside and external to NCAR, to advance climate modeling science through leveraging machine learning and data science
- Utilizing climate information to provide actionable information to a variety of stakeholders
- Downscaling climate data using physics-based methods, machine learning, and a combination of the two to provide local information on climate analysis and risk, including specialized information for stakeholders with specific needs
- Advancing the science of S2S, decadal, and longer-scale forecasts by applying novel big data and artificial intelligence approaches
- Quantifying user specific uncertainties through application of ensemble post-processing techniques, verification and machine learning.
- Helping the stakeholders to design best practices to alleviate and mitigate climate change by providing actionable information, communicating uncertainty, providing decision support tools, and accomplishing scenario analyses that enable carbon-free energy and transportation options

5 Supporting the Implementation

RAL has pride in its history of being proactive and achieving our goals and objectives through targeted program development, solid program and project management, excellence in science and engineering, and dependable delivery on research and technology transfer results. RAL maintains this level of excellence by hiring, training, and supporting a highly capable workforce endowed with the best complement of skills and passions to accomplish our goals.

5.1 Promote a Convergent Approach to Developing Actionable Science

As described in section 3.1, RAL has a long history of employing a convergent-science approach. For example, the GIS Program serves as a critical bridge between disciplinary communities with different expertise and points of view to facilitate innovative, interdisciplinary research. RAL has been an active participant in supporting NCAR's Early Career Faculty Innovators Program and incorporating social science into our applied projects. RAL will continue to work within NCAR and across the community to promote this approach to research and advance the way we work collaboratively.

5.2 Foster a Diverse and Inclusive Workforce

RAL's greatest strength lies in its excellent and deeply committed staff having strong scientific skills and a passion for serving society through their science. RAL management is committed to supporting and empowering these staff members. To that end, RAL has established the RAL Representative Council (RRC) to represent RAL staff to management, working together to foster programs to strengthen broad range of support for staff members. The RRC has tested a mentoring program, co-organized the annual RAL retreats, created initiatives to help staff balance their work and home lives, and initiated various staff social functions, ranging from monthly theme days through annual picnics.

RAL welcomes new staff through a quarterly orientation program when we introduce the history of RAL, discuss issues of relevance to new staff, and explain cultural expectations. Thus, while welcoming our new staff into our fold, we also set the tone for how we respect each other and work together to accomplish our goals. RAL recognizes staff excellence through annual awards and archives major awards through the RAL Wall of Excellence. We seek to train our project managers in ways to include staff in planning their projects and provide tools for these managers to learn best practices for managing projects in the NCAR RAL environment. We support periodic Thematic Internal Program Reviews when we present science and engineering updates on themes that cut across the laboratory. In addition, RAL hosts several affinity groups in which staff with similar technical or programmatic interests meet regularly to discuss advances and best practices. By carving out space for our staff to develop their talents and interests, we empower them to lead science and technology advances.

5.3 Maintain Existing and Forge New Strategic Partnerships

Given its overwhelming proportion of soft money support, RAL will remain dedicated to an ongoing effort in strategic program development to meet our goals. Given the uncertain timing in which these efforts bear fruit, the Laboratory is, by necessity, opportunistic in addressing specific research topics and must remain agile in its ability to design, propose, and undertake new projects. It is essential for RAL's continued existence to maintain a diversity of projects across our theme areas with multiple sponsors in order to minimize risk in any single sector. At the same time, RAL is increasing its interactions with the other management units at NCAR, and its expertise is sought out and cross-utilized by other groups in the same way that RAL programs seek to entrain colleagues from other parts of NCAR and from universities into our projects. RAL scientists and engineers will continue to contribute to, and sometimes lead, large flagship programs convening multidisciplinary teams at NCAR or within the community. Using our goals, objectives, and priorities as guidance, RAL will seek to advance research in the various themes described in section 4.

5.4 Strategic Partnership Engagement Guidelines

At the highest level of consideration, a new sponsored research effort in RAL must conform to the NSF mission:

> *To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense.*

RAL's research program makes identifiable profound contributions in each of these three areas and avoids work outside of these areas. NCAR's mission statement also addresses three areas: (1) to understand the behavior of the atmosphere and related physical, biological, and social systems; (2) to support, enhance, and extend the capabilities of the university community and the broader scientific community, nationally and internationally; and (3) to foster the transfer of knowledge and technology for the betterment of life on Earth. The latter area is clearly consistent with the "translation of new knowledge" and "innovation" referenced above. RAL adopts the NCAR mission statement and makes important contributions in each of these three areas.

At NCAR, NSF base funding has been focused almost entirely on the first two areas. The third element has been supported in RAL and other groups by leveraging small amounts of base support (sometimes zero) with the judicious pursuit of external funding. It is clear that the pursuit of external funding is necessary if significant activity in the third area is to exist. RAL has in place, by necessity, a concerted effort in program development. Part of this effort involves motivating individual scientists and engineers to pursue new ideas and new opportunities (within the guidelines to be presented below); this can be construed as instilling in the staff what is sometimes called an entrepreneurial spirit, in a way similar to what often happens in universities. Over the last several decades, RAL senior staff have brainstormed a number of new "enterprise" areas of endeavor that might involve major portions of the lab staff, other NCAR colleagues, university partners, and partnerships with other centers. Decisions on which areas to pursue do not occur overnight, but often take a year or more to develop.

Diligent effort is required to effectively interact with potential sponsors, learn how the relevant community might benefit, develop a network of concerned stakeholders, and undertake a dialogue in the "art of the possible." Another year or more might be required to arrive at some mutual understanding, write a proposal, and win funding. As this process moves on, the various criteria regarding suitability of the proposed work (listed below) may be applied all at once, or circumstances may require their consideration sequentially. At any point in the program development process, the effort can be terminated if it is seen that the parameters being assessed fall outside the acceptable range. Whether the proposed work is large ("enterprise") or that of a small team, the suitability guidelines below are followed, the supervisors and Program Directors are consulted (typically they have been in the loop from the start), and their approval is mandatory before a new proposal can be submitted.

The following list illustrates the guidelines for evaluating the appropriateness of a new research effort in RAL. The guidelines fall under the general areas of (a) the fit to NCAR and NSF, (b) the opportunity, and (c) the viability of the proposed work, including the associated "business" engagement aspects. The criteria listed are not intended to be in priority order after the first few. A final decision to pursue some area and actually develop a proposal is based on a qualitative weighting of the various items listed.

1. The partnership under consideration is consistent with the NSF and NCAR mission & strategic priorities.
2. The proposed engagement promotes the progress of science.

3. There is a clear societal benefit associated with the activity (NSF's "Broader Impacts" criterion).
4. The work is designed to pursue new challenging scientific/technical problems or to produce advances to previous approaches, and not be primarily duplicative.
5. The proposed work does not compete unfairly with the university community.
6. There may be a meaningful role for a university partner.
7. Personnel with the appropriate interest and skillsets to lead and carry out the program are identified.
8. The business aspects of the proposed effort are workable (SOW, liability, export control, indemnification, indirect costs, intellectual property, and publication agreement).
9. The expectations of the partner are understood, and are in line with the work proposed and resources available.
10. There is an anticipation of being able to work effectively with the proposed partners.
11. The partnership allows NCAR to accelerate progress in strategic priority areas.
12. The engagement enhances NCAR's leadership role to advance discovery, innovations and education.

In the 2010 BASC report "When Weather Matters: Science and Service to Meet Critical Societal Needs," seven of the eight important areas identified are currently underway in RAL (these include: weather modeling, quantitative precipitation estimation and forecasting, coupled atmosphere-hydrologic modeling, impacts forecasting, urban meteorology, and renewable energy). In many of these areas, RAL and its collaborators are considered national or international leaders.