

Date: November 2016

From: Dr. Antonio J. Busalacchi
President, University Corporation for Atmospheric Research

To: The Administration of the 45th President of the United States
The Members of the 115th Congress

Subject: **Recommended Research and Education Priorities for the Federal Investment in the Academic Atmospheric, Earth, and Related Sciences**

The University Corporation for Atmospheric Research (UCAR), representing more than 100 member colleges and universities, respectfully submits this white paper recommending a set of research priorities for the academic atmospheric, earth, and related sciences to the new Administration and the 115th Congress.

A focused investment of federal resources in the atmospheric, earth, and related sciences will make significant contributions towards meeting important societal concerns including: protection of American lives and property; expansion of new economic opportunities; enhancement of national security; and strengthening the U.S. leadership in research and development. This white paper focuses on the challenges and importance of investing in the following priority areas:

- Weather;
- Water;
- Climate;
- Air Quality;
- Space Weather; and
- Education

These recommendations relate directly to the Federal agencies for which the atmospheric, earth, and related sciences play an important role in their various missions – including the Office of Science and Technology Policy (OSTP); the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), Department of Agriculture (USDA), the Federal Aviation Administration (FAA); the Department of Defense (DOD), the Department of Homeland Security (DHS), the Department of the Interior (DOI), the Environmental Protection Agency (EPA), and others.

The recommendations are also consistent with pending legislation including the American Innovation and Competitiveness Act, the Weather Research and Forecasting Innovation Act of 2015, the Seasonal Forecasting Improvement Act, the Space Weather Research and Forecasting Act, as well as current and past guidance provided by the House and Senate Appropriations Committees.

This UCAR white paper also **supports** and **builds** on the May 2016 American Meteorological Society (AMS) [Policy Statement on Weather, Water, and Climate Priorities](#). In that statement the AMS outlined the need for continued development of people, knowledge, observing capabilities, physical and cyber infrastructure, and the evolving partnership between the public, private, and academic sectors of the weather, water, and climate enterprise.

Background Information

UCAR is a nonprofit consortium of more than 100 North American member colleges and universities focused on research and training in the atmospheric, earth, and related sciences. Founded in 1960 to manage the National Center for Atmospheric Research (NCAR) on behalf of the NSF. Today UCAR's mission is to empower its Member Institutions and NCAR by: promoting research excellence; developing fruitful collaborations; managing unique resources; creating novel capabilities; building critical applications; expanding educational opportunities; and engaging in effective advocacy.

NCAR was established as a center of excellence for research and education in the atmospheric sciences; and providing research support, facilities, and services for the atmospheric, earth and related sciences and the wider geosciences community. NCAR is designated as an NSF Federally Funded Research and Development Center (FFRDC) with approximately 750 full-time equivalent staff. The NCAR mission is to understand the behavior of the atmosphere, earth, and related systems; to support, enhance, and extend the capabilities of the university community and the broader science community, nationally and internationally; and to foster the transfer of knowledge and technology for the betterment of life on earth. This mission is accomplished through scientific research; the development, improvement, and operation of a number of facilities; and educational and outreach programs.

In collaboration with the university research and education community, NCAR focuses on fundamental research aimed at improving our ability to predict meteorological, air quality, and space weather hazards and increasing our understanding of the variability in and changes to the earth's climate system at regional and global scales. These research themes are enabled by NCAR-operated facilities such as unique aircraft; petascale supercomputing capabilities; and state-of-the-art community models. Partnerships with researchers in complementary fields, such as hydrology, cryospheric science, oceanography, terrestrial biology, public health and social sciences, broaden NCAR's activities beyond the traditional atmospheric, earth, and related sciences.

UCAR, as the manager of NCAR for NSF, is responsible for:

- Planning, executing, staffing, and managing the NCAR program;
- Providing and maintaining advanced observational, computational, and modeling facilities and services to support the research and education community;
- Operating and maintaining the NCAR buildings and facilities, developing and incorporating new facilities, as appropriate;
- Recruiting, developing and retaining a highly competent and diverse staff;
- Planning for and implementing future initiatives in partnership with UCAR Member institutions and the research and education community;
- Overseeing and sustaining an innovative and vigorous program of basic and applied research in support of the atmospheric, earth, and related sciences.

UCAR believes that in order for the research and education community to contribute both the knowledge and human resources needed by society, it is essential that the NSF, NOAA, NASA and the other related mission agencies receive priority support for their research and education activities as well as the continued improvement of operational programs. In addition, the agencies should be commended for and encouraged to build on their highly collaborative relationships not only within the Federal enterprise, but also with the academic and private sector.

UCAR provides important scientific support not only for the university based atmospheric, earth, and related sciences community, but also for the agencies with missions that require research, data analysis and management, and training in these disciplines. UCAR endorses a set of core values to ensure the Nation's research and education enterprise remains strong, vital, and productive. These values include:

- Dependence on merit review and the pursuit of objectivity in research;
- The federal investment in research and education should to be broad and inclusive if we are to be successful in the endeavors discussed below; and
- The responsibility of the research and education community to enable the beneficial use of scientific discovery by society.

Recommended Research and Education Priorities for the Academic Atmospheric Earth and Related Sciences

WEATHER: Accurate weather forecasts are critical in providing important information for short term and longer term forecasts as well as early warnings of impending severe weather. The goal of weather prediction is to provide timely and accurate information that will serve to reduce weather-related losses, protect life and property, improve public health and safety, support economic prosperity and national security, and improve the quality of life for all citizens.

According to the National Academies, the benefit of investing to improve public weather forecasts and warnings is substantial: the estimated annualized benefit is about \$31.5 billion, compared to the \$5 billion spent annually by the Federal Government for generating the baseline information.

Improvements in short term and seasonal forecasting would benefit society in many ways beyond being better prepared for severe weather events. Weather-related aircraft delays could be reduced which would reduce operational costs for the commercial airline industry. Use of weather information will allow for better options in the decision-making of various stake holders in the transportation sector, such as commuters or tourists, transport infrastructure owners and transport service and maintenance operators. Improved seasonal forecasts would be of value to the agricultural sector of the economy allowing farmers and others to either take full advantage of predicted beneficial weather conditions as well as prepare for forthcoming challenging weather conditions such as drought or flooding.

The United States should unambiguously lead in operational numerical weather prediction and earth observing capabilities yet by some measures, our capabilities lag behind our international competitors. This suggests the U.S. could be mitigating the economic, national security, and public safety implications of severe weather more effectively. The university community is working to develop a better fundamental understanding of the integration of earth system sciences as well as better models (and the computing capabilities needed to use such models) to simulate local, regional, national and

global-scale conditions that impact severe storm development.

In addition, the university community strongly supports the need for the sophisticated integration of the social sciences in the design and execution of future weather and climate research activities as well as the dissemination of weather and climate relevant information. Such research will enable better predictions of and responses to storms and other forms of severe weather that can reduce loss of life and property, and limit economic damage to areas experiencing severe weather.

Fundamental research and research training, via support provided by the National Science Foundation and, to a more limited extent by other Federal agencies, underpins any meaningful effort to improve the quality of weather forecasts. This includes such areas as: studies of the physics, chemistry, and dynamics of earth's upper and lower atmosphere and its space environment; research on weather and climate processes and variations; and research to understand the natural global cycles of gases and particles in earth's atmosphere.

Given the continuing evolution of the weather enterprise – particularly the significant growth of the private sector's ability to provide unique weather related products and services, and the demise of some observing capabilities, there is a real need for one or more forums that enable public-private sector strategic planning. A valuable contribution would be a National Academies' decadal survey related to weather, involving representatives of the public and private sectors. Such a survey could develop a prioritized set of Federal (domestic and defense related) research and operational priorities for weather research and weather forecasting which should be useful for decision and policy makers in an era of constrained resources.

WATER: Water challenges are facing communities and regions across the United States and the world, impacting billions of lives and costing billions of dollars in damages. These challenges are particularly problematic in predominantly poor, minority, or rural communities, where water inequality can go hand-in-hand with socioeconomic inequality. Recent events, including record-breaking drought in the

West, severe flooding in the Southeast, and the water-quality crisis in Flint, MI, have elevated a national dialogue on the state of our Nation's water quality, resources and infrastructure. This dialogue is increasingly important as a growing population and changing climate continue to exacerbate these water challenges. Issues related to water quality, energy production, water resource management, and water infrastructure are even more challenging in developing countries. Accordingly, we must work together to build a sustainable water future—one in which everyone has access to the safe, clean, and affordable water they need, when and where they need it.

Weather and climate models are fundamental for understanding the earth's water cycle and issues related to availability, quality, water resource management, energy production, flooding, and drought. One focus of water research is to reduce uncertainty through improved understanding and integration of the water cycle in weather and climate models. Another component of the effort is the examination of the impact of climate change on water systems, and to determine potential effects on water management policy.

Research support is needed in areas related to improving modeling that will deliver more timely and detailed flooding forecasts. Water managers and planners need advancements in estimating snowpack and stream flow that will provide more information about spring runoff, flooding, and municipal water supply availability. Research that will result in reliable drought forecasting a year or more in advance would give the government and private sector the time and information to prepare accordingly.

Changing precipitation patterns and growing populations have made the regions, such as the Southwest, increasingly vulnerable to water shortages and drought. Science is needed to improve flood forecasts and anticipate drought far in advance. Research can facilitate the improvement of the nation's existing urban water systems through the development of innovative water technologies, management tools and systems-level analysis. Urban water management would benefit from a set of decision-support tools that will allow utilities to quantify regional urban water resiliency and sustainability; promote the diversification of urban water supply portfolios by enabling virtual trading in

regions with shared water resources; and support integrated management of water reuse and storm water recharge systems.

A complete understanding of the water system requires an approach that extends beyond the atmosphere to include how the earth's water system is linked with climate change, land use and ecosystems.

CLIMATE: Today's global climate changes are having a noticeable impact via heat waves, extended drought, wildfires, migration of disease-carrying insects and pests, warming oceans, and other events. Global climate change has already had observable effects on the environment. Glaciers have shrunk, ice on rivers and lakes is breaking up earlier, plant and animal ranges have shifted and trees are flowering sooner. Effects that scientists had predicted in the past would result from global climate change are now occurring: loss of sea ice, accelerated sea level rise and longer, more intense heat waves.

Global climate change is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, and how sensitive the earth's climate is to those emissions. Temperatures will continue to rise. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, uniform across the country or throughout the world thus impacting different regions in different ways. Frost-free and growing seasons will lengthen impacting world-wide agricultural food production.

Changes in precipitation patterns will continue. For example, more winter and spring precipitation is projected for the northern United States, and less for the Southwest, over the course of this century. More extensive droughts and heat waves are expected to occur and severe storms, such as hurricanes and typhoons are expected to become stronger and more intense. Sea level rise could increase anywhere from 1 to 4 feet by 2100 depending on the location. Sea level rise has national security implications for relevant coastal facilities and may also contribute to societal unrest in developing countries.

As a public policy issue, global climate change presents a number of key issues: climate is changing; people are causing climate to change; the societal consequences of climate change are highly uncertain but include the potential for serious impacts; and there are numerous policy options for climate change risk management. Global climate change risk management approaches generally fall into the following categories: mitigation; adaptation; geoengineering or climate engineering; and knowledge-base expansion—efforts to learn and understand more about the climate system, which can help support proactive risk management.

Comprehensive global climate change risk management includes a combination of policy responses. However, policy choices necessarily integrate both objective information about the climate system and our relationship with it, and subjective value judgments such as whether we are more averse to the risks of changes in climate or the policy responses, the ways we assess issues of fairness among nations and peoples, and the consideration we give to cultural heritage or nonhuman species. This creates a complex and often contentious risk management challenge.

Nevertheless, understanding global climate change is critical to this country's and the world's welfare. Fundamental use-inspired research, made possible by cutting-edge tools for collecting and analyzing data, can provide the knowledge that governments, businesses, and communities need as they address the climate-related changes that pose growing risks to life, property, natural resources, and the economy. Research advances understanding of the interacting physical, chemical, biological, and societal components of the earth system; the vulnerability and resilience of its natural and human dimensions; and the means by which scientific knowledge can effectively inform responses to global change. Such research depends on sustained programmatic investments in multidisciplinary observations, process studies, and modeling. These foundational components of scientific inquiry require their own expertise, infrastructure, and planning horizons, but they ultimately work together to produce a more comprehensive and integrated understanding of global change.

AIR QUALITY: Air quality affects broad sectors of society, from human health to crop yields to enjoyment of our national parks. Particulate matter, in addition to ozone, triggers most air quality alerts

and health effects. Scientists are improving pollutant tracking and developing detailed air quality predictions. Research is also focused on developing detailed air quality forecasts days in advance. Improved forecasts offer the promise of significant benefits to society.

Additional work is needed regarding the development of modeling tools to characterize air quality and predict exposures at local to urban scales, regional to continental scales, and global to hemispheric scales; and the linkage of air modeling tools with modeling tools for other media (e.g. water) and development of an integrated multi-media modeling system. More than 110,000 people in the U.S. die each year due to outdoor air pollution, and the annual cost to the nation is estimated at nearly \$150 billion due to disease, missed work, and damage to crops and forests. Scientists are improving particulate matter and pollutant tracking, and developing detailed air quality predictions as both play an important role in improving modeling and forecasting.

SPACE WEATHER: Space weather can disrupt vital technology – both space based as well as ground based -- that forms the backbone of this country's economic vitality and national security, including satellite and airline operations, communications networks, navigation systems, and the electric power grid. Effective actions to prepare for space weather events require a better understanding of the sun-earth connection. Benchmarks will help government and industry assess the vulnerability of critical infrastructure, establish decision points and thresholds for action, understand risk, and provide points of reference to enable mitigation procedures and practices and to enhance response and recovery planning.

Opportunity exists to improve the fundamental understanding of space weather and increase the accuracy, reliability, and timeliness of space-weather observations and forecasts (and related products and services). The underpinning science and observations will help drive advances in modeling capability and improve the quality of space-weather products and services. A better capacity to develop and transition the latest scientific and technological advances into space weather operations centers will enable an improved rate of forecast improvement.

To advance space weather capabilities, it is essential that relevant Federal agencies coordinate their actions and their assets to improve, and design appropriately, observation systems. A mix of assets is needed: space-based measurements that provide the coverage necessary for detecting space weather hazards, some of which cannot be discovered from the ground, and ground-based measurements that provide more extensive spatial coverage.

EDUCATION & TRAINING: The success of the research challenges above is dependent on a science, technology, engineering and mathematics (STEM) education system that produces a diverse and well-prepared workforce of scientists, technicians, engineers, mathematicians and educators and a well-informed citizenry that have access to the ideas and tools of science and engineering. STEM education – at all levels, from K-12, to the undergraduate level, and graduate level --

will contribute to the enhancement of the quality of life of all citizens and the health, prosperity, welfare and security of the nation.

The goals for this Nation’s STEM education activities should be to: prepare the next generation of STEM professionals – in the geosciences and beyond -- and attract and retain more Americans to STEM careers; develop a robust research community that can conduct rigorous research and evaluation that will support excellence in STEM education and that integrates research and education; increase the technological, scientific and quantitative literacy of all Americans so that they can exercise responsible citizenship and live productive lives in an increasingly technological society; and broaden participation (individuals, geographic regions, types of institutions, STEM disciplines) and close achievement gaps in all STEM fields.

Understanding how the earth system works and transforming this knowledge into action will allow our nation and the world to effectively respond and adapt to changing environmental conditions. National investment and leadership combined with enhanced partnerships across all levels of government, the private sector, the academic sector, and the nongovernmental organization sector are necessary to make this vision a reality. Enhancing research and education support in the areas outlined above will better enable individuals, communities, businesses, and governments to manage risks, adapt and mitigate in due to changing environmental conditions, and enhance national security and economic and social prosperity.

The UCAR university community stands ready to assist policy makers as requested, including serving on agency and interagency advisory and policy making boards, testifying at hearings, conducting briefings for policy makers, engaging in workshops and other exercises designed to develop knowledge and implement relevant strategic plans, recommending candidates for key positions within the Executive Branch, and responding to requests from the Congress and its committees for scientific and technical information as it relates to policy and legislative issues under review.