

# RESEARCH APPLICATIONS LABORATORY



## Science in Service to Society

Strategic Plan for the Research Applications Laboratory  
National Center for Atmospheric Research  
2011-2015





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# 1. Background on the Research Applications Lab

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## About this Plan

This document is the strategic plan of the Research Applications Laboratory (RAL), one of five laboratories in the National Center for Atmospheric Research (NCAR). It describes RAL's mission, vision, broad goals, and priorities for the next five years. This plan is used in the ongoing process of program management and program development, and provides the basis for more detailed program and budget decisions that occur on an annual basis.

This strategic plan updates and extends previous plans written in 2006 and 2009. It is well aligned with the strategic plans of NCAR, UCAR, and the National Science Foundation (NSF), and shows how RAL contributes to the goals of the parent organizations. The plan builds on RAL's demonstrated success in directed research and in executing efficient procedures for technology transfer, on the experience of its staff over the past twenty-nine years, and on advice provided by its Advisory Panel and by colleagues both internal and external to NCAR.

This plan is not a comprehensive description of RAL projects and activities; rather, it attempts to show the Laboratories overall direction, an overview of key program elements, and a description of frontier areas that represent developing programs and opportunities over the next five years. Much more detailed descriptions of the items addressed here – and of many other RAL research, technology transfer, education, and service activities – can be found on the RAL web site ([www.ral.ucar.edu](http://www.ral.ucar.edu)) and in the RAL Annual Reports. To aid the reader, a list of acronym definitions is included at the end of the document.

## RAL Mission and Structure

NCAR is a Federally Funded Research and Development Center of the National Science Foundation (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.*”

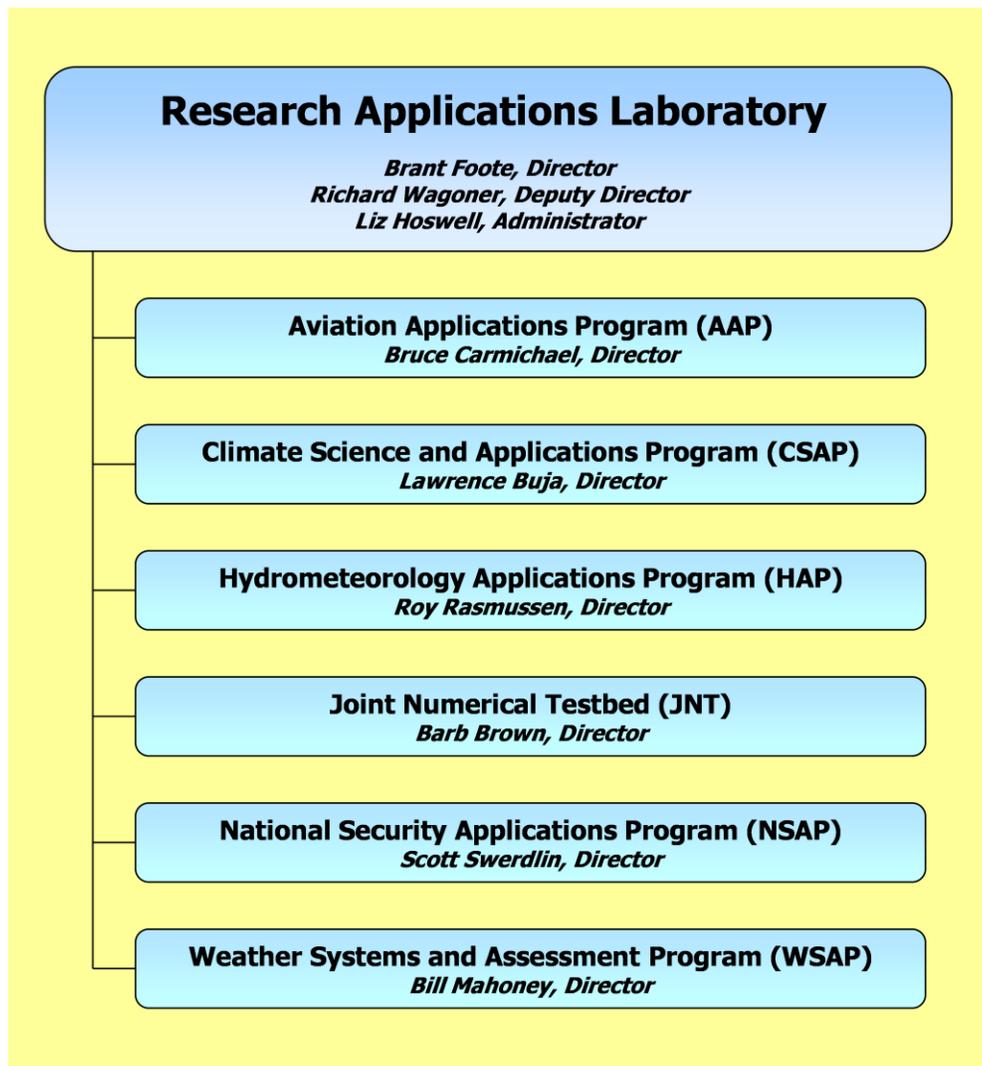
In conformance with the NSF statements above, the RAL mission closely follows the NCAR mission and may be stated as:

- ***To conduct directed research that contributes to the depth of fundamental understanding of the atmosphere and its interaction with society***
- ***To support, enhance, and extend the capabilities of the scientific community, nationally and internationally***
- ***To develop and transfer knowledge and technology that contributes to the betterment of life on Earth***

The latter area is closely connected to the Broader Impacts Criterion of NSF and the “translation of new knowledge” for the benefit of society. RAL makes important contributions in each of the three elements listed, though it places an emphasis on carrying advances from the first two elements into the third as a matter of course. Such emphasis is sometimes called an “end-to-end” approach.

While NCAR is largely supported by NSF, RAL receives over 90% of its funding from other sources including other Federal agencies, the private sector, and foreign entities. In fact, a hallmark of RAL’s effort has been building programs directly with the operational agencies, stakeholders, and end users, and by keeping their requirements in focus at all times, developing and transferring capabilities to them that are put into practical use.

RAL has grown from its origins as a small research program at NCAR in the early 1980s to its current status as one of the five laboratories of NCAR, with six divisions as shown below. The staff is comprised of approximately 240 persons with a diverse set of skills and experience in the physical sciences, social sciences, mathematics, software engineering, project management and administration.



*Organization chart for the Research Applications Laboratory.*

The Laboratory is managed through its Executive Committee, which is comprised of the RAL Director (who also serves as an NCAR Associate Director), the Deputy Director, the RAL Administrator, and the Directors of the programs listed above. This management team provides oversight and direction to a strong cadre of middle-level managers who are given both authority and responsibility for leading the many projects within RAL.

A companion document to this Strategic Plan, the RAL Compendium (also available at [www.ral.ucar.edu](http://www.ral.ucar.edu)) provides a more extensive description of RAL's background and activity, and how its emphasis on an end-to-end approach fits into the missions of NSF, UCAR, and NCAR. A more complete discussion of what is meant by "directed research" is included there, along with its relationship to the concept of "use-inspired basic research." The Compendium also provides discussion of how specific projects are chosen (or rejected), the interactions of RAL staff with other parts of NCAR and the external community, the compilation of a large number of program metrics, and other related topics.

## Vision and Values

### RAL Vision

***RAL seeks to be a world-class leader in performing collaborative end-to-end research, development, and technology transfer that expands the reach of atmospheric and related sciences by addressing important problems that impact society.***

Achieving this vision requires the willingness and ability to work in an interdisciplinary way with teammates inside the Laboratory, with other units of NCAR, with stakeholders, and with a host of colleagues in universities, federal laboratories, and the private sector. Ensuring that people, projects, and programs are woven into a diverse, but coherent whole is a primary objective of RAL management.

### Operating Principles and Associated Values

The operating principles that contribute to a group's success and that define its fabric and culture may be considered to reflect the values that it holds. For RAL these include:

- Recognition of the importance of excellence and maintaining the highest possible scientific and engineering standards
- Recognition of the importance of specialized knowledge and expertise, as well as breadth of interest and experience and ability to see the big picture
- Recognition of the value of multidisciplinary teamwork, both within the Laboratory and more broadly with members of the research and operational communities, as well as with stakeholders on specific projects
- Recognition of the importance of systematic validation of all our products; this includes a rigorous scientific evaluation of the inherent skill of the product; it also includes an evaluation of the operational benefits that can be derived from the product
- Creation of opportunities for staff to grow professionally and to contribute to the development, application and transfer of fundamental scientific and technological understanding

- Creation and maintenance of a workplace in which openness, transparency, respect and trust are fostered, and in which diversity of background and diversity of approach are respected
- Creation and maintenance of a working environment in which people can be creative, ask hard questions, and take risks
- An entrepreneurial approach to program development that continually seeks new ways to apply knowledge and expertise to societal needs
- A strong connection with sponsors and stakeholders extending from the initial stage of identifying their needs, capabilities, and constraints through the delivery of solutions
- Conduct of programs with a diverse set of government and non-government sponsors both nationally and internationally

## **Building Advocacy**

In pursuing its vision, RAL sees the important need to advocate on behalf of both the science and operational communities for research, development, and transfer of weather- and climate-related technologies that serve end-user needs. For many years RAL has emphasized the transportation, national defense and water resources communities; these efforts will be continued and in some cases expanded. Newer advocacy efforts include alternative energy, climate, weather, and health, urban issues including air quality, and the public service sectors. An effort is made to convince members of these communities that advanced weather- and climate-related R&D can lead to societal benefits such as increased safety and efficiency of their operations. Increased attention will be given to social science aspects that provide an underpinning for decision makers in these communities.

## **Liaison to Stakeholders**

RAL maintains strong relationships with decision-makers in business and industry, with local, national, and international governmental bodies and agencies, and with non-governmental organizations. RAL seeks to remain a catalyst in connecting science and society. Policy questions and information needs will be considered as research plans are developed. RAL will investigate decision-making processes and develop decision-support mechanisms to help ensure efficient and effective application of science to societal needs. Both research and operational goals will be pursued in model development. RAL will seek engagement with those interested in the atmospheric, social and Earth-system sciences, will conduct its work in an open and transparent manner, and will pro-actively inform the public about its programs and results.

## **Context of RAL's work**

### **In a Rapidly-Changing World**

RAL's success over the past two and a half decades has been related in part to its ability to foresee problems that evolving communities and technologies face as they are exposed to weather hazards. Two decades ago it was common for organizations like the Federal Aviation Administration (FAA) to design very large systems without factoring in the effects of weather hazards. That is not true today in large part because of RAL's ability to convince FAA managers that such systems could not operate with sufficient safety or efficiency without incorporating weather information. Surface transportation planners and designers have adopted similar practices, again largely due to RAL and its partner organizations playing an early role in developing weather-resilient systems and infrastructure.

It is useful to try to anticipate critical national imperatives that will drive public funding for research. Such a consideration led RAL to start a new Climate Science and Applications Program in 2009 to address a national priority related to societal vulnerability and adaptation to global change, in parallel with a federal effort in what is termed “climate services.” Similar reasoning led RAL to get involved more deeply in the atmospheric side of homeland security and public safety issues more than a decade ago.

## **An End-to-End R&D Process**

NCAR’s founder, Dr. Walter Orr Roberts, promoted “Science in Service to Society” from the earliest days of NCAR’s history. RAL adopted that theme to describe its primary mission. In order for this mission to be carried out successfully, a process that is sometimes referred to as “end-to-end R&D” must be employed. The process begins with basic science (physical and social), which is always the foundation of any successful effort to transfer technology. The process continues with directed research and development aimed at finding tailored solutions to specific weather and climate problems. The end point is the delivery of a new technology that increases productivity, safety, mobility or efficiency within some operational environment, or social science results that provide a basis for making difficult decisions. RAL participates in all phases of this cycle, with careful assessment of the science and its readiness for application, thoughtful discussions with the user community about real needs and the readiness to accept and exploit new capabilities, and focused attention on the necessary human and computational resources (on both the developer and recipient sides) required to test, validate and deliver the technology. In the last step, it is usually critical that operational stakeholders receive suitable training to use the new technology.

While the phrase “end-to-end” is commonly used, a term like “spiral development” more accurately portrays the iterative development process between researcher/developer and user that is almost always necessary for successful technology transfer. Careful attention to user needs always needs to be a hallmark of such work.

## **Need for On-Going Program Development**

With its overwhelming fraction of soft money support, RAL will remain dedicated to an on-going effort in program development. Given the uncertain timing in which these efforts bear fruit, the Laboratory is of necessity opportunistic in addressing specific issues, and must remain agile in its ability to design, propose, and take on new projects. At the same time, RAL is increasing its interactions every year 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 in other parts of NCAR and in the universities. RAL scientists and engineers will continue to contribute to, and occasionally to lead, large flagship programs bringing multidisciplinary teams together at NCAR. See also the RAL Compendium for a more complete discussion of these interactions.

## **Involvement with Sponsors and Other Stakeholders**

RAL is committed to ensuring that its research and the products it delivers to its sponsors reflect the highest quality science and technology allowed by project budgets and timetables. This requires RAL to develop a detailed knowledge of a sponsor’s needs and requirements. This takes some time and patience on the part of both parties, but has proven to be a key element in completing a successful transfer of technology while keeping an accurate focus on relevant societal issues. We will continue to make this investment of time and energy as we develop new programs as part of this strategic plan.

## Dialogue in the “Art of the Possible”

Experience has shown that as a new project is designed in partnership with a sponsor, neither party tends to have a clear understanding of the exact nature of the scientific or technological package to be delivered, or, in fact, the problem to be solved. Many times people simply “don’t know what they don’t know.” To design a project as effectively as possible, RAL attempts to engage the sponsor in a dialogue concerning the “art of the possible.” By this is meant an interactive process whereby each party, with its pre-conceived notion of the problem and the deliverable, begins to exchange information regarding what might be possible on the science and technology side and what changes in operating procedures might occur if these changes were deployed for the sponsor. This normally results in a much more detailed understanding of the sponsor’s real needs as compared to perceived needs, and an in-depth understanding of the sponsor’s decision process. Both parties shift their thinking to a set of common ideas regarding requirements and deliverables. This iterative process, which has worked well, will continue to be applied in future projects.

## Sponsor’s Role in Guiding the R&D

Having established the goals of the program as outlined above, the next essential step is to guide the research and development carefully so that the deliverable is focused (and sometimes re-focused, within the constraints of time and budget) to meet the needs of the sponsor. Two mechanisms are employed to allow the sponsor to guide the R&D from beginning to end: a) formal feedback from user groups (typically operational stakeholders from the sponsor’s community) who work regularly with RAL developers and provide input on interim developments; and b) frequent program reviews with senior managers in the sponsoring organization who can approve work done and make mid-course corrections. This collaborative development process prevents sponsors from being disappointed at the end of the technology transfer, a possibility in many industrial procurements where the sponsor and developer may have different visions of the deliverable.

## Evaluating Program Success

### Scientific and Operational Validation of Work

The scientific validation of meteorological forecast products is an essential step in determining their utility and represents an important part of our work. Developing improved techniques for forecast validation is a scientific research topic in its own right, and one in which RAL strives to maintain a strong program. In recent years, major new evaluation tools have been developed by RAL and its collaborators, and have been made available to the community through the activities of the Joint Numerical Testbed.

From the viewpoint of technology transfer and the end user, the operational evaluation of forecast products is as important as the scientific evaluation. How useful is the capability to the customer? What are the actual efficiency and safety gains attained? What is the anecdotal feedback from the “front lines” regarding whether the product is helpful to their decision process? Such subjective evaluations are often as informative as formal benefit/cost studies, are more readily obtained, and are commonly the primary basis for establishing customer satisfaction. The operational evaluation is critical in that it literally takes the science and technology out of the laboratory and puts it into a societal, operational setting.

## Other Specific Metrics of Performance

In the research applications arena one may consider metrics related to the research part itself, metrics related to support to the community, and others related to the applications, the technology transfer, and the societal benefit parts.

The first two are quite familiar to the traditional research community, and consist of things like:

- The advancement of scientific knowledge as measured by refereed publications
- Citation indices
- Patents
- Visitor interactions (numbers of visitors, co-authored papers)
- Support to the community through
  - Development and support of community models and community software tools
  - Service on national and international advisory panels, editorial boards, AMS Committees, National Academy of Science committees, etc
  - Planning and chairing national and international conferences, and leading or participating in field campaigns
  - Organizing and conducting community tutorials and workshops
  - Education and outreach to national and international groups
  - Service on academic thesis committees

Regarding the applications-oriented part of our work there are, in addition, measures like:

- Longevity of relationship with the sponsor as a metric of the sponsor's satisfaction with the work being conducted (for example, has the work led to a higher level of safety, productivity, efficiency, or public health to point that the sponsor seeks to continue the relationship?)
- Numbers of scientific and operational evaluations conducted as described above
- Adoption of the product or capability by the sponsor, or by other economic sectors (public, private, or academic)
- Development of international standards and their subsequent adoption
  - Examples are turbulence, snowfall measurement, "check time", work on OGC standards, RTCA standards
- Technologies licensed

## 2. Introduction to Strategic Goals and Priorities

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The following sections describe six areas in which RAL will focus its efforts. The goals and priorities here have been defined in ongoing discussions between RAL managers and technical staff, our collaborators in other parts of NCAR, the RAL Advisory Panel, our external colleagues, and interested public and private-sector stakeholders. The process of defining goals and priorities has also been informed by careful consideration of:

- RAL’s mission and vision for the future within the context of the strategic plans of NCAR and of the National Science Foundation
- National and international needs and opportunities in science and technology as reported, for example, in reports of the National Research Council
- The expertise, interests, and capabilities of RAL staff and research partners

Throughout this process, every attempt has been made to balance RAL’s responsibility to attack large-scale, difficult problems with its judgment about the tractability of such problems and prospects for progress (see the more complete discussion regarding project selection in the RAL Compendium).

The work described in the six areas presented below corresponds, to an extent, to work that is concentrated in the six RAL Program units described in Section 1. However, by design, the correspondence is only a rough one. It is important to recognize that many scientific and development topics that are being pursued contribute to a broad spectrum of applications goals. There is thus no attempt to “pigeon hole” a piece of research into only one applications topic, or to confine a subject to only one of RAL’s six management units. For example, the cross-cutting topic of forecast verification and product quality assessment is an activity that naturally affects each of the programs, though it is centered in the JNT. The topic of precipitation forecasting, though it is clearly a strong aspect of hydrometeorological research and a key aspect of understanding the water cycle, is also highly relevant to the Laboratory’s work involving numerical weather prediction (NWP) advances, coupled model applications, and a host of other topics dealing with water resource management, transportation, agriculture, climate, etc. It is believed that the research overlap between application themes and the cross-strapping of scientists and research topics across RAL program units are strengths of the program. RAL seeks out and maintains similar collaborations and overlapping subject areas with other parts of NCAR, as well as with the universities and other government labs. In the NCAR context it is worth noting that RAL currently leads a number of cross-laboratory programs including the Water System Program, NCAR Vulnerability, Impacts and Adaptation Program associated with the Integrated Science Program, the Short-Term Explicit Prediction program, and the Developmental Testbed Center.

The discussion here is intended as a summary, as noted earlier. More detailed descriptions of RAL science and technology transfer can be found in the project plans of the laboratory’s six management units and the RAL Annual Report on the Web at [www.ral.ucar.edu](http://www.ral.ucar.edu).

The strategic planning elements that follow are grouped into six general goal areas that are regarded as imperatives for the laboratory. In each of these areas the high-level goal is first stated as an Overarching Priority, followed by a discussion of the motivation for this effort. The specific plans are then presented in terms of Near-Term Objectives. These are followed by other long-term objectives termed Frontiers. Generally the former involve the continuation of important work presently underway, along with follow-on projects that expand the scope and capabilities developed. The Frontiers describe research projects that only recently began, or those in the formative or planning stages. They often involve strong elements of program development, building of new collaborations, and interactions with Potential or Expected Sponsors.

## 3. Goal Area: Weather Technologies for the Global Air Transportation System

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### Overarching Priority

***Provide national leadership, research, and technical innovation toward development of advanced weather technologies that enable a vastly improved air transportation system.***

### Motivation

RAL has spent the past three decades addressing and supplying the needs of aviation stakeholders in the U.S. and other countries. This work has yielded fundamental improvements in the scientific understanding of aviation weather hazards as well as a broad array of practical tools and systems that reduce the vulnerability of aviation to such hazards.

Current and projected growth in the volume, complexity, and economic importance of air and space transportation clearly demonstrates the need for a new paradigm supporting the organization and control of air traffic services in the 21<sup>st</sup> century. Since weather conditions seriously impact air traffic operations and the levels of service available to system users, the manner by which weather is observed, forecast, disseminated and used within air traffic decision processes and systems is of critical national importance.

***“The paradigms we have relied on for 50 years cannot accommodate the massive change that has already begun.”***

*- Robert Pearce, Acting Director, Next-Gen, in Journal of Air Traffic Control, 2006*

Many new factors compound the challenge to safe and efficient air and space operations during the first twenty five years of this century. Among these factors are the following:

- Aircraft passenger and freight load requirements will be 2-3 times higher.
- No new airports are planned during the next decade.
- Airport expansion is limited at some major airports.
- New aircraft types such as very light jets and unmanned aerial vehicles (UAVs) are proliferating.
- Commercial space vehicles are beginning operations.
- Increasing use of polar routes will introduce new hazards to crews and passengers.
- New navigational technologies that allow more flexible routing and separation of aircraft are not fully compatible with the current air traffic control system.
- Increasing concerns about environmental impacts.

Capacity will become an increasingly limiting factor at many airports. Efficiency of flight operations en-route will become more critical. Predicting traffic loading accurately at all locations within the airspace system several hours in advance will be critical to efficient operations. Space operations with commercial passengers will require many safeguards for launch, sub-orbital flight, orbital flight and recovery.

*Weather affects all of these operations and in most cases, precise weather information integrated into decision support systems will be critical for maximizing the performance of the 21<sup>st</sup> century system.*

The Next Generation Air Transportation System (NextGen) is now beginning to take shape on the design board of several federal agencies under the auspices of the Joint Program Development Office (JPDO). The JPDO has parsed the complex next generation system into several components and has endorsed the concept of Interagency Working Groups to manage the R&D associated with each. One such Working Group is dedicated to developing the weather information needs of NextGen and providing common weather-related decision information to all stakeholders within the system.

## **Near-Term Objectives**

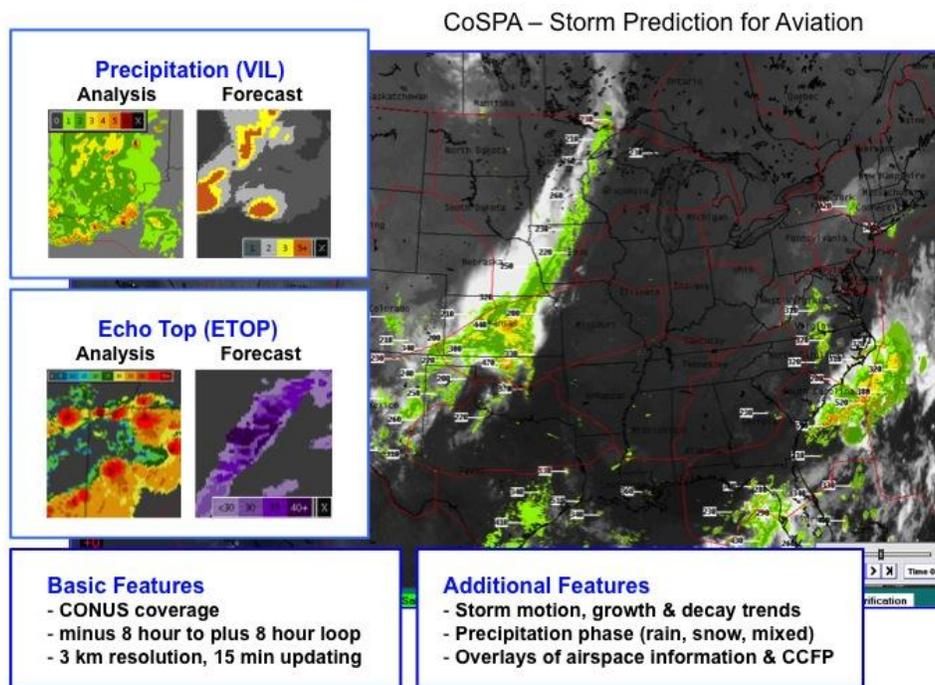
### **Advanced Weather Products for the Next Generation Air Transportation System**

*Play a leadership role within the atmospheric research community to provide the necessary scientific underpinning and technology to support the weather- and climate-related needs of NextGen including: a) collaboratively determining the role of weather in aviation operations with operational stakeholders, b) tailoring solutions to operational user's needs via focused and integrated (weather and operational parameters) decision information to address safety, capacity and efficiency issues, c) collaboratively (with other NextGen partners) build and test the weather component of NextGen referred to as NextGen Network Enabled Weather (NNEW), and d) collaboratively build and test fully integrated components of NextGen.*

The NextGen System is a national priority to meet the air transportation needs of the U.S. in the 21<sup>st</sup> century – in particular, a significant growth in demand for air traffic services, possibly on the order of three times today's demand levels. Since weather conditions can seriously restrict aircraft operations and levels of service available to system users, the manner by which weather is observed, forecast, disseminated, and used in decision-making is of critical importance.

### **Storm Prediction for Aviation**

The current focus of storm prediction is on the development of Consolidated Storm Prediction for Aviation (CoSPA), a national scale 0 – 8 h forecast of storm hazards for aviation, based upon feature extraction and extrapolation techniques, numerical weather prediction models, and intelligent blending of multiple forecast fields. The ability to skillfully predict storm organization and structure, and the evolution of storms throughout their life cycle, will be particularly relevant. Moreover, through the use of RAL's thunderstorm Auto-Nowcaster, we are learning how a human forecaster can add value to an automated weather prediction process in order to enhance the forecast quality. The lessons learned from this work will be incorporated into CoSPA. The research and development efforts have to include a better grasp of convective storm initiation and model performance, and advance model development through improved initialization and data assimilation procedures. Furthermore, information from new sources, such as advanced radar technology and satellite observations, will have to be harvested for CoSPA. For oceanic convective forecasts in data-sparse areas it will be essential to combine satellite-based products with global-scale models.



*CoSPA Forecast Display of Precipitation Intensity and Echo Top.*

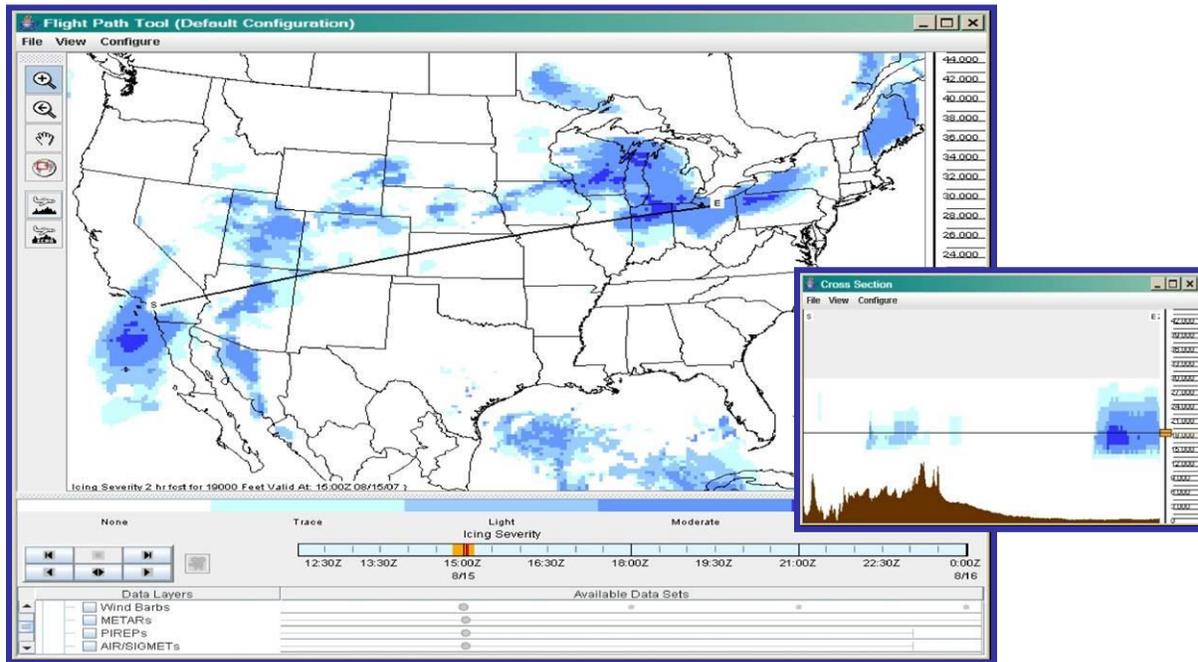
**Actions:**

2011-2015 – Work collaboratively with the Massachusetts Institute of Technology (MIT) Lincoln Laboratory and the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) to build and operationally evaluate Version 1 of CoSPA that will serve as the initial single authoritative source to NextGen for summer and winter storms. This will require significant research that is directed toward numerical model development and improved understanding of the full convective storm life cycle. It also includes quantification of the effects of convective weather on airspace capacity, defining and evaluating uncertainty, coupling intelligent forecast algorithms with automated traffic flow models and evaluating air traffic management requirements for forecast specificity at forecast periods out to 12 hours.

**Icing**

RAL will continue to improve automated in-flight icing diagnosis and forecast algorithms by upgrading them as operational models are upgraded (such as the Weather and Research Forecasting model, WRF), by investigating and incorporating new data sets (including NASA Langley’s advanced satellite products), and by learning how to use existing data sets more intelligently (such as NEXRAD radar data). Collaborations with aircraft manufacturers and aerospace engineers will result in improved descriptions and depictions of icing severity. A new project is the development of a warning tool for regions of high ice water content (HIWC), which have been responsible for jet engine power rollbacks and, in some cases, total power loss during flight. Better parameterization of cloud processes in numerical weather models for 0-12 h forecasts will focus on weakly-forced cloud systems, the impact of cloud-active aerosols and parameterizations of size distributions for water drops and ice crystals. Global applications using combinations of global weather models and satellite information will be developed to support oceanic flight routes, as well as to provide guidance for re-entry of space vehicles. RAL will also seek opportunities to work with NASA and industry on improved terminal-area in-flight icing detection

systems (such as the NASA Icing Remote Sensing System) incorporating previous research results into operational facilities.



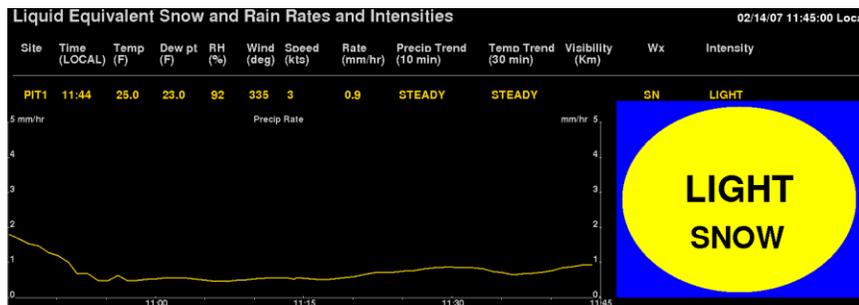
Current Icing Product map view and vertical cross-section.

Actions:

2011-2015 – Extend the capabilities of the current and forecast icing algorithms by a) incorporation of newly developed parameterization of cloud process, b) use of high-resolution numerical models that incorporate radar reflectivity and dual-polarization data c) incorporation of new data sets such as NASA Langley’s advanced satellite product suite, d) development of a HIWC warning system and testing it during a field project, and e) expansion to global coverage by incorporating data from global numerical models and satellite information to support oceanic flights and Extended Twin Engine Operations.

**Winter Weather**

The Weather Support for Deicing Decision Making (WSDDM) system combines a radar feature extraction and extrapolation algorithm with high-resolution surface liquid-equivalent precipitation measurements to estimate how much water substance will fall on aircraft between a de-icing event and



Weather Support for Deicing Decision Making liquid-equivalent display.

takeoff. Recent research activities have focused on improving the accuracy and reliability of the liquid water-equivalent system, including the ability to automatically detect various precipitation types. This system will be transferred to a vendor for commercialization as soon as the FAA develops an Advisory circular to define the approval process for the system. This capability will be one of the core technologies used to detect the presence and intensity of freezing drizzle and freezing rain in support of the development of a Terminal Area Weather Information System. The latter will support anticipated new FAA rules that will limit takeoff and landing under freezing rain and drizzle conditions.

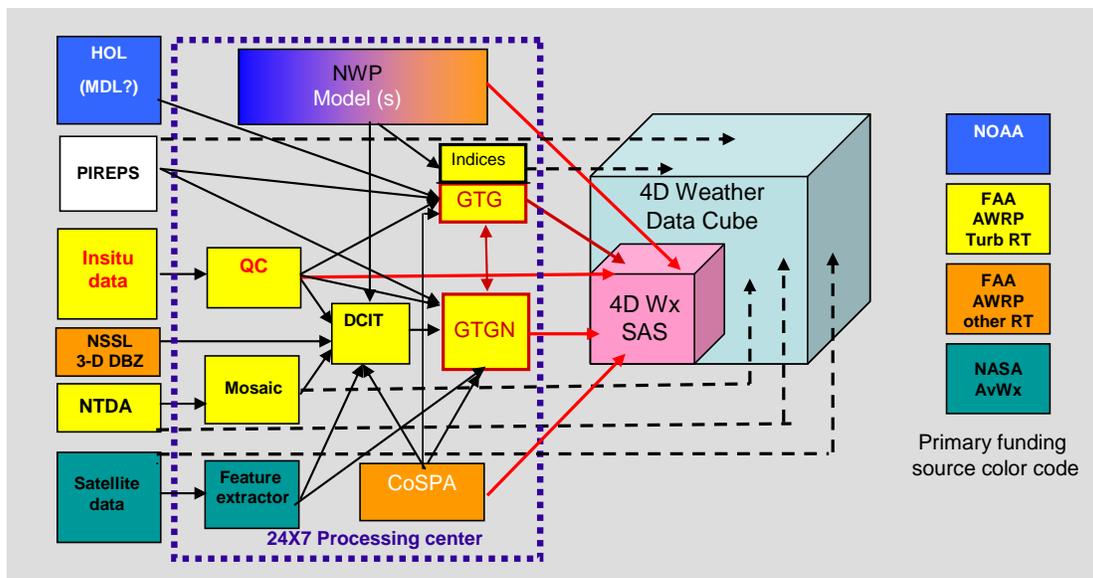
Future research activities will also be focused on understanding how snow bands are organized, how their movement and behavior can be accurately predicted (especially on a 0-6 h timeframe), and real-time identification of precipitation type. Research will also be conducted on development of improved deicing fluid test systems, and on snow gauge evaluations. Combining the small-scale WSDDM detection and prediction capability with the larger-scale CoSPA effort will produce better situational awareness for both winter and summer storms.

**Actions:** 2011-2012 – Conduct research that supports the development of a Terminal Area Weather Information system. Conduct research to better forecast specific snow bands in terms of movement, precipitation type and evolution. Migrate these new capabilities into CoSPA in the 2011-2012 timeframe.

### Turbulence

RAL will continue to develop and implement methods for making both *in situ* and remotely-sensed observations of turbulence, and to further refine turbulence nowcasting and forecasting algorithms for use by the aviation community.

The forecast product, Graphical Turbulence Guidance (GTG), has operational and experimental versions that predict clear-air turbulence based on diagnoses of NWP model output related to upper-level fronts and jet streams and mountain waves out to 12 hr. Future versions will include terrain-induced turbulence and turbulence associated with convection, and provide forecasts out to 18 hr, thus expanding the altitude range covered as well as the utility of the product. Research will also be conducted on improved



Connection of turbulence products to NextGen 4D data cube. The red box indicates the “Single Authoritative Data Source” (SAS).

turbulence parameterizations, better use of increased model resolution, increased understanding of all turbulence generation and downscaling mechanisms, and incorporation of new observational data. This will be done through high-resolution model simulations and by pursuing opportunities for collecting research quality *in situ* aircraft data. A nowcasting product, termed GTGN, is also being developed to provide rapid updates (every 15 min) of GTG background analyses that incorporate all available turbulence observations (from *in situ* or remote measurements). This product is necessary due to the rapidly evolving nature of atmospheric turbulence. Both GTG and GTGN fields will ultimately populate the NextGen four-dimensional data cube, probably as “Single Authoritative Data Sources” (SAS), as shown in the figure above. A global turbulence forecast product is also under development that combines NWP model output results with satellite imagery to detect and predict turbulence from clear air and convective sources.

Improvements to the quality and quantity of turbulence observations will continue. The turbulence detection network based on NEXRAD radars will be expanded and incorporated into GTGN. *In situ* turbulence measurements (from commercial airlines and TAMDAR sensors) will supplement pilot reports (PIREPs) and airborne radar forward-looking turbulence detection algorithms (in cloud). The feasibility of using forward-looking IR sensors as well as GPS scintillation to detect turbulence will be assessed as these new technologies continue to mature. Finally, RAL will complete the deployment of the Juneau turbulence warning system and the subsequent handover to the FAA.

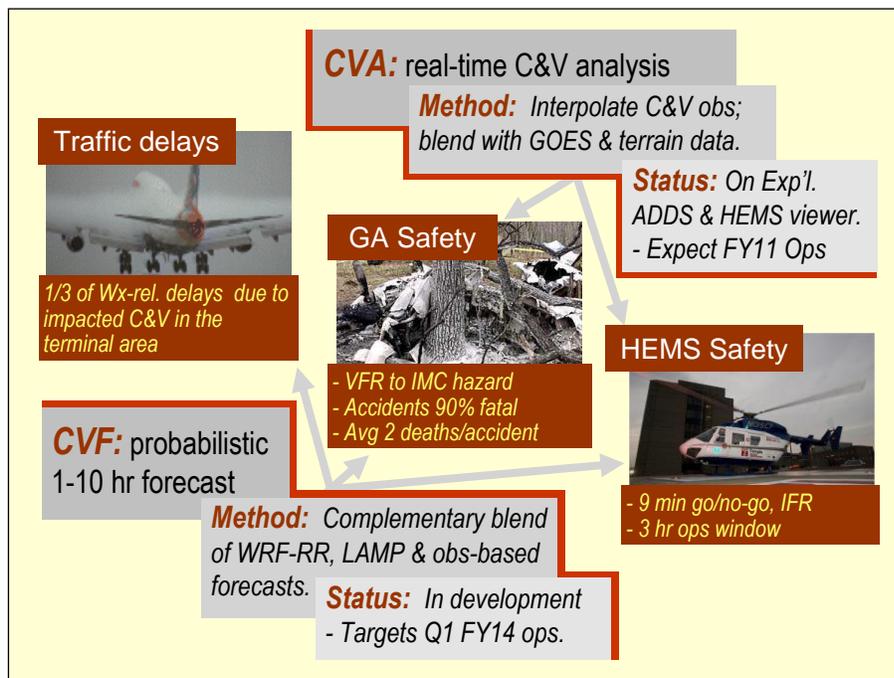
*Actions:* 2011-2015 – Extend the capabilities of the GTG and GTGN by a) extending the altitude range to include all tropospheric levels, b) including convection and terrain-induced turbulence and c) incorporating of national radar network data, satellite-based inferences of turbulence, and new sources of *in situ* measurements. Assess the capability of GPS and forward-looking IR instruments to reliably detect turbulence. Continue case study analyses of severe turbulence encounters using high-resolution numerical simulations

### **Ceiling and Visibility**

RAL’s work toward development of real-time products for the analysis and forecasting of ceiling and visibility conditions uses FAA and NOAA funding toward R&D which will yield improvements in both the efficiency and safety of aviation across the continental U.S. As shown in the figure below.

- The real-time analysis product (CVA) supports improved situational awareness critical to the safety of general aviation (GA) and helicopter emergency medical services (HEMS) operations. FAA approval for operational use of CVA is expected late in FY11.
- RAL’s probabilistic 1-10 hr. ceiling and visibility forecast (CVF) will improve forecasting of C&V conditions responsible for commercial air traffic delays and will further aid GA and HEMS pilots anticipate expected changes in conditions. CVF development targets operational readiness by or before FY14.

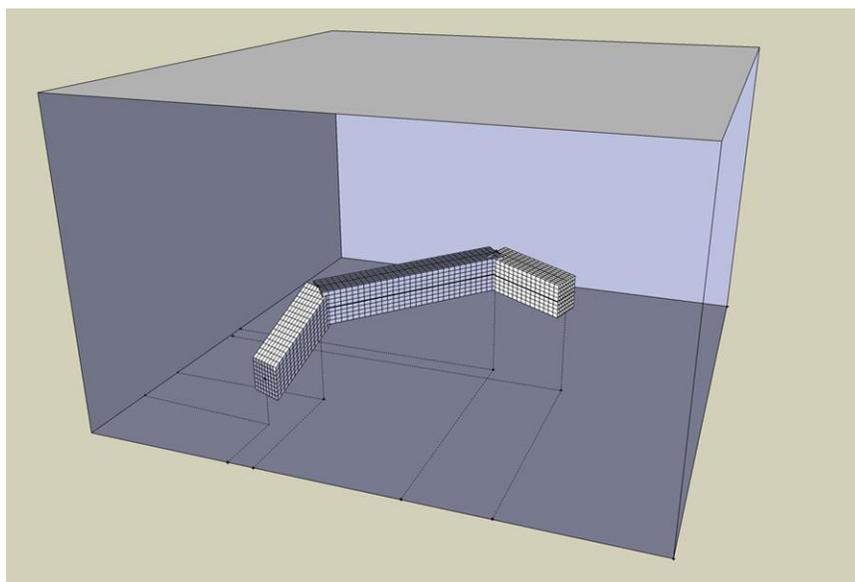
*Actions:* 2011-2015 – For CVA, support the FAA FY11 evaluation of CVA, anticipating approval for operational use late in FY11. For CVF, continue development focusing on a) best use of available operational forecast inputs and b) best methods to capture the superior skill of data-rich point forecasts within a full-CONUS gridded CVF product. Work following the operational implementation of CVF expected in 2014 will focus on a) adaptation of CVF techniques to a system serving the Alaska domain, b) use of high-resolution numerical models such as the HRRR to improve CVF skill, and c) initial research toward 1-8 hr. forecasts of RVR (runway visual range) for critical CONUS airports.



*Principal impacts of ceiling and visibility hazards within U.S. national air space (in red): delays of commercial traffic and reduced safety of general aviation and helicopter emergency medical services (HEMS) operations. Arrows show areas where CVA and CVF will help mitigate these impacts.*

### NextGen Network Enabled Weather (NNEW)

RAL is heavily engaged with the FAA, NOAA, and MIT/Lincoln Labs in the development of a capability called NextGen Network Enabled Weather (NNEW). This capability will provide a global four-dimensional database of all weather information relevant to aviation decision-making. This so-called “4D weather data cube” will be a distributed entity that exists through the application of modern information technology to store and retrieve data. To facilitate this effort, RAL is involved with the Open Geospatial Consortium to motivate the development and extension of open standards and technology that will make NNEW possible.



*NNEW will provide weather parameters along a planned flight trajectory within the gridded “data cube”*

*Actions:* 2009-2015 – Build and test the first operational version of NNEW by 2013 working collaboratively with the FAA, NOAA, and MIT Lincoln Laboratories (LL) to ensure open standards and commonly agreed on technology for a global four dimensional “data cube.”

*Potential or Expected Sponsors:* FAA, NOAA, DOD, NASA

*Anticipated Collaborators:* MIT/LL, NOAA Meteorological Development Laboratory, NOAA Earth System Research Laboratory, Center for Advanced Aviation Systems Development (CAASD), commercial airlines, commercial federal system development contractors

*Specific Measurements of Success:* Initial Operational Capability of the 4D Data Cube by NOAA in 2013 and the FAA in 2015, including 0-6 hr forecasts of summer and winter storms, turbulence, icing, and ceiling/visibility.

## Frontiers

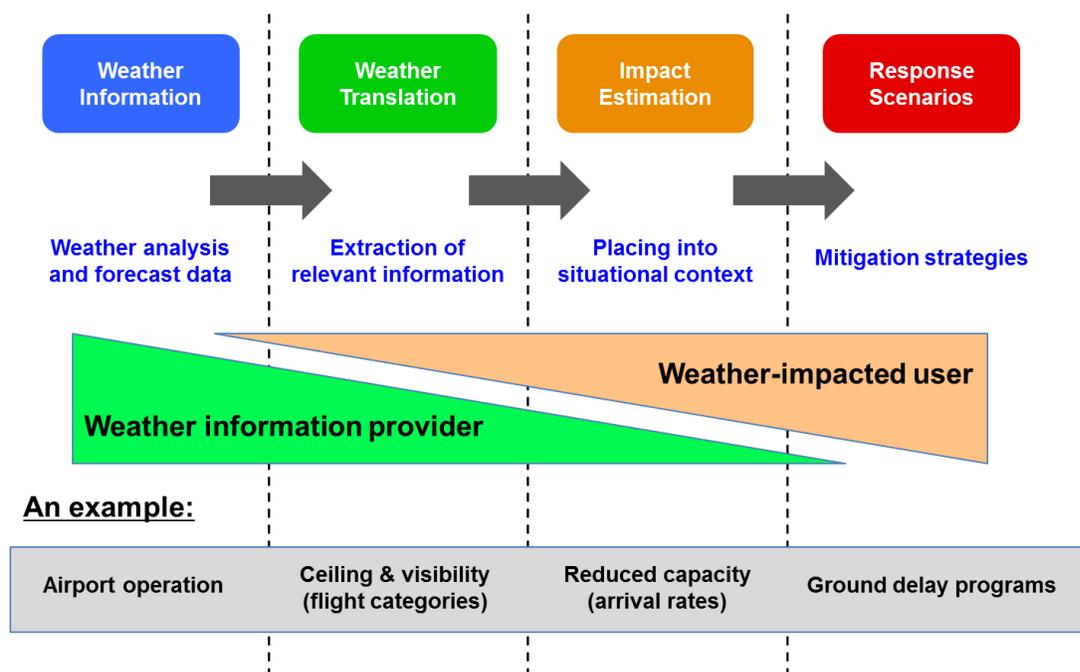
### Integration of Weather Information into Air Traffic Management Decision Support Systems

*Incorporate deterministic and probabilistic weather information into real-time decision support tools for managing the national airspace.*

Historically the FAA plans for management of the U.S. national airspace system (NAS) have simply ignored the existence of weather impacts. When hazardous weather occurred, the system entered what could be called a reactive mode. As the volume of air traffic has increased, the impact of weather on the system has also increased. It is recognized that new, pro-active solutions are required. While progress has been made over the last decade in presenting weather information to non-meteorologist end users in the NAS (that is, dispatchers, air traffic controllers/managers, pilots) this will not by itself lead to the efficiencies required. The NAS is too complex. Automated air traffic management tools are needed that optimize decisions while taking probabilistic weather information into account. The concept of “risk management” verses “risk avoidance” recognizes the fact that weather information will never be totally certain (hence the integration of probabilities) but at some point the decision must be made based on deterministic thresholds. Options for human intervention in the system will still be required.

The figure below portrays the process of translating weather information into air traffic impacts and constraints, and finally into thresholds for taking action. Risk management using probabilistic weather information is expected to lead to a reduction in weather impact by not having to fully close airspace in many cases, but rather by managing the air traffic flow around weather constraints that have varying degrees of hazard. How to effectively accomplish this process with the human in or over the control loop, adding value where appropriate, is the challenge and the future of weather information R&D.

## Weather Translation and Integration Concept



*Weather Integration into Air Traffic Management Decision Support Tools.*

An essential element of the R&D plan continues to present prototypical deterministic and probabilistic weather information to end users during every opportunity possible, including pilots while in-flight. There are two reasons why this is so important. First, user feedback tells us how well we are doing toward reducing the uncertainty of weather forecasts and diagnoses. And second, this gives us a chance to better understand how the human integrates weather into his/her decision-making.

Through collaboration with NASA, NOAA, academia, and the community of aviation weather users, we are learning how to translate ensemble storm forecasts into probabilistic information about the airspace capacity available to the air traffic system when impacting weather is expected. This is information that aviation planners may use in the future to provide for a more orderly flow of air traffic, without actually having to look at or try to interpret weather forecasts. RAL will continue efforts in this area, by incorporating more sophisticated analysis techniques and also by applying them to real-world conditions. Exploration of similar approaches to other aviation weather hazards, such as turbulence and in-flight icing, will be conducted as well.

*Actions:* 2011-2013 – Define and validate through the use of prototypes specific methodologies for translation of weather information into probabilistic information useful to air traffic management decision support tools. The initial R&D will model probabilistic weather information against actual traffic flows to further understand NAS and pilot response to uncertain weather information. The next logical step is to introduce decision support tools to end-users to better understand their use in today’s NAS operation and eventually the NextGen concept of use.

2012-2014 – Work with the community of users and implementers to further refine the NextGen Concept of Use to incorporate the translation and conversion processes described above. The R&D planning to

support this refinement comes from intense user interaction and continued RAL involvement with FAA advisory committees within the RTCA and Society of Automotive Engineers (SAE).

2013-2015 – Work with the community of users to present the benefits to the NAS that support the funding of this effort within NextGen budgets.

*Potential or Expected Sponsors:* FAA, NASA, NOAA.

*Anticipated Collaborators:* MITRE or similar ATM R&D organization, commercial airlines, NextGen implementers from industry

*Specific Measurements of Success:* Demonstration of a successful integration effort in 2014 that includes convection, turbulence, and in-flight icing and effective decision support with human in and over the loop systems.

## En Route Wake Vortex Hazard Research

***Identify the potential hazard to air traffic from en route wake vortices as aircraft separation is reduced in the NextGen environment.***

In the airport environment, much is known about wake vortex longevity and transport, but much less is known about wake vortex characteristics in the en route environment: for example, the longevity of wake vortices in the vicinity of the tropopause. For today's aircraft separations, en route wake vortex encounters are not considered to be a safety or capacity problem. However, there have been turbulence reports that may have been caused by en route wake, but attributed to clear air, convective, mountain wave or other forms of turbulence.

In the NextGen timeframe, aircraft en route separations will be reduced vertically, laterally, and longitudinally. Additionally, there is an on-going increase in fleet diversity, including a large number of lighter jets, which may be strongly impacted by wake encounters. However, it is not definitively known whether these paradigm changes will result in an increased likelihood and severity of en route wake encounters, or increased risk of injury and fatality.

In order to perform its due diligence with regard to this open question, the FAA is embarking on a research study to determine whether there is currently or may eventually be an en route wake vortex encounter problem. If so, the proposed research will quantify the risk and recommend mitigation strategies, as appropriate. The research is planned in phases so that mitigation strategies can be approached in a way that is consistent with the magnitude of the hazard given specific aircraft separation standards.

*Actions:* 2011-2012 – Perform a thorough en route wake vortex literature search across agencies and organizations, both domestic and international.

- As appropriate, collaborate with the German Aerospace Center (DLR), USAF, and airlines on en route wake vortex common interest areas
- Identify and analyze known wake vortex encounters to determine the associated atmospheric and operational conditions
- Establish a baseline of aircraft response, i.e., the impact of a given wake vortex wind field on a given aircraft

- Perform theoretical and numerical studies of wake vortices in conditions representative of the upper troposphere and lower stratosphere to gain a better understanding of en route wake longevity and descent rates
- Perform realistic numerical simulations of wake vortex drift in actual upper level wind and stability environments and compare results with what has been observed in the case studies
- Create software to statistically analyze whether a correlation exists between these suspected wake encounters and the proximity and relative angle to a preceding aircraft, and whether the relationship appears to vary by geographic location, season, or altitude

2012-2013 – If warranted,

- Conduct a field study to verify the en route wake models used by or developed during the research.
- Develop mitigation strategies, as required.
- Conduct mitigation proofs of concept, as required.

*Potential or Expected Sponsors:* FAA.

*Anticipated Collaborators:* DLR, airlines, University of New Hampshire

*Specific Measurements of Success:* Analytical and operational definition of the en route wake vortex hazard, and identification of mitigation strategies that include allowable aircraft separation standards for NextGen.

## Detection and Transport of Volcanic Ash

***NCAR will undertake research to improve dispersion models on scales appropriate for volcanic ash tracking, satellite detection of ash clouds, and early detection of eruptions.***

Due to the extreme vulnerability of aircraft to volcanic ash, NextGen has a requirement for detection and forecasting of ash clouds for incorporation into NNEW to drive the air traffic flight planning process.

*Actions:* Define and validate the specific requirements of the 4D Data Cube for volcanic ash forecasts. Develop a plan for a 2016 capability that will meet as many of the requirements as are feasible. Work with the community of users to argue the funding of this effort within NextGen budgets.

*Potential or Expected Sponsors:* FAA, DOD, NASA

*Anticipated Collaborators:* Volcanic Ash Advisory Centers, commercial airlines, MITRE

*Specific Measurements of Success:* Initiation of an R&D program by 2013.

## Space Weather Support for Aviation

***Develop fully operational predictive models and current space weather observations that can be blended to provide a consolidated probabilistic space weather forecast that is available through the NNEW 4D data cube to support NextGen.***

In NextGen, the air transportation system can be adversely impacted by space weather events. The volume of polar flights is projected to increase. NextGen will rely on satellite-based systems for communication, positioning, navigation, timing, and surveillance. A real-time forecast of the impact of space weather events along a particular route of flight is critical to system safety. Furthermore, it is becoming clear that there can be health hazards to flight crews who are repeatedly exposed to the higher than normal radiation levels inherent in flights along polar routes. A real-time forecast of human health effects along a flight path is needed. This capability will require the completion of research efforts and algorithms.

Actions:

2012-2013 – Define and validate the specific requirements of the 4D data cube for space weather.

2013-2014 – Develop a plan for a 2016 capability that will meet as many of the requirements as are feasible.

2014-2015 – Work with the community of users to argue the funding of this effort within NextGen budgets.

Potential or Expected Sponsors: FAA, DOD, NASA, NOAA

Anticipated Collaborators: Commercial airlines, MITRE/CAASD, NCAR's High Altitude Observatory, various universities

Specific Measurements of Success: Initiation of an R&D program by 2015.

## **Environmental Forecasts**

### ***Develop a forecast system for assessing the environmental impacts of aviation operations in real time.***

Real-time mitigation of environmental impacts of aviation requires an understanding of those environmental impacts and their dependencies on real-time weather. NextGen's fully operational predictive models (including climatology) and current weather observations will be fused to provide a consolidated probabilistic environmental forecast that is available to users over a Network-Enabled Infrastructure. This capability will build on a body of research and algorithms that will forecast real-time noise propagation, dispersion of airborne pollutants (including from a terrorist attack or accidental release), and forecasts of the sensitivity of atmospheric volumes to exhaust emissions, including greenhouse gases and formation of cirrus clouds.

Actions:

2012-2015: 1) Define and validate the specific requirements of the 4D data cube for noise, dispersion, greenhouse gas, and induced cirrus cloud forecasts; 2) Develop a plan for a 2016 capability that will meet as many of the requirements as are feasible; 3) Work with the community of users to argue for the funding of this effort within NextGen budgets.

Potential or Expected Sponsors: FAA, DOD, NASA, NOAA

Anticipated Collaborators: FAA, DOD, NASA, NOAA, airlines, MITRE/CAASD, NSSL

Specific Measurements of Success: Initiation of an R&D program by 2015.

## 4. Goal Area: Weather and Climate Information for Improved National Security and Public Safety

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### Overarching Priority

***Advance fundamental understanding and the community's ability to predict fine-scale weather and climate processes for the purpose of providing forecasters, decision makers, and emergency managers with accurate information to save lives and property.***

### Motivation

NCAR has developed several technologies, mostly model-based, over the past decade that are focused on Department of Defense and National Security needs. This work began well before the September 11, 2001 attack on the U.S. but has increased dramatically since that event. Much of this work has been focused on coupled-model concepts, model-based climatologies for data sparse regions, atmospheric scales ranging from neighborhood-scale to mesoscale, and science and technology education and outreach to our operationally minded sponsors. By necessity, urban areas, particularly those with high-valued national assets, have received much attention. Great challenges exist in tuning and operating these models at the scales of large turbulent eddies (Large Eddy Simulation (LES) models), in terms of ensuring that they are representing physically realistic processes, that they are verifying reasonably against observed quantities, and that they run efficiently on cutting edge hardware platforms. Aside from the scientific and technical challenges, the end users who are presented with products at such fine scales require substantial and sustained education on how to interpret the model output. The material must be presented in a manner that properly communicates information that is critical to their operations, where this communication is often very different from how scientists communicate among themselves. This ongoing work provides an excellent scientific and technical basis for strategically planning NCAR research and development over the next five years.

Sponsor-needs for research and development in this work area continue to grow rapidly. As stakeholders gradually incorporate advanced weather and climate-based decision systems, they continually see new application areas. It is imperative that this science base and its associated technologies be pushed even farther in the following areas: a) plume modeling in urban areas with a focus on street canyons effects of flow around buildings, b) overall modeling of the flow regimes and atmospheric conditions in a metropolitan area down to street scale, c) coupling of atmospheric models to other sector models such as agriculture and public health, and d) for sponsors in the realm of homeland security and defense, the production of regional climatologies to provide planning information to decision makers with regard to the effect of climate change on their region.

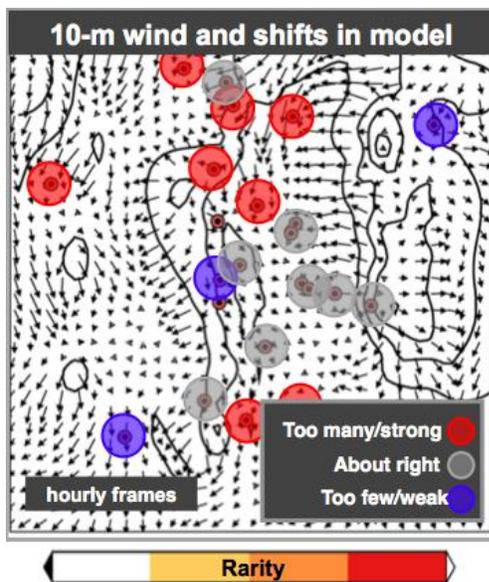
### Near-Term Objectives

**Improve Mechanisms of Transferring Customized Modeling Capabilities and Knowledge, Based on Fine-Scale Weather and Climate Forecasts, to the Community, to our Sponsors, and to End Users That Employ These Products**

RAL has at its immediate disposal a large array of “outdoor laboratories” that span unique weather and climate zones across the United States, called the Army Test Ranges, which are managed by the

developmental test arm of the U.S. Army Test and Evaluation Command (ATEC) called the Developmental Test Command (DTC). In RAL's role as the outsourced R&D and educational outreach contractor, tasked with providing seven DTC ranges with advanced meteorological analysis and forecast capabilities, and with transferring knowledge to personnel ranging from interns just out of grad school to 20-year operational forecasting veterans, there is a unique opportunity to develop and refine our methods of transferring the fruits of R&D to the community.

In our role to support the component of the National Science Foundation's mission that addresses "securing the National defense," RAL has the responsibility to not only develop and provide the very best technologies to a number of U.S. and allied agencies involved in protecting the Homeland and our warfighters, but to effectively transfer the required knowledge to the end users in a way that permits them to fully exploit what these capabilities have to offer. Because atmospheric scientists are accustomed to, and are comfortable with, communicating highly technical information to peers, the tendency is for them to develop a presentation and teaching style that efficiently communicates the essence of the science, which is replete with domain-specific jargon, and omits transmitting the fundamental concepts. Consequently, the communication barrier can be substantial when those scientists are tasked to communicate their knowledge to those who use, but do not develop, the model output for their local applications. These barriers can lead to misunderstandings, and worst, improperly using the models for decision-making, which can lead to loss of property and life. The figure below provides information about how well the model has recently predicted the occurrence of wind shifts relative to observed wind shifts, at 10 m AGL, at one of the DTC test ranges. A trained and skilled forecaster can take advantage of this information in terms of calibrating his expectations of how much to trust the model's current predictive skills. The first time this figure was presented and explained in highly technical terms, the forecasters in the audience appeared bored and disinterested. Only much later, when the figure was re-explained in a more applied fashion better suited for operational applications, did the forecasters come to appreciate and start using the information.



*WRF-based 24-h forecast of winds (black vectors) on a grid with horizontal spacing of 3.3 km at one of the DTC Test Ranges. The colored circles indicate how well the model predicted wind shifts at 10m AGL, as compared to the winds observed by range anemometers*

Each test range that RAL supports with R&D and educational outreach represents a wealth of opportunities to advance important topics in the NWP weather modeling community: heavily instrumented with *in situ* and standoff weather sensors collecting many hours of data daily, numerous tests are conducted from near-surface through the upper troposphere, providing important verification data for coupled weather/test-materiel experiments against which to compare modeling results. Regularly

staged improvements to the range forecast systems result from R&D that is focused at the range-scale, and provide RAL with frequent opportunities to deploy cutting-edge research into operational use. This supports the community effort to put the best tools possible into the hands of researchers, universities, government, and private industry. In a climate of rapid advances made by emerging technical superpowers such as China and India, the U.S. can ill afford to languish in long delays between when advances are made in research and when they appear in operations at our civilian and defense-based weather prediction centers. RAL hopes to help the nation to maintain its competitive edge in both R&D and operational forecast capabilities

Actions: 2011-2015 – Streamline and accelerate the process of moving new NWP capabilities that RAL develops into the community software repository, subject to constraints imposed by ITAR (International Traffic in Arms Regulations). Gather technical material that has been applied to numerous formal trainings of operational forecasters for the Test Ranges and for other sponsors, and consolidate into a widely available repository

Potential or Expected Sponsors: Sponsors include those for which RAL already provides specialized forecasts, as well as those in any sector that requires specialized NWP-based analysis and forecast capabilities, including coupled-model applications (transport and diffusion, energy, water-resources, air-quality, etc).

Anticipated Collaborators: Scientists across all of RAL's and NCAR's programs who are users or developers of NWP modeling applications.

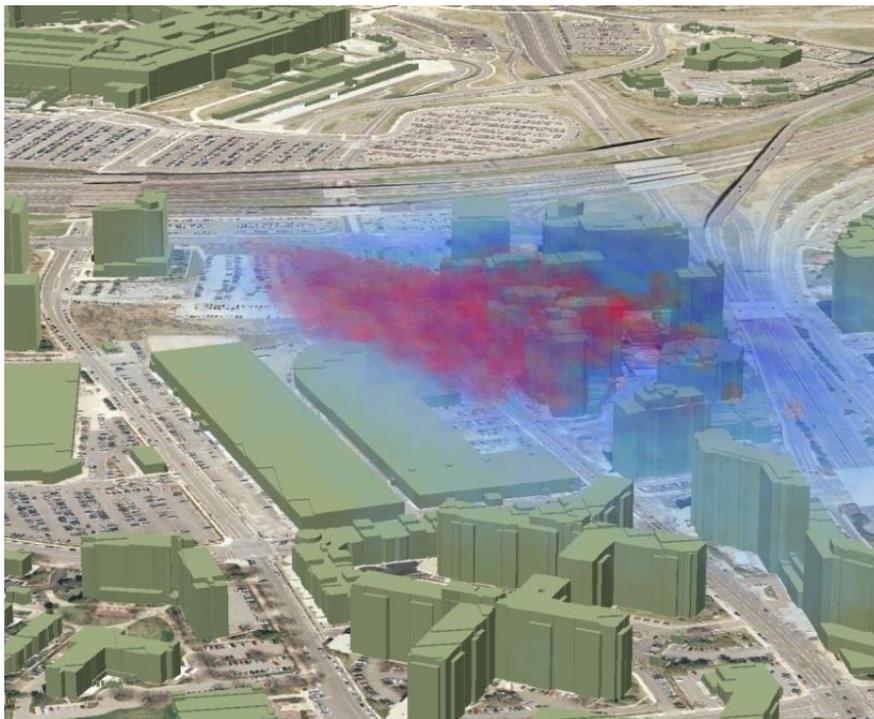
Specific Measurements of Success: Broader use of RAL's specialized NWP modeling resources than exists today, and increasing activities in educating end users.

## Development of Customized NWP Solutions

***Utilizing the WRF and LES-WRF models, and building-aware diagnostic models, develop modeling technologies that meet the needs of a variety of users for real-time weather information. Provide web-based graphical interfaces for this information which allow rapid interpretation and decision making. Couple the meteorological-model output with secondary models that calculate special variables such as sound and radio-wave propagation, and transport and diffusion. Extend the range of the predictions to inter-seasonal time scales.***

RAL has developed and deployed very high fidelity, computer-based weather analysis and forecasting systems for many applications worldwide. For example, new weather-prediction systems have brought the DTC Test Ranges into the 21st century, in terms of advanced weather products. The improved weather information for test planning has saved taxpayers millions of dollars. Numerous other domestic projects include providing advanced weather-modeling capabilities to support Navy operations in California and Hawaii, and for potential Space Shuttle landings at alternate sites. Other such systems focus on urban areas and urban impacts on the weather. In contrast to most NWP models that don't recognize the existence of cities in a meaningful way, recent RAL models resolve the large-scale effects of the cities, and some even represent the complex winds in street canyons. In addition to these domestic applications, weather systems are being deployed worldwide to support special missions. For example, they have been used by the National Ground Intelligence Center (NGIC) during Operations Enduring Freedom and Iraqi Freedom to assess the consequences of the potential release of hazardous airborne material, and thus provide a higher degree of safety to U.S. and allied military personnel potentially downwind of hazard zones. Similar models have also been employed by RAL for counter-terrorism support to the Defense

Threat Reduction Agency for the Salt Lake City, Athens, and Torino Olympics. This work will continue, meeting the needs of a growing number of sponsors with specialized requirements.



*6-h forecast from WRF model coupled to the Los Alamos National Lab's (LLNL) QUIC-Urban diagnostic windfield model, and further coupled to the LANL QUIC-Plume Lagrangian particle transport and dispersion model, for predicting the urban transport and dispersion of simulated material released in the vicinity of Crystal City, Arlington, VA*

Actions: 2011-2015 – Continue to explore new ways in which WRF, LES-WRF, and other diagnostic models can be applied to produce specialized forecasts on short-range to seasonal time scales.

Potential or Expected Sponsors: Sponsors include those for which RAL already provides specialized forecasts, as well as those in the energy, water-resources, and air-quality industries.

Anticipated Collaborators: NWP modeling scientists throughout RAL and MMM, and working closely with system end users.

Specific Measurements of Success: The ability of user-centric metrics of forecast accuracy to show superiority over forecasts from national weather services and private vendors.

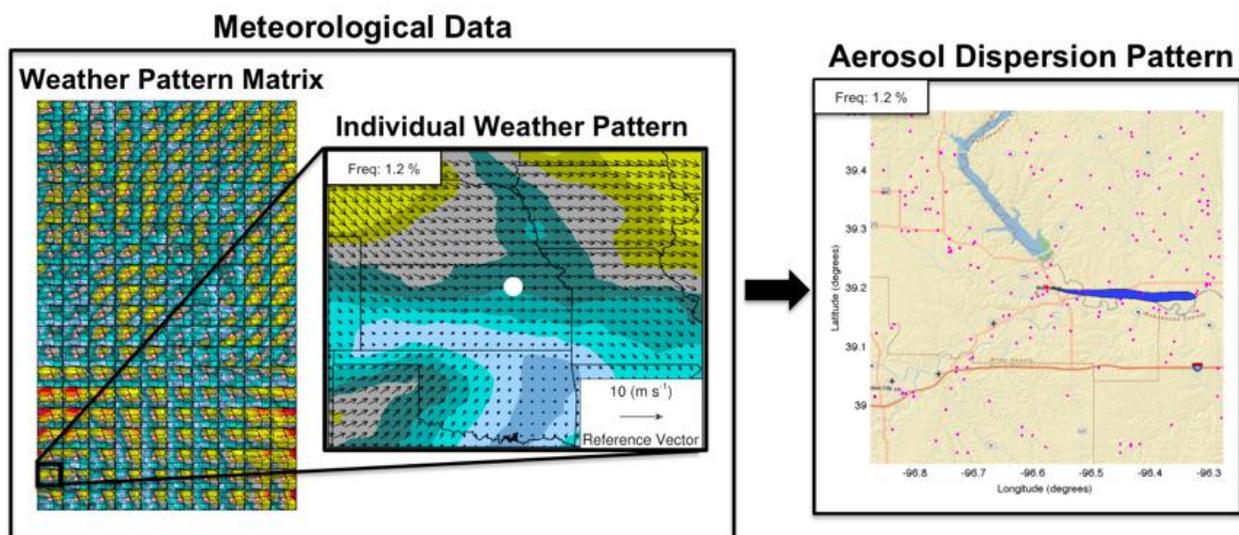
## **Fine-scale Climatologies**

*Utilizing output from RAL's Climate-Four-Dimensional Data Assimilation (Climate-FDDA) system, further develop software for creatively interpreting the climate statistics in ways that have special relevance for sponsors. Evaluate the impact of higher resolution on the quality of the climatologies, and consider the possibility of using ensemble climatology-generation*

**methods. Produce a well-verified global climatology with a grid increment on the order of 4 km, or finer, over continents and littoral zones for use in a variety of applications such as wind-energy prospecting. Re-design Climate-FDDA to be capable of running hybrid dynamical and statistical downscaling techniques, in order to produce model output on increasingly finer grid increments that can address smaller areas of interest. Implement WRF-LES inside the Climate-FDDA system and demonstrate LES-scale downscaling capabilities in areas of high-interest to RAL's defense and homeland security sponsors.**

Mesoscale analyses of current climates can be used for many purposes, including optimal siting of wind-energy farms and airports, calculating the most probable direction of the transport of hazardous material at some future date and time, and scheduling the time and season for events that require specific meteorological conditions. To construct such climatologies for the many areas of the world where there are few routine four-dimensional (4D) observations of the atmosphere, RAL has developed a Climate Four-Dimensional Data Assimilation (Climate-FDDA) system that uses WRF to downscale present-day climates from archived global analyses.

The Climate-FDDA system is able to generate a 4D description of the diurnal and seasonal evolution of regional atmospheric processes, with a focus on the boundary layer. Unlike point measurements, the gridded fields define coherent multi-dimensional realizations of complete physical systems. Not only does the Climate-FDDA system define mean values of variables as a function of season and time of day, extremes are also estimated, and example days are produced.



*Conceptual diagram of aerosol transport inputs/outputs. The climate-FDDA model output generated over Manhattan, KS (future site of the National Bio- and Agro-Defense Facility) is pattern-analyzed to extract dominant weather features, which are then passed into a bio-aerosol model to determine likely airborne plume patterns in the event of an accidental release from the facility*

As an example of one Climate-FDDA application, the figure above shows a thumbnail map of the prevalent modes of wind speed and direction, and temperature that are expected over the Midwestern United States for a particular time of the year. Individual members of the cluster matrix, representing a typical weather condition expected to occur at a certain frequency, can then be fed into an aerosol model to determine the expected plume characteristics in the event of an accidental airborne release of material from a facility within the depicted area.

Actions:

2011-2015: Develop the climatology software to creatively interpret climate statistics in ways that have special relevance for sponsors. Ongoing: Evaluate the impact of higher resolution on the quality of the climatologies

2011-2013: Design, then implement, hybrid dynamical and statistical method.

2013-2015: Implement WRF-LES and generate proof of concept LES-scale climatology.

Potential or Expected Sponsors: RAL currently has several sponsors for this technology, including three groups in France, the U.S. National Ground Intelligence Center, The Army Test and Evaluation Command (ATEC), and the Defense Threat Reduction Agency (DTRA).

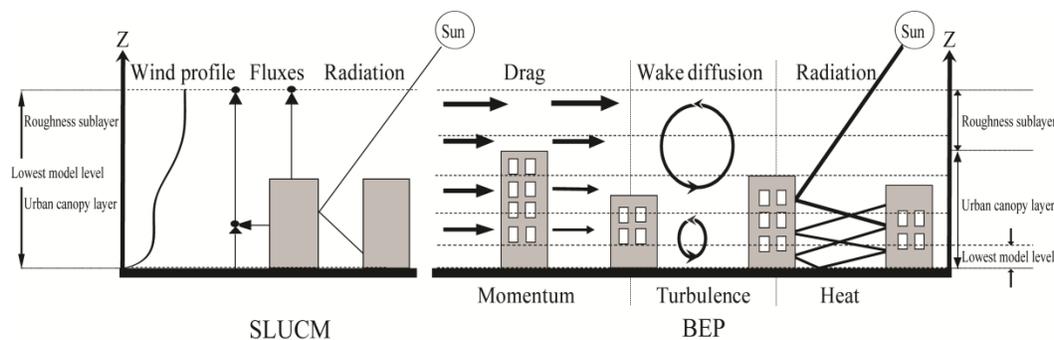
Anticipated Collaborators: Climate scientists throughout NCAR, the Univ. of Colorado, and other experts on Self-Organizing Maps.

Specific Measurements of Success: Demand for climatologies and the frequency of use for long-term physical-process studies.

## Understanding, Modeling, and Forecasting Urban Atmospheres (2011-2015)

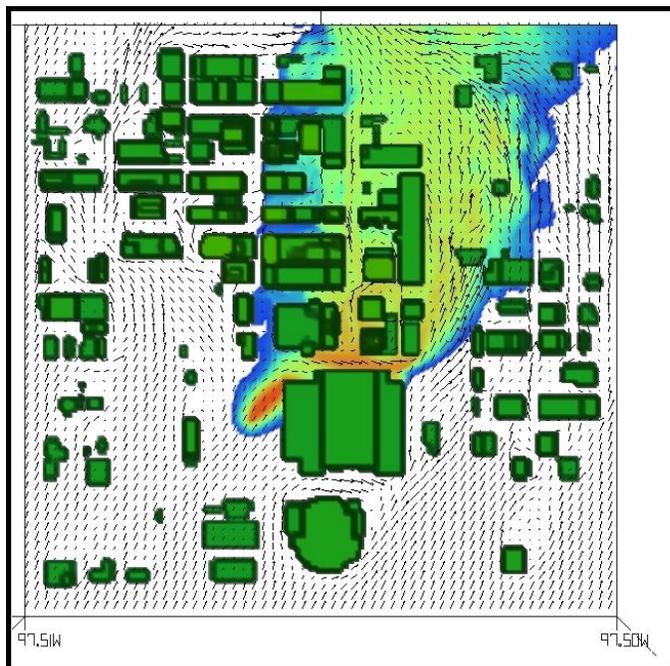
*Develop multi-layer, urban-canopy parameterizations for mesoscale models; extend building-aware wind modeling to even larger urban areas; explore further development of a Large Eddy Simulation (LES) version of WRF that explicitly includes buildings; and develop better methods for coupling models that represent different scales. Develop an improved knowledge of the relationship between mesoscale weather and urban microclimates, with the goal of guiding the future development of urban areas to make them more energy efficient and livable. Develop an operational multi-scale forecasting system for an urban area that can be used by multiple stakeholders (e.g., surface and air transportation, emergency managers).*

Atmospheric processes are influenced by urban complexes over a wide range of scales. The larger metropolitan area produces an aggregate effect on the mesoscale atmosphere, and RAL is developing improved urban-canopy parameterizations for representing the bulk dynamic and thermodynamic effects of buildings for use in the community version of WRF.



*A schematic of the single-layer UCM (SLUCM, on the left-hand side) and the multi-layer BEP models (on the right-hand side). An integrated urban modeling system was developed for the community WRF mesoscale model and released to the public in 2009*

On the smaller scales of neighborhoods, a variety of models and measurement systems have been used to define boundary-layer structure. For example, Doppler lidar radial-wind data are ingested into a four-dimensional variational data-assimilation (4DVAR) system to produce a three-dimensional dynamically consistent analysis of winds every five minutes, with a horizontal grid increment of 100 m. The figure below shows an example of a prediction of a plume of gas released in Oklahoma City during a recent field experiment there.



*Dispersion footprint for SF6 tracer release during Joint Urban 2003 field experiment calculated by WRF/EULAG coupled system.*

Both the WRF LES model and the NCAR EuLag model are building-aware models that are being used for a variety of projects that require urban winds on the scale of meters. The EuLag LES model has been coupled with the WRF mesoscale model to produce multi-scale simulations of the mesoscale to the street-canyon scale. For rapid operational generation of building-aware winds in urban areas, RAL has collaborated with the Los Alamos National Laboratory (LANL) to adapt their QUIC-URB software package that algorithmically calculates the effects of buildings on the wind field. The QUIC model is a component of the Urban-Shield system that RAL has deployed in Washington, DC for the calculation of the transport of hazardous material in the city.

Research is aimed at developing an improved general understanding of atmospheric boundary-layer processes and their parameterization. Scientific and technological contributions have been based on the analysis of field-program data and on modeling studies.

#### Actions:

2011-2015 – We must develop ways of aligning the disparate capabilities that we already have, related to urban atmospheric modeling, and redirect them so that they satisfy the needs of a broader community, encompassing air quality, architectural climatology, public health, emergency response, etc. A first step will be to better coordinate the varied urban-related activities within NCAR.

Potential or Expected Sponsors: We have discussed our urban-scale modeling capabilities with state and local organizations, and will continue to do so. There may also be opportunities related to traditional air-quality sponsors, and non-ATM entities in NSF. Most U.S. agencies involved in homeland security are likely to be very interested in these advances, including the Defense Advanced Research Projects Agency (DARPA), the Department of Homeland Security (DHS), the Defense Threat Reduction Agency (DTRA), and the Pentagon Force Protection Agency (PFPA).

Anticipated Collaborators: LANL should continue to be an important partner in urban modeling at fine scales, especially since they are the principal urban modelers for DHS.

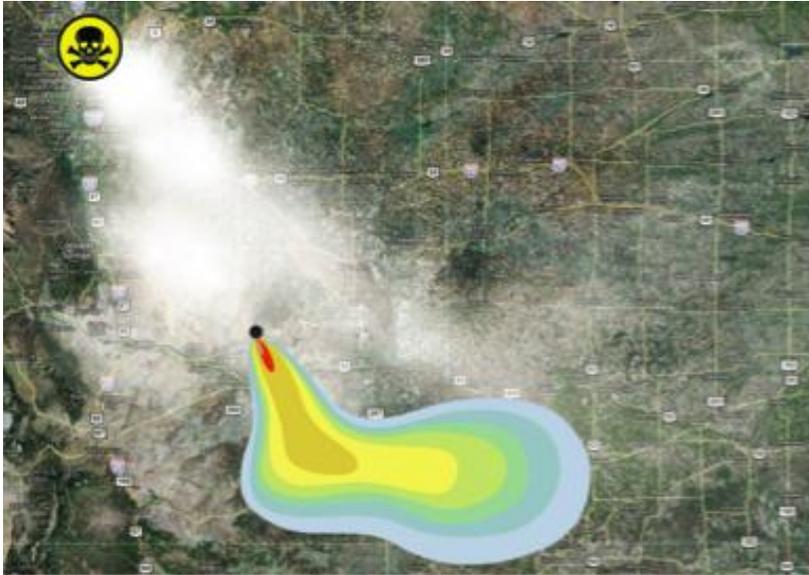
Specific Measurements of Success: Making advances in this area would create new opportunities with our Potential or Expected Sponsors, which would result in new tasking from them. The development of better organization and coordination of urban activities within NCAR will be an early metric of success. In addition, our ability to reach out to other groups and to garner support from non-traditional sources will be another measure.

## Characterizing Plumes of Hazardous Material

***Extend work on plume transport in stable boundary layers, reverse-locating plumes in urban settings, and coupling indoor and outdoor dispersion models. Extend our LES-model physics so that the resulting winds allow plumes to respond to the “chimney effect” in which anthropogenic and solar heating of buildings cause plumes to rise rapidly.***

The mesoscale and urban-scale meteorological modeling activities provide essential input data for multi-scale capabilities that track the movement of plumes of hazardous material. Numerous Department of Defense and civilian (e.g., Environmental Protection Agency) plume models are employed, depending on the need with the models being verified with urban field-program data. As with the LES models, there are quickly executing plume models, such as LANL’s QUIC-Plume model that are designed for operational applications such as the previously mentioned Urban Shield project, and there are more complex models that are used for research and for verifying the fast models. One aspect of this work area is the development of methods for characterizing the source of a plume (size, time of release, location, etc.) based on downstream measurements, thus allowing for intervention if material continues to be released.

The figure below shows a plume simulation for a hypothetical release over complex terrain, with the skull and crossbones symbol depicting the point of release. The black dot at the origin of the color-coded estimated plume represents the location of a fielded chemical agent collector which detected significant chemical concentrations. The standard operating procedure is to use the collector concentration as the release location, as depicted in this figure, which results in the downstream plume pattern shown, and suggests that the peak concentration area of the event is south of the actual concentration pattern. This results in a grossly inaccurate estimate. If this were a real event, emergency responders following the modeled plume guidance could easily decide to move people to the north of the collector location, effectively exposing them to the maximum agent concentration. Our efforts are improving upon this technology.



*A simulated plume of hazardous material hypothetically released into the atmosphere in complex terrain, superimposed on a measured plume. The standard simulation approach would estimate that the release occurred where the black dot is shown, while in fact the actual release point is located at the skull and crossbones symbol.*

*Actions:* 2011-2015 – Enhance plume modeling capabilities in the following areas: a) plume transport in stable boundary layers, b) coupling of indoor and outdoor dispersion models, and c) reverse-modeling of plume transport and diffusion in urban terrain.

*Potential or Expected Sponsors:* All of our DoD sponsors have continuing interest in seeing progress in this area (ATEC, DTRA, DHS, DARPA, MDA, and PFPA).

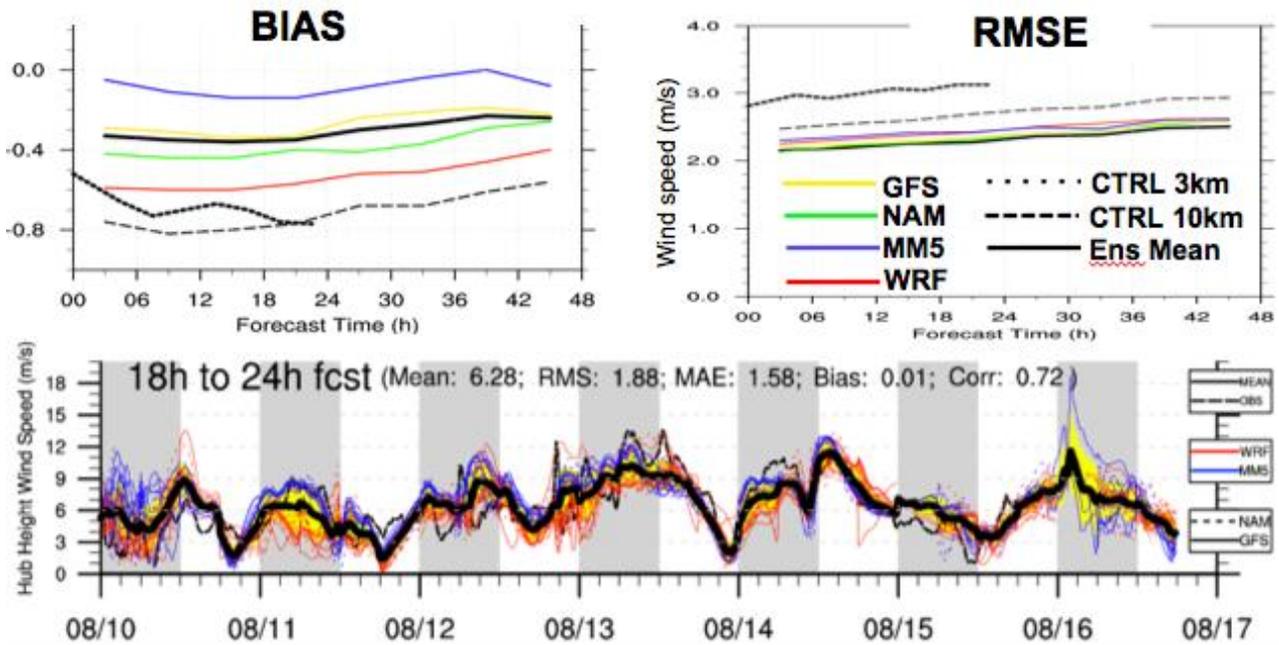
*Anticipated Collaborators:* Our partnership with LANL continues to be important, and government facilities such as the Edgewood Chemical Biological Center (ECBC) and others are showing increasing interest in our work.

*Specific Measurements of Success:* Success will be measured by significant increases in the accuracy of plume predictions compared to measured concentrations of contaminants, and the ability to extend this technology to address traditional air-quality problems.

## **Mesoscale Ensemble Prediction**

***Conduct research to determine optimal methods for defining ensemble members for fine scale features in the urban environment and develop methods for calibrating these new forecasts for operational use by stakeholders. Make the ensemble model the standard for routine delivery of forecasts to RAL sponsors, and educate users so they can confidently use the statistical information.***

Many weather-sensitive agencies and industries make operational decisions based on mesoscale model forecasts. Quite often these decisions can be improved through the availability of probabilistic information. Thus, mesoscale ensemble prediction systems are being developed, and prototype systems are now in operational use. For example, the following figure shows a montage of displays for a nested WRF ensemble system that is being run operationally for a sponsor over one of their wind farms. It is a 30-member ensemble system, with a fine-grid increment of 10 km, which generates four 48-h forecasts per day. A challenging and exciting aspect of this effort is working with forecast users to help them better incorporate stochastic information into their decisions.



Three displays of statistical wind and temperature information on the fine grid (10 km increment) from a forecast from a triply nested 30-member ensemble system applied to a wind farm. Four 48-h forecasts are produced per day.

Actions: 2011-2015 – Develop optimal methods for defining ensemble members and calibrating forecasts for specific user groups. Work with ensemble-forecast users to help them develop improved methods for integrating the statistical information into their decision-making systems

Potential or Expected Sponsors: This is an area of high interest to all of our current DoD sponsors, but we see this effort as being relevant to any end user needing forecast uncertainty information as part of their decision-making process. One example sponsor category is the wind energy sector, but there are many more.

Anticipated Collaborators: Various Programs in RAL, the NCAR Data Assimilation Research Testbed (DART), the National Center for Environmental Prediction, and others.

Specific Measurements of Success: Ability to educate the users of the statistical information about its merits in decision-making processes, and ability to optimize forecast calibration techniques.

## Frontiers

### Urban-Scale-Climate Coupled Applications for Defense and Homeland Security

*Develop methods for creating fine-scale climate data sets that represent current conditions as well as projections on seasonal and longer time scales.*

The Department of Defense, Department of Homeland Security, and Intelligence organizations are showing an increasing interest in using climate data to inform their decision-making processes. NGIC regularly uses fine-scale climate data generated by RAL models as an important component of mission-timing and counter-proliferation operations. The Central Intelligence Agency recently created the Center on Climate Change and National Security, where the focus is not on climate change per se, but to predict National security impacts that could result from events such as drought and flooding, and possible regional responses to such events, like large-population migration, increases in skirmishes due to water shortage, etc. The Army DTC hopes to attract more customers to the Test Ranges by providing them with detailed climate analyses to aid in test planning and optimizing the locale in which to test. DTRA publishes a RAL-created 40-km grid increment global climate database that a large community of users queries regularly for military and domestic-security applications related to chemical and biological defense.

RAL's military and homeland security sponsors have expressed interest in obtaining finer scale climate information than is currently available, and typically request it for small areas such as a city and its suburbs, or a Test Range. Much work needs to be done to eventually be able to do simulations on the order of 100-500 m horizontal grid increments, including:

- Improving the applicable model parameterizations to be able to generate physically realistic results at that scale
- Optimizing such models on advanced hardware platforms that will probably utilize GPU technology;
- Developing hybrid downscaling methods that do not purely rely on computationally expensive dynamical downscaling
- Developing model-verification techniques that are suitable for assessing model output at the sub-kilometer scale, and
- Establishing criteria for generating a statistically sound climate record, which might include developing and applying innovative sampling strategies to allow for a more-efficient creation of the weather variable probability-density functions at lower computational expense.

The above can be partitioned into three areas of endeavor in order to meet sponsor needs and, at the same time, perform the level of R&D required to place RAL at the leading edge of mesoscale and urban-scale climate analysis and forecasting:

- Improve the model's data assimilation capabilities, building upon the successes of the RAL Real-Time Four-Dimensional Data Assimilation (RT-FDDA) system (for which sponsor-funding exists), and transfer these improvements into the Climate-FDDA system
- Efficiently generate the sub-kilometer climatologies in areas of high-interest to sponsors in the defense and homeland security sectors, which combines optimizing hardware platforms, using efficient sampling methods, and verifying the climate database
- Couple the fine-scale climate output to a variety of applications within the defense and homeland security sectors, such as disease-propagation models, transport and dispersion models, explosive sound-propagation models, unmanned aerial vehicles and missile-flight simulators, human-health models, etc.

*Actions:* 2011-2015 – Improve the RT-FDDA and Climate-FDDA data-assimilation capabilities. Develop and test 4D-REKF system (Four-Dimensional Relaxation Ensemble Kalman Filter), which is an observation-nudging, Ensemble Kalman Filter hybrid.

2011-2013 – Develop high-efficiency system for generating sub-kilometer climatologies

2013-2015 – Generate sub-kilometer climatologies for areas of high interest to defense and homeland security sponsors, and couple output to various secondary applications

Potential or Expected Sponsors: The existing sponsor base for downscaling and future-climate applications should be sufficient to fund most of this effort, although additional funds and other sponsors will be sought to acquire the specialized platforms required to support this computationally intensive system

Anticipated Collaborators: We anticipate working closely with other groups across RAL and NCAR that are involved in climate modeling, as well as various universities that we are already working with.

Specific Measurements of Success: The accuracy of these models in depicting future patterns of weather.

## 5. Goal Area: Hydrometeorological Research and Applications on Local to Global Scales

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### Overarching Priority

***Improve the understanding of interconnected cloud, precipitation, and surface hydrological processes, and develop tools to promote societal resilience to changes in the water cycle across a wide range of temporal and spatial scales.***

### Motivation

Hydrometeorology is the science that combines the study of the atmosphere and the hydrosphere, and the processes that control the hydrologic cycle. Understanding the hydrologic cycle is the key to understanding what will happen to water resources in the 21<sup>st</sup> century in the face of global change that now seems virtually certain. Earth's water supply when considered on a regional basis may not be sustainable relative to agricultural and industrial practices of the last century. RAL's intention in this area is to work toward meeting the associated needs of national (federal, state, county and municipal) and international organizations in the public and private sectors by bringing state-of-the-art science and methods to support operational decision making and future scenario planning. Users of such information vary from meteorological services, to flood control districts, to emergency managers, and to a variety of water resource managers.

The many questions that arise in this area can only be addressed by multi-year, interdisciplinary research programs. Two of the programs led by RAL involve significant cross-laboratory research efforts, the Water System program and the Short-Term Explicit Prediction (STEP) program. Both of these have been very successful in bridging efforts across multiple NCAR management units.

Current research foci include the following:

- Short-term storm prediction
- Hydrometeorological processes at the land-atmosphere interface
- Microphysical parameterizations for models
- Water systems under global change
- Winter precipitation and snowpack
- Aerosols and precipitation
- Water resources management

*"...of all the social and natural resource crisis we humans face, the water crisis is the one that lies at the heart of our survival and that of planet Earth"*

*U.N World Water  
Development Report,  
"Water for People, Water  
for Life" (2003)*

This spectrum of research activities aims to improve understanding of hydrometeorological processes and increase the accuracy and value of related community-based prediction systems. These efforts extend from basic research to highly sophisticated applications.

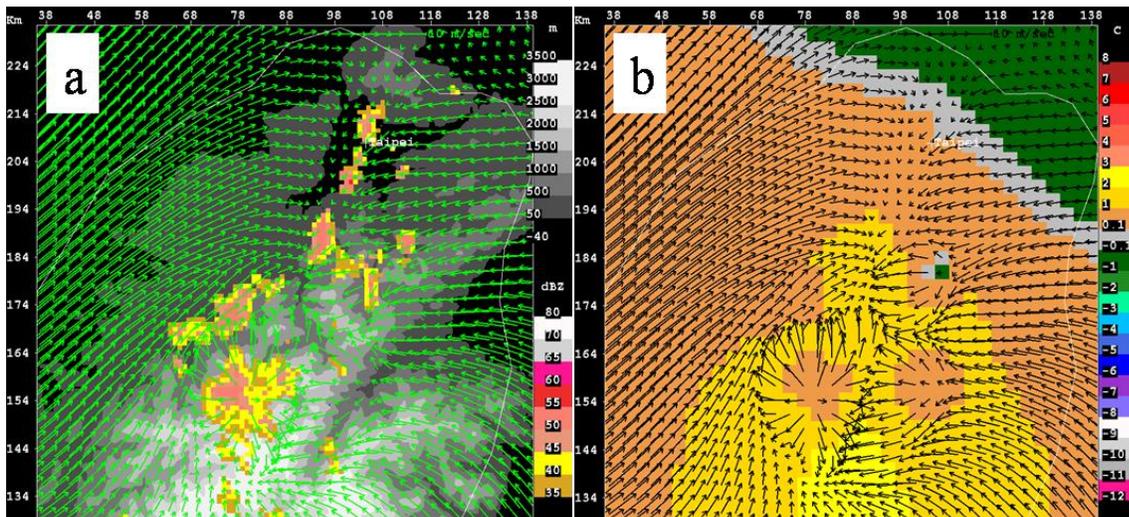
## Near-Term Objectives

### Short-Term Storm Forecasting

*Participate in the cross-NCAR Short-Term Explicit Prediction (STEP) research program to address topics required to improve forecasts with a short time horizon: observations (data acquisition, quality control and data analysis); data assimilation; numerical weather prediction; nowcasting; physical parameterization; and end-user needs.*

The skill of observation-based nowcasts decreases rapidly with lead time. NWP has limited predictive ability in the first few hours due primarily to the problem of model spin-up. The purpose of the research and development efforts described here is to bridge the gap in skill represented by these forecast techniques through the optimal combination of observation-based nowcasts and numerical modeling in collaboration with scientists at NESL and EOL. NSF base funds used here are leveraged more than 3:1 by projects funded from other U.S. and international groups.

An example of wind and temperature analyses using the 4DVAR radar data assimilation system termed VDRAS is shown in the figure below. These analyses provide insights to the mechanisms of orographic convection and improve our understanding of storm initiation and development of conceptual models for nowcasting convective weather.



(a) Variational Doppler Radar Assimilation System (VDRAS) wind vectors at a height of 180 m above the terrain. The plot covers a 100 x 100 km area over northern Taiwan. The longest vectors are about 10 m/s. The gray shades are terrain height given by the scale on the right of the plot. Height range from sea level to over 2500 m. The colored objects are radar reflectivity in dBZ given by the scale on the right. (b) The same as (a) but the color fill is VDRAS-derived temperature perturbations (deg C) given by the right hand scale. The temperature perturbations are with respect to the mean temperature at each height at the start of the VDRAS run which was several hours earlier.

***Actions:*** These include a) completing the retrospective studies over the FRONT (Front Range Observation Network Testbed) region, b) completing the orographic precipitation study, c) establishing 4DVAR and EnKF with radar data as a real-time component of cloud resolving modeling systems (by 2013), d) establishing FRONT as a nowcasting, high-resolution data assimilation, and short term forecasting testbed, e) transferring the AutoNowcaster and VDRAS to the NWS AWIPS and CWB of Taiwan, and f) expanding the STEP program to include winter weather .

***Potential or Expected Sponsors:*** NSF, FAA, NASA, NOAA, CWB (Taiwan), CRIEPI (Japan)

***Anticipated Collaborators:*** RAL will work collaboratively with NESL, EOL and externally with NOAA (GOES-R applications), university partners, MIT Lincoln Laboratories, and international storm-related research and development in Japan and Taiwan.

***Specific Measurements of Success:*** These include a) improvement in the 2-6 hour CSI of storm forecasts by 5% over current performance by 2014; b) improvement of the 4DVAR system component by a factor of ten in execution speed by 2013; c) real-time QPE and QPF over the FRONT region by 2013; d) establishment of a real-time 0-6 hour nowcasting system that assimilates radar and other high-resolution data; and e) further operational use of the storm AutoNowcaster by NWS personnel via AWIPS by 2013 and by CWB of Taiwan by 2012.

## **Coupled Land Surface/Hydrology Modeling**

***Develop an integrated community WRF-Hydro modeling system for the hydrometeorological and regional climate research community to provide a framework from which to examine both terrestrial and atmospheric hydrological processes across a range of temporal and spatial scales.***

RAL scientists are involved with a variety of projects related to hydrometeorological processes at the land-atmosphere interface such as snow accumulation and ablation, infiltration, evaporation, soil moisture dynamics, and runoff generation processes associated with flash floods. A major goal is to improve our understanding of land-atmospheric interactions spanning a variety of time and space scales (weather to climate) and their representation in coupled weather and climate models. This includes development of the community Noah land-surface and coupled WRF-Hydro models to facilitate community research on hydrologic processes and land-atmosphere interactions, and, ultimately, help water managers to more effectively plan for both flash flood events and future climate change.

Current projects include a Front Range flash flood project, research studies on the North American Monsoon, collaborative projects with government agencies and university communities to improve the Noah land surface model, investigating land-atmospheric feedback in semi-arid regions in the US and China, ten-year reanalysis of land-surface component for arctic region, climate forecasting applications in Bangladesh and California, impacts of forest disturbances (bark-beetle kill and wildland fire) on regional climate in western North America, and an improved WRF/Noah modeling system for Taiwan.

Key tools for these process studies include radars, satellites, surface meteorological stations, surface flux measurements, and the WRF Hydro model and Noah land surface model for both weather and regional climate. WRF Hydro is designed to be a framework for the community to link their hydrological models to WRF. RAL has linked a distributed version of the Noah land-surface model to this framework. These community models that include the Noah land surface model and the coupled WRF-Hydro model will serve as the vehicle by which further interaction with the hydrological community will occur.

Actions:

- Execute strategic field campaigns to collect observational data on hydrometeorological processes, including improved rainfall estimation and hydrometeor identification with polarization radars and land surface fluxes in complex terrain
- Develop a community WRF-Hydro modeling system as an option available within the WRF package that incorporates a suite of land-surface modeling options developed by our university and agency partners.
- Evaluate the use of satellite and *in situ* data in the new Noah-Multiple Physics (Noah-MP) model containing the following components:
  - Groundwater module
  - Multi-layer snowpack
  - Dynamic vegetation
  - Multi-layer canopy vegetation
  - Improved snow albedo treatment
  - Irrigation treatment
  - Spatially varying soil layer thickness
  - New frozen soil scheme
  - A multi-layer urban module
- Incorporate alternative physical parameterizations into the Noah-MP model (especially with respect to snow processes), to both improve the fidelity of model simulations and the capability to quantify model uncertainty.
- Conduct detailed evaluation of WRF-Hydro model options.
- Implement a diagnostic approach to model evaluation that uses data from field experiments to evaluate competing model hypotheses
- Conduct climate change studies for the Colorado Front Range, State of California, electric power industry, and the Bureau of Reclamation with WEAP
- Conduct a community effort to compare land-surface/snow models over the Colorado Headwaters region with data from 112 SNOTEL sites and MODIS snow and vegetation products
- Conduct the Colorado Headwaters program on the impact of climate change on snowpack.
- Integrate nowcasting, NWP and hydrological models for streamflow prediction from flash flood to seasonal timescales.

Potential or Expected Sponsors: NSF, NASA, NOAA, foreign government agencies, USAID, World Bank

Anticipated Collaborators: To accomplish these goals RAL will expand upon existing collaborations with university partners in the hydrological community. These collaborations will provide the backbone of new algorithm development efforts. RAL scientists will also maintain close ties to research efforts in the Water System program element conducted by scientists outside of RAL.

Specific Measurements of Success: These include a) completion of the upgrades listed above for the Noah land-surface model by 2013; b) 30% improvement of flash-flood forecasts out to 6 h in the Colorado Front Range by 2014; and c) a release of the first version of WRF-Hydro by spring 2012.

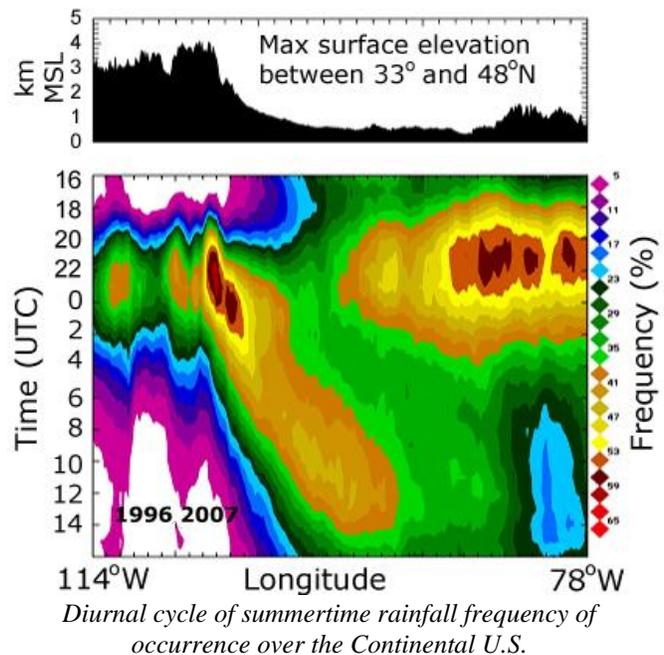
## **Water Systems Program: Water Resources under Global Change**

***Investigate how water vapor, precipitation, and land surface hydrology interact across scales to define the hydrological cycle, including under global change. Examine the impact of global change on snowfall, snowpack and runoff in headwaters regions by conducting high-***

*resolution WRF simulations. Apply the Water Evaluation and Planning (WEAP) tool, in collaboration with users, to a variety of issues concerned with climate change impacts on water resources and develop science-based adaptation strategies.*

### **Improving the representation of the diurnal cycle of precipitation and soil moisture in climate models**

An important goal of the Water System Program is to improve the representation of the water cycle in climate models. While climate models typically predict temperature with reasonable confidence, predictions of precipitation are notably weak. Our focus has been on the diurnal cycle of warm season precipitation including diagnoses of the rainfall climatology downwind of major mountain ranges over continental regions. These global and regional studies have shown that such regions are frequented by organized convection, which propagates and may produce up to 70% of the observed warm season precipitation. An example of the frequency of occurrence of summer convection in the lee of the Rocky Mountains is shown in the figure to the right. The coherent yellow band of frequency from the Rockies at 22 UTC to the central U.S. by 14 UTC the next day is reflective of the occurrence of propagating convection.



These systems, however, are inadequately represented in current global and regional climate models. IPCC4 projections of precipitation trends highlight these regions as having the largest variability or uncertainty. To address this deficiency, the Water System program will focus on three areas during the next 5 years: 1) the development of an improved parameterization of convective precipitation over continental regions globally; 2) the role of soil moisture in modulating the quantity of convective precipitation over continents; and 3) the impact of climate change on these types of system.

#### Actions:

- Facilitate and support the convective parameterization working group.
- Develop and test prototype convective parameterizations that take into account the observed behavior of convection downwind of major mountain ranges.
- Examine the role of soil moisture in modulating these propagating systems.
- Examine the impact of future climate change on these systems.
- Diagnose the behavior of the global water cycle through examination of re-analysis datasets, observations, and CCSM output, and based on this improve all aspects of the hydrological cycle in CCSM.
- Use global water cycle diagnoses to constrain and improve the water cycle observed in climate models, in particular the CCSM model, in coordination with existing efforts at CGD.
- Examine extreme hydrological events such as drought in the AR4 multi-model simulations.

### **Hydrometeorological research for the BEACHON project**

RAL scientists will also be conducting hydrometeorology research related to the coupling of the carbon and nitrogen and aerosol cycles as part of BEACHON, as well as conducting modeling studies on the impact of biogenic aerosols on clouds.

#### Actions:

- Provide instrumentation and scientific expertise to add a water component to the BEACHON project, including the measurement of soil moisture, clouds, and precipitation.
- Provide microphysical modeling expertise to the BEACHON program to enable studies that examine the role of biogenic CCN and IN on cloud and precipitation formation.
- Work with BEACHON scientists to examine the interaction of the water cycle with the carbon, nitrogen, and aerosol cycles.

### **Colorado Headwaters Project**

The Colorado Headwaters project has been initiated to focus on critical questions concerning the effect of climate change on snow processes in the western cordillera of North America. It employs both high resolution models and observations, and addresses the resulting implications for water management and policy. This project is a major focus of the ongoing Water System program and examines through observations and modeling the likely impact of climate change on snowfall and snowpack over the headwaters of the various rivers originating in Colorado. The project extends across several units of NCAR and to collaborators in the university community. RAL staff are leading and conducting key aspects of this program. Pseudo-climate change scenarios will be analyzed with fine-scale WRF simulations down to 2-km horizontal grid increment. These will be coupled with the distributed hydrological model (discussed above), and the water resources management tool (discussed below).

#### Actions:

- Conduct a community effort to compare land-surface/snow models over the Colorado Headwaters region with data from 112 SNOTEL sites and MODIS snow and vegetation products
- Examine the impact of climate change on snowpack using a Pseudo Global Warming (PGW) technique.
- Use the NCAR distributed hydrological model to simulate runoff in the Headwaters region for current and future projected climate change.
- Examine the sensitivity of the simulated snowfall to various physical parameterizations, especially the microphysical parameterizations.
- Evaluate the skill of dynamical versus statistical downscaling techniques using the Headwater's high resolution simulations compared to PRISM snowfall data.
- Examine the impacts of future climate change on the mesoscale features of orographic precipitation and dynamics under climate change.
- Assess the impact of climate change using the NCAR Nested Regional Climate Model simulations of the Western U.S. at 12 km and compare with the Headwaters simulations.
- Downscale the NARCAPP regional model simulations at 50 km to 2 km using the Headwaters high resolution model output at 2 km and examine impacts on various hydrological variables including runoff.

### **Water Evaluation and Planning Tool (WEAP)**

WEAP comprises a sophisticated model that allows water managers to assess, among other things, the impact of future climate-predicted precipitation on the operation of their watershed or other water

resource issues. The development of this model was led in RAL in recognition of the growing need for new tools and methods to study the impacts and adaptation strategies related to global change. The model couples physical hydrology and the water management within a single framework, allowing the direct inference of the consequences of climate change on water-management decisions.

With several thousand users worldwide, the model has been used by many urban water providers to help them in their integrated resource planning process. Notably, the Inland Empire Utility Agency (IEUA) of Southern California used WEAP as its analytical tool to help define robust strategies to ensure system reliability. The El Dorado Irrigation District used WEAP to develop a drought master plan. An unexpected outcome of the WEAP model has been its flexibility in capturing regional differences in the dominant hydrologic processes, whether they are snow-melt dominated watersheds in the Colorado Rockies or fast-response, shallow-groundwater systems found in the Kissimmee River system of Southern Florida. The hydrology of both regions has been successfully modeled, and served as input to WEAP's water-management module. A second unexpected outcome has been the degree to which WEAP has been successful in describing a variety of disparate water-management problems, from drought planning to capital investment, to ecosystem valuation, and others.

Actions:

- Conduct climate change studies with WEAP for the Colorado Front Range, State of California, electric power industry, the Bureau of Reclamation, and Colorado Headwater's project.
- Integrate the WEAP water management model with the LEAP energy management model.
- Improve the physical and water management aspects of the WEAP model.
- Conduct workshops and provide training to future users of WEAP.

Potential or Expected Sponsors: NSF, NASA, NOAA, USAID, World Bank

Anticipated Collaborators: Collaboration will be undertaken with university and other government laboratory scientists as well as water managers.

Specific Measurements of Success: These include, a) success in expanding support for the WEAP model and its applications, including hiring a support scientist; b) completing the Colorado portion of the Headwaters program by 2015; and c) expanding the Headwaters Project to consider climate change in other mountain ranges of the world.

## **Aerosols and Precipitation**

### ***Understand and quantify the relationship between atmospheric aerosol, clouds, and precipitation at the ground.***

Aerosols (natural and anthropogenic) influence clouds through microphysical processes during droplet and ice nucleation in both summer and winter clouds. Understanding the basic microphysical properties of natural, smoke and pollution particles and relationships between cloud properties and aerosol supply are important parameters in the efficiency of precipitation development in clouds. RAL conducts basic and applied research on the impact of aerosols on cloud microphysical processes such as cloud droplet nucleation and formation of rain and snow.

Many countries around the world practice cloud seeding (injecting aerosols into clouds) to enhance precipitation, but in most regions of the world there is little if any evidence of its effectiveness. In trying to understand this issue RAL research has focused on various aspects of advertent and inadvertent modification of clouds and precipitation by aerosols. Past efforts have emphasized cloud and aerosol

measurements at a variety of locations around the world (Saudi Arabia, UAE, Turkey, Mali, Australia, and India). A program has been followed that emphasizes airborne and radar measurements and cloud climatology studies as a prelude to conducting any randomized seeding trials. Education and other kinds of capacity building are a major part of the effort.

RAL's current work in this area involves the evaluation of a cloud seeding experiment in the State of Wyoming for orographic snowpack augmentation. The seeding itself is carried out by a commercial operator, and RAL is involved with the University of Wyoming in both statistical and physical aspects of the evaluation.

RAL expects to participate in an upcoming NSF program called ASCII to study the physics of ground-based silver iodide seeding in the Sierra Madre Mountains of Wyoming on precipitation formation. This will be conducted jointly with the University of Wyoming.

*Actions:* These include a) incorporation of advanced instrumentation, such as advanced airborne *in situ* instrumentation, multi-parameter radars, multiple frequency satellite data, as well as advanced cloud modeling systems into future weather modification studies, b) focus efforts on the establishment of programs that include significant scientific challenges and opportunities including NSF and NASA sponsored programs, and c) develop a cloud model specifically for weather modification evaluations that can be run in real time.

*Potential or Expected Sponsors:* Various national and foreign government agencies, World Bank, U.S. Agency for International Development.

*Anticipated Collaborators:* Univ. of Texas, Texas A&M, Univ. of Wyoming, Univ. of North Dakota, Arizona State Univ., Univ. of Arizona, Indian Institute of Tropical Meteorology, Khalifa University, Univ. of Witwatersrand

*Specific Measurements of Success:* These include a) publishing at least one peer reviewed scientific paper for each project undertaken, b) scientific analysis of the Wyoming seeding experiment, including case studies, modeling and statistical studies and participation in the upcoming ASCII field program during winter 2012, and c) development of a scientifically-based description of the physical processes relating hygroscopic aerosols and precipitation by 2015.

## **Microphysical Parameterization**

### ***Improve forecasts of winter weather conditions at the ground, including quantitative precipitation forecasts.***

Research activities related to microphysical modeling are designed to improve the simulation of cloud water (including super-cooled cloud water), rain and drizzle, freezing rain and freezing drizzle, snow, snow pellets, ice pellets and hail in the WRF Rapid Refresh and other WRF models. Super-cooled cloud water and freezing drizzle are emphasized due to their importance to aircraft icing. Several new components will be added to the Thompson et al. microphysics scheme. A key aspect of the microphysical parameterization is the use of non-dimensional observed snow spectra to constrain the snow species. Robust testing of the new approach will be undertaken.

*Actions:* These include a) adding cloud active aerosol to the Thompson et al. microphysical parameterization, b) creating a new module for hydrometeor melting and evaporation designed specifically to improve the simulation of downdrafts in storms, c) providing updated versions of the

Thompson et al. scheme to the WRF model support group at MMM and NOAA/ESRL group in support of the Rapid Refresh model, d) testing the microphysics scheme with observations from programs such as ICE-L, IMPROVE II, and Colorado Headwaters and e) deploying snow gauges at the Fraser Experimental Forest and other appropriate sites in the Colorado Rockies in support of model verification.

*Potential or Expected Sponsors:* FAA Aviation Weather Research Program, NCAR base (STEP program), Water System Program.

*Anticipated Collaborators:* Univ. of Washington, Univ. of Pecs (Hungary), St. Louis Univ.

*Specific Measurements of Success:* These include a) improving the 0-12 hour forecast of the spatial distribution and magnitude of supercooled liquid water and freezing drizzle by 30% by 2013, b) improving the surface distribution and magnitude of snowfall in complex terrain by 20% by 2013, c) incorporation of an aerosol component into the microphysics by 2011 which includes the activation of cloud droplets and ice nuclei based on aerosol characteristics, and d) publishing at least one peer reviewed article related to the microphysical modeling work every two years.

## Winter Precipitation and Snowpack Measurement

***Improve the measurement of winter precipitation rate, type, and snow size distribution by direct measurement at the ground and via remote sensors.***

Efforts in this area include the development of radar based algorithms to detect winter precipitation type, winter microphysics studies using a video disdrometer and other data at the Marshall Field Test Site, participation in winter field programs and analysis of resulting data to improve understanding of winter precipitation processes, and snowfall measurements to evaluate the Wyoming orographic snowfall enhancement experiment.. Scientists in this area are also heavily involved with the Colorado Headwaters research effort (see earlier section). An X-band dual-polarization radar will be used to map out orographic precipitation in the Colorado Rockies and in south-east Wyoming starting in 2012. A recent development is the decision by the NOAA Climate Reference Network program to move their Sterling, VA test facility to the Marshall Test Site. We anticipate that future research opportunities related to snow gauges and other winter surface based instrumentation may develop out of this effort. We recently participated in testing an upgraded All Weather Precipitation Accumulation Gauge at the Marshall Test Site. The World Meteorological Organization (WMO) recently decided to make the Marshall Test Site the U.S. testbed for an upcoming Solid Precipitation Inter-comparison study for automated snow gauges. In addition, snow on the ground represents an integration of multiple hydrometeorological processes, including precipitation, sublimation, and redistribution by wind; we will continue the development of a new technique to map out snow depth using a scanning laser at the Marshall and Niwot Ridge Test Sites.

*Actions:* These include a) obtaining support for research at the Marshall Test site from non-NSF sponsors, b) maintaining a research focus on the Colorado Headwaters project, especially regarding model verification with snow gauges, hydrometeor characterization, X-band radar characterization of precipitation profile measurements, simulation of the snowfall, surface sublimation, runoff, linkages to water resource managers, and other societal impacts, c) scientific analysis of the Wyoming weather modification program, including case studies, modeling and statistical studies and participation in the upcoming ASCII field program during winter 2012, and d) working with the NOAA National Weather Service to implement new algorithms supported under this effort into operational systems such as NexRad (the freezing drizzle detection technique, for example).

Potential or Expected Sponsors: These include NSF (STEP program), NOAA (NWS and NESDIS), FAA.

Anticipated Collaborators: Univ. of Wyoming, NOAA

Specific Measurements of Success: These include a) publication of at least one scientific peer reviewed paper every year; b) expansion of research involving the Marshall Test Site by 50% by 2013; c) successful completion of the Colorado Headwaters Project by 2015, including substantive peer reviewed articles on the RAL areas of emphasis listed in the actions above; d) Implementation of techniques developed through this effort into operational systems (the freezing drizzle detection technique using WSR-88D radar data for example; and e) development and analysis of new hydrometeor measurement techniques in complex terrain regions to support radar precipitation estimates and model validation.

## Frontiers

### Water and Energy in the West

***Define and implement a community-wide initiative to address the pressing problem of water availability and water-related disasters and the exploration of the water-energy nexus in the Western U.S.***

Climate model projections suggest that the Southwest U.S. could experience severe drought in the next 25-50 years. NCAR scientists have the requisite skills and tools to address many of the key scientific and societal issues related to understanding and adapting to this change. Climate change also suggests the increased occurrence of extreme events such as floods.

Research is needed that explores the interactions, and possible collisions, between water-management and energy-management decision making. National-scale guidance is needed on energy policy and decision making that leads to reduced greenhouse gas emission, and avoids unintended consequences related to water management in the context of energy generation. Different energy management strategies will have different water management implications that extend from the local, to the regional, and ultimately to the national scale. Further, it is recognized that the local importance of these impacts will be defined by the characteristics of individual water systems within which energy management strategies are implemented.

“Both the availability and use of water are changing. The reasons for concern over the world’s water resources can be summarized within three key areas: water scarcity, water quality, and water related disasters.”

U.N World Water Development Report,  
“Water for People, Water for Life”  
(2003)

Proposed areas of focus for this initiative are:

- Improve scientific understanding of seasonal changes in precipitation, sublimation, snow water equivalent, snowmelt, soil moisture, and transpiration in the western USA, with particular attention to changes associated with a shift to earlier snowmelt and the potential shift from energy-limited to water-limited systems.
- Improve scientific understanding of the magnitude of the expected drought through the use of high-resolution climate models (in association with the Colorado Headwaters Project).
- Evaluate water resource impacts through use of the WEAP model.

- Implement RAL's flash flood decision support system into the infrastructure of Western water utilities.
- Study societal impacts through interactions with RAL social scientists

*Actions:* Complete simulation and analysis of extended (8-year) climate warming experiments with WRF to assess future changes in the seasonal patterns of precipitation, snowpack and runoff. Hire an additional support scientist for the program to help build capacity in water resource management and capitalize on societal impacts opportunities with Western water utilities. Further develop the RAL flash flood decision support system to the point that it can be deployed at Western water utilities.

*Potential or Expected Sponsors:* NSF, NOAA, NASA, Bureau of Reclamation, National Renewable Energy Lab (NREL), Western Electric Coordinating Council, Western water utilities.

*Anticipated Collaborators:* USGS, Bureau of Reclamation, The Water Research Foundation (WaterRF); NREL, Idaho Power.

*Specific Measurements of Success:* Completion of end-to-end programs regarding the impact of climate change on the water resources associated with Colorado Headwater basins. Establishment of a new program examining the impact of climate change in the West, and a new project on the water-energy nexus in the Western US. Implementation of flash flood decision support system by Western water utilities.

*Challenges and Opportunities:* There is a lot going on within the federal agencies regarding the water-energy nexus, and figuring out NCAR's role will be a challenge. We have been collaborating with the Stockholm Environment Institute (SEI) and were successful in getting a NOAA Societal Applications Research Program project on exploring the water-energy nexus in California. We are linking two Planning Purposed Models (WEAP and the Long Range Energy Applications Program, LEAP).

## **Water Resource Vulnerability and Adaptation in Developing Countries**

***Prepare a strategically-based research and development plan and an implementation plan for providing assistance to the developing world in managing scarce water resources, ensuring water quality and mitigating hydrologic-related disasters.***

United Nations World Water Development reports in 2003 and 2005 identified water as one of the key issues that need to be addressed in order for the developing world to progress beyond current poverty levels. Key issues include water scarcity, water quality, and water-related disasters. NCAR scientists and their collaborators have developed a number of approaches that can be applied to help developing countries address these issues, including water management and disaster preparedness tools. Examples include the SE Asia Flood forecast system, the Front Range Flash Flood Nowcast system, and the WEAP system for evaluating optimal water management in a changing world. A number of current efforts are addressing some of these issues in developing countries, but much more needs to be done.

*Actions:* These include a) identifying research and development collaborators to constitute a team for the initiative, b) organizing a team workshop with potential stakeholders and sponsors to identify primary needs of the developing nations with regard to water, c) identifying team members to draft subsections of the proposed plan and an overall plan coordinator, d) creating the Implementation Plan to identify R&D needs, e) creating the R&D Plan with associated costs and priorities, f) spending 1-2 years discussing these plans with potential sponsors until the first component of funding is identified, g) adopting the Headwaters-type research approach for Nepal and other third world countries with significant topography.

Potential or Expected Sponsors: USAID, World Bank, Inter-American Development Bank, Asian Development Bank, NOAA and NSF

Anticipated Collaborators: Interested universities and Federal agencies and foreign governments.

Specific Measurements of Success: Successfully submit a plan and receive funding to begin a program.

Challenges and Opportunities: One major outcome of the recently completed 16<sup>th</sup> Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) was the Cancún Adaptation Framework, which provided the boldest affirmation to date that reducing vulnerability and building resilience to climate change are an important element of a global effort to confront the challenge of a changing climate, alongside efforts to reduce greenhouse gas emissions. The Cancún Adaptation Framework calls upon all parties to (i) pursue a series of specific adaptation actions, (ii) establish a National Adaptation Plan development process that will assist developing countries to identify medium and long-term adaptation needs, and (iii) have developed countries provide:

“...long-term, scaled up, predictable, new and additional finance, technology, and capacity building...to implement urgent, short-, medium- and long-term adaptation actions...at local, national, sub-regional, and regional levels, in and across, different economic and social sectors and ecosystems.”

This outcome represents a major opportunity to contribute to the global dialogue on adaptation. A challenge is that this dialogue is not merely technical but is truly inter-disciplinary, and will require substantial collaboration among institutions and disciplines.

A proposal in support of this type of activity was submitted to the Inter-American Development Bank with SEI and university collaborators in Chile: “Knowledge and Capacity Building Product: Water and Sanitation Climate Change Adaptation Case Studies.”, as the IDB begins to seriously consider how to facilitate the development of methodologies to expedite deployment of resources to finance adaptation action.

## 6. Goal Area: Research and Applications for Surface Transportation, Energy, and Other Emerging User Sectors

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### Overarching Priority

***Identify, develop, and implement advanced weather decision support systems for new and emerging user sectors such as surface transportation, renewable energy, precision agriculture, and other applications.***

### Motivation

Life and property could be spared and economic performance improved if weather information were utilized more effectively by decision makers across the nation. This is the motivation for engaging stakeholders in various economic sectors, many of which have not been historically well served by the meteorological community, to explore new solutions to specific problems.

During the next five years, stakeholders in wireless vehicle technology programs, wildland fire management and mitigation, energy and particularly alternative energy, precision agriculture, and retail operations (just-in-time delivery concept) will be proactively engaged to understand and document their unmet needs for weather and climate information and to consider addressing their needs through science and technology development.

The quote by Senator Mikulski, in the box to the right, correctly identifies the need for improved weather information to serve societal needs, though it is interesting to note that RAL research since 2006 has done a more careful study of the magnitude of the U.S. weather sensitivity, and though quite substantial (~ \$500B in 2010 dollars) it is less than stated in the quote.

*“One-third of our gross domestic product is weather sensitive -- \$3 trillion. That’s why I’m fighting in the US Senate to make sure ...[we] have the funding needed for the latest technology to keep improving our weather forecasts.”*

*- Senator Barbara Mikulski (2006)*

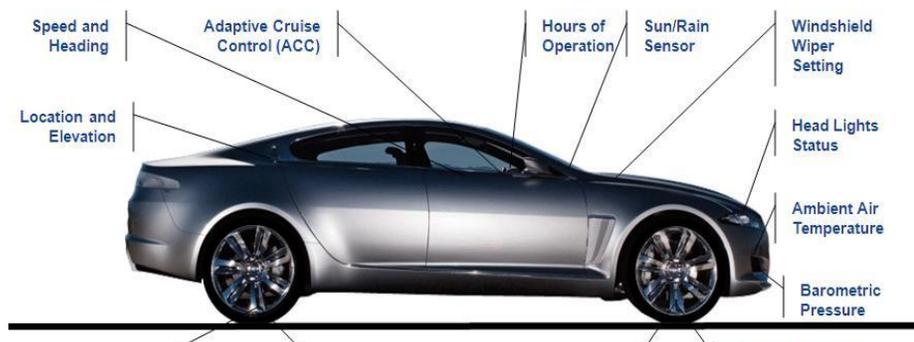
### Near-Term Objectives

#### Surface Transportation Weather

***Become the central focus for research and development for the weather component of Federal Highway Administration’s wireless vehicle technology program. Accelerate the adoption of the Maintenance Decision Support System technology across the nation and extend this technology by developing transportation decision support systems focusing on traffic, incident, and emergency management and maintenance beyond snow and ice control. Perform research to seamlessly blend the strategic prediction component of the system with tactical short-term weather and road condition technologies.***

Since the late 1990s, RAL has played a pivotal national role bringing the surface transportation and weather communities together to improve the performance of surface transportation weather services.

RAL will continue this community building process, as the concept of advanced weather information for the surface transportation sector holds great promise. RAL will continue to work with the surface transportation stakeholders in a proactive manner to implement a research agenda that addresses national and international needs for improved surface transportation weather services for the surface transportation community and the traveling public. Surface transportation research efforts include the further development of: the winter Maintenance Decision Support System (MDSS) that focuses on pavement condition modeling, precipitation prediction, data fusion techniques, and snow and ice control rules of practice; the use of vehicles as weather and road condition sensors; the Vehicle Data Translator that will ingest, process, and generate derived weather and road condition products for road segments; in-vehicle information systems for communicating weather and road hazards; and advanced data quality control techniques for fixed and mobile datasets.



*Illustration of several data elements available from passenger vehicles that may be utilized in algorithms to diagnose weather and road condition hazards.*

**Actions:**

2013-2015– Coordinate with the Federal Highway Administration (FHWA), State DoTs and private sector stakeholders to define specific R&D initiatives required to provide wireless in-vehicle operations with advanced weather and climate information in the following categories: a) diagnosing pavement condition, b) use and quality assurance of vehicles being used as weather probes, c) precipitation detection and nowcasting, d) processing of weather data from vehicle sensors, and e) formulation of informational products to communicate weather and road hazards to drivers, road maintenance, traffic management centers, and road safety stakeholders.

2011-2015 – Coordinate with the FHWA, Federal Railroad and Transit Administrations, State DoTs and the private sector to define specific research and development initiatives required to provide these sponsors with decision support systems based on advanced weather and climate information to support their operations.

2011-2014 – Design, build and test prototype systems for sponsors identified below. Transfer software systems to the private sector for broad implementation.

**Potential or Expected Sponsors:** FHWA, U.S. DoT Research and Innovative Technology Administration (RITA), State Departments of Transportation, private sector road weather service providers, vehicle manufacturers, and vehicle technology developers.

**Anticipated Collaborators:** Internal NCAR collaborations include WRF model developers, data assimilation researchers and land surface modelers at NESL. External collaborators include NOAA (GSD) that is transitioning MADIS to operations, Mixon/Hill, developer of the *Clarus* System, State DoTs, University of North Dakota, Surface Transportation Research Center, Iowa State University, Center for Transportation Research and Education, and Noblis.

**Specific Measurements of Success:** Expanded adoption of MDSS technologies by State DoTs performing snow and ice control and by private sector road weather service providers. National deployment of wireless vehicle technologies and the utilization of weather and road condition data from passenger

vehicles including establishing a national demonstration of the wireless Vehicle Data Translator technology.

## Renewable Energy

### *Develop new methods to more accurately predict wind and solar radiation in support of renewable energy industries*

Risks associated with energy supply and demand revolve around market dynamics, financial conditions, politics, technology choice, fuels, environmental quality, and weather. The recent policy trend to require a larger fraction of the energy portfolio devoted to renewable energy sources, such as wind and solar, puts additional strain on the energy industry as these sources are less predictable than traditional generation sources. The influence of significant weather events on the energy industry has increased with diminishing reserve margins to meet peak loads. In the Western U.S., weather factors have not only included unusually hot summer and cold winter events, but also low precipitation that reduces hydropower capacity and increases electrical demand for irrigation pumping and groundwater withdrawal. Improved weather prediction and precise spatial analysis of mesoscale weather events are crucial to both short- and long-term energy management.



*Photo of wind turbines at an Xcel Energy wind farm in Northern Colorado*

#### Actions:

2011-2015 – NCAR and its research collaborators will actively engage the renewable energy industry and seek opportunities for improving the analysis and prediction of weather, particularly wind and solar radiation. Improving the prediction of wind and solar radiation will require research investments in weather modeling (global to local scales), data assimilation, boundary layer meteorology, cloud and precipitation processes, turbulence, statistical post processing techniques, and land surface characterization and prediction.

2011-2015 – NCAR will engage this new economic sector by forming partnerships in the research and business community, joining the American Wind Energy Association (AWEA), Utility Wind Integration Group (UWIG) and other relevant alternative energy organizations, form collaborations with the National Renewable Energy Laboratory (NREL) and the Center for Research and Education in Wind (CREW), serve on committees focused on the utilization of climate and weather information in alternative energy operations, present relevant papers at alternative energy conference, and exhibit NCAR capabilities at relevant stakeholder conferences and trade shows.

2011-2015 – NCAR and its research collaborators will focus on weather and climate systems and science that are critical to infrastructure planning and management, prediction of energy demand, management of energy supply, energy pricing and markets, energy system operations and regulatory compliance, and economic risk minimization. The energy industry has expressed needs in the following areas which will be NCAR's specific foci:

- Improved weather forecast accuracy
- Improved weather nowcasting capabilities (0-3 hour predictions)
- Improved resolution of forecast information and diagnostic data in time and space (e.g., hourly heating and cooling degree day calculations, hourly and shorter term wind and solar predictions)
- A better understanding of the uncertainty that is inherent in the forecasts
- Increased attention to understanding sponsor requirements
- Improved understanding of user capabilities to utilize information for specific applications
- Understanding of barriers to the use of improved information in decision making
- Additional weather observations at strategic locations as determined by quantitative methods.

Potential or Expected Sponsors: DOE (National Renewable Energy Laboratory), NASA-ROSES, NOAA, renewable energy foundations, and the private sector energy industry

Anticipated Collaborators: NESL, University of Colorado, Colorado School of Mines, Colorado State University, Pennsylvania State University, and private sector energy and weather service provider companies.

Specific Measurements of Success: Reduce mean absolute error in wind energy prediction by 10% by 2015. Develop an international standard definition of a “wind ramp” event, and develop user-focused verification metrics for the wind energy prediction community. Begin research effort in insolation prediction and verification. Seek adoption of advanced wind and solar prediction technologies across the renewable energy industry.

## Wildland Fire Management and Mitigation

***Identify opportunities to field test the new WRF-Fire coupled model, which was developed in NCAR (RAL and NESL), in a near-operational environment in collaboration with stakeholders in the land management community.***

The number and intensity of wildland fires continue to grow taking a huge toll on society. Wildland fire costs the U.S. approximately \$10B annually. Climate change and the expansion of developed lands will likely increase the impact of wildland fires. Over the last decade, significant progress has been made developing and coupling NWP models (e.g., WRF) with fire behavior models. In addition, significant scientific and technical interactions have occurred between the operational and research components of both the atmospheric and fire communities. These efforts have significantly improved our understanding of fire behavior and mitigation strategies. Researchers are at the threshold of being able to run near-real-time fire behavior models to support fire control operations. Continued sponsorship of fire research and development activities will ensure that wildland firefighters have the tools they need to safely perform their duties and advance research associated with coupled modeling systems.



*Output of fire behavior model showing fire spread the Esperanza, CA fire in October 2006*

Actions:

2011-2013 – Coordinate with potential sponsors to identify opportunities to demonstrate the new WRF-Fire capabilities to support near real time fire operations.

2011-2014 – Expand testing program to a national and international program level that would be comparable to the existing NCAR Joint Numerical Testbed capabilities and resources.

*Potential or Expected Sponsors:* NSF Cyber-Enabled Discovery and Innovation (CDI) Initiative, NOAA, Department of Agriculture-Forest Service, State governments, and possibly NIST.

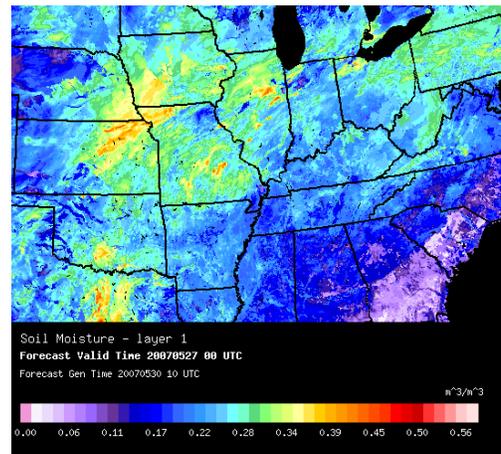
*Anticipated Collaborators:* Internal NCAR collaborations include WRF model developers and data assimilation researchers at NESL. External collaborators include University of Denver (Dr. Jan Mandel), NOAA, NIST, OFCM National Wildland Fire Weather Needs Assessment Joint Action Group, International Association of Wildland Fire.

*Specific Measurements of Success:* Implementation of a numerical modeling testbed applicable to fire weather-centric issues based upon the Joint Numerical Testbed concept. This testbed, with the participation of a broad group within the wildland fire community, would a) establish relevant metrics for model evaluation, b) provide a baseline of current capabilities, and c) establish a neutral environment to test and evaluate various model configurations (including numerous meteorological and fire behavior models) against datasets using decision-maker-defined metrics in various research and operational scenarios.

## Precision Agriculture Decision Support

*Using previous work with HRLDAS, DICAST<sup>®</sup> and the Noah Land Surface Model as a baseline, develop decision support systems focused on precision agriculture concepts for various stakeholders (agricultural companies and weather provider companies) in the agricultural sector.*

Weather, both directly and indirectly, is the critical factor in the success of a harvest and farmers' livelihoods. Severe weather events, such as hail, high winds, tornados, and flash floods can destroy an entire harvest in a very short period. However, many agricultural decisions simply require more accurate forecasts of the weather and the resultant soil conditions. Precise soil temperature and soil moisture forecasts are critical to the timely application of pesticides and to efficient irrigation practices. With NASA funding, RAL collaborated with industry to develop a prototype agricultural decision support system that optimizes the timing of pesticide application and irrigation to minimize the impact of emerging pests. The project utilized advanced weather and land surface models and a data fusion technology that continuously optimizes the weather and soil predictions. This research has led to improvements in the High-Resolution Land Data Assimilation System (HRLDAS), Dynamic Integrated Forecast System (DICAST), and Noah Land Surface Model. A major objective of the research was to evaluate the impact of incorporating NASA MODIS data into the system. This research was instrumental in providing critical feedback to the weather and land surface modeling, and satellite communities and represents a cross disciplinary effort. Continued work in this area will lead to more precise prediction of weather and soil conditions and more efficient and



*Output from RAL's soil condition prediction system showing soil moisture ( $\text{kg}/\text{m}^3$ ) in the top centimeter of soil.*

profitable agricultural operations. RAL has an interest in continuing this research with additional sponsorship.

Actions:

2011-2013 – Coordinate with potential sponsors to identify needs within the precision agriculture sector that can benefit from decision support systems using advanced weather and climate information.

2012-2014 – In collaboration with sponsors and development team members, design, build and test prototype agriculture-oriented decision support systems.

2013-2015 – License all fully tested and documented software to the private sector for broad implementation.

Potential or Expected Sponsors: NASA ROSES, private sector weather service providers (e.g., DTN/Telvent, Monsanto, Deere), and USDA.

Anticipated Collaborators: Internal NCAR collaborations include WRF model developers and data assimilation researchers at NESL.

Specific Measurements of Success: Improved soil temperature forecasts, higher resolution soil temperature and moisture datasets, and industry adoption of these products to support precision agriculture operations.

## **Statistical Post-Processing and Probabilistic Prediction**

***Explore new statistical processing methods such as data mining and ensemble techniques to improve the overall forecast skill of RAL's DICAST system and develop new capabilities to generate probabilistic weather prediction products (e.g., probability density functions) and calibrated ensembles. Develop new user-focused techniques for communicating uncertainty.***

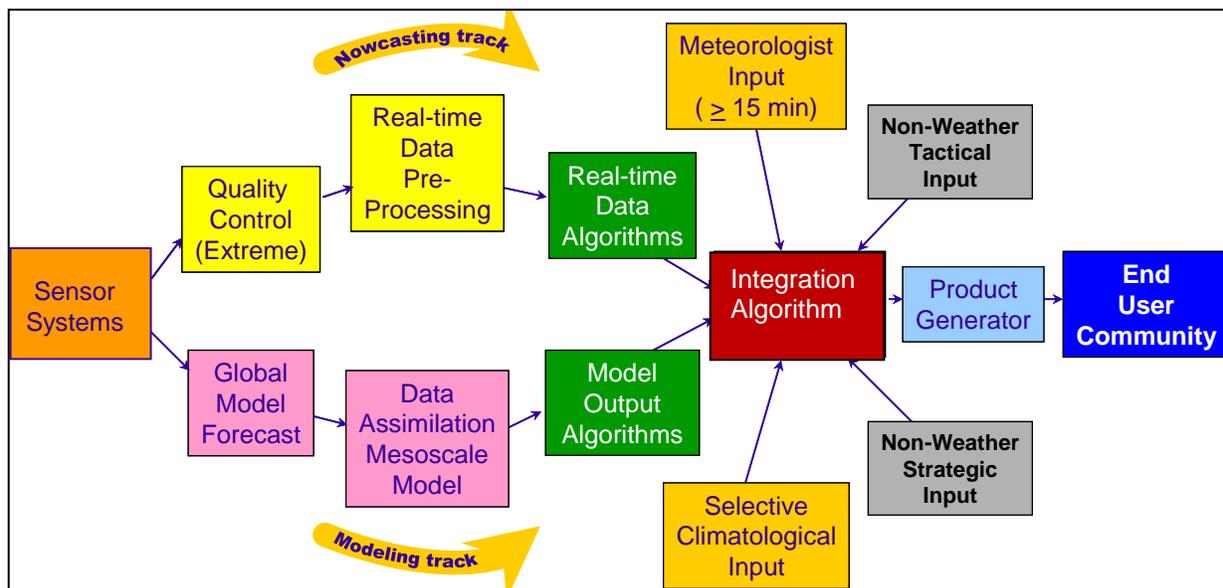
RAL has been a leader in the development of weather prediction systems that blend data from numerical weather prediction models, statistics datasets, real-time observations, and human intelligence to optimize forecasts at user-defined locations. The Dynamic Integrated Forecast System (DICAST) is an example of this technology and it is currently being used by two of the nation's largest private sector weather service companies. There is a growing desire in industry to have fine-tuned forecasts for specific user-defined locations. This trend is clear in the energy, transportation, agriculture, and location-based service industries. RAL's expertise in meteorology, engineering, and applied mathematics and statistics, will be utilized to address society's growing need for accurate location-specific weather information.

Actions:

2011-2013 – Coordinate with potential sponsors to identify and prioritize operational needs for probabilistic prediction systems and advanced post-processing methods (Kalman filters, analogs, BMA, etc.); pursue the top three priority applications as long as required to obtain funding.

2011-2014 – In collaboration with sponsors and development team members, design, build and test prototype decisions support systems.

2011-2015 – License fully tested and documented software to the private sector for broad implementation.



*Outline of the concept involving the blending of algorithms based on real-time data and on forecasts to generate weather products tailored to an end user and incorporating non-meteorological information.*

Potential or Expected Sponsors: NSF, NASA, NOAA, FHWA, State DoTs, and private sector weather service providers.

Anticipated Collaborators: NESL, IMAGE, University of Colorado, Pennsylvania State University, and others.

Specific Measurements of Success: Expand utilization of RAL's DICast core technology by public and private sector organizations into new markets (e.g., location-based services) by 2015. Develop and implement a high-resolution gridded capability that includes probabilistic forecast variables.

## Frontiers

### Atmospheric Boundary Layer Research

***Perform research to significantly advance our knowledge of the atmospheric boundary layer and develop new methods and techniques to more accurately characterize and model the boundary layer to improve the prediction of surface and near-surface weather conditions.***

The lower atmospheric boundary layer (ABL) is characterized by strong thermodynamic and kinematic turbulent energy exchanges between the atmosphere and the land surface. As such, the ABL is sensitive to terrain characteristics, surface roughness, vegetation, albedo, and soil conditions. Synoptic and mesoscale dynamical processes also impact the ABL including, but not limited to, low-level jets, frontal processes, thermally driven circulations, gravity waves, and critical levels.

Our ability to accurately predict near-surface weather conditions is highly constrained by our lack of knowledge of ABL processes and by their excessively simple treatment in NWP models. A better

understanding of the ABL will lead to improved prediction of ABL structure and evolution and in turn improved near-surface weather forecasts. Major stakeholder communities that are sensitive to near-surface weather include agriculture, surface transportation, wind energy, aviation, construction, water resources (evaporation), air quality, homeland security (e.g., hazardous plume transport), and recreation.

In addition to this research leading to improved forecasts of ABL weather, the knowledge gained and new parameterizations developed will have an equally large impact on regional simulations of future climates. Virtually all of the stakeholders, for whom climate-downscaling simulations aim to provide information for critical decisions, care most about conditions at or near the surface. Modeling the ABL properly in regional climate models is essential to capitalizing on the large investment in the IPCC model runs used to drive the downscaling work.

It is becoming increasingly apparent that ensemble weather prediction on the mesoscale and synoptic scale should include the effects of uncertainties in the parameterizations. The proposed research on ABL processes and parameterization will benefit the further development of such stochastic methods for representing the ABL and its interaction with the land and water surface.

Actions:

2011-2013 – Seek opportunities for funding to improve our understanding of the ABL with an initial focus on turbulence, momentum mixing, and the low-level jet, because these phenomena play a critical role in the weather community’s ability to predict surface and near-surface wind conditions, which is critical for both the wind energy industry and aviation. NCAR will seek opportunities to participate in field experiments that focus on boundary-layer processes and measurements. Large eddy simulation models will also be utilized to evaluate new and improved physics schemes and their impact on predictability.

2011-2015 – Expand the research to include the convective atmospheric boundary layer and its sensitivity to surface characteristics. During this period, knowledge obtained from the ABL research will be focused on improving the boundary layer physics schemes (explicit and parameterized) contained in advanced numerical weather prediction models such as WRF. Research will be performed to verify the performance of new schemes. The Joint Numerical Testbed will be used to test the new schemes. Successful improvements will become part of the WRF community modeling system.

Potential or Expected Sponsors: NSF, DOE, FAA and the private sector energy industry.

Required Collaborations other than Sponsors: NESL, Penn State, and the University of Colorado.

Specific Measurements of Success: Initial measurements of success will focus on improved near-surface wind and turbulence physics schemes that will result in a 10% improvement in NWP predicted surface wind speed and turbulence from 400 m to the surface. Longer-term goals will be to improve the characterization (location, depth, and strength) of low-level jets and improve storm forecasts through better characterization of the low-level wind field.

## 7. Goal Area: Testing, Validating and Verifying Advanced Numerical Forecasting Techniques

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### Overarching Priority

***Provide a state-of-the-art test and evaluation function (in collaboration with others) for numerical forecast systems serving both research and operational users, and facilitate the transfer of research into operations.***

### Motivation

A long-standing goal within the numerical prediction community, and particularly within the community of operational users of numerical models, is to have a facility that has expertise in testing and evaluating all types of numerical techniques. It would be expected to provide unbiased information to operational entities to aid in making decisions regarding, for example, optimal configurations for specific prediction needs, determining requirements for new research, maintaining code repositories for both research and operational users, and providing support for these communities via help desks, workshops and tutorials. Additionally, model and forecast system developers in the research community have required a more efficient method of responding to operational requirements, obtaining access to operational codes, and collaborating on new research work related to the Weather Research and Forecasting (WRF) model. The seeds for such a group were planted in RAL in 2004 with the creation of the Joint Numerical Testbed (JNT). The JNT was founded on the principle that no development would be undertaken by staff members, except for verification and evaluation tools, and that staff would be seen as having a neutral role in the testing of any numerical technique. This “honest broker” concept has served well in building a strong trust relationship between the JNT and its various collaborators and sponsors.

A central emphasis of the JNT is on activities of the Developmental Testbed Center (DTC), which focuses on the WRF model, including community support and testing and evaluation activities. While the DTC is a distributed facility, with staff residing in the JNT and the Global Systems Division of NOAA’s Earth System Research Laboratory (ESRL), the office of the national DTC director and approximately two-thirds of the DTC staff reside in the JNT. The JNT has expanded significantly in recent years, with the addition of a Data Assimilation Team in 2006 and a Tropical Cyclone Modeling Team in 2009. Because forecast evaluation is at the heart of many JNT activities, and because new high-resolution forecasts require new approaches for forecast verification, the DTC and the JNT have concentrated a great deal of effort on providing verification tools for the community, and the development of verification tools that can meet the needs of specific users. In addition, the JNT provides extensive outreach related to verification methods and tools, as well as the various modeling components that are supported by the DTC.

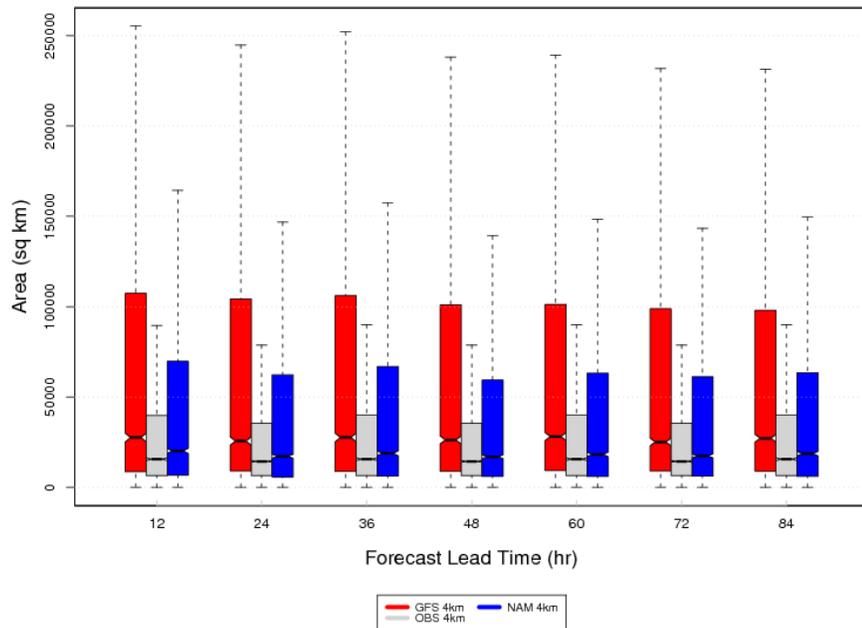
### Near-Term Objectives

#### Mesoscale Modeling

***Provide testing and evaluation of mesoscale numerical weather prediction models for general forecast applications, and support services for a state of the art community modeling system that includes current operational technology.***

The JNT participates in a collaborative effort with NCAR's Earth System Laboratory (NESL), the operational and research branches of the National Oceanic and Atmospheric Administration (NOAA) and the Air Force Weather Agency (AFWA) through the DTC to test and evaluate configurations of the WRF model. The DTC provides unbiased assessments of the operational weather prediction systems as well as new techniques that have shown potential to improve the operational systems. These assessments are based on carefully controlled, extensive tests that utilize both traditional and advanced verification techniques. In addition to conducting extensive tests of WRF configurations, the JNT through its participation in the DTC provides a wide range of potential WRF users, including both researchers and developers, with access to the state of the art software that makes up this prediction system, including code access, documentation and user support.

These community code efforts provide a critical framework for the operational and research communities to collaborate in order to accelerate the transition of new technology into operational weather forecasting. Over the next several years, the DTC will broaden the scope of its testing and evaluation activities to include new software frameworks utilized by relevant operational centers (i.e., NOAA and AFWA) in order to continue to serve as a bridge between research and operations. Facilitating technical discussions regarding the exchange of new features or capabilities between the operational frameworks and the community codes will also be critical to enabling the transfer of the latest research into operations. In addition, the DTC has recently initiated a focus on ensemble forecasts, and these forecasting systems will become an integral part of JNT activities in the coming years.



*Example of a model comparison produced by the DTC using new diagnostic verification tools for evaluating precipitation forecasts. The models being compared are the Global Forecast System and the North American Model.*

#### Actions:

2011 – Expand the number of WRF configurations that undergo extensive testing and evaluation for each new release of WRF.

2011 – Facilitate a stronger connection between research and operations in the area of physics parameterizations by hosting, in collaboration with the NOAA Environmental Modeling Center (EMC), a physics workshop where discussions will focus on both short-term and longer-term strategies for accelerating improvements in physics parameterizations through close collaborations between the research and operational communities.

2011-2015 – Maintain a strong connection between research and operations in the area of physics parameterizations by hosting, in collaboration with EMC, a series of physics workshops focused on specific parameterization types.

2011-15 – Work with WRF developers and developers of the NOAA Environmental Modeling System (NEMS) to put in place technical procedures that facilitate the exchange of new features and capabilities between the two modeling frameworks.

2011-15 – Develop and maintain testing and evaluation systems that are functionally similar to the relevant operational centers so that results from testing and evaluation exercises can directly impact future operational implementation decisions.

2011-15 – Implement capabilities to provide community code support, verification tools, and testing and evaluation for ensemble modeling systems.

Potential or Expected Sponsors: NOAA (NWS, OAR), AFWA, NCAR, NSF, FAA

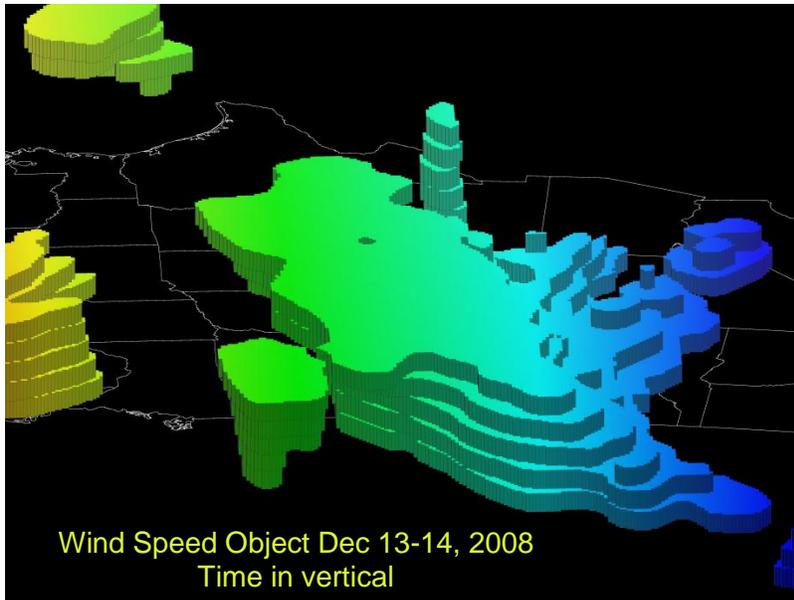
Anticipated Collaborators: NESL/MMM, NOAA ESRL, NOAA NCEP, NRL, universities

Specific Measurements of Success: DTC viewed as an authoritative resource for testing and evaluating mesoscale NWP models, research and operational communities working together to advance physics parameterizations and successful transition of new features or capabilities between WRF and NEMS.

## **Advanced Verification Techniques and Tools**

***Develop, test, and implement as a community resource a suite of advanced verification tools with an emphasis on the special needs of the research, operational and specific user sectors.***

Evaluation of the quality of forecast system performance is essential for model developers, forecasters and operational users. In particular, it is increasingly important to utilize verification approaches that are user-specific, and that provide information about the quality of forecasts relative to the purposes for which the forecast information is used. In response to JNT and community needs, the DTC has developed and implemented the state-of-the-art Model Evaluation Tools (MET), which includes traditional and new forecast evaluation methods and is freely available to the operational and research communities, along with support in the form of tutorials, documentation and helpdesks. The community of MET users includes operational modeling groups, university researchers, and private forecasting organizations. Because the needs of users are diverse, and because traditional approaches are often inadequate to meet the specific needs for forecast quality information, the JNT also engages in research to develop new, improved forecast verification and evaluation methods, such as spatial verification approaches, and leads community efforts to compare and evaluate the new methodologies. New method research also focuses on new types of observations, such as new measurements from NASA satellites that can be used to evaluate cloud properties (e.g., cloud top and base) and attributes of forecasts over oceanic and other data-sparse regions.



*Example of an object-based verification tool applied to a wind forecast. The vertical stair steps represent the time dimension and show the evolution of the object with time. Temporal and spatial attributes of the forecast and observed objects can be compared using the object-based methodology, to provide more complete information about the performance of the wind speed forecast.*

Actions:

2011–2015 – Design and implement community verification tools for tropical cyclone track and intensity, in collaboration with the JNT Tropical Cyclone Modeling Team.

2011–2015 – Develop new methods to evaluate forecasts of various additional attributes of tropical cyclones (e.g., precipitation, storm surge, and genesis).

2011–2013 – Develop and implement new tools and spatial methods that make use of NASA satellite information (e.g., CloudSat Radar).

2011–2015 – Investigate additional applications of new methodologies using remotely sensed data.

2011–2015 – Extend the verification research effort to include a variety of additional methods. Conduct research and tool development focused on approaches that are appropriate for ensemble and probabilistic forecasts, including forecasts of probability distribution functions and tropical cyclones. Engage the international verification community in evaluations of new methods in complex terrain environments and methods focused on additional variables (e.g., wind).

2011–2015 – Coordinate with the international community through conferences, working groups, committees and tutorials to continue to assess the needs of the community that can be addressed through expansion of MET and implement these added capabilities as resources allow.

Potential or Expected Sponsors: NSF, NASA, NOAA, FHWA, AFWA, private sector weather service providers.

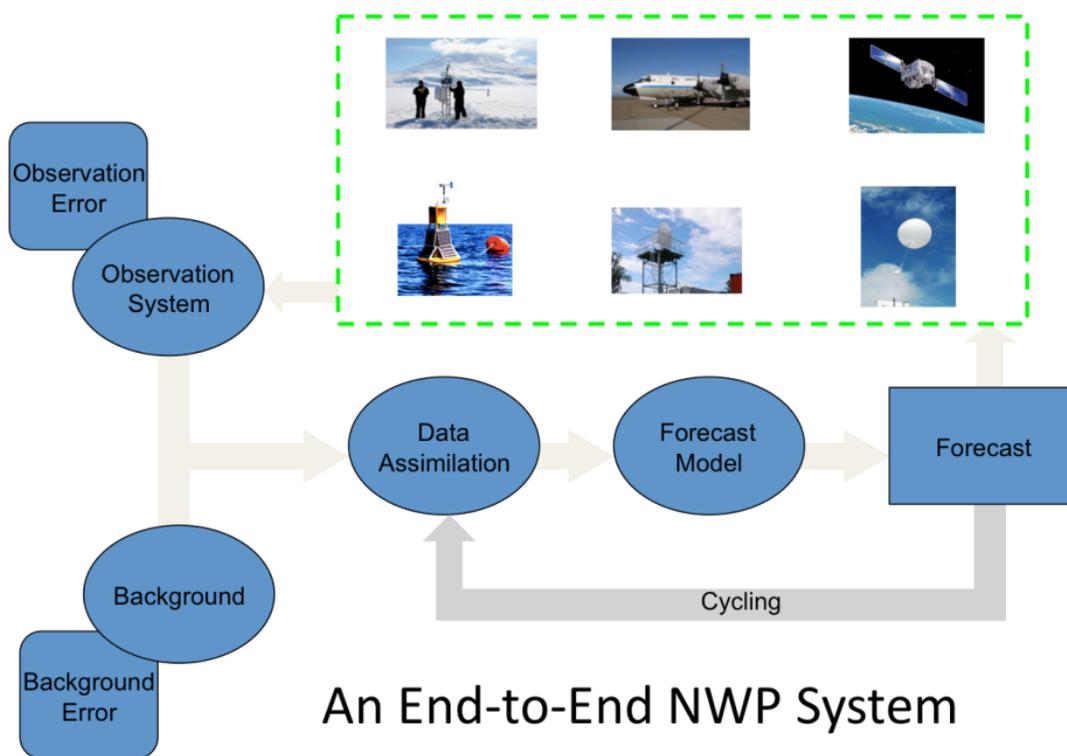
Anticipated Collaborators: Meteorological Service (Canada), NESL, IMAGE, University of Colorado, Centre for Australian Weather and Climate Research, UK Met Office, NOAA AOML/HRD, NOAA Storm Prediction Center, NOAA NHC, NOAA GFDL, ESRL, Purdue Univ.

*Specific Measurements of Success:* Number of international users of MET and positive feedback from this user group, success in implementing verification tools for hurricane forecast evaluation, engagement of international verification community in meta-verification activities.

## Data Assimilation

*Provide testing, evaluation and support services to all developers and users of data assimilation systems and techniques.*

The Data Assimilation Team (DAT) provides a collaborative effort with DTC partners and sponsors to test and evaluate data assimilation systems and techniques. The DAT will maintain a neutral position between all potential developers and coordinate development of the data assimilation systems supported by the DTC between operational centers and research community. The main functions of the DAT include maintenance of data assimilation systems, including testing and evaluation of new data assimilation techniques or configurations in an end-to-end NWP system, transfer of data assimilation technology to operational facilities and providing support via help desks, tutorials, workshops and code repository access.



*Schematic diagram of the end-to-end NWP system used for testing and evaluation of new data assimilation capabilities.*

### Actions:

2011 – Respond to specific sponsors to test, evaluate and maintain their data assimilation systems. Collaborate with the model developers to coordinate data assimilation code development and provide user support to sponsors and the community.

2011–2013 – Review and improve existing end-to-end testing and evaluation system for data assimilation components.

2011–2015 – Review and perform new test and evaluation tasks for all sponsors of the DTC based on available resources and input from the DTC Science Advisory Board and sponsors.

2011–2015 – Provide continuous support to the research and operational communities via support desks, tutorials, workshops, visitor programs and code repositories.

Potential or Expected Sponsors: AFWA, NOAA, NSF

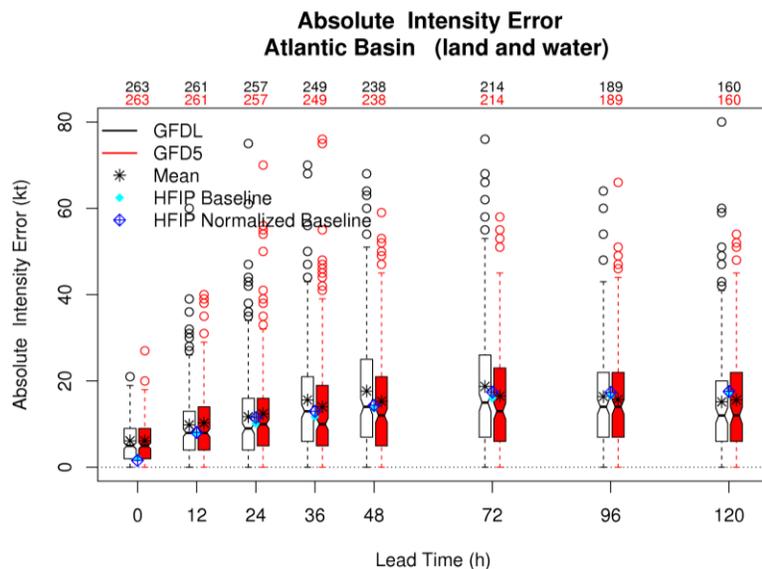
Anticipated Collaborators: NESL, NOAA/GSD, NOAA/NCEP, AFWA, NASA Global Modeling and Assimilation Office

Specific Measurements of Success: Ability to respond to data assimilation developments and growth of DAT testbeds. Build strong trust relationships with sponsors and the community. Provide data assimilation reference configuration and support to research and operational communities.

## Tropical Cyclone Model Testing and Evaluation

*Provide testing and evaluation of tropical cyclone prediction models and support services for a state of the art coupled community modeling system that includes current operational technology.*

The JNT’s Tropical Cyclone Modeling Team (TCMT) performs objective evaluation of NWP models with a focus on numerical guidance for tropical cyclones. This evaluation work ranges from next generation global and regional models to new features or capabilities for the current regional operational models. Work related to advances for the current regional operational models is a collaborative effort with NESL and the operational and research branches of NOAA through the DTC. In addition to its extensive testing and evaluation activities, the JNT through its participation in the DTC provides both researchers and model developers with access to state of the art software that makes up the WRF-for-Hurricanes system, including code access, documentation and user support. These community code efforts provide a critical framework for the operational and research communities to collaborate in order to accelerate the transition of new technology into operational weather forecasting.



*Example of results for a hurricane model evaluation, comparing the distributions of hurricane intensity errors for two versions of the GFDL model.*

Actions:

2011 – Establish a code management plan for the regional operational tropical cyclone prediction systems that will provide an efficient framework for making new development available to both the operational and research community. Conduct extensive testing and evaluation to determine the impact of promising new capabilities on the current regional operational tropical cyclone prediction systems.

2011 – In collaboration with NOAA Hurricane Forecast Improvement Project (HFIP) collaborators, establish a community tropical cyclone diagnostics tool kit that will provide a framework for performing in-depth diagnostics of the strengths and weaknesses of tropical cyclone forecasts; apply these diagnostic tools to internal testing and evaluation activities and provide constructive feedback to model developers about their method's strengths and weaknesses.

2011 – In collaboration with NOAA HFIP collaborators, continue to evaluate experimental tropical cyclone prediction systems; lead the planning and coordination for the evaluation of experimental tropical cyclone forecasts; perform in-depth evaluations of collected tropical cyclone forecast datasets.

2011–2015 – Develop and maintain a testing and evaluation system that is functionally similar to the relevant operational centers, so that results from testing and evaluation exercises can directly impact future operational implementation decisions; continue to facilitate the exchange of new features and capabilities between research and operations.

2011–2015 – Continue to lead the evaluation of experimental tropical cyclone modeling systems and perform in-depth evaluations of collected tropical cyclone forecast datasets.

2011–2015 – In collaboration with NOAA HFIP collaborators, continue to improve and implement new methods for diagnostic evaluation of tropical cyclone forecasts, which could include (but not limited to) tropical cyclone wind structure, rain band structure, and thermodynamic phases of tropical cyclones.

Potential or Expected Sponsors: NOAA (NWS, OAR), NOAA HFIP, NCAR, NSF, international operational and research communities

Anticipated Collaborators: NOAA NHC, NOAA GFDL, NOAA ESRL, NOAA NCEP, NOAA NWS, NOAA AOML, NRL, NESL/MMM, Naval Research Laboratory, various universities

Specific Measurements of Success: JNT and DTC viewed as an authoritative resource for testing and evaluating tropical cyclone NWP models, research and operational communities working together to advance tropical cyclone prediction and successful transition of new features or capabilities between research and operations.

## Frontiers

### Global Modeling

***Establish a component of the JNT to test and evaluate the next generation of global numerical models, and serve as a neutral evaluator of the various global model development efforts currently underway.***

Given the expertise and tools currently being used, adding testing and evaluation of the next-generation global model is a natural next step. Parallel model development efforts are already underway at various institutions (e.g., NCAR, NOAA NCEP, and NOAA OAR). The National Unified Operational Prediction Capability (NUOPC) is an agreement to coordinate activities between the Department of Commerce

(NOAA) and the Department of Defense (Navy and AFWA), in order to accelerate the transition of new technology, eliminate unnecessary duplication, and achieve a superior national global prediction capability. Hence, establishing a global modeling component within the JNT would likely involve strengthening the JNT's connection with NUOPC. Some, or all, of this work could eventually fall under the JNT's involvement in the DTC, depending on direction provided by the DTC's external management, which is currently composed of representatives from the DTC's sponsoring agencies (NOAA OAR and NWS, AFWA and NCAR).

Actions:

2011–2012 – Work with targeted sponsors to identify needed testing and evaluation activities and avenues for funding these activities.

2012–2015 – Perform extensive testing and evaluation of candidate global modeling capabilities deemed promising by sponsors.

Potential or Expected Sponsors: NOAA, Navy, NRL, AFWA, FAA

Anticipated Collaborators: NESL/MMM, NOAA ESRL (including ESMF group), NOAA GFDL, NOAA NCEP, university partners, NSF

Specific Measurements of Success: Ability to respond expeditiously to sponsor requests for testing and evaluation projects; JNT, possibly under auspices of DTC, viewed as an authoritative resource for testing and evaluating global NWP models.

## Coupled Models for Specific User Applications

***Establish a component of the JNT to test and evaluate the use of coupled and secondary applications with NWP models, including derived products and user impacts. Specific applications may include hydrologic, air quality, aviation weather, biological, and regional climate models.***

NWP modeling systems are often coupled with other numerical models to describe the effects of weather on other systems. This can be done with tightly coupled models (ocean, land surface), or may involve a one-way coupling (e.g., providing NWP datasets as input for a sound propagation model). In addition, mesoscale NWP models are often used for particular applications, such as regional climate or aviation-specific parameters. An independent assessment of the combined modeling system and applied forecasts, based on user-relevant evaluation approaches, allows end-users of the products to meaningfully assess the quality of the information with which they are making decisions. Work in these areas will require close partnerships with organizations with expertise in the application area and a developed understanding within the JNT of the forecast aspects to be evaluated. Due to the breadth of knowledge and capabilities represented by the JNT, it is well-poised to successfully take on these forecast evaluation challenges.

Actions:

2011–2015 – As resources allow, investigate system definitions, error characterization and predictive evaluation of some key secondary models

2011–2015 – As resources allow, investigate assessment methods for user interactions with weather and weather-influenced products, tools and data.

Potential or Expected Sponsors: NOAA, NSF, NASA, FAA, application-focused U.S. government departments (e.g., Department of Energy), private forecasting organizations, international operational forecasting centers

Anticipated Collaborators: NESL, various universities

Specific Measurements of Success: Ability to respond expeditiously to sponsor requests for testing and evaluation projects; JNT viewed as an authoritative resource for testing and evaluation of coupled models and model applications.

## 8. Goal Area: Climate, Weather and Society

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### Overarching Priority

***Promote societal resilience to environmental variability by conducting interdisciplinary research on the interactions among society, weather, and climate, and enhance societal gains by infusing social science into new weather and climate research and products.***

### Motivation

Society is experiencing profound impacts from the recent weather and climate changes across almost all scales, ranging from global resource availability, migration, political stability, to regional agricultural and ecosystem sustainability to local/individual watersheds, and urban centers. Human society is increasingly vulnerable, not only to changing climate, but also to increasingly erratic, and often extreme, atmospheric phenomena such as hurricanes, floods, and drought. The fundamental goal of RAL's climate, weather, and society research program is to create societal value by providing usable information for decision making.

RAL leads research on social, economic, and governance activities related to weather, climate, and environmental change at local, regional and global scales. Connected to NCAR's Integrated Science Program, the research emphasizes interdisciplinary research to help society benefit from current and emerging weather and climate prediction capabilities by integrating social science knowledge and methods into the weather/climate research and policy-making communities. Research on adaptation to environmental change is conducted by generating scenarios of projected change, developing tools and methods for analyzing current and future vulnerability, and performing integrated analyses. The involvement of various stakeholders and users with the research effort is central to the approaches to develop actionable science that serves society. In both the climate and weather arenas, RAL scientists work across physical and social science disciplines to bring research at the society-environment-atmosphere interface to bear on critical societal decision-making processes.

Advances in weather and climate information are dependent on improvements in models, frameworks, and tools for assessing adaptive capacity, as well as on integrated interdisciplinary research efforts that draw on and join diverse science domains such as ecology, sociology, economics, statistics and other social and environmental sciences. Development of science-based planning approaches incorporating changes in the probability of weather and climate extremes, characterizing observational, model, and vulnerability-assessment uncertainties, and integrating climate change information with planning tools used for urban and water resource management that are responsive to the specific needs of the wide spectrum of decision-makers are also essential. Finally, improved weather forecasts and climate information may well reduce societal and environmental vulnerability *only* if the information is developed and presented to decision makers in ways they understand, value, and can use.

### Near-Term Objectives

#### Governance and Adaptation: Dynamics and Policy Implications

***Enhancing climate resilience, adaptive capacity and effective adaptation planning by improving the scientific foundation for policy analysis.***

It is widely recognized that governance systems play crucial roles in determining the capacity of human communities to manage the impacts of climate variability and to adapt to climate change, but research is needed to understand how governance systems evolve and what types of policy interventions make sense. Descriptions of desirable characteristics of governance systems are widely available, and “governance reform” invariably appears on laundry lists of recommended adaptation options. However, considerably less attention has been given to understanding the processes by which “reform” becomes reality. We will develop a theoretically grounded framework for analyzing the dynamics of governance system evolution and for evaluating how vulnerability and adaptive capacity interact with that evolutionary process. This framework will be applied, initially, to case studies of water resource management and policy processes in developing countries. Subsequent applications are envisioned for water policy processes in the United States and for policy development for other climate-sensitive natural resources. Results will be used to refine the framework in order to provide broadly-applicable guidance for climate change adaptation planning.

*Actions:* 2011-2015 - The proposed Governance Framework will be developed and applied to a comparative analysis of the historical development of urban water systems and ongoing policy challenges in Mexico City and Sana’a City, Yemen. The framework also will be used to analyze how recent water policy conflicts in California are affecting climate adaptation planning by Southern California urban water providers.

*Potential or Expected Sponsors:* The work is anticipated to contribute to projects to be funded by the Inter-American Development Bank, as well as to possible future work for the World Bank or Asian Development Bank. Additional sponsorship will be sought from NSF and NOAA, as appropriate.

*Anticipated Collaborators:* Drs. Miller and Romero-Lankao will collaborate with Dr. Robert Wilby, Loughborough University, UK on development of the framework, the initial case studies and resulting papers. The work also is expected to contribute to collaborations with ISP and ISET.

*Specific Measures of Success:* This work will provide the basis for a paper to be presented at the Colorado Conference on Earth System Governance, May 2011. It will also lead to a collaborative journal paper focused on understanding the role of governance dynamics in adaptation. Finally, it is anticipated that the work will provide the basis for a funded proposal for additional case studies and further development of the theoretical framework.

## **Communication, Use, and Value of Weather Information**

***Improve the effectiveness of the weather forecasting and warning system by integrating diverse social sciences and meteorology to study the communication, interpretation, use, and value of weather forecast information, including uncertainty.***

The ultimate goal of the weather forecast and warning system is to create societal value by providing usable information for decision-making. For information to be usable, it needs to be scientifically sound, communicated effectively, interpretable, and actionable. Lack of research at the weather-society interface has been identified as a major gap in NRC reports and other community documents. There is insufficient empirical knowledge about how diverse actors in the forecast system communicate, interpret, and use currently available weather forecast and warning information, much less new or improved information.

The social sciences offer comprehensive theories, research methods, and applications that, when integrated with meteorology, can build this critical knowledge.

Actions:

For 2011-2015:

- *HFIP Socio-Economic Impact Assessment:* Develop monetary benefit estimates of the hurricane forecast improvements proposed under the Hurricane Forecast Improvement Project (HFIP) by applying non-market valuation methods to study households' values for improved hurricane forecasts.
- *Public Perspective of Storm Surge Information:* Evaluate the hurricane-vulnerable public's understanding, use of, and preferences for storm surge forecast and warning information through focus groups, interviews, and surveys followed by extending this evaluation to extra-tropical cyclone vulnerable populations.
- *Extreme Weather Warning Decisions:* Identify and fill gaps in how hurricane and flash flood forecast information is created, interpreted, and used in decision making by eliciting mental models through interviews with forecasters, media, public officials, and members of the public and through a household survey.
- *Social Science Integration for Improving NWS Forecasts:* Examine the format, content, and usability of forecast web pages (such as the NWS Point and Click website) through focus groups, interviews, and surveys to elicit users' needs for, uses for, interpretations of, and preferences for the public forecast information.
- *Communicating Hurricane Information:* Improve the communication of hurricane warnings by characterizing communication channels and message content and investigating how stakeholders (forecasters, emergency, managers, broadcasters, and the public) and at-risk populations comprehend and react to warnings through structured observation and interviews, focus groups, and a household survey.

Potential or Expected Sponsors: NSF, NOAA.

Anticipated Collaborators: Florida International University, Univ. of Colorado, Univ. of New Mexico, University of Washington, University of Kentucky, NWS, and Univ. of Oklahoma.

Specific Measurements of Success: Publication of the results of these studies in refereed domain journals. Present results at the annual AMS meetings, National Hurricane Conference, Society for Risk Analysis. Present seminars at the stakeholder institutions with executive summaries and full documents sent to stakeholder leadership and line offices. Communicate findings to the hurricane research, forecasting, broadcast, and emergency management communities. Secure follow-on funding to support this work in the out years.

## **Resilient and Sustainable Cities**

***Promote more resilient and sustainable cities by conducting interdisciplinary research on the processes shaping urban emissions, impacts, vulnerabilities and capacities to respond to climate and global environmental change***

Urban areas play crucial roles in the arena of climate and global environmental change. Not only are they key sources of environmental pollutants, but they are also hotspots of vulnerability to hazards that climate and global environmental change are expected to aggravate. These opposing roles create a great incentive for change in urban areas and provide a unique opportunity for cities to prove their talents as sources of adaptation responses and as innovators in the transition to more sustainable, resilient, and less carbon intensive pathways of urban development. Effective decision making about mitigation and adaptation

requires an array of accurate and practical knowledge on the crucial intersections between urban development and the environment, including its impacts on carbon cycle, the climate system and the water cycle.

Actions:

For 2011-2015:

- *Societal and Environmental Drivers:* Explore how societal and environmental factors such as population size, migration, geographical location, density, and affluence, and the use of public transportation affect emissions at the urban, national and international levels.
- *Urban Vulnerabilities and Impacts:* Investigate the dynamic determinants of common and differentiated vulnerabilities and capacities to respond to hazards and stresses (impacts) within and across urban centers.
- *Governing Urban Carbon and Climate:* Assess the societal and institutional factors shaping city-relevant mitigation and adaptation (responses).
- *Climate-Induced Migration and Cities:* Examine the role of cities as “development hubs” in the interactions among development, migration, and global environmental change.

Potential or Expected Sponsors: NSF, NOAA, international development agencies (World Bank, Inter-American Development Bank)

Anticipated Collaborators: NESL, IMAGE, Data Conservancy (Library), Global Carbon Project; Universities of Arizona, Manchester, Chile, Los Andes, Johns Hopkins, California and Buenos Aires; CIIFEN Ecuador, International Institute for Environment and Development; UN-Habitat, ECLAC and UNEP.

Specific Measurements of Success: Collaborative development, implementation and publication in refereed journals of a) new frameworks and models (STIRTAP, ADAPTE) that cross traditional NCAR physical/social science boundaries incorporating compatible and comparable data sources such as surveys, time series, socioeconomic indicators, satellite images and inventories; b) assessments of the linkages between urban development and global environmental change (IPCC, US-National Climate Assessment)

## **Weather, Climate and Health**

***Improve our understanding of the complex interactions among weather and climate processes, ecosystems, and human health.***

There is widespread scientific consensus that the world’s climate is changing and that there will be a broad range of impacts on health through a variety of factors, including greater heat stress, air pollution, respiratory disease exacerbation, and changes in the geographic distribution of vector-, food- and water-borne disease. A multi-disciplinary, multi-institutional approach is required to address these complex climate-related public health challenges. Currently, there is a lack of appropriately scaled and integrated social-physical models for the development of adaptation and mitigation strategies to reduce negative health outcomes in the face of climate variability and climate change.

Actions:

For 2011-2015:

- *Integrated Climate Health Modeling*: Investigate the complex relationships among weather, climate, human health and ecosystems through development of models that integrate the physical and social sciences at multiple space and time scales (e.g. Modeling Plague in Uganda; SIMMER; *Ae. aegypti* at the margins of transmission: sensitivity of a coupled natural and human system to climate change)
- *Population Vulnerability*: Develop new tools to assess population vulnerability to human health impacts of climate variability and change
- *Adaptation/Mitigation Strategies*: Determine appropriate adaptation and mitigation strategies to address current and emerging health issues.
- *Education and Outreach*: Educate the next generation of scientists in these complex yet interconnected areas. Biannual Climate and Health workshops targeting graduate students, postdocs, early career scientists and health professionals

Potential or Expected Sponsors: NSF, NASA, CDC, NIH, and international development agencies such as Inter-American Development Bank and the U.S. Agency for International Development.

Anticipated Collaborators: NESL, CISL. U.S. and international universities, federal agencies such as CDC, state and local health departments and health research centers.

Specific Measurements of Success:

Short term (2-3 years)

- Conduct field work in funded areas with a focus on reducing negative health impacts.
- Publish results of the field studies in refereed journals that bridge both climate and health.
- Support CDC funded postdoctoral fellowship programs co-located at NCAR and the CDC.

Medium term (3-5 years)

- Continue to build a program at NCAR in weather, climate and health
- Implement integrated social-physical models developed over preceding years, in order to assess population vulnerability to climate-related health risks for Potential applications.

## GIS Science Program

***Enhance our ability to conduct research across atmospheric, geo- and social sciences through the development and application of new methods and spatial analysis tools, and the interoperability of georeferenced information.***

The Earth system science community is challenged not only with integration of complex physical processes into weather forecast and climate prediction models but also with understanding the interactions among climate, environment, and society, and integrating societal and environmental information with weather and climate. In addition, climate-and weather-related policy and decision-making largely depend on usability of Earth system science output and accessibility of data. The GIS Science program is an interdisciplinary effort to foster collaborative science, spatial data interoperability, and knowledge sharing through GIS. Working toward the definition, standards and interoperability of atmospheric information for usable science, the GIS program is conducting research integrating the Earth system and social sciences through spatial analysis and interoperability of geo-referenced information; supporting the use of GIS as both an analysis, and an infrastructure tool in atmospheric research; improving usable science and knowledge sharing between science groups, educators and stakeholders; and addressing broader issues of spatial data management, interoperability, and geo-informatics within the geosciences.

### Actions:

For 2011-2015:

- Develop new methods and tools for integrating social and natural sciences in assessments of societal vulnerability to weather extremes and climate change (examples: SIMMER, Phoenix extreme heat, Upper Colorado River Basin water demand)
- Improve spatial accuracy and usability of atmospheric models for terrestrial and societal applications (examples: Climate Change GIS portal, WRF-GIS extreme weather pilot, global heat waves)
- Community and capacity building (examples: development and implementation of GIS-climate-vulnerability-focused training programs, community workshops)

Potential or Expected Sponsors: NOAA, NASA, NSF, DOE, NIH

Collaborators: NCAR laboratories, Unidata, NOAA laboratories, universities, NASA-funded centers (e.g., JPL, CIRES), stakeholders (i.e., departments of public health, water managers, GIS users at local governments)

Specific Measurements of Success: Publication of the results of methodological studies in refereed journals. Presentation of results at conferences (i.e., AMS, AGU, ESRI). Securing follow-on funding to support this work in the out years. Release of new version of climate change portal Publication of Web-based educational resources that link GIS, climate science and societal impacts.

## Frontier

### Regional Adaptation to Climate Change

***Deliver sound climate science to decision-makers at regional and local scales to promote sustainability and reduce human system vulnerabilities to anticipated climate change impacts.***

As the reality of human-induced climate change is accepted by policymakers and the public at large, the demand for actionable, regional-scale information and knowledge about observed and projected climate changes and impacts at individual, local, and regional levels is increasing rapidly. Effective decision-making about adaptation will require accurate and usable information about regional-scale climate change and the relationships among climate change and other important environmental and socio-economic stressors, including land use change, invasive species, “conventional” pollution, and market forces.

### Actions:

For 2011-2015:

- *Usable Climate Science:* Investigate, assess, and document the climate science needs of decision-makers in critical end-use domains (e.g., urban planning, water resources, natural resources, and ecological sustainability) within multiple development contexts, recognizing the significant divergence of capacity in regions around the world.
  - Understand the role and effectiveness of a new generation of regional climate models and associated science outputs in local decision-making, particularly for understanding the internalization of product/information uncertainty among nontechnical actors.
  - Provide research support to the emerging NOAA Climate Services
- *Integrated Vulnerability and Adaptation Assessments:* Couple climate change impact research – particularly on specific ‘high impact’ geographies such as urban, coastal, and high Alpine systems –

with societal vulnerability frameworks to understand the integrated effects of changes in climate, land use, seasonality, and human systems.

- Develop and apply tools and metrics to measure and quantify the effectiveness of climate adaptive interventions under co-occurring changes to social and bio-geophysical conditions and particularly at system boundary thresholds.
- *Capacity Building*: Develop training workshops, fellowship programs, and scientist exchanges with local and regional partners to foster collaboration, innovation, and multi-directional capacity building. Develop tools, methods and techniques to assist in the translation of climate science information to support localized decision-making, particularly in the contexts of extreme societal vulnerability in specific geographic regions. Focus on bridging from historical information to current observations to future projections.

Potential or Expected Sponsors: NSF, DOE, EPA, international development agencies (World Bank, IDB), USAID, foreign government development assistance organizations (DANIDA, DFID, etc), private foundations (Rockefeller, Ford, etc), reinsurance corporations (Munich Re, Swiss Re, etc)

Anticipated Collaborators: CGD, IMAGE, NOAA RISA Centers, DOI Climate Science Centers.

Specific Measurements of Success: Development of methods for incorporating information on uncertainty into assessments of regional impacts and evaluation of adaptation strategies, and publication of journal articles describing and using these methods. Development of methods for evaluating cross-sector interactions among potential adaptation activities, quantification of such cross-effects, and publication of this research in journal articles.

## 9. Appendices

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### RAL organizational structure

In the fall of 2004, the Research Applications Laboratory was formed from two previous groups: the Research Applications Program (RAP), and the Developmental Testbed Center (DTC). Given the very aggressive growth history of RAP over the previous 15 years, the senior managers determined it was time to reorganize around a number of central themes with management units of appropriate size to efficiently carry on the activity of the laboratory into the future. In the summer of 2008 the Institute for the Study of Society and Environment (ISSE) was also placed in RAL, though it was dissolved the following year. A number of the ISSE staff, though, elected to remain in RAL and now make up the core of the Climate Science and Applications Program, formed in 2009. The current organization chart is shown in the earlier Section 1, and is amplified for easy reference below to highlight the principal directions of each division.

- The Aviation Applications Program (AAP) plans, develops, and transfers advanced weather technologies to support current and future aviation operations nationally and internationally.
- The Climate Science and Applications Program (CSAP) conducts research on the interactions among society, the atmosphere and the environment to better understand weather- and climate-related risks and to incorporate this improved understanding into decision making and policy.
- The Hydrometeorological Applications Program (HAP) works to understand how water vapor, precipitation, and land surface hydrology interact across scales to define the hydrological cycle, including under global change.
- The Joint Numerical Testbed (JNT) serves as both a facility and a national distributive network of collaborators for testing, validating, and comparing numerical techniques for analyses and forecasts of atmospheric parameters important to scientists and operational decision makers.
- The National Security Applications Program (NSAP) emphasizes research and development in urban-scale meteorology and plume transport modeling to give operational forecasters, decision makers and emergency planners accurate, timely guidance and support.
- The Weather Systems and Assessment Program (WSAP) develops and implements advanced weather decision support systems for new user sectors such as surface transportation and renewable energy. It also seeks to quantify the needs and economic benefits of improved weather information for society.

It should be noted that the programs and plans outlined in Chapter 3 through 8 correspond only loosely to the management units indicated above, as many of the projects that are carried out span efforts in several groups, and the research carried out often involves multiple sponsors. Sponsors are thus able to leverage off the support of one another, and RAL is able to build programs of significant size and scope from smaller pieces funded independently.

## RAL Advisory Panel

The RAL Advisory Panel consists of members of the academic community along with government and private-sector members of the operational community. They are nationally or internationally recognized as leaders in their respective fields of expertise. The panel members cut across all aspects of the Laboratory's work. They meet once per year to provide advice regarding the status, future directions, and conduct of RAL programs.

2011 members of the RAL Advisory Panel include:

- Mr. Joe Burns, United Airlines Flight Center, Denver, CO
- Ms. Pam Clark, U.S. Army Research Laboratory, Adelphi, MD
- Dr. James Doyle, Naval Research Laboratory, Monterey, CA
- Dr. Efi Foufoula-Georgiou, University of Minnesota, Minneapolis, MN
- Dr. Sharon Harlan, Arizona State University, Tempe, AZ
- Mr. Rod MacKenzie, Intelligent Transportation Systems America, Washington, DC
- Dr. Ron McPherson, American Meteorological Society, Boston, MA
- Dr. Robert Rauber, University of Illinois – Urbana-Champaign
- Dr. Scott Sandgathe, University of Washington, Seattle, WA
- Dr. Agam Sinha, The MITRE Corporation, McLean, VA
- Ms. Sheila Steffenson, ESRI, Vienna, VA
- Mr. Bradley Udall, NOAA/ESRL, and University of Colorado, Boulder, CO

Additional Advisory Panel members during the period from 2005 to present include:

- Mr. Mark Andrews, Joint Planning and Development Office, Washington, DC
- Dr. Bruce Davis, Department of Homeland Security, Washington, DC
- Dr. Leland Ellis, Department of Homeland Security, Washington, DC
- Ms. Jeanne Foust, ESRI, Eau Claire, WI
- Mr. Robert Francis, National Transportation Safety Board (ret.), Washington, DC
- Mr. Art Handman, KMJ Consulting, Gorham, ME
- Dr. Paul Houser, George Mason University, Fairfax, VA
- Dr. Richard Johnson, Colorado State University, Ft. Collins, CO
- Mr. Carl McCullough, FAA (ret.), Aerospace Consultant, Trinity, FL
- Ms. Shelley Row, Institute of Transportation Engineers, Washington, DC
- Dr. Don Veal, University of Wyoming (ret.), Particle Measuring Systems

## Acronym dictionary

- 4DVar** – Four Dimensional Variation data assimilation technique
- AAP** – Aviation Applications Program in RAL
- ABL** – Atmospheric Boundary Layer
- ACD** – Atmospheric Chemistry Division in ESSL
- AFWA** – Air Force Weather Agency
- ADAPTE** – Adaptation to the Health Impacts of Air Pollution and Weather in Latin American Cities
- AGL** – Above ground level
- AID** – United States Agency for International Development
- AGU** – American Geophysical Union
- AMPS** – Antarctic Mesoscale Prediction System
- AOML** – Atlantic Oceanographic and Meteorological Laboratory, FL
- AOML/HRD** – Atlantic Oceanographic and Meteorological Laboratory, Hurricane Research Division
- AMS** – American Meteorological Society
- APL** – Applied Physics Laboratory of John Hopkins University
- ATEC** – United States Army Test and Evaluation Command
- ATM** – Air Traffic Management
- AWEA** – American Wind Energy Association
- AWIPS** – Advanced Weather Interactive Processing System
- BEACHON** – Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, H<sub>2</sub>O, Organics, and Nitrogen
- C&V** – Ceiling and visibility
- CAA** – Civil Aviation Administration in Taiwan
- CAASD** – Center for Advanced Aviation Systems Development, MITRE Corporation
- CCMC** – Community Coordinated Modeling Center in NASA
- CCSM** – Community Climate System Model
- CDC** – Centers for Disease Control and Prevention
- CDI** – Cyber-Enabled Discovery and Innovation
- CGD** – Climate and Global Dynamics Division of ESSL
- CIESIN** – Center for International Earth Science Information Network
- CIIFEN** – Centro Internacional para la Investigación del Fenómeno de El Niño.
- CISL** – Computational and Information Systems Laboratory in NCAR
- CISM** – Center for Integrated Space Weather Modeling in Boston University
- CONUS** – Continental United States
- CoSPA** – Consolidated Storm Prediction for Aviation
- CRIEPI** – Central Research Institute of Electric Power Industry
- CSEM** – Center for Space Environment Modeling in University of Michigan
- CSI** – Critical Success Index
- CVA** – Ceiling and visibility analysis product
- CVF** – Ceiling and visibility forecast product
- CWB** – Central Weather Bureau, Taiwan
- DANIDA** – Ministry of Foreign Affairs of Denmark
- DARPA** – Defense Applied Research Program Administration
- DART** – Data Assimilation Research Testbed
- DATC** – Data Assimilation Testbed Center
- DFID** – UK Department for International Development
- DHS** – Department of Homeland Security
- DICast** – Dynamic Integrated Forecast system
- DOE** – U.S. Department of Energy
- DOD** – U. S. Department of Defense
- DOI** – U. S. Department of the Interior
- DOT** – U. S. Department of Transportation
- DTC** – WRF Developmental Testbed Center
- DTC** – Developmental Test Command
- DTRA** – Defense Threat Reduction Agency
- EOL** – Earth Observing Laboratory in NCAR
- EPA** – U.S. Environmental Protection Agency
- ECLAC** – Economic Commission of Latin America and the Caribbean
- EMC** – Environmental Modeling Center
- ESM** – Earth System Model
- ESMF** – Earth Systems Modeling Framework
- ESRL** – Earth Systems Research Laboratory in OAR
- ESSL** – Earth and Sun Systems Laboratory in NCAR
- EuLag** - A model; underlying equations are either solved in an Eulerian or a Lagrangian framework
- FAA** – DOT Federal Aviation Administration
- FDDA** – Four Dimensional Data Assimilation
- FHWA** – Federal Highways Administration
- FIM** – Flow-following finite-volume Icosahedral Model
- GA** – General Aviation
- GFDL** – Geophysical Fluid Dynamics Laboratory
- GFS** – Global Forecast System model
- GIS** – Geographical Information System
- GOES-R** – Geostationary Operational Environmental Satellite, Series R
- GPS** – Global Positioning Satellite
- GSD** – Global Systems Division of NOAA Earth Systems Research Laboratory in OAR
- GSI** – Gridded Statistical Interpolation
- GTG** – Graphical Turbulence Guidance
- HAO** – High Altitude Observatory
- HAP** – Hydrometeorological Applications Program

**HFIP** – Hurricane Forecast Improvement Program  
**HIWC** – High ice water content  
**HPAC** – Hazard Prediction and Assessment Capability  
**HRLDAS** – High-Resolution Land Data Assimilation System  
**IA** – Integrated Assessment  
**ICE-L** – Ice in Cloud Experiment  
**IDB** – Inter-American Development Bank  
**IMAGE** – Institute for Mathematics Applied to Geosciences  
**IMPROVE II** – Improvement of Microphysical Parameterization through Observational Verification  
**IPCC AR4** – Intergovernmental Panel on Climate Change Fourth Assessment Report  
**ISET** – Institute for Social and Environmental Transition  
**ISP** – Integrated Science Program  
**ISSE** – Institute for the Study of Society and Environment  
**IT** – Information Technologist  
**JNT** – Joint Numerical Testbed  
**JPL** – Jet Propulsion Laboratory  
**JPDO** – Joint Program Development Office for NGATS  
**LANL** – Los Alamos National Laboratory  
**LES** – Large Eddy Simulation  
**MADIS** – Meteorological Assimilation Data Ingest System in NOAA  
**MDA** – Missile Defense Agency  
**MET** – Model Evaluation Tools  
**MDSS** – Maintenance Decision Support System  
**MIT-LL** – Massachusetts Institute of Technology, Lincoln Laboratories  
**MMM** – Mesoscale and Microscale Meteorology Division  
**MODIS** – Moderate Resolution Imaging Spectrometer (NASA satellite sensor)  
**MOS** – Model Output Statistics  
**NAS** – National Airspace System  
**NCEP** – National Center for Environmental Prediction in NOAA  
**NEMS** – NOAA Environmental Modeling System  
**NESDIS** – National Environmental Satellite and Data Information Services  
**NESL** – NCAR Earth Systems Laboratory  
**NEVS** – Network Enabled Verification Service  
**NEXRAD** – Next-Generation Radar  
**NextGen** – Next Generation Air Transportation System  
**NGATS** – Next Generation Air Transport System  
**NHC** – National Hurricane Center  
**NIH** – National Institutes of Health  
**NIST** – National Institute of Science and Technology  
**NGIC** – National Ground Intelligence Center  
**NNEW** – NexGen Network Enabled Weather

**NOAA** – United States National Oceanic and Atmospheric Administration  
**Noah** – NCEP--Oregon State University –Air Force--Hydrologic Research Lab Land Surface Model  
**NUOPC** – National Unified Operational Prediction Capability  
**NVIA** – NCAR Vulnerability, Impacts, and Adaptation program  
**NRC** – National Research Council  
**NREL** – National Renewable Energy Laboratory  
**NRL** – United States Naval Research Laboratory  
**NSAP** – National Security Applications Program  
**NTSB** – National Transportation Safety Board  
**NSF** – National Science Foundation  
**NWP** – Numerical Weather Prediction  
**NWS** – National Weather Service  
**OAR** - Office of Atmospheric Research in NOAA  
**OFCM** – Office of the Federal Coordinator for Meteorology in NOAA  
**OGC** – Open Geospatial Consortium  
**PFFA** – Pentagon Force Protection Agency  
**PIREPS** – Pilot Reports  
**Quic-URB** - Quick Urban & Industrial Complex Dispersion Modeling System (LANL)  
**R&D** – Research and Development  
**RAL** – Research Applications Laboratory in NCAR  
**RISA** – Regional Integrated Sciences & Assessments in NOAA  
**RITA** – Research and Innovative Technology Agency in DoT  
**ROSES** – Research Opportunities in Space and Earth Sciences (grant program in NASA)  
**RVR** – Runway Visual Range  
**SEI** – Stockholm Environment Institute  
**SIMMER** – System for Integrated Modeling of Metropolitan Extreme Heat Risk  
**SIP** – Societal Impacts Program  
**STEP** – Short-Term Explicit Prediction  
**STIRPAT** – Stochastic Impacts by Regression on Population, Affluence, and Technology  
**TAMDAR** -- Tropospheric Airborne Meteorological Data Report  
**UAV** – Unmanned Aerial Vehicle  
**UNEP** - United Nations Environment Program  
**USDA** – United States Department of Agriculture  
**USGS** – United States Geological Survey  
**USWRP** – United States Weather Research Program in NOAA  
**WEAP** – Water Evaluation and Planning Tool  
**WRF** – Weather and Research Forecast model  
**WS** - Water System Program  
**WSAP** – RAL Weather Systems and Assessment Program  
**WSDDM** – Weather Support for De-icing Decision Making