NCAR EARTH SYSTEM LABORATORY

National Center for Atmospheric Research
University Corporation for Atmospheric Research
Boulder, Colorado

STRATEGIC PLAN

May 2010

Five Years and Beyond

NESL

The Mission of the NCAR Earth System Laboratory is:
To advance understanding of weather, climate, atmospheric composition and processes;
To provide facility support to the wider community; and,
To apply the results to benefit society.

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Contents

1. The NESL Mission

To advance understanding of weather, climate, atmospheric composition and processes;
To provide facility support to the wider community; and,
To apply the results to benefit society.

NESL contributes to the fabric of NCAR by maintaining the highest level of academic excellence and integrity; through our involvement with the academic community; by maintaining and developing leading community modeling and instrumentation facilities; through our commitment to diversity and mentoring young scientists; and through our strong and expanding contacts with society that enable us to respond to and support major societal needs, and to inform and educate appropriate sectors. In support if this, NESL aims to:

- work closely with other NCAR groups in furthering both our and NCAR's strategic goals;
- sustain and nurture fundamental disciplinary programs, while reaching out to engage other disciplines in accomplishing our goals;
- undertake transformational research, which involves an element of risk but is essential to improving our understanding of the earth system and to developing major community facilities;
- engage with community leaders and policy makers to convey research findings, to develop new research directions, and to emphasize the importance of investment in research and major facility development;
- invest wisely in the maintenance and continuing development of community modeling, instrumental and experimental facilities;
- develop next-generation tools and techniques in support of the atmospheric and related sciences utilizing cutting-edge research and in collaboration with the wider community;
- encourage and promote new, diverse talent into our field through participation in educational programs from K12 through graduate university, and by mentoring students and young scientists.

2. NESL Overview

NESL is managed by an Executive that makes all strategic decisions, an Administrative Group who coordinate our day-to-day functions, and a Systems Group who coordinates our systems needs, ensures common IT activities across the Lab and maintains our web portal to the world.

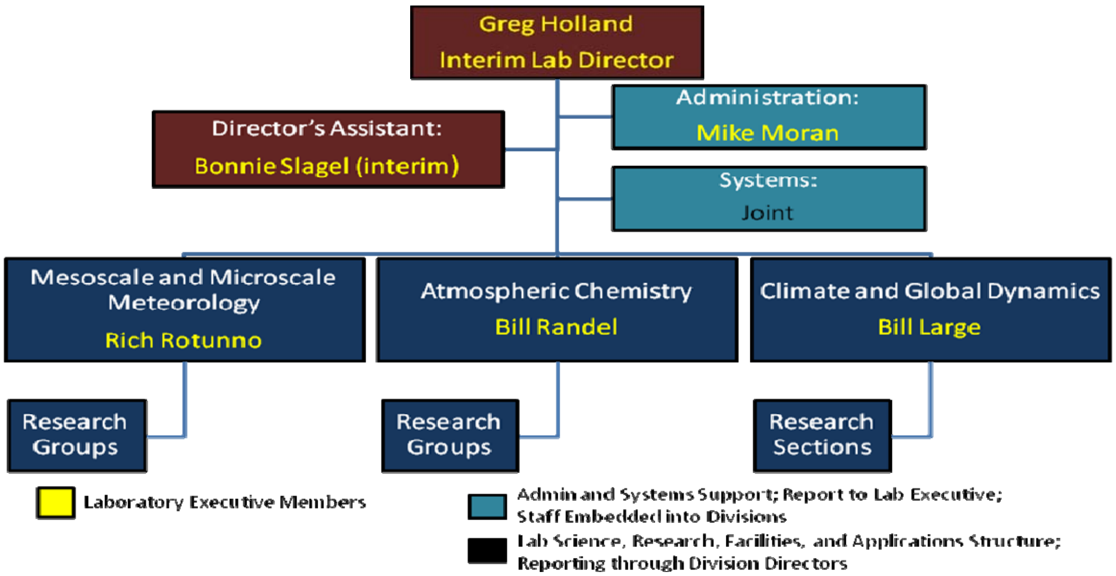

Figure 1: NESL Organizational Structure

Aside from the Director's Office all staff are in three divisions: Atmospheric Chemistry, Climate and Global Dynamics and Mesoscale and Microscale Meteorology. These divisions further breakdown into specialized groups based on common interest. And major programs are maintained laterally across the divisional structure in a loose matrix mode. A brief description of each of the divisions, the program structure, the results of a UCAR community survey, and NESL partnerships and collaboration follow.

2.1 The Atmospheric Chemistry Division (ACD)

The NESL Atmospheric Chemistry Division conducts research aimed at quantifying and predicting the role of atmospheric chemistry in the Earth system. This includes:

- evaluating the effects of emissions, deposition, transport, and chemical transformations on atmospheric composition, as well as quantifying coupling with the physical climate system across a broad range of scales (process to global);
- improving understanding of mechanisms by which chemical and dynamical processes couple;
- developing and deploying chemistry instrumentation to support the scientific needs of a national center and the community (particularly for aircraft-based observations and satellite measurements); and,
- developing and maintaining state-of-the-art community chemistry and aerosol modeling tools including the WACCM, WRF-Chem, Cam-Chem and Mozart.

These capabilities are especially relevant for addressing future challenges linked to air quality, climate change and ozone depletion on regional and global scales with regard to population growth and economic development.

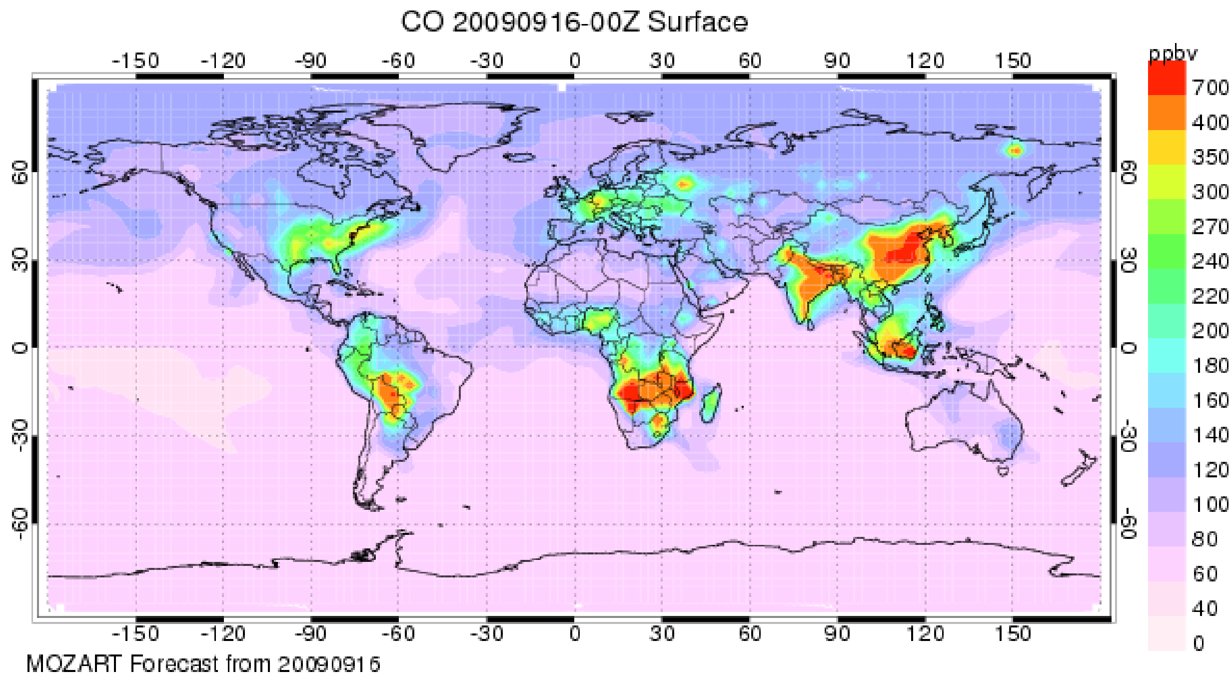

Figure 2: Near-surface mixing ratio of carbon monoxide (CO) on September 16, 2009, produced by a chemical weather forecast from the MOZART chemical transport model incorporating MOPITT and MODIS satellite measurements. Daily forecasts are available at: http://www.acd.ucar.edu/acresp/forecast/

ACD also advances understanding in atmospheric chemistry from the synthesis of process studies, observations and models. Process studies include fundamental chemical mechanisms of gas phase and multiphase systems, including laboratory and sometimes targeted field studies. Observational capabilities focus on the development and application of trace gas, aerosol, and radiation measurements from aircraft and ground-based instruments, and provide comprehensive data on atmospheric composition and processing across a wide range of scales. Photochemical processing is quantified by measurements of source gases, free radicals, oxidation products and aerosol precursors (plus subsequent aerosol formation and growth). These in situ data are complemented by the development and use of satellite measurements for quantifying global-scale chemical structure, variability and trends.

2.2 The Climate and Global Dynamics Division (CGD)

The NESL Climate and Global Dynamics Division (CGD) conducts research and development into key climate system processes through research, community modeling, and data set development with extensive community collaboration and contributions. This includes:

- understanding the components of the Earth's climate system and the interactions among them;
- developing a capacity to represent these interactions in models and thus provide a basis for climate prediction;
- applying understanding and models to scientific problems of societal relevance;
- extensive involvement in leadership positions for national and international climate observing and research programs; and,
- in collaboration with DOE and the academic community, developing and maintaining CCSM and CESM plus provide climate model data for community use.

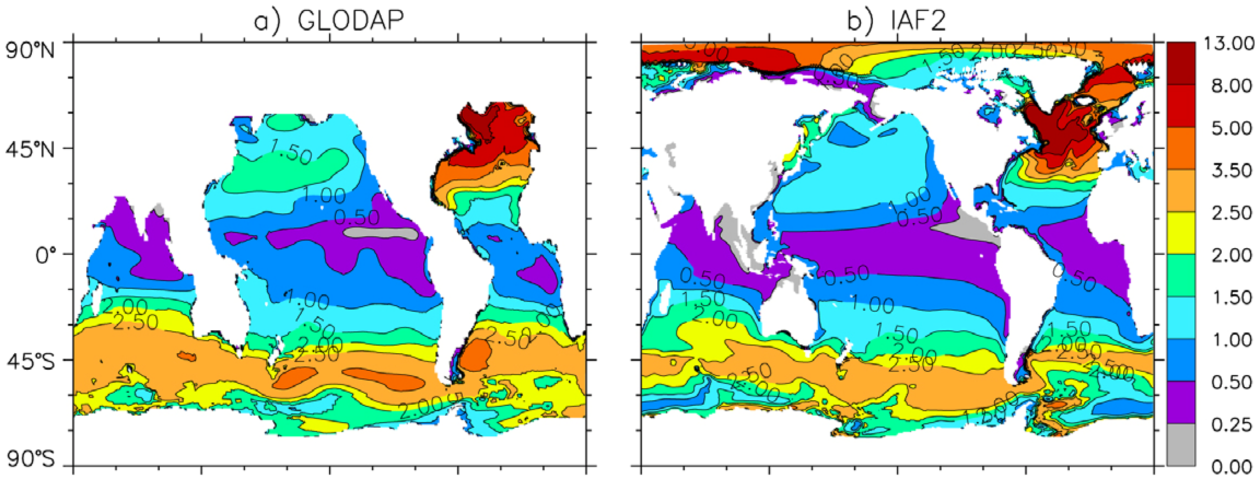

Figure 3: CFC-11 column inventory in moles km ^-2 for 1994 from (a) GLODAP and (b) IAF2 (Danabasoglu et al 2009).

Two broad research themes are pursued in CGD:

- development and application of climate models; and,
- climate analysis: diagnostic, theoretical, observational and modeling studies.

The first theme includes the Community Climate/Earth System Model (CCSM, CESM) as well as its component models, the Whole Atmosphere Community Climate Model (WACCM), Nested Regional Climate Modeling (NRCM) as well as the iPETS integrative assessment model. These models enable fundamental research on climate processes operating in the atmosphere, ocean, land and cryosphere. Included is basic research on chemistry and climate, aerosols, clouds and convection, the global carbon, nitrogen, water and energy cycles, ocean and atmospheric eddies, snow and ice, dynamic vegetation, and land use change. The second theme aims to increase understanding of atmospheric and climate variability, change, and predictability through parallel development and analysis of observational, assimilated, model-generated and model-forcing datasets. These are used in empirical studies, diagnostic analyses, and model experimentation to study climate variability and change, their causes and the processes involved. Work in this area includes analysis of the global water, heat and energy cycles, phenomenological studies of dominant modes of climate variability, attribution of observed ocean, atmospheric, and cryospheric variability to processes and causes, examinations of the dependencies between climate and land cover and land use change.

2.3 The Mesoscale and Microscale Meteorology Division (MMM)

The NESL Mesoscale and Microscale Meteorology Division (MMM) conducts collaborative research aimed at:

- advancing understanding of the physical, chemical and biological processes affecting the Earth's atmosphere;
- advancing the science of atmospheric prediction across all scales;
- developing advanced research and application tools (including models, instrumentation and data sets) and providing these to the community;
- responding to major societal needs addressable using applications of our research.

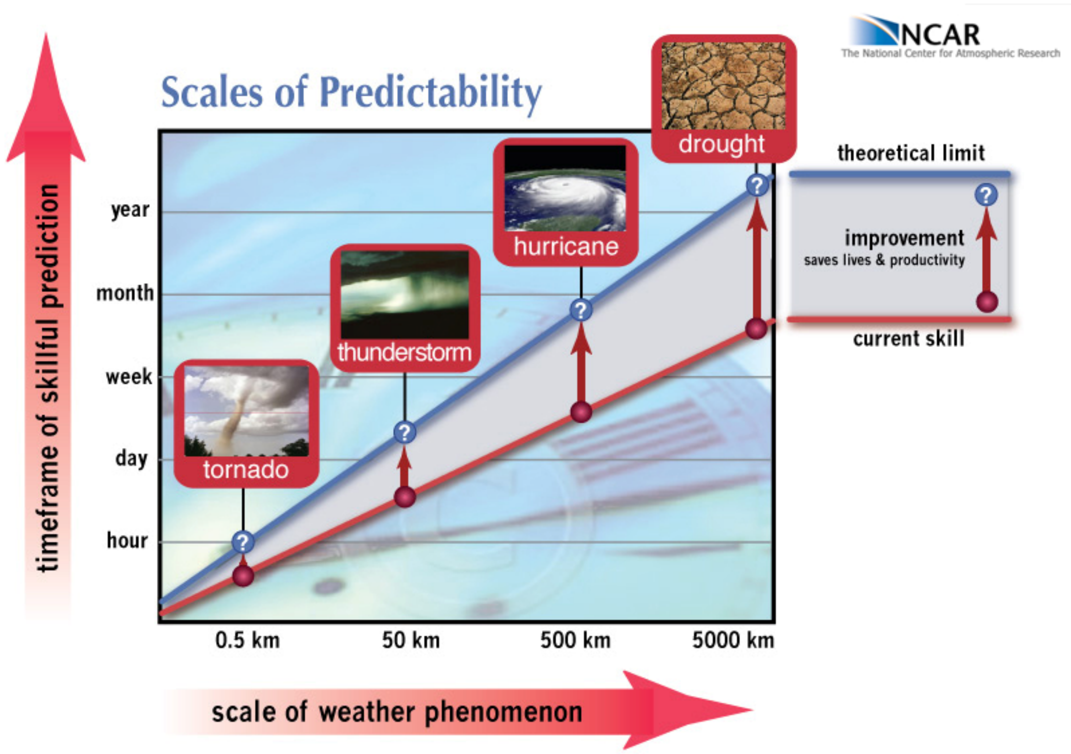

Figure 4: A prime objective of MMM research is to improve current predicative skill (red line) across the spectrum of meteorological phenomena towards its limit of predictability (blue line).

MMM conducts leading-edge research in weather dynamics, prediction, and forecast verification; precipitation processes; boundary-layer turbulence and turbulent fluxes of atmospheric chemical and biological constituents over heterogeneous surfaces. These research areas allow development and support of our facilities to the community. These facilities include the Advanced Research WRF Model (ARW), WRF Data Assimilation (WRF/DART, WRF Var), the Nested Regional Climate Model (NRCM) and a new program to develop a Model for Prediction Across Scales (MPAS). This research also fuels applications of NCAR facilities that benefit human activity. There is demonstrable benefit in the 2-way flow of information between our research and its applications; both areas involve comprehensive collaborations within and outside NESL, and contribute to our world-class science and publications output.

MMM contributes to the fabric of NESL through its high level of academic excellence and integrity, involvement with the academic community, commitment to diversity and mentoring young scientists, and contacts with society. In particular, MMM maintains a popular visitor program, support for students, lectures at universities and other institutions, membership on graduate thesis committees, and high level of collaboration and joint publication. MMM are also committed to developing and maintaining the WRF modeling system including support for community-developed modules, a help desk, tutorials and workshops and development of the next generation Model for Prediction Across Scales.

2.4 NESL Strategic Programs

2.4.1 Program Management Process

NESL operates on a loose matrix structure: resource and staff management, reporting, evaluations and such occur through the vertical structure shown in Fig. 1; program management operates horizontally across the vertical structure in Fig. 1, with the program manager being directly responsible for the budget and conduct of the overall program.

The research sections/groups represent natural affinities that can be disciplinary, multi-disciplinary and inter-disciplinary in nature. As such, they contain the NCAR core of many small, but critical and numerous major research and development activities. Many of these involve important external collaborations with partners from universities, national labs and foreign countries. Major research and development activities requiring multiple disciplinary and scientific perspectives are therefore accomplished by a program structure that lies horizontally across the vertical columns and extends to the rest of NCAR and thence to the external community as required. Each program has a lead PI, who is responsible for overall management of the program, including its budget. The home *unit* (either a NESL Division or another NCAR Lab) of the lead PI is also the lead *unit* for the program. Where a program is led from outside of NESL, the lead NESL scientist and their Division assume responsibility for the program activities within NESL.

The full PI, lead Division and participating Division responsibilities and procedures are described in a separate NESL Program Management document.

Within NESL we have a few major programs and a number of focus programs, as described in the following sections. These programs cover a range of activities along a common theme, and major programs include several focus programs.

2.4.2 Major Cross-Cutting Initiative: Prediction Across Scales

Society is becoming increasingly more complex and vulnerable to weather and climate events, especially those at the severe and high-impact end of the spectrum. This has been demonstrated by recent bursts of Atlantic hurricane activity, heat waves, droughts and flash flooding. Yet uncertainty over potential climatic changes in these high-impact events is severely hampering our capacity to plan for, adjust to, and mitigate their impacts.

The goal of the Prediction Across Scales Initiative is to develop advanced predictive techniques that improve society's capacity to respond to, adapt to, and mitigate the effects of high-impact weather and climate on scales from hours to decades with special focus on advanced community modeling facilities.

Developing cyber-infrastructure is enabling our moves towards a full capacity for prediction across all scales, both temporal and spatial. Traditional grid scales used for climate (on the order of 10s to 100s of km), are insufficient to constrain process-based representations of the climate system and to generate weather statistics and extreme event probabilities that are critical for impact assessment. We are initially addressing these aspects using the Nested Regional Climate Modeling (NRCM) approach. By nesting the well-developed ARW model into CCSM, we are able to both explore high-resolution prediction with existing computing infrastructure and to develop both experience and techniques for future development. In the next stage, CESM will be extended using high-end computational power to further develop our capacity to predict climate (and weather) at the regional and soon local scale. These programs on scales of order of 10s of km and less will enable further progress in: evaluation of processes at the cloud scale (aerosol activation, cloud microphysical and dynamical interactions) that affect regional and global climate sensitivity; and, estimation and assessment of impacts using self consistent models to produce statistics of weather and extreme events to drive impact assessment model (e.g.: of the hydrological cycle). Ultimately, we shall move towards a full capacity for nonhydrostatic modeling on the sphere, a goal that has its foundations in the current development of the Model for Prediction Across Scales.

This major NCAR initiative thus involves a wide range of scientists and disciplines within and outside NCAR. It includes CCSM/CESM, WRF and their components (CESM, NRCM, WACCM, WRF-Chem, WRF-Fire, and AHW), the next-generation Model for Prediction Across Scales development, the Regional Climate Prediction Program, and the incorporation of human dimensions and communication into modeling system predictions. These component programs are described in the following sections.

2.4.3 Major Programs

2.4.3.1 Major Program: The Regional Climate Prediction Program (PI Greg Holland)

The RCPP brings together several previously diverse groups with a common interest in various components of regional climate research, simulation and prediction. It encompasses part of the NCAR Prediction Across Scales Initiative, and is a coordinated effort to bridge the weather and climate divide; to enable progress in simulating a wide range of physical and dynamical phenomena with associated physical, biological and chemical feedbacks; and to provide improved analyses and predictions to a society that is becoming much more sophisticated in its requirements for assessing and adjusting to weather, air quality and climate conditions. The analysis and prediction components will require advances in coupled data assimilation for application to NRCM simulations. Integral to this societal focus will be the development of sophisticated assessment methodologies for predictability and uncertainty in regional climate prediction.

RCPP goals are to support community, economic and industry planning requirements for regional climate, air quality and weather statistics information on seasonal to decadal time scales. This will be accomplished by developing an advanced regional climate system model capable of investigating all regional climate scale aspects, but with an emphasis on improved:

- regional analyses of current climate at high resolution;
- understanding and simulation of the complex, up- and down-scale interactions that are critical to climate projections at regional and decadal scales;
- dynamical and statistical downscaling from global climate simulations to accurate regional predictions, with emphasis on high impact weather statistics, water cycle and air quality;
- integrated assessment modeling and decision making related to adaptation and mitigation.

2.4.3.2 Major Program: Community Climate and Earth System Models (CCSM and CESM, PI Jim Hurrell)

This program is devoted to maintaining the Community Climate System Model (CCSM) and to its further development into the CESM (Community Earth System Model), as a major community facility. The program encompasses models of the atmosphere, both into (CAM) and beyond (WACCM), the stratosphere, of land processes (CLM), of land-ice, of the ocean (POP), of sea-ice (CICE), plus the coupling infrastructure (CPL7). Advancing the state-of-the-art of all these elements simultaneously has been the strength of this program, and it is essential that it continue to do so.

However, a number of the most pressing scientific questions regarding the climate system and its response to natural and anthropogenic forcings cannot be readily addressed with traditional models of the physical climate. A prime example is the response of terrestrial (and ocean) ecosystems to increased concentrations of carbon dioxide. Will plants (phytoplankton) begin releasing carbon dioxide to the atmosphere (ocean) in a warmer climate, thereby acting as a positive feedback, or will they absorb more carbon dioxide and hence decelerate global warming? Related issues include the interactions among land use change, deforestation by biomass burning, emission of greenhouse gases and aerosols, weathering of rocks, carbon in soils including permafrost, and marine biogeochemistry. In order to address these emerging issues, physical models will be extended to include the interactions of climate with biogeochemistry, atmospheric chemistry, ecosystems, and anthropogenic environmental change.

2.4.3.3 The Weather Research and Forecasting Modeling System (WRF, PI Joe Klemp)

This program revolves around the Weather Research and Forecasting (WRF) model system and its many components, which include: the Advanced Research WRF (ARW), the Advanced research Hurricane WRF (AHW), WRF-Chem, WRF-Fire, WRF-Var, Data Assimilation systems, and the Antarctic Mesoscale Prediction System (AMPS). NESL is committed to the further development, application, and support of this major community facility including providing user assistance, delivering WRF tutorials, and organizing WRF Users' Workshop. NESL utilizes both base and outside funding for such development, with NESL personnel addressing the system's scientific and software needs, while collaborating extensively with university and institutional partners on further development. NESL is also responsible for oversight of the WRF repository and WRF releases, through its leadership of the Developers' and Release Committees, respectively.

In addition to purely research activities, the WRF program will maintain an element of real-time applications for special purposes. A prominent example is AMPS, which provides experimental forecast guidance in support of the United States Antarctic Program. ARW is also run each spring as part of the NOAA/National Severe Storms Lab (NSSL) Hazardous Weather Testbed's Spring Forecast Experiment. This sees various mesoscale modeling groups running at convection-permitting resolutions in the continental U.S., with the output provided to forecasters and scientists analyzing severe convective weather. A third notable real-time activity is AHW hurricane forecasts for the Atlantic Basin summer. WRF-Chem, the atmospheric chemistry component is applied to understanding the chemical and meteorological processes affecting gas and aerosol concentrations, for example those measured during field programs and associated with specific phenomenon [e.g., thunderstorms, as in the Deep Convective Clouds and Chemistry (DC3) effort]. These real-time and research applications serve as a vehicle for examining the model's performance and behavior and point to required further developments. The NESL plan aims to continue these and similar real-time WRF applications.

2.4.3.4 Major Program: Data Assimilation Research and Implementation (PI Chris Snyder)

Data assimilation (DA) is an important discipline in numerical weather prediction, and NESL's WRF program will advance data assimilation research, techniques, and technologies. Both variational and ensemble methods will be pursued. At this time, the WRFDA system has both 3DVAR and 4DVAR components and work will continue to improve these capabilities and to assimilate new data types. NESL scientists are also actively researching and developing ensemble approaches to data assimilation - efforts that will continue.

2.4.3.5 Major Program: Atmospheric Chemistry and Biogeosciences

Global and Regional Tropospheric Composition

Human activities have perturbed the chemical composition of the atmosphere at local, regional and global scales, and the resulting degradation of air quality has significant impacts on the ecosystem and on human health. Scientists in NESL observe atmospheric composition across local, regional and global scales to quantify the impact of anthropogenic and natural emissions on air quality. These observations include ground-based field studies (e.g., BEACHON, OASIS), aircraft campaigns (MIRAGE, DC3), and satellite observations (MOPITT, HIRDLS). The study of emissions within megacities and their impacts around the globe will greatly benefit from these cross-scale observational techniques, as implemented for the MIRAGE Mexico City study in 2006. ACD has been actively studying megacities around the globe, including: Shanghai, Tianjin, Mumbai, Dubai and Tokyo.

Chemistry Climate Interactions

Atmospheric composition and climate are strongly related through a variety of physical, chemical or biological processes. At present, the most documented processes are radiation and aerosol-cloud interaction. In the case of radiation, climate forcing is affected by the distribution (in time and space) of radiatively-active gases and aerosols. In the case of aerosol-cloud interaction (i.e. the so-called indirect effects), chemistry and climate are linked through the influence of aerosol size and composition on cloud and ice condensation nuclei and other cloud characteristics. These processes are already included in our global (CCSM) and regional models (WRF, NRCM). There is, however, growing evidence that chemistry and climate also interact through a variety of biological processes on land and in the ocean.

Over land, emissions of biogenic volatile organic compounds are strong drivers of ozone and aerosol chemistry in many regions of the world. Scientists in NESL observe and model those emissions, their dependence on climate variables, and their impact on atmospheric composition including the formation of secondary organic aerosols. Changes in climate conditions are also changing methane emissions both from wetlands and in association with methane reservoirs under permafrost. In addition, nitrogen deposition and ozone poisoning strongly influence the ability of plants to take up carbon dioxide and to regulate water and energy fluxes. Such processes are being implemented in CCSM in collaboration with scientists outside NCAR. Similarly, the ocean biogeochemistry (developed at NESL with outside university collaborations) as implemented in the Community Earth System Model is affected by nitrogen fluxes (along with other airborne or river-transported nutrients) with the overall impact of modulating the ability of the ocean to uptake CO_2. Finally, the potential release of methane clathrates from under the permafrost or under the ocean sea-floor could lead to a positive feed back, as methane is a very strong greenhouse gas. Scientists at NESL and collaborating institutions are actively involved in the development of observation and modeling capabilities to comprehensively tackle these issues.

Tools for cutting–edge atmospheric chemistry studies

Supporting the goals of NCAR and the atmospheric chemistry community requires cutting-edge investigations of atmospheric composition, emission fluxes into the atmosphere, and photochemical processing of atmospheric tracers. Thus, NESL develops, maintains, and deploys a comprehensive suite of instruments for state-of-the-art airborne and ground-based measurements of a wide variety of atmospherically relevant tracers and photochemical products. NESL has also been instrumental in pioneering the development and operation of satellite instruments designed to measure tracers in the troposphere and stratosphere. NESL works closely with NCAR's Earth Observing Laboratory (EOL) to provide frequently requested tracer measurements (such as CO, CO_2, ozone, reactive nitrogen, and water vapor) to the community and supports EOL by maintaining and operating a number of HAIS (HIAPER Airborne Instrumentation Solicitation) instruments. The atmospheric chemistry community is strongly reliant on this service. NESL also collaborates with a number of universities and with the NASA Earth Science Program, NOAA, and the EPA in both development and deployment of measurement techniques and their adaptation to airborne science. This provides leverage for NCAR in meeting its goals, the goals of the agencies involved, the external scientific community, and society.

NESL is committed to maintaining the existing instrumentation to ensure the highest level of data quality and to improving and expanding its measurement capabilities as new technology becomes available in accordance with our community's needs and requirements. More detail and a table listing existing and newly developed instruments and measurement techniques can be found in the ACD strategic plan.

Air Quality

With increasing world population and industrial effluents, more and more anthropogenic gases are being injected into the atmosphere. Similarly, changes in land use, biomass burning and agricultural practices are also impacting atmospheric composition. Climate change will modify the transports, lifetimes, and ultimate products of these species in important ways. This program brings together groups that observe tropospheric composition and mechanisms from the urban to the regional and global scales, using ground based, aircraft and satellite observations. The program links them to scientists modeling on corresponding scales, employing WRF-Chem and WACCM, and assimilating satellite data in models to support field campaigns. An important near-term example of such a field program is the Shanghai Project, which will study the Shanghai megalopolis as a source of trace species.

All of these activities are carried out in conjunction with, and in support of, university collaborators.

Biogeoscience and Ecohydrology

The coupling of physical, chemical, and biological processes emerged as scientific fields of study because of the need to integrate the key role played by biology in the earth system. This NESL program addresses interactions among various physical, chemical, and biological disciplines to study natural and human changes in land cover and ecosystem functions, the resulting consequences on energy, water, and biogeochemical cycles, and their effects on climate, weather, atmospheric chemistry, water resources, and ecosystems. Ecohydrology is a specialized field of hydrology that addresses the connections between the hydrologic cycle and plant ecosystems, especially ecological processes involved in the hydrological cycle. The two fields share a common intellectual and methodological challenge in linking the microscopic scales of variability in topography, soils, biota, and ecosystems to the macroscopic scales of change in the earth system.

Specific programs include the Community Land Model (CLM, PI Gordon Bonan), Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, H_2O, Organics and Nitrogen (BEACHON, PI Alex Guenther), and the development of additional components with highly integrated model and observational activities.

The CLM project provides the development, analysis, and application of land surface process models for CCSM/CESM, including the carbon and other biogeochemical cycles such as nitrogen and mineral and biogenic aerosols, vegetation dynamics, and human land use and land cover change. CLM also provides development of global, gridded datasets of land cover, land use, and population for the past, present, and future. The BEACHON project conducts field and laboratory studies to improve understanding of land surface processes and their roles in linking and regulating carbon, water and biogeochemical cycles. Research is focused on an emphasis on surface-atmosphere exchange of energy, aerosols, CO_2, water, oxidants and organic and nitrogen compounds and their response to ecohydrological disturbances.

2.4.4 Focus Programs

Focus programs are specialized in nature, and include staff and facilities across more than one Division. Current focus programs headquartered in NESL include:

- Arctic Chemistry (PI John Orlando);
- Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, H_2O, Organics and Nitrogen (BEACHON, PI Alex Guenther);
- Connecting Past, Present and Future Climates;
- Chemistry Climate Interactions (PI Jean-Francois Lamarque);
- Climate Analysis through Diagnostic, Theoretical and Modeling Studies (PI Kevin Trenberth)
- Cloud Physics;
- Community Atmosphere Model (PI Rich Neale);
- Community Chemical Instrumentation (PI Geoff Tyndall);
- Community Land Model (PI Gordon Bonan);
- Deep Convective Clouds and Chemistry (DC3, PI Mary Barth);
- Integrated Assessment Modeling (PI Brian O'Neill);
- Megacity Impacts of Regional and Global Environments (MIRAGE, PI Sasha Madronich);
- Model for Prediction Across Scales (MPAS, PI Bill Skamarock);
- Nested Regional Climate Model (NRCM PIs Greg Holland and Jim Hurrell);
- Ocean Climate Modeling (PI Gokhan Danabasoglu);

- Paleo Climates (PIs Bette Otto-Bliesner and Jeff Kiehl);
- Polar Climate Science (PI Marika Holland);
- Upper Troposphere and Lower Stratosphere integrated studies (UTLS, PI Laura Pan);
- Whole Atmosphere Community Climate Modeling system (WACCM, PI Dan Marsh);
- WRF-Chem (PI, Mary Barth);
- WRF-Fire (PI, Janice Coen);
- Advanced research Hurricane WRF (PI, Chris Davis)

In addition, NESL staff play a strong role in programs headquartered outside of NESL. These include:

- Water System (RAL);
- Water in the West (RAL).

2.5 UCAR Community Survey

In 2009 UCAR commissioned a major community survey covering a wide range of UCAR and NCAR programs community activities and facilities. The full results are archived at www.ucar.edu/survey/2009_comm and the summary by the UCAR President is at www.ucar.edu/communications/quarterly/spring09/president.jsp. In all there were 2,215 respondents of which 1,078 completed the whole survey. As indicated by the snapshots in the accompanying figure, NESL was the standout NCAR Laboratory in its strong community support, with many more compliments than complaints in all areas. The general results are recorded below as they are an important indicator that our strategic approach is both relevant to our community, and appreciated by them.

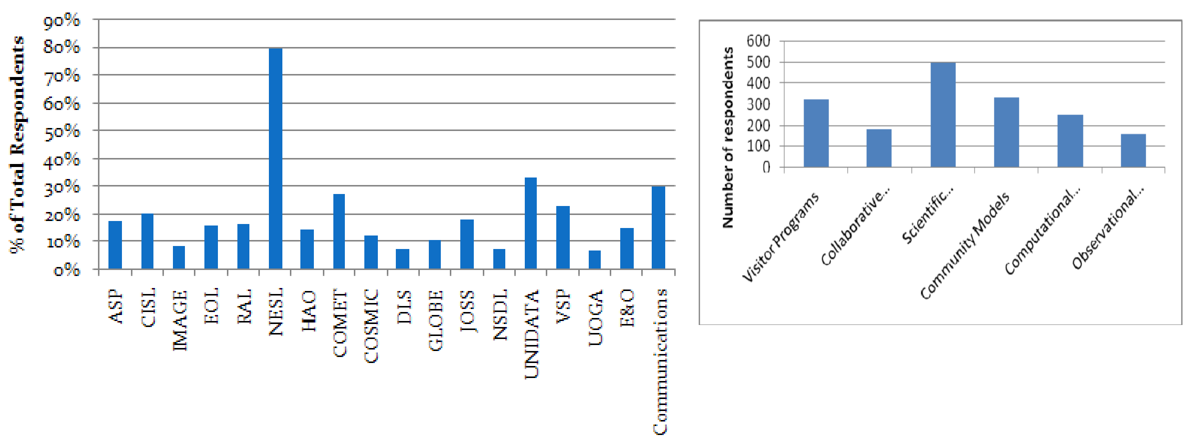

Figure 5: Snapshot of UCAR community survey responses relevant to NESL: Left, percentage of total respondents who had direct interactions with NESL and other UCAR units; Right, number of respondents broken down by types of interactions.

NESL recorded very strong positive responses on our community interactions, visitor programs, modeling maintenance and support, community chemistry instrumentation, and the organization of related workshops and tutorials. Areas in which improvements were recommended have been given serious attention in our strategic planning process. In particular, the following have received priority:

- improved interdisciplinary collaboration across the sciences;
- increased focus on core activities, and particularly on modeling and field program work;
- more support for experimental and instrument-development activities
- further development of our young scientist collaborative and support activities;

- continued model development, especially development of a next-generation modeling capacity at cloud-resolving to global scales;
- expand modeling workshops and tutorials with a priority on those outside Boulder, and including web and on-line tutorials.

2.6 Partnerships and Collaboration

NESL places a strong emphasis on community interactions and collaborations. Our modeling facilities are developed with widespread contributions and collaboration from our communities. A new approach has been established by the success of some pilot CLIVAR Climate Process Teams (CPTs), which has led to three new CPTs in NESL. These teams are headed by university PIs, and they are responsible for delivering new ideas from the observational, theoretical and process modeling communities that are ready to be implemented in our community models.

All major NESL facilities (CCSM, CESM, WRF, WRF-Var, WRF-DART, WRF-Chem, CAM-Chem, WRF-Fire, NRCM, WACCM, and AHW) are maintained for community use, with supporting help desks, tutorials and workshops. The community usage is impressive and well ahead of any other modeling facility use in the world. NESL also maintains strong partnerships with universities and outside agencies for development and application of community chemistry instrumentation.

Other indicators of our strong partnerships and collaborations from 2009 include:

- Staff Publications: 389 total, and 150 joint with university and other external collaborators;
- Staff Education & Outreach:
    - 16 external teaching positions held;
    - advisors for 56 graduate students, dissertation or thesis committee members for 57 graduate students, and supported 13 student & post-doc positions;
- Staff Community Service:
    - hosted 13 colloquia, symposia, and tutorials, and conducted 34 workshops;
    - served on 173 scientific, technical, policy and/or educational committees;
    - gave 749 scientific & technical presentations and 21 informal science education presentations;
    - participated in 25 field projects.

These speak to an excellent record of supporting the key NCAR mission of community support. However, more can always be done to further improve our community support role. For example, the unprecedented uptake of CCSM and WRF modeling systems has not been matched with increases in staff to support community requests, tutorials and growing requirements.

3. NESL Strategic Imperatives and Frontiers

All of NCAR participated in a comprehensive strategic planning process over 2008-2009 and this has formed the basis of the NESL Strategic Initiative and Frontiers. In particular, we have relied on information contained in:

- the strategic planning activities and priorities of the 3 divisions;
- the new NCAR Strategic Plan (www.ncar.ucar.edu/publications/stratplan09.pdf);
- the NSF GEO Vision: Unraveling Earth's Complexities through the Geosciences (http://www.nsf.gov/news/news_summ.jsp?cntn_id=115717&WT.mc_id=USNSF_51);
- the NCAR Workplace Management Plan recommendations; and,

- the recent UCAR Community Survey (www.ucar.edu/communications/quarterly/spring09/president.jsp).

This section addresses Laboratory-wide issues and priorities. Detailed approaches within specific disciplines and groups are contained in the related plans of the three Divisions.

3.1 NESL Strategic Imperatives

NESL Strategic Imperatives address our fundamental programs and activities that are to be protected and nurtured as the highest priority. These support the Priority Programs outlined in Section 2.4 and NCAR community interactions and support activities. All have the same priority, and in random order they are to:

- promote innovation and creativity within our institution and across the community;
- improve capacity for prediction and attribution of variations and changes in climate; prediction of severe weather and air quality; assessment of the related impacts on ecosystems and human well-being; and methods of communicating the results to society;
- advance our world-leading numerical modeling systems of the atmosphere and earth system, and support their wide community use;
- support the development and provision of advanced supercomputing and data services that will enable advancement of the atmospheric and related sciences;
- support earth system research and understanding through development and support of observational facilities, and leadership of focused observational studies; and,
- attract a diverse group of students and early career scientists and engineers to the atmospheric sciences, and provide them with exciting opportunities for educational and professional development.

Our approach to sustaining and growing each of these strategic imperatives follow.

3.1.1 Strategic Imperative: Promote innovation and creativity within our institution and across the community.

The outcomes of discovery-oriented research have been a major factor in science advances and societal development throughout history. Such research is of continuing importance as our increasingly complex society struggles to adapt to the many challenges of coping with our variable and changing climate, and with the stresses imposed by high impact weather and air quality issues. Within NESL, advances with our major community facilities are critically dependent on related research that brings forth new understanding, techniques and approaches.

Yet it is often discovery-oriented research that suffers first during times of budget or other stresses!

NESL is committed to resist this tendency by priority support for discovery-oriented research and by facilitating activities that promote its advancement. This is emphasized by the prominence that advancing understanding has in our mission statement. We also recognize the importance of carrying new discoveries through to improvements in facilities, and techniques that maintain and improve our level of our service to society. We are committed to:

Conducting discovery-oriented research across the atmospheric and related sciences to improve understanding, identify emerging issues, develop new approaches, guide the direction or redirection of ongoing research programs and facility development and enable the provision of informed advice to community leaders.

This theme runs through all of our programs and imperatives.

In addition to supporting discovery-oriented research by individuals and groups, NESL will help expand our research capacity through:

- enabling staff to pursue high-risk, potentially path-breaking research projects;
- developing and supporting collaborative research efforts that combine ecological, hydrological, biogeochemical, and social science expertise with core atmospheric disciplines to address challenging and multifaceted Earth system science problems;
- expanding our scientific visitor program, to and from the community, with flexibility to entrain a broad community of scholars, and to encourage exchange of information and development of new perspectives;
- working with universities, the broad science community, and the public- and private-sector to identify grand challenge problems of societal and scientific interest, and to build these into future research approaches and methods;
- enhancing observational and modeling facilities by evaluating new technologies, experimenting with advanced computational architectures, and developing prototype instruments, models, and model components;
- supporting policy and climate impact planning through the development and application of quantitative models integrating biophysical components of the climate system with socio-economic components; and,
- supporting societal response to high-impact weather by improved predictive models and new approaches to communicating risk.

3.1.2 Strategic Imperative: Improve capacity for prediction and attribution of variations and changes in climate; prediction of severe weather and air quality; assessment of the related impacts on ecosystems and human well-being; and methods of communicating the results to society.

We have seen tremendous advances in our capacity to forecast weather and to project changes in global climate associated with both natural variability and greenhouse warming. Society also has become much more complex and sophisticated in its demands for information about the future. Alas our ability to communicate the implications of forecasts and projections has not kept pace with the scientific and technical advances in prediction.

NESL is committed to the continued improvement of weather, air quality and climate predictions across all scales, from hourly to decadal. We will work with targeted societal groups, the public and private sectors, and our community colleagues to improve communication of the impacts of these predictions; and to ensure that societal decisions are based on the best-possible objective scientific advice.

Specific foci over the next 5-years include:

- developing direct interactions with major societal, industry and government interests with the goals of developing a close communication on needs and capabilities, and of influencing long-range research activities to the benefit of society;
- advancing modeling, observational and analysis programs focused on informing policies for adapting to, and mitigating the impacts of climate variability and change on society and ecosystems, with a strong focus on regional climate and decadal time-scales, including:

- developing a state-of-the-art Community Earth System Model capable of addressing scientific questions that span the spectrum of the earth's system and contributing to assessments of the IPCC;
    - predicting the glacial-interglacial Earth system and extending this to examine the sequence of processes that led to the great mass extinction events in Earth history;
- developing a capacity through advanced modeling and data assimilation systems to improve the accuracy and utility of forecasts of high-impact weather focused on hurricane landfall and intensity, severe thunderstorms, high air pollution episodes, and other extreme events;
- developing improved techniques and modeling systems for predicting air quality across hours to decades; and,
- improving communication of the implications of weather and climate predictions to the public, and to public and private decision-makers.

3.1.3 Strategic Imperative: Advance our world-leading numerical modeling systems of the atmosphere and earth system and support their wide community use.

The NESL modeling facilities encompass a diverse array of systems, from advanced dynamical cores to data assimilation systems, and to modules incorporating land surface, ice, and physical, biological and chemical processes. The community-based development of these systems and their uptake by the community has been one of the great NCAR success stories. As of January 2010, community uptake of our two major modeling systems has been:

- CCSM data or models have 7,000 registered users at over 2700 sites in 120 countries;
- WRF modeling systems have over 11,000 registered users in 125 countries and are used in over 50 operational sites.

There are also a number of specialty combinations of these basic systems, including WACCM, NRCM, WRF-Chem, CAM-Chem, WRF-Fire, and AHW.

Our capacity to maintain these community facilities in the face of exponential growth in usage has fallen below maintainable levels in recent years; restoring this capacity is a high NESL priority. In addition, the current model cores are not well suited to the massively parallel computing systems that are coming on line. Thus development of the next-generation modeling system capable of handling advances in supercomputing, while providing improved service to our community users is a high priority.

In addition, NESL has a number of advanced specialized modeling systems, such as Large Eddy Simulators, that are maintained by individual scientists, but extensively applied to community research programs and societal requirements. One example is LES modeling of boundary-layer flow in support of design and implementation of wind energy systems. This and other specialized models are regarded as valuable components of our overall modeling suite, and contribute substantially as analysis tools of observational data sets.

Specific foci over the next 5-years include:

- continuing program of updates, improvements and community releases for the CCSM and WRF modeling systems and their variants;
- further developing and improving coupled data assimilation systems to provide optimal initial state definition for weather forecasting and regional climate prediction, including chemical weather capabilities;
- establishing NRCM as an interim regional climate prediction system by full integration of WRF into CCSM, and evolving this towards a full Regional Earth System Climate Model;
- developing the WRF capacity for predicting high-impact weather focusing on severe local storms, hurricane landfall and extreme air pollution events;

- supporting and further developing LES model capacity and usage, emphasizing boundary-layer dynamical, biological and chemical processes;
- building innovative, extensible, and maintainable software design into our next generation earth-system models which continues our tradition of incorporating best practices and new approaches to optimal performance on massively parallel computing structures;
- supporting continued research and development of processes and modules in support of the overall earth-system modeling development, including microphysical, chemical, land-surface, oceanic, biological, cryospheric, and human activity processes;
- testing and validating all modeling systems in field programs and other quality data collection efforts.

Note also the next-generation and earth system model development priorities under our Frontier activities.

3.1.4 *Strategic Imperative: Support the development and provision of advanced supercomputing and data services for the atmospheric sciences through scientific advice and the use of advanced modeling systems in test mode;*

The new NCAR-Wyoming Supercomputing Center will open up tremendous opportunities for advancing modeling systems, as well as understanding and prediction of weather and climate. NESL is an active supporter of this development and has emphasized the resulting benefits with test cases including: high-resolution LES modeling, hurricane and air quality simulation at very fine scales, and high-resolution regional and global climate simulations. We also see an urgent and growing need for improved approaches to data storage and analysis capacity. NESL is an active participant in the CAVES virtual disk data storage and accessibility system maintained at CISL.

NESL will continue to encourage and support further development of advanced computing and data storage systems on behalf of ourselves and our community colleagues. Coupled with this will be support for next-generation analysis approaches capable of efficiently analyzing the ever-increasing volume of data that is being generated by both modeling and observing systems.

3.1.5 *Strategic Imperative: Develop and provide observational facilities, including state-of-the-science instrumentation, that meet the needs of NSF, NCAR, and the atmospheric and related sciences community.*

The development of field programs and observing systems is essential to understanding weather, climate, and atmospheric composition and processes. Our commitment to this activity is emphasized by our participation in 25 field programs during 2009, much of this as leaders and providers of equipment and modeling support. We are also active and major participants in a number of international observing programs, such as BEACHON, and on specific field projects with national and international partners. NESL-developed instrumentation and modeling systems are integral to this involvement and we work closely with EOL and external groups in these activities.

One key NESL activity is the development, maintenance and application of a critical mass of community chemical instruments, particularly for airborne measurements, that are often provided as community-requested support. These include measurements of O_3, CO, CO_2, H_2O, NO_x, NO_y, organic nitrates (PAN), HO_x, various volatile organic compounds (VOCs), in addition to highly detailed radiative flux measurements. Continuation of this important role hinges on the ability to maintain and upgrade state-of-the-art instrumentation, and also to enhance the related scientific expertise. A particular strength is our ability to measure chemical composition over a range of scales, including aircraft and satellite data developed in NESL. A suite of specialized in situ aircraft measurements, particularly when deployed in concert, provide detailed information on the chemical state of the atmosphere and provide stringent tests for models.

It is unfortunate that the overall proportion of experimental and instrument development in NESL has fallen in the last decade. We shall endeavor in the next five years to increase this activity, with specific foci being to:

- develop and support software and archival infrastructure specific to the curation and analysis of major research data sets, with an emphasis on rendering the data openly and easily available to users through advanced analysis, visualization, archive, and access tools;
- develop, maintain, and provide robust and portable observational infrastructure to support field campaign operations, acquisition of data from instruments and observing platforms, and near-real-time analysis;
- advance observational capabilities for atmospheric chemistry research by enabling instrument development and improvement to ensure highest quality data and scientific return. Focus on new airborne capacity for HOx and VOC measurements, plus time-of-flight mass spectrometry systems for analyzing organic trace gases and aerosols.

3.1.6 Strategic Imperative: Attract a diverse group of students, early career scientists and engineers to the atmospheric sciences and provide them with exciting opportunities for educational and professional development.

Attracting bright new minds to our field is critical for our continued success and development, as is demonstrated by the remarkable success of the ASP over the years. NESL remains firmly committed to ensuring that new, highly-motivated staff from diverse backgrounds are attracted into our scientific areas. We shall continue to encourage and support ASP activities, mentoring through the SOARS program, supervising and collaborating with graduate and undergraduate students, and providing ad hoc lectures and teaching opportunities from early school to college.

Specific foci include:

- increasing the number of postdoctoral appointments in NESL;
- conducting and participating in educational activities/programs that integrate research and education; including work-study and summer programs for undergraduates in engineering, applied mathematics, and computer sciences that supplement the educational experiences they receive at universities;
- continuing aggressive outreach to qualified candidates for educational programs with particular attention to attracting candidates from diverse backgrounds and disciplines;
- increasing the involvement of NESL scientists and engineers in teaching, supervising students, and other educational activities in the university community, and engaging this community in increasing our diversity;
- introducing a pilot program supporting visits to NCAR by graduate students.

3.2 NESL Frontiers

Frontiers represent new directions or growth areas. These may be in response to scientific and technical developments, changing societal emphases, and approaches from the community. Their adoption or progress is subject to available resources and staff.

Current NESL frontiers are to:

- advance modeling and analysis focused on informing weather prediction and climate change adaptation and mitigation;
- conduct and enable studies of water resource availability, vulnerability and adaptation planning;
- develop and support new community tools for integrating Earth system measurements with models;
- develop methods to more accurately assess and predict wind and cloud cover in support of renewable energy industries. Improve understanding of the impacts of biofuels and other renewable energy technologies on water resources, air quality, and regional climate; examine the effects of the cultivation of biofuels, and of the use of these and other renewable energy resources on air quality on local to regional scales.

Because of the need to obtain resources to implement these Frontiers, they are listed in priority order. However, actual implementation will be subject to external resources and priorities, so the implementation may vary and some areas may not be implemented at all. More detail on these follows.

3.2.1 Frontier Priority 1: Advance modeling and analysis focused on informing weather prediction and climate change adaptation and mitigation.

Foci:

- develop and implement the Model for Prediction Across Scales (MPAS), a next-generation modeling system capable of efficient performance on massively-parallel computing systems and of prediction across all relevant weather and climate scales;
- explore higher resolution in coupled climate modeling, including eddy resolving ocean models and global atmospheric models down to order 10km. The latter will include a rigorous evaluation of presently available, scalable dynamical cores such as being developed under HOMME and MPAS;
- evolve CCSM into a Community Earth System Model (CESM), including capabilities for ocean acidification, higher marine trophic levels, atmospheric chemistry including its interactions with the biosphere, ocean and sea-ice, polar processes, and human dimensions;
- produce very-high-resolution (4 km) regional-scale predictions of climate change and impacts (including air quality impacts) with NRCM, including detailed characterizations of prediction uncertainty;
- examine potential rapid positive feedbacks arising from methane emissions out of wetlands, tundra, soils and clathrates and the impacts on inducing rapid climatic change;
- develop new partnerships and involve stakeholders with priority on creating regional assessments of vulnerability and adaptation options and on analysis of climate impacts on human health, air quality, ecosystems, and water resources;
- establish a multi- disciplinary regional research program on the rapidly changing Arctic environment, where feedbacks act to amplify the forced climate response; add and refine components of the iPETS model, including improved representation of spatial land use change, emissions, and mitigation of non-CO2 greenhouse gases, and more detailed representation of key energy technologies;
- explore new ways of linking integrated assessment models to earth system models; of incorporating impacts and adaptation into these; and for evaluating mitigation strategies and emissions pathways.

3.2.2 Frontier Priority 2: Conduct and enable studies of water resource availability, vulnerability and adaptation planning.

Foci:

- determine the leading drivers of societal vulnerability and adaptive capacity to changes in water availability in western North America, and determine how state-of-the-art model scenarios can best inform water resources planning decisions;
- determine the principal controls (large-scale dynamics, moisture sources, orography, convective processes, etc.) on precipitation character (seasonality, frequency, intensity, and phase) in western North America and how these will respond to a changing climate;
- improve model physics parameterizations (convection, microphysics, land surface, snow processes, planetary boundary layer) to enable credible climate model simulations of the water cycle over western North America;
- create an observationally driven focus in the US for sub-grid physical parameterization evaluation and development in atmospheric models;
- improve the characterization and parameterization of interactions among biosphere, atmosphere, and hydrosphere cycles through the BEACHON project.

3.2.3 Frontier Priority 3: Develop and support new community tools for integrating Earth system measurements with models

Foci:

- confront models, and their components with observations via data assimilation and extensive diagnostic analysis. Extend data assimilation procedures to the upper atmosphere (such as the regions covered by WACCM). Exploit the capabilities of NSF aircraft and other airborne observing platforms in model and satellite validation, Doppler radar reflectivity, and initialization of decadal-scale and longer climate predictions with a focus on high-impact weather;
- with the university community, continue to assemble observations of the carbon and nitrogen cycles for the evaluation and improvement of biogeochemical models through testing against observational constraints;
- develop a prototype system for chemical weather analysis and prediction by combining remote sensing and other observations with data assimilation and a prediction system with particular regard to integrating remote sensing data into models;
- exploit the capabilities of and provide tools for comparing measurements with model derived 'instrument simulator' representations;
- with the university community, evaluate and improve biogeochemical models through testing against observational constraints;
- create a focal point at NCAR for U.S. climate scale physical oceanography.

3.2.4 Frontier Priority 4: Develop methods to more accurately assess and predict wind and cloud cover in support of renewable energy industries. Improve understanding of the impacts of biofuels and other renewable energy technologies on water resources and regional climate

Renewable energy is critical to the economic growth and security of the United States, and renewable energy industries are in a period of rapid technology development and growth. NESL is responding to these with a frontier program in support of the renewable energy community.

Foci:

- develop collaborative weather and climate research programs focused on infrastructure planning and management, such as boundary layer studies and characterization of land use interactions with regional climate;

- develop partnerships with the National Renewable Energy Laboratory (NREL) and utilities that are investing in wind power system to develop, evaluate, and improve sensor technology, observational systems, and short-term wind prediction models;
- develop improved short-term and seasonal weather prediction in support of energy demands, management of energy supply, pricing and markets, system operations, regulatory compliance, and minimization of economic risk;
- develop an understanding of the environmental impacts of alternative fuels on the environment.

4. ACRONYM LIST

ACD – Atmospheric Chemistry Division
AHW – Advanced research Hurricane WRF
AMPS – Antarctic Mesoscale Prediction System
ARW – Advanced Research WRF
BEACHON – Biosphere-atmosphere Exchange of Aerosols within Cloud, Carbon and Hydrologic cycles, including Organics & Nitrogen
CAM – Community Atmosphere Model
CCSM – Community Climate System Model
CESM—Community Earth System Model
CGD – Climate and Global Dynamics Division
CISL – Computational & Information Systems Laboratory
DC3 - Deep Convective Clouds and Chemistry
DOE – Department of Energy
DTC – Developmental Test Center
EnKF – Ensemble Kalman Filter
EOL – Earth Observing Laboratory
HAIS – HIAPER Airborne Instrumentation Solicitation
HAO – High Altitude Observatory
HIAPER – High-performance Instrumented Airborne Platform for Environmental Research
HFIP - Hurricane Intensity Forecasting and Impacts Projection
LES – Large-Eddy Simulation
LSM – Land Surface Model
MIRAGE - Megacity Impacts on Regional and Global Environments
MMM – Mesoscale and Microscale Meteorology
MPAS – Model for Prediction Across Scales
NASA - National Aeronautics and Space Administration
NCAR – National Center for Atmospheric Research
NRCM – Nested Regional Climate Model
NOAA – National Oceanic and Atmospheric Administration
NSF – National Science Foundation
PAS – Prediction Across Scales
PI – Principal Investigator
RAL – Research Applications Laboratory
SOARS – Significant Opportunities in Atmospheric Research and Science
UCAR – University Corporation for Atmospheric Research
WRF – Weather Research and Forecasting
WRF-Chem – Weather Research and Forecast coupled with chemistry
WRF-Fire – Weather Research and Forecast coupled with a fire module
WRF-Var – WRF Variational Data Assimilation System