NOAA
National Severe Storms Laboratory Strategic Plan

2015-2025

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1. Message from the Director

Severe weather impacts thousands of people every year across the United States, damaging property and threatening lives. Forecasts and warnings provided by the National Weather Service (NWS) help communities prepare for oncoming severe weather by prompting citizens to take cover and secure valuable equipment and other property. However, deficiencies in our understanding and capability to predict severe weather processes, together with the Nation's inability to monitor key elements of the atmosphere before and during severe weather, greatly hamper the ability of the NWS to issue accurate and timely forecasts and warnings, leaving communities vulnerable.

Since its formation 50 years ago, NOAA's National Severe Storms Laboratory has endeavored to be the world's leader in severe weather research and its transition into NWS operations, resulting in highly significant improvements and saving thousands of lives. NSSL pioneered development and use of Doppler radars to monitor convective storms and detect signatures of severe weather, which eventually led to the establishment of a national network of Doppler radars (WSR-88D). Our subsequent work demonstrated the ability of polarimetric radar to improve precipitation estimates and identify hydrometeor types, leading to a powerful recent enhancement of the WSR-88D capabilities. NSSL's basic research with lightning strike mapping systems contributed to incorporation of lightning strike data into NWS operations and provided a foundation for the development of applications for the future Geosynchronous Lightning Mapper (GLM). Experience with data integration systems led to the recent implementation of the Multi-Radar/Multi-Sensor System (MRMS) into NWS operations, resulting in improvements to warnings for flash floods and other high impact weather. NSSL scientists have worked closely over the past two decades with the Storm Prediction Center (SPC) and NWS Forecast Offices at the Hazardous Weather Testbed (HWT) to demonstrate the value of cutting-edge ensemble weather prediction systems to determine the probability of a severe weather event.

Advancements in observing system capabilities and physical understanding of processes that produce hazardous convective weather are core to NSSL research. Numerous gaps in our knowledge of these processes remain. NSSL will maintain its leadership in the understanding of storm structure, processes, and evolution, and the use of polarimetric radar observations to understand the interrelationships among microphysics, dynamics, electrification, and lightning activity across a broad spectrum of convective storms. At the same time, we place tremendous value on the cultivation of collaborations and will continue to invest in these relationships, both new and old, in the coming decade. Collectively, these collaborations provide a strong foundation for NSSL's basic research, allowing research initiatives to be driven by the needs of stakeholders such as NWS forecasters, to provide a clear pathway for the transfer of science and technology to operations and applications. This framework allows NSSL to have significant societal impact, ultimately saving lives and reducing the economic impact of severe weather.

This document outlines a vision for the research and development activities that will be conducted by NSSL over the next decade. Woven throughout this document is the idea that science is a continuum: basic research is the root through which everything flows, but that ideally the basic research performed at NSSL will ultimately be used to improve the ability to understand, model, and forecast severe weather to allow more timely dissemination of warnings by the NWS to the public.

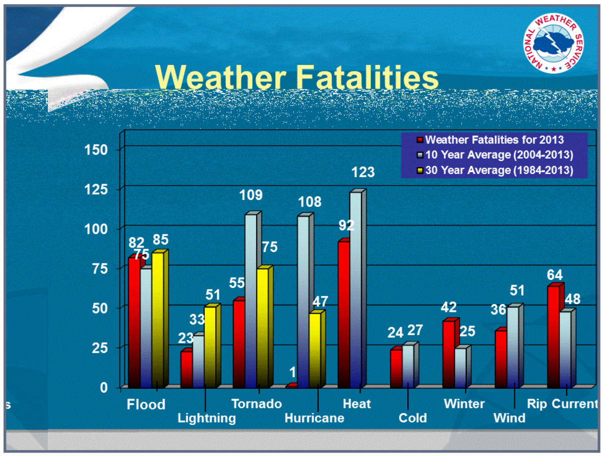
This document is built around six grand scientific challenges, followed by a strategy to improve the NSSL workplace to assure an intellectually stimulating work environment that challenges and rewards people, and which fosters equality among all employees. The grand scientific challenges represent achievable, societally important problems that will be difficult to address but will have substantial or even game-changing impacts. Specifically, within the next 10 years, NSSL scientists seek to have met the goal of the Warn-on-Forecast program to provide NWS forecasters with the probabilistic guidance needed to extend lead-times for severe thunderstorm and tornado warnings out to one hour with substantially reduced false alarms. Second, we consider it necessary to enhance WSR-88D capabilities while addressing this aging operational radar technology, current gaps in radar coverage, and longstanding limits of tornado lead time with high false alarm rates by developing advanced radar concepts such as phased array radar. Third, NSSL aims to achieve the capability to reliably predict flash flooding for both urban and complex landscapes several hours in advance, providing a probabilistic hydrologic prediction with much longer lead time and more accurate prediction than current systems. Fourth, we intend to demonstrate that useful warnings of lightning activity can be predicted one hour in advance from the very onset of convection to its demise, both in-cloud (as an indicator of storm intensity changes and short-term predictor of severe weather potential) and cloud-to-ground lightning (for public safety and aviation concerns). Fifth, our plans are to develop a reliable nowcasting system for convection initiation that goes well beyond the current reliance on surface, radar and satellite detection of low-level boundaries, so as to address fundamental gaps in our understanding of how the pre-convective environment is evolving in terms of available moisture, instability, wind shear, and storm generation mechanisms. Finally, NSSL will provide uncertainty information for high impact weather to reduce tornado and other severe weather warning false alarms significantly and provide the public with probabilistic, risk-based information to replace current “binary” yes/no warning areas. This is needed to greatly improve public decision-making to attain a better-informed Weather-Ready Nation that is resilient to dangerous, high-impact weather events.

Dr. Steven Koch, Director

2. Executive Summary

Motivation

Severe weather touches every state in the U.S. and is a real threat to our property and our lives. Changing demographics will place more people in the path of natural hazards. NSSL has a responsibility to translate discoveries into tangible benefits that can impact society for generations to come. We also have a responsibility to enable the nation and society to make informed decisions in the decades to come to prevent loss of human life, and to continue exploration and discovery in new areas to lay the foundation for services of the future.



NSSL Vision

The National Severe Storms Laboratory will be our world's leader in basic and applied research on severe convective storms to support an informed society that is resilient to high impact weather.

NSSL Mission

The National Severe Storms Laboratory conducts fundamental research to advance our knowledge and understanding of meteorological processes associated with severe convective storms. NSSL performs applied research and development leading to the transition of new and improved tools and techniques for observation, analysis, and prediction to the National Weather Service and other stakeholders. These efforts are aimed at improving the accuracy and lead-time of severe weather forecasts and warnings, lending support to a Weather-Ready Nation that is resilient in the face of increasing vulnerability to severe and disruptive weather.

Relevance

NSSL's focus on severe weather research advances NOAA's agency-wide mission "to understand and predict changes in climate, weather, oceans, and coasts and to share that knowledge and information with others."

DOC Strategic Plan

- "Advance the understanding and prediction of changes in the environment through world class science and observations

NOAA Strategic Plan

- "Society is prepared for and reponds to weather-related events"
- "A holistic understanding of the Earth system through research"
- "Accurate and reliable data from sustained and integrated Earth observing systems"

NOAA Research Strategic Plan

- "Improve forecasts, warnings, and decision support for high-impact weather events"

Weather-Ready Nation Roadmap

- "Improve weather decision services for events that threaten lives and livelihoods,
- "Deliver a broad suite of improved water forecasting services to support management of the Nation's water supply,
- "Enhance climate services to help communities, businesses, and governments understand and adapt to climate-related risks"
- "Improve sector-relevant information in support of economic productivity"
- "Enable integrated environmental forecast services supporting healthy communities and ecosystems"
- "Sustain a highly-skilled, professional workforce equipped with the training, tools, and infrastructure to accomplish our mission."

NSSL Core Values

Our mission touches the lives of every American, and we are proud of our role in protecting life and property. We embrace our core values of integrity, customer service, and striving for excellence.

Integrity

By making every effort to “do the right thing” for the American public and consistently meeting stated milestones and performance measures, we set high standards of integrity for everyone at NSSL.

Customer Service

The ultimate goal of our research and development is to produce groundbreaking products and services that are transitioned into NOAA operations and other applications serving the American people. It is essential to retain focus on, and be well aligned with, the plans of our primary and subsidiary customers – including the National Weather Service, other line offices in NOAA, and our external customers, and both anticipate and meet the future needs of our customers.

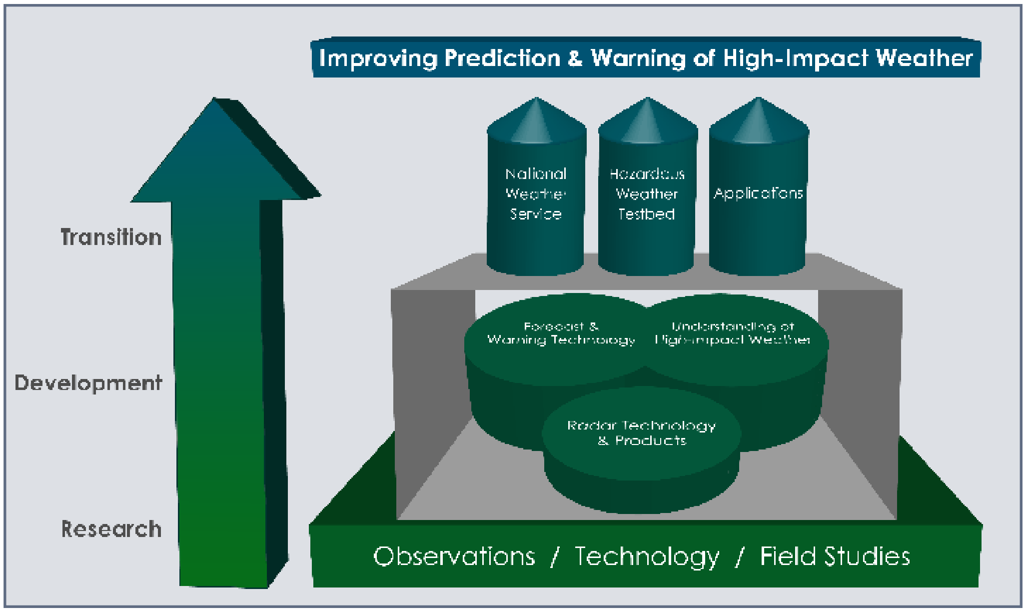
Excellence

NSSL scientists, engineers, administrative support personnel, and technicians all strive for individual excellence and collaborate to achieve organizational excellence by getting it right, delivering on time, and making the most of available resources.

NSSL’s Science Themes

There are gaps in our ability to warn the public of impending weather hazards that put our nation at risk. High false alarm rates cause people to ignore warnings. Short lead-times prevent them from reaching safe shelter in time. NSSL research is focused on these basic societal needs.

NSSL’s fundamental science themes are based on a foundation of improved observations, technology advancements, and exploratory field studies, as illustrated below. The upward arrow shows how these themes are driven by the process of moving research through development, to demonstration and transition into applications that benefit society. Advancements are made and refined in the NOAA Hazardous Weather Testbed (HWT) and lead to improved National Weather Service (NWS) products and services in other ways. New applications are developed either jointly or in a “handoff” of new technology to the private sector, academia, or other stakeholders.



2. Executive Summary, continued

NSSL's Grand Scientific Challenges (GSC)

NSSL's science strategy outlined in the following pages is built around six grand scientific challenges, followed by a strategy to improve the workplace itself. These grand challenges represent problems that will be difficult to address but will have substantial or even game-changing impacts. Here we identify what the challenge is, and why it is important, and how we will address it.

GSC 1: Develop reliable probabilistic guidance products

The improving skill of numerical models (particularly convective resolving model improvements and ensemble based probabilistic forecasts) combined with emerging model post-processing techniques and model diagnostic tools, will be the dominant source of better weather information for the NWS during the next decade. In addition, the assimilation of higher resolution satellite-derived data sets in the GOES-R era will enhance the accuracy, reliability, and value of model output information for a broad spectrum of forecasting services. NSSL will develop reliable probabilistic guidance products for prediction of the development and evolution of severe convection, including intensity changes, storm interactions, upscale growth, and attendant societal impacts. We aim to attain the goal of the Warn-on-Forecast (WoF) program to provide NWS forecasters with the probabilistic guidance needed to extend lead-times for severe thunderstorm and tornado warnings out to one hour with reduced false alarms. NSSL plans to develop and implement into operations a convection-allowing atmospheric ensemble prediction system (EPS) using advanced data assimilation and improved model physics to predict individual thunderstorm character and interactions. In parallel, we will build a prototype sub-kilometer resolution numerical simulation system to improve understanding of the atmospheric processes at work for tornado-cyclone scale phenomena and their representation in numerical models.

GSC 2: Produce enhanced capabilities for WSR-88D

NSSL will produce enhanced capabilities for WSR-88D radars to continue to meet evolving requirements through its end-of-life, and also develop radar replacement technologies leading to an NWS acquisition/deployment program by 2030. It is necessary to enhance WSR-88D utility while addressing this aging operational radar technology, current gaps in radar coverage, and longstanding limits of 14-minute average tornado lead time with ~75% false alarm rates. NSSL will build and assess phased array radar technologies with dual-polarization capability, assess gap-filling strategies, and design advanced radar signal processing to optimize radar advancements. We will also work on breakthrough methods for dual polarization data assimilation for better microphysical representation in multi-phase hydrometeor environments, and improved algorithms to derive geophysical variables (e.g., hydrometeor classification) with greater accuracy.

GSC 3: Reliably predict flash flooding

NSSL intends to demonstrate the capability to reliably predict flash flooding for both urban and complex landscapes several hours in advance, providing a probabilistic hydrologic prediction with much longer lead time and more accurate prediction than current systems. Municipal and emergency response officials need this capability since flash floods remain the number one hazardous weather-related killer in the U.S. We will leverage advances in convection-allowing EPSs and in Multi-Radar Multi-Sensor (MRMS) operations to initialize ensemble models for surface hydrology, inundation, and landslides. Probabilistic precipitation forecasts from the EPSs will be used to drive the hydrology models hours in advance of an event, and these models would be frequently updated with precipitation estimates from MRMS as an event begins. The quality of the EPS forecasts depends upon advances made in basic research to better understand processes leading to storm intensification.

GSC 4: Predict useful warnings of lightning activity one hour in advance


Credit: Dave Sills

NSSL aspires to predict useful warnings of lightning activity one hour in advance from the very onset of convection to its demise, both in-cloud (as an indicator of storm intensity changes and short-term predictor of severe weather potential) and cloud-to-ground lightning (for public safety purposes). Accurate short-term prediction of lightning activity is needed to improve public safety (Weather Ready Nation), and to address aviation concerns for ground operations and warning of possible lightning strikes to aircraft in terminal areas (cloud-to-ground lightning). Our approach consists of integrating data from radar, ground-based lightning mapping systems, and geostationary satellite sensor systems into very short-range numerical weather prediction models. We will also conduct basic research to understand and hence improve representation of microphysical processes and electrification processes in numerical models that include lightning production.

GSC 5: Develop reliable nowcasting system for convection initiation

Another goal is to develop a reliable nowcasting system for convection initiation that goes well beyond the current reliance on surface, radar and satellite detection of low-level boundaries. We need to address fundamental gaps in our understanding of how the pre-convective environment is evolving in terms of available moisture, instability, wind shear, and storm generation mechanisms. NSSL will develop and field test innovative new atmospheric observing systems and use this data in conjunction with Observing System Simulation Experiments (OSSE) to determine the optimal design of a mesoscale observing system composed of Unmanned Aircraft Systems (UAS), and ground-based and satellite remote sensing systems, to meet the need to provide short-term forecasts of if, where, when, and what type of deep convection will develop. We will also continue basic research on atmospheric processes responsible for convection initiation and assimilation systems to take advantage of these new data.

GSC 6: Provide and communicate warning uncertainty information for high impact weather events

NSSL will provide uncertainty information for high impact weather with the goal of reducing tornado and other severe weather warning false alarms by at least 30%, and produce probabilistic, risk-based information to replace current “binary” yes/no warning areas. This will support improved public decision-making required for a better-informed Weather-Ready Nation that is resilient to dangerous, high-impact weather events. NSSL will integrate MRMS, advanced observational systems, social science, and other innovations into future development of FACETs (Forecasting a Continuum of Environmental Threats), a next-generation hazardous weather watch/warning paradigm built on the concept of a continuous stream of high-resolution, probabilistic hazard information. FACETs will also help the NWS provide greater consistency of products and services associated with the severe weather warning process, through the development of situational awareness visualizations and decision support tools. We will also perform basic research on how to best represent probabilistic, grid-based information to the decision maker, how best to communicate probabilistic results to different constituencies to obtain the desired response, and other social science areas of research.

3. NSSL Observation Systems

NSSL aims to be a world leader in providing innovative instruments and observations for "a holistic understanding of the Earth system through research." While this is a core NOAA goal, the primary motivation for this focus is even more fundamental to NSSL's specific mission, which is (1) to advance our knowledge and understanding of meteorological processes associated with severe convective storms, and (2) to apply improved understandings in ways that lead to the transition of new and improved tools and techniques for observation, analysis, and prediction to the National Weather Service and other stakeholders.

Atmospheric observations are the foundation of the NWS weather forecasting and warning enterprise. Furthermore, the fundamental research needed to advance knowledge and understanding of the processes associated with severe convective storms requires improved observations. While new theories can lead to improved understanding that helps guide the design and acquisition of new observations, observations are essential to test and refine theories concerning the storm processes that lead to the formation of high-impact hazards. Observations are also used to inform and validate numerical cloud and weather prediction models, and to develop diagnostics to aid NWS forecasters. NSSL's development of applications for Doppler radar and polarimetric radar are prime examples of successes in transferring basic research to NWS operations. Other examples include NSSL's lightning research, which helped motivate the installation of the Geosynchronous Lightning Mapper (GLM) on the GOES-R satellite, and NSSL's development of the MRMS decision support system for integrating data and products from multiple radars and other sensors, which is now being implemented in NWS forecast offices.

Challenges

The key challenges for making the observations necessary to address the core mission of NSSL include developing, maintaining, and deploying systems for observing the enormous range of scales affecting the processes associated with hazardous weather, including many processes which must be observed by sensors within a hazardous environment. Many microphysical and boundary layer processes are still a mystery because they are difficult to observe, yet understanding them is critical for modeling storms and forecasting severe weather. Organized field programs such as the International H2O (IHOP) project, Verification of the Origins of Rotation in Tornadoes – Experiment (VORTEX-2), and the Plains Elevated Convection At Night (PECAN) provide our best opportunities to bring together the extensive suite of instruments needed to measure the relevant properties of severe thunderstorms and the environment in which they grow, but executing them requires many years of planning, cross-agency coordination, extensive technical support, and unwavering organizational commitment.

New and evolving in-situ, satellite, radar, and ground-based passive remote sensing technologies provide capabilities to observe storm and environmental properties that were difficult or impossible to observe previously. New capabilities include polarimetric mobile and WSR-88D radars, phased-array radar, the GLM and the Advanced Baseline Imager (ABI) on the future GOES-R satellite, low-earth-orbiting satellites (e.g., Suomi NPP, JPSS, MetOp), total lightning observations from research systems and commercial vendors, and other research instrumentation such as ground-based passive infrared spectrometers and Doppler lidars. NSSL scientists will use our remote sensing and severe weather expertise to take advantage of these new observations to better diagnose the pre-convective and convective environment, improve understanding of the storm processes leading to severe weather, and produce more useful products from storm-scale Numerical Weather Prediction (NWP) and other models. Primary challenges in this area include maintaining in-house expertise to build and support NSSL's unique observing systems, including mobile radars, mesonets, and the Collaborative Lower Atmospheric Mobile Profiling System

(CLAMPS), the funding and opportunities to deploy these assets in field programs with other investigators both inside and outside NOAA, and learning to fully utilize all the new observing capabilities in both research and operations.

To acquire the observations NSSL needs to: (1) Find ways to extract information about storm inception and severe weather potential from existing routine observations, particularly those provided by NOAA satellite and ground-based systems; (2) Determine what observations are needed to improve understanding and warnings of storm hazards and help bring together the suite of existing observing systems needed to provide those observations; (3) Develop new technology and uses these systems to acquire needed observations of difficult-to-observe storm processes.

Objectives

NSSL will help lead and carry out field programs to fill gaps in understanding of processes critical to the production of high-impact weather, including processes involved in storm initiation, storm intensification, precipitation production, large hail, strong winds, lightning, and tornadoes. This is essential to address most of NSSL's Grand Scientific Challenges. The PECAN field project planned for summer of 2015 is an example of NSSL's participation in a field project relevant to the production of storm hazards (in this case the upscale growth of storm systems at night). Future field projects will be needed to better predict hazards such as flash flooding and tornado genesis, particularly in regions beyond "Tornado Alley", such as the southeastern U.S., which is very prone to devastating societal impacts from severe thunderstorms and tornadoes.

NSSL will use new in situ systems, including balloon-borne instruments (e.g., NSSL's Particle Size Image and Velocity Probe [PASIV]), miniaturized sensors for UAVs, large unmanned vehicles above storms, and the new National Science Foundation (NSF) A10 storm-penetrating aircraft, which can measure properties inside and around storms which have been impossible or extremely difficult to measure previously. Properties for which new or improved in situ measurements are needed include ice microphysics, continual characteristics of storm inflow and outflow, thermodynamics of updrafts and entrained air, electric fields inside and above storms, and above-storm video and radiation from lightning. Some suitable instruments already exist, but others need further development to be made suitable for the size and power constraints of the new platforms.

A key objective is to extract new information about storms and storm initiation from a variety of remote sensing systems, including satellite systems, fixed-base polarimetric and phased-array radars, mobile radars, VHF lightning mapping arrays, national lightning detection networks, Doppler wind lidars, and multi-channel microwave and spectral infrared radiometers. The last three are being incorporated into the mobile, trailer-based CLAMPS. Properties for which new or improved measurements are needed include high temporal resolution profiles of the evolving boundary-layer winds and thermodynamics influencing storm initiation, subcloud processes leading to tornadogenesis, kinematic processes influencing hail and lightning production, and the impact of outflow boundaries on storm formation and evolution (GSC#1, 3-6).

NSSL intends to develop, maintain, and deploy its mobile observing capabilities in order to address its research mission. Current systems include the NOXP mobile X-band polarimetric radar, CLAMPS, the Oklahoma Lightning Mapping Array (operated jointly with the University of Oklahoma), and several mobile mesonet and radiosonde systems. This includes the development of future field campaigns that, together with collaborators from other NOAA laboratories and external partners, focuses on collecting high-resolution datasets of a multitude of geophysical variables in order to better understand the initiation and evolution of hazardous weather systems.

4. Understanding High Impact Weather

Improving physical understanding of the processes that produce hazardous convective weather is a fundamental component of both basic and applied research at NSSL. Numerous gaps in our understanding of these processes remain, including the boundary layer processes that precede convection initiation, the environmental, dynamical, and microphysical processes controlling the mode, intensity, and longevity of convection, the processes involved in producing tornadoes, hail, and lightning, and the precipitation processes that lead to winter weather hazards and flash flooding. NSSL scientists are at the forefront of efforts to make progress in these areas. The knowledge they develop provides the foundation and focus for applied research that addresses the complicated problems associated with improving estimates and forecasts of precipitation amounts and increasing skill in predictions and warnings of extreme events. NSSL's research in these areas directly addresses NOAA's objectives to "Reduce loss of life, property, and disruption from high-impact events".

When NSSL scientists transition new physical understanding of severe weather to forecasting and warning operations, they help save lives and mitigate property loss. For example, the knowledge of supercells and tornadoes gained provided by analysis and modeling of the data collected by field experiments such as VORTEX and VORTEX-2 have resulted in a skillful increase in lead times for tornado warnings. NSSL scientists pioneered the use of polarimetric and Doppler radar observations to better estimate precipitation amount, intensity, and location. NSSL scientists have combined surface, radar, and thermodynamic observations with modeling studies to improve understanding of convective initiation and the evolving interactions of microphysics, kinematics, electrification, and lightning activity in a broad spectrum of hazardous storms.

Challenges

The key challenges for understanding high-impact weather include learning more about the processes responsible for supercell generation and evolution, heavy rainfall production, and freezing precipitation. We currently have little skill in making specific predictions of convection initiation or the strength of tornadoes and straight-line winds. Because these phenomena can evolve rapidly and vary markedly across small distances, new observations and analyses of properties such as temperature, humidity and wind structure in the lower troposphere are required at better temporal and spatial resolution to capture the evolution of the atmospheric state in the convective environment (GSC # 1 and 5). For example, evaporating precipitation often impacts temperature and humidity structures and generates secondary circulations that impact various processes within the storm that affect its evolution.

Water resources are already strained in much of the U.S., and climate model projections suggest that the hydrologic cycle will be amplified, resulting in more heavy precipitation events and longer droughts. As the impact of local convective storms becomes increasingly important for flash flood prediction and water resource management, new surface and subsurface instruments are needed to understand the complex interactions among local rainfall, streamflow, reservoirs, and ground water. In regions for which radar coverage is poor or absent, the resulting uncertainties in determining quantitative precipitation amounts impact downstream hydrological modeling systems that utilize these precipitation values as input, so techniques for using gap-filling observations from other observing systems will be developed (GSC # 2 and 3).

NSSL's research to better understand high impact weather includes answering questions such as: What initiates convection? Where, when, and what type of deep convection will develop? How intense will it be? How will the boundary layer evolve? What are the microphysical processes that electrify a storm and cause lightning? What influences tornadogenesis, its lifecycle, demise, and winds? What influences the strength of straight-line winds? What processes need to be better understood in order to better forecast precipitation duration and intensity in convective situations?

Objectives

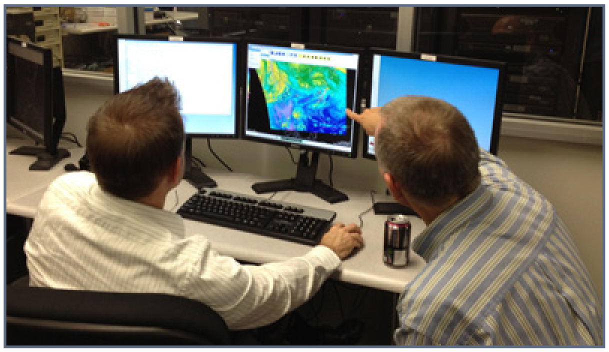
NSSL will use observations from polarimetric radars and phased-array radars having polarimetric capability to improve basic understanding and representations of the microphysical processes and structure of storms. To verify and improve hydrometeor classification schemes for radars and microphysics packages for numerical cloud models, we also will collect in situ microphysics data from novel NSSL platforms (e.g., the videosonde), and other platforms (e.g., GOES-R and the new A-10 storm penetration aircraft). Improving understanding and representations of microphysics are essential for developing methods to assimilate dual-polarization data. In doing so, it is important to obtain polarimetric estimates of the number concentration and size distribution of each type of hydrometeor (including hail) and to determine the evolution of near-ground frozen precipitation.

Our scientists will use advanced models and observations from field projects to improve understanding of convection initiation and of the processes that contribute to the mode of convective storms, including mesoscale convective systems (MCSs). This directly supports GSC #5 to develop nowcasting systems for convection initiation and contributes to GSC #1, 3, and 4. We will analyze data sets from new and previous field projects to learn more about the boundary layer processes that initiate convection and to determine the environmental characteristics that cause upscale growth of storms and control the mode of MCS organization.

Working with our partners, we will use innovative numerical models and observations from field programs to improve understanding of processes that produce storm hazards, including lightning, the tornado lifecycle, and tornadic and straight-line winds. This work will be guided by GSC #1, 4, and 5, to develop reliable probabilistic guidance products for warning and prediction of severe convection, including intensity changes, storm interactions, upscale growth, and attendant societal impacts. We will obtain state analyses of the lower troposphere at cloud-scale resolution and will use fixed and mobile radars, surface and satellite lightning mapping systems, observations from manned and unmanned aircraft, and the new GOES ABI to explore the relationships among the many interacting macro and microphysical properties of clouds and mesoscale convective systems. We will also build a prototype sub-kilometer resolution numerical simulation system to improve understanding of the atmospheric processes at work for tornado-cyclone scale phenomena, storm electrification, and lightning and their representation in numerical models. This work will also help us understand potential changes to severe storm frequency, intensity, and impacts in future climates.

5. Forecast and Warning Technology Research

NSSL's combination of basic research and tight collaborations with NOAA operational units (e.g., the Storm Prediction Center (SPC), NWS Weather Forecast Offices, River Forecast Centers, the Environmental Modeling Center (EMC), etc.) provides a unique environment and opportunity to develop technologies that move results from basic research closer to operations. NSSL is a world leader in developing state-of-the-art real-time decision support systems and storm-scale numerical weather prediction models, which are then demonstrated to front-line forecasters in operational settings. These strategic partnerships with NWS forecasters, local experts, and strategic planners together with NSSL's new technologies help to reduce the threat and impact of hazardous weather, and thus enable NOAA to better achieve its goal of a Weather-Ready Nation "in which society is prepared for and responds to weather-dependent events."



NSSL is developing several technologies that will enable better forecasts and warnings. NSSL's Warning Decision Support System – Integrated Information (WDSS-II) project, now known as MRMS, contributed to many of the capabilities in the NWS Advanced Weather Interactive Processing System (AWIPS-2). NSSL is the nation's leader in event-driven rainfall estimation and flash flood prediction, based on our historical expertise in radar meteorology, technology, and quality control and in merging data from multiple radars. Future research will include improved support for flash flood forecasts through the MRMS and Flooded Locations And Simulated Hydrographs (FLASH) systems to improve the accuracy, timing, and specificity of flash flood warnings.

WoF scientists at NSSL are world leaders in storm-scale modeling and data assimilation. They have developed ensemble-based numerical prediction techniques that produce reliable probabilistic predictions of thunderstorms and provide the potential to predict even smaller scale phenomena such as tornadoes. NSSL's collaborative work with the operational community is developing an innovative new paradigm for FACETs with the goal to produce better forecasts and warnings. FACETs is a prominent tool in the NWS Science and Technology Roadmap Capstone plans. We will also work with social scientists to investigate how to elicit an optimal response from the public and weather sensitive industries.

Challenges

Translating the basic science associated with improving understanding of high impact weather processes into better forecast and warning technologies requires an ongoing effort with the SPC, EMC, the NWS Forecast Offices, Center Weather Service Units, River Forecast Centers, and other collaborators to consider how new understandings might improve forecast and warning operations. For example, NSSL is currently running storm-scale numerical weather prediction models every day, with an intense focus occurring every spring in the HWT Spring Forecast Experiments. These 'quasi-operational' frameworks allow NSSL scientists and our operational partners in the SPC, the NOAA Earth System Research Laboratory (ESRL), the UK Meteorological Office and elsewhere to evaluate how useful new observations and state-of-the-art research techniques are in an operational setting. However, shortcomings with model forecasts for many events are typically traced back either to errors in the models themselves or to shortcomings in the atmospheric parameters the model uses.

Overcoming the inadequacy of observations is a significant challenge facing the development and evaluation of any improved forecasting technology. New operational observational platforms are coming on line, such as the GOES-R with its rapid sample ABI and Lightning Mapper, and our new forecasting technologies must take advantage of these observations.

Extracting information relevant to forecasters from an increasingly large and diverse set of observation systems is a major challenge. The development and evaluation of a storm-scale EPS is a significant, but extremely valuable, challenge. An EPS can help combine multiple data sources to extract the severe weather potential of storms. These systems also help estimate the uncertainty in the forecast that is due to uncertainties in the model physics or in the atmospheric analysis that drives the forecast. However, there are many challenges with constructing an EPS and understanding how to best utilize the output so that a concise statement about the forecast can be made.

Water will continue to become a central topic to the scientific community given climate projections of an accelerated hydrologic cycle resulting in more heavy precipitation events and longer droughts. At longer time scales, freshwater resources management and supply forecasting will grow in importance, attracting the need for advanced hydrometeorological observational, modeling, and forecast product capabilities that NSSL can provide.

It is critical that the customers of hazardous weather forecasts and warnings take appropriate actions, and different groups of the general population respond to current NWS forecasts and warnings in very different ways. Social science research will be required to develop improved messaging and delivery mechanisms for NWS watches and warnings in order to take advantage of today's (and tomorrow's) technology. The NWS needs more reliable methods to estimate and communicate uncertainty for hazardous events. These improvements will occur only with dedicated collaborations among NSSL's scientists, NWS operational staff, and social science researchers to improve the technology and to evaluate the design of new tools that improve the reception of forecasts and warnings by different sectors of the customer base.

Objectives

An important general objective for us is to develop and implement a storm-scale EPS using advanced data assimilation and improved model physics to predict the hazards of individual thunderstorms, including the storm's potential to produce significant lightning (GSC #1 and 4). The goal is to demonstrate the value of a sub-kilometer resolution numerical prediction system to forecast thunderstorm hazards for the public and aviation. Accomplishing this goal will require improving our knowledge of atmospheric processes at work at these scales, improving their representation in numerical models, and utilizing new observational datasets for more accurate specification of the atmospheric state. It will also require the continued advancement of data assimilation techniques as well as tools to diagnose the uncertainty of the probabilistic location, timing, and severity of the hazardous weather event from the EPS.

New observations will be required in order to improve the accuracy and timeliness of future forecasts and warnings. We will conduct basic research using OSSEs to evaluate the degree to which new instruments, different network configurations, denser observations, and other observational parameters improve forecasts and warnings (GSC #2). This work will contribute to the discussion of future observation systems within NOAA.

NSSL intends to achieve the proven capability to reliably predict flash flooding for both urban and complex landscapes several hours in advance, providing a probabilistic hydrologic prediction with much longer lead time and more accurate prediction than current systems (GSC #3). We will improve hydrometeorological observations including radar-based snow-water equivalent estimates, multi-sensor Quantitative Precipitation Estimation (QPE) in WSR-88D sparse regions using gap-filling radars, and new remote sensing methods to measure streamflow, subsurface water, soil moisture, surface water inundation, evapotranspiration, and water table depth. We will make advances in ensemble hydrologic modeling that incorporate NSSL nowcasts and ensemble Quantitative Precipitation Forecasts (QPFs) that can be coupled to a landslide prediction system and surface inundation forecasts. We will develop and test forecast products that are probabilistic and communicate anticipated magnitude and uncertainty of specific events, including winter weather and flash flood events, and evaluate them in the HWT and with our expanding database of flash flood events.

NSSL endeavors to lead the nation in applied warning science advancement, and capitalize on opportunities provided through the convective-scale observation and modeling advances described above. We will integrate the existing MRMS system, advanced observation systems, social science, and other innovations into future development of FACETs, a next-generation hazardous weather watch/warning paradigm. FACETs will be built on the concept of a continuous stream of high-resolution, probabilistic hazard information for high-impact weather, with the goal of reducing tornado and other severe weather warning false alarms by at least 30%. Furthermore, we plan to provide the public with probabilistic, risk-based information to replace current "binary" yes/no warning areas (GSC # 6). Through relationships with the NWS and private sector partners, NSSL will explore new avenues of personalized, actionable hazardous weather information using 21st century communication technologies. We will also establish an efficient mechanism to identify which NWS severe convective forecasting needs and gaps are routinely identified and addressed, and develop a comprehensive system that uses the HWT year-round to fashion NSSL research into NWS operations.

NSSL will use the HWT, which provides a critical interface between NSSL scientists and NWS forecasters, to introduce forecasters to new concepts and products such as WoF, FACETs, the GOES-R lightning mapper, and other next-generation observation and forecast systems (GSC #1, 4, 5). We will continue to engage NWS forecasters to help evaluate output so that a close alignment is maintained with the operational community. By including hydrological aspects, the HWT will also be used to demonstrate and evaluate improved QPE and flash flooding forecasts and warnings (GSC #3).

6. Radar Technology and Products

NSSL has a long history of developing radar technology and products for operational use within the National Weather Service and the private sector. NSSL obtained a military surplus radar in the early 1970's and modified it to perform Doppler processing. The Norman Radar Observatory was used to track the Union City tornado and led to the discovery of the mesocyclone and tornadic vortex signature. The Norman Radar Observatory was later used to demonstrate the operational benefit that Doppler radar data would provide to NWS forecasters when issuing public warnings of severe and hazardous weather. These demonstrations led to the development and deployment of the Weather Surveillance Radar - 1988 Doppler (WSR-88D). Another military surplus radar was obtained and modified for research and development activities at NSSL's Cimarron facilities. NSSL was a pioneer in the development of dual polarization and the Cimarron radar was modified to provide real-time dual polarization data. Demonstrations of dual polarization advantages and enhancements of capability in operations led to the deployment of the dual polarization upgrade to the WSR-88D that was completed in 2013.

Likewise, NSSL received a Navy surplus phased array radar and has since used it to demonstrate the performance benefits that phased array radar could provide to improve NWS warning capabilities. The National Weather Radar Testbed / Phased Array Radar (NWRT/PAR) was installed at NSSL in 2003 as one of the preliminary steps of the Multi-function Phased Array Radar (MPAR) program. There are currently a multitude of radar networks deployed across the nation to support the radar observation needs of several federal agencies (DOT/FAA, DOC/NOAA, DOD, DHS) to perform the aircraft and weather surveillance functions. The MPAR program is an ambitious initiative to combine the operational radar functions of the various agencies into a single radar system delivering the required performance for aircraft and weather surveillance. The FAA and NOAA have collaboratively conducted several research and development activities and funded several industry studies.

This radar research also makes significant contributions to the success of other NSSL programs and projects via improved observation capabilities and increased understanding of meteorological processes associated with severe convective storms. NSSL works to transfer meteorological and engineering applications, techniques and new scientific understanding to NOAA's National Weather Service (NWS) and other government, public and private organizations in support of NOAA's objective for "a more productive and efficient economy through environmental information relevant to key sectors."

Challenges

NSSL supports the WSR-88D by performing research to improve data quality, enhance signal processing techniques, and develop better radar products for use in forecast and warning operations. The recent addition of dual polarization to the WSR-88D will necessitate the continued research and development to provide operational benefits throughout its remaining life cycle. Exploitation of dual polarization will lead to new products (such as tornado debris signatures, hydrometeor classification), improved quantifiable precipitation estimates (through differential reflectivity, differential phase, and/or specific differential attenuation), and will allow new understanding of the relationships between observed microphysical signatures and storm thermodynamic, dynamic, and kinematic structure and evolution. The added information has the potential to improve numerical weather prediction models through the development of new data assimilation techniques.

NSSL must balance the need to support the current operational weather radar (WSR-88D) with the need to develop new technology (phased array radar) that will eventually replace the current radar to meet evolving performance objectives and support future observational requirements.

The MPAR program has identified three technical challenges that must be overcome in order to make MPAR a technically and economically viable radar technology for the future. There has been an ongoing collaboration between NOAA and the FAA for over 10 years to perform research and related concept and technology development. These activities have concentrated on dual polarization capability for phased array radars and means to meet the simultaneous multi-function mission performance requirements while reducing the cost of phased array radar technologies.

Objectives

NSSL is the primary NOAA organization that conducts research and development aimed at exploring and advancing weather radar science, technology, and radar products. The radar program has a long and glorious history of technology transfer, and NSSL will continue to improve the value of the WSR-88D by continuously transferring research concepts and techniques to operational use. The improved signal processing techniques and radar algorithms/products will provide NWS forecasters with enhanced tools needed for their evolving forecast and warning operations.

NSSL must continue work to improve the value of the national network of weather surveillance radars by effectively and continuously transferring dual-polarization radar research into operations. This includes developing advanced techniques to classify surface precipitation type, hail size, and quantify precipitation accumulation for both warm- and cold-seasons. In addition to precipitation type, recent work also has demonstrated that dual-polarization radar signatures provide a wealth of information on thermodynamic and microphysical processes. NSSL therefore needs to work to develop a better understanding of the relationship between these dual-polarization signatures and storm microphysical, thermodynamic, and dynamic structure. With expertise in both radar and numerical modeling, NSSL is also well positioned to advance and continue to grow techniques to assimilate dual-polarization radar data into numerical models.

NSSL should also be at the forefront of the development of new, cutting edge radar systems to meet emerging performance requirements driven by WoF and other Weather Ready Nation objectives. The MPAR program has exploited the NWRT/PAR over the last decade and has engaged in small-scale dual polarization phased array radar technology demonstrations to perform critical pathfinding activities. A major initiative is to replace the technically obsolete NWRT/PAR with a modern, dual polarized, active phased array radar (an Advanced Technology Demonstrator, or ATD) to continue pathfinding of the technologies and capabilities that would be employed by MPAR. The ability to simultaneously track aircraft and perform polarimetric weather surveillance is one such pathfinding capability that will require the ATD. Other radar technologies (such as low-power gap-filling radar networks) should also be investigated for the potential to improve NWS operations.

One of the key performance objectives of the MPAR program is to provide rapid-update, tailored scans to better resolve the evolution of storm features. The development of new phased array radar technologies must also be followed by the investigation and evaluation of these new radar capabilities to improve the warning decision process. Previous work has demonstrated the potential to improve tornado warning lead times of EF0 and EF1 tornadoes sampled by the NWRT/PAR as evaluated by NWS forecasters and future work may determine the optimal update rate and how the forecaster may best use this information.

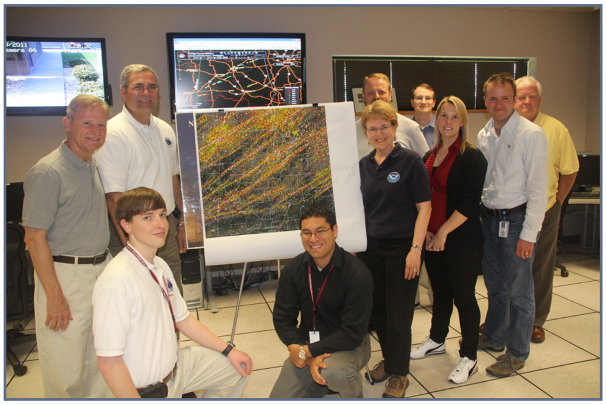
7. Engagement and Collaborations

NSSL is part of a collaborative community dedicated to understanding, detecting, and forecasting the atmosphere and the severe weather it produces. Collaboration minimizes duplication of effort, broadens horizons, inspires new perspectives and initiatives, and promotes efficient and relevant research and development and migration to operations.

We are fortunate to be co-located with the NOAA Storm Prediction Center, NOAA NWS Forecast Office – Norman OK, the Warning Decision Training Branch, and the Radar Operations Center, making close partnerships possible. The University of Oklahoma and its School of Meteorology also provides rich opportunities to collaborate and advance severe weather science.

Challenges

Collaborations are a challenge to establish and maintain because they take time and effort that is often hard to quantify and reward, and potential collaborators are sometimes seen as competitors. Travel restrictions limit our foreign outreach and collaborations. Nonetheless, NSSL has a vibrant history of healthy national and international collaborations and will endeavor to build further upon these relationships.



Objectives

The NWS has the responsibility to provide weather, water, and climate information to protect life and property, and enhance the national economy. NSSL will continue close partnerships with the NWS to support a Weather-Ready Nation society that is prepared for and responds to weather-dependent events. This will require creative and innovative thinking, being willing to embrace change, and a commitment to achieving success that benefits all Americans. We will engage with users and core partners to improve knowledge of the needs of the end users, and how weather and water information can be applied to create value and benefit that will help them manage risk. NSSL will continue to work towards a nationally-consistent real-time weather picture, allowing NWS forecasters to better maintain situational awareness, focus on scientific interpretation, and monitor forecast challenges. We will also continue to explore and develop integrated observations, high-resolution computer models, quantifiable forecast uncertainty, and advanced technologies to enable more accurate and timely warnings.

We will leverage external funding sources to afford NSSL the flexibility to rapidly shift priorities through partnerships, yet while staying true to our core mission and keeping external funding to a manageable fraction of our base funding levels. We will establish an active visiting scientist program to support greater cross-fertilization of NSSL expertise with the broader scientific community. NSSL will strengthen conduits for new talent to enter and improve the laboratory through support for and mentoring of students, post-docs and early career scientists. NSSL will seek support and involvement from non-traditional partners and engage with peers, colleagues around the world in other disciplines, decision-makers and the public at large.

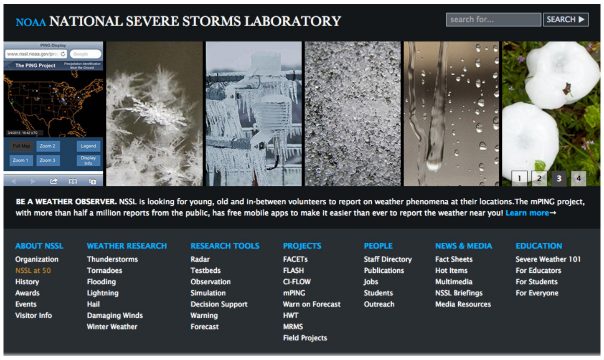
Scientific conferences and meetings of professional societies provide critical opportunities to engage with peers, colleagues, and stakeholders to share knowledge and information. NSSL will continue support attendance at these meetings, and encourage service of its professional staff as editors and reviewers, conference chairpersons and session chairs, and on national advisory committees. NSSL will also maintain strong partner relations with universities through Sea Grant and Cooperative Institutes.

NSSL will maintain a healthy relationship with the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) and the other members of the National Weather Center in Norman

(SPC, Radar Operations Center, NWSFO-Norman, Weather Decision Training Branch), and continue to support and expand NOAA HWT experiments. NSSL will enhance existing collaborations as formalized in Memoranda of Agreements NSSL has with the UK Meteorological Office, the National Center for Atmospheric Science, and other international organizations conducting R&D well aligned with the NSSL mission. We will also continue to utilize and strengthen our existing informal collaborative efforts with other NOAA research laboratories such as the Atmospheric and Oceanic Meteorological Laboratory (AOML), the Global Systems Division and Physical Sciences Division of ESRL, our formal coordination efforts with other federal agencies, notably the Federal Aviation Administration (FAA) and the Department of Defense (DOD), and joint research studies with universities.

8. NSSL Communications and Outreach

NSSL is part of an international community of research laboratories, educators, environmental decision-makers, engineers, and weather and climate forecasters. To support NSSL's mission, it is critical to show how society benefits from NSSL's research to a diverse audience that includes stakeholders, policy-setters, and an ever expanding public.



BE A WEATHER OBSERVER. NSSL is looking for young, old and in-between volunteers to report on weather phenomena at their locations.The mPING project, with more than half a million reports from the public, has free mobile apps to make it easier than ever to report the weather near you! Learn more→

NSSL began a regular print newsletter in 1995 called "NSSL Briefings," to inform colleagues and leadership about current research. As technology evolved, the newsletter transitioned to an online blog in 2007, "NSSL Briefings Online," where the latest NSSL news can be found and shared. Through email campaigns, regular NSSL science updates are shared with hundreds of subscribers. NSSL embraced social media in 2009, just in time for the VORTEX-2 field project with Facebook and Twitter, and now have more than 68K followers. Our arsenal of educational videos on YouTube creatively teaches NSSL science, logging more than 30,000 views. We launched an updated website in 2012, designed to make learning about NSSL easier for people with no knowledge of acronyms or project titles. Part of this update was our "Severe Weather 101" educational pages, which remain the most popular pages on our site.

Challenges

Communicating science in useful and meaningful ways for both science and society remains a challenge in a paradigm that is constantly changing. Messages about NSSL research to reach a broad range of audiences requires different mechanisms at different times, along with perseverance to "get the science right." Social media is a relatively new beast - we know quite a bit about what the current social media landscape looks like, but not very much about how it works, or how it serves our agenda.

Objectives

Our virtual presence must be as vibrant and dynamic as our body of research to make our science accessible to the general public with no background in meteorology. NSSL will use "plain language" and innovative technologies and platforms to build interest in atmospheric science, foster community dialogue, and to educate citizens and students about severe weather and the work at NSSL.

9. Workforce Management

At the heart of NSSL operations is the creative work of scientists, engineers, software developers, technicians, managers, and administrative staff. Only by investing in this stock of intellectual capital can NSSL achieve its vision to be our world's leader in basic and applied research on severe convective storms to support an informed society that is resilient to high impact weather.

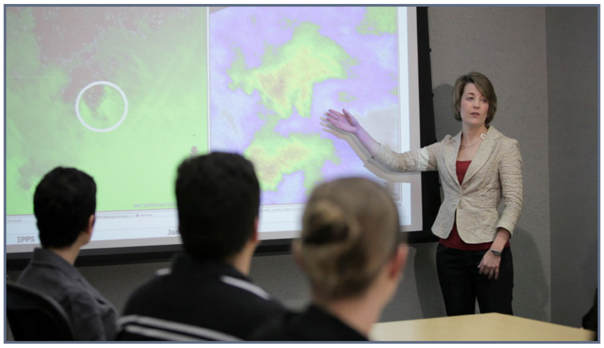
NSSL management and staff have established a joint venture to assure an intellectually stimulating work environment that challenges and rewards people, and that fosters equality among all employees. This undertaking began with the collection of anonymous survey responses from "Vital Signs" in 2012 and subsequent efforts by the NSSL Staff Development Working Group, composed of both federal and CIMMS staff, purposed to identify the lab's strengths and weaknesses, and the ability of management to effectively recruit, retain, and develop the most talented people.

Our vision is that NSSL should be a place where people want to work because they understand that they are making important impacts for NOAA, they are contributing to the prestige of NSSL, they are recognized for their contributions, and they are empowered to make positive change with management support.

Challenges

Due to a combination of budgetary pressures, a NOAA-wide hiring freeze lasting until February 2014, and the lack of an effective non-competitive promotion process for several years, this has been a huge challenge for management. Also, as recognized in the 2009 NSSL Laboratory Review recommendations by the Review Panel, the impending retirement of senior staff (41% being eligible to retire within just five years), the lack of sufficient diversity (e.g., average age of our federal workforce is 58 and insufficient gender, racial, and ethnic diversity), and other issues presented additional difficulties.

Objectives



NSSL will develop a hiring strategy to replace our aging workforce through the attraction and retention of preeminent scientists, engineers, and technical staff. To evolve our workforce capability over time, we will cultivate both existing and new sources of talent by workshops, professional courses, internal training, mentoring, and job shadowing. NSSL will provide "Onboarding" programs for new employees and conducting "stay interviews" with employees to solicit their opinions about what they want out of their jobs and what is missing in the NSSL workplace. NSSL will also encourage staff to create Individual Development Plans for themselves to assist their supervisors in supporting their needs for training and attaining personal career development goals.

NSSL will increase collaboration with academia and create opportunities to support undergraduate and graduate students and foster their interest in NOAA -related work. We will continue to use the NOAA Hollings and Research Education for Undergraduates programs, and develop a new summer intern program for aspiring senior undergraduates. NSSL will also participate in NOAA's Educational Partnership Program Graduate Research and Training Program that gives graduate students from under-represented communities experiential opportunities at NSSL. Management will encourage and reward employees who work with student interns, including those from under-represented groups, allowing for hands-on experience with researchers. NSSL will continue strong support of the University of Oklahoma School of Meteorology by offering graduate student stipends, and increase use of postdoctoral programs at CIMMS and the National Research Council.

NSSL management will provide performance evaluation training to all team leads and supervisors to help them provide meaningful and helpful feedback to employees. NSSL managers and supervisors will use consistent performance attributes, and will evaluate employee performance based solely on an individual's performance plan, in accordance with the merit principles provided by the Commerce Alternate Personnel System.

NSSL will work to improve NSSL-CIMMS interactions. In part, this mirrors the need for consistent employee performance evaluations, though in this case NSSL federal leaders can only provide feedback to CIMMS management about the performance of their employees. NSSL will work to clarify the evaluation process to CIMMS employees, establish a rotating NSSL-CIMMS liaison position to enhance communications about this and other areas of concern, and provide more opportunities for CIMMS employee professional development within legal constraints. NSSL and CIMMS will also coordinate to establish joint "celebrations" on a regular basis to recognize outstanding contributions from CIMMS employees and to present awards.

Useful acronyms

AWIPS – Automatic Weather Interactive Processing System
CI – Cooperative Institute
CIMMS – Cooperative Institute for Mesoscale Meteorological Studies
CLAMPS – Collaborative Lower Atmosphere Mobile Profiling System
ESRL – Earth System Research Laboratory
EPS – Ensemble Prediction Systems
FAA – Federal Aviation Administration
FACETs – Forecasting a Continuum of Environmental Threats
FLASH – Flooded Locations and Simulated Hydrographs
GLM – Geosynchronous Lightning Mapper
GSC – Grand Scientific Challenge
HWT – Hazardous Weather Testbed
IHOP – International H2O Project
MCS – Mesoscale Convective System
MPAR – Multi-function Phased Array Radar
MPAR ATD – Multi-function Phased Array Radar Advanced Technology Demonstrator
MRMS – Multiple Radar Multiple Sensor system
NWP – Numerical Weather Prediction
NWRT/PAR – National Weather Radar Testbed Phased Array Radar
NWS – National Weather Service
OSSE – Observing System Simulation Experiment
PECAN – Plains Elevated Convection At Night
SPC – Storm Prediction Center
UAS – Unmanned Aerial System
UAV – Unmanned Aerial Vehicle
VORTEX – Verification of the Origins of Rotation in Tornadoes Experiment
VORTEX2 – Verification of the Origins of Rotation in Tornadoes Experiment 2009-2010
WDSS-II – Warning Decision Support System – Integrated Information
WoF – Warn-on-Forecast
WSR-88D – Weather Surveillance Radar-1988 Doppler radar