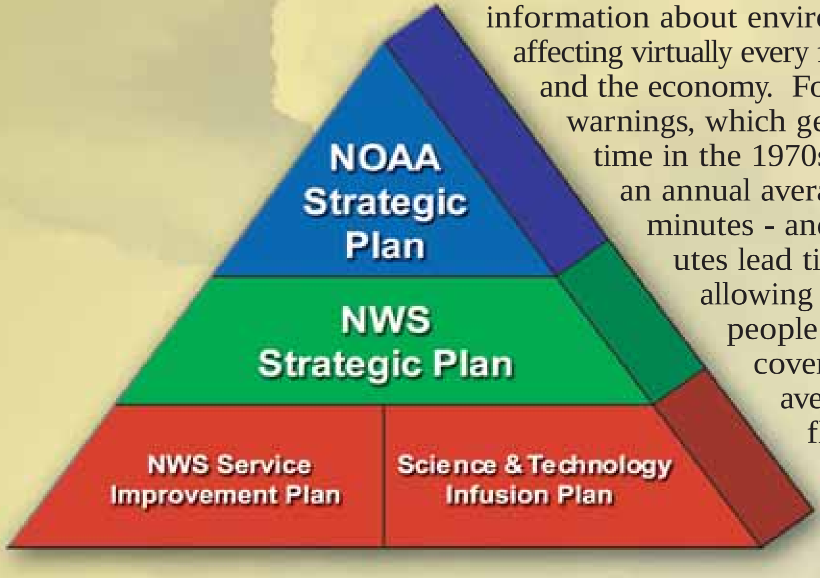
NOAA's National Weather Service

Science and Technology Infusion Plan

2004

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NOAA's National Weather Service

Preface



Over the last decade, infusing new science and technology (S&T) into National Oceanic and Atmospheric Administration (NOAA) operations has significantly improved weather, water, and climate forecast and warning lead times, accuracy, and overall National Weather Service (NWS) product and service quality. Deployment of the Weather Surveillance Radar-1988 Doppler (WSR-88D), Advanced Weather Interactive Processing System (AWIPS), Automated Surface Observing System (ASOS), geostationary- and polar-orbiting environmental satellites, advanced high-performance computing, and data assimilation and modeling systems, coupled with restructuring field operations and forecaster training, have enabled major improvements in critical information about environmental conditions affecting virtually every facet of people's lives and the economy. For example, tornado warnings, which generally had no lead time in the 1970s, are now issued with an annual average lead time of 12 minutes - and as much as 30 minutes lead time in some cases - allowing precious time for people to seek protective cover. Similarly, the annual average lead time for flash flood warnings has increased from 8 minutes to nearly 50 minutes - giving people approximately six times the period of alert they once had. Hurricane forecasts have been extended from three to five days providing emergency managers and urban-planners two extra days to plan for orderly evacuations and disaster preparedness activities. New temperature and precipitation outlooks extending to two weeks, a month, and a season give resource managers additional information they can use to make better decisions.

Over the next decade, continued improvements in forecast accuracy and other NWS products and services are required. Emergency managers need hours, not minutes, of lead time to prepare the public for hazardous weather and water conditions; and businesses and natural resource managers need days, not hours, advance notice to prepare for environmental changes that will affect their bottom line and threaten precious resources. To meet these improvement challenges and sustain service excellence to the Nation, the NWS must stay near the leading-edge of S&T supporting its mission. This Science and Technology Infusion Plan (STIP) defines strategies and capability improvements the NWS will pursue to meet operational requirements and exploit scientific opportunities. The plan emerged from a national workshop attended by experts from academia, the private sector, NOAA, and other agencies. It is linked to the NWS Service Improvement Plan and other plans all working together toward NWS and NOAA strategic goals. The STIP is a “living” plan, which will respond to changing needs and opportunities, and evolve as necessary to best serve NOAA and the Nation.

Jack Hayes
Director, NWS Office of Science and Technology

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Introduction and Purpose

NOAA's Mission

To understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs

The National Weather Service (NWS) supports the National Oceanic and Atmospheric Administration's (NOAA's) mission by providing weather, water, and climate forecasts and warnings to protect life and property, and enhance the national economy. NWS data and products form a national information database and infrastructure which can be used by other governmental agencies, the private sector, the public, and the global community.

To achieve NOAA's mission, the NOAA[1] and NWS[2] Strategic Plans define four overarching goals:

- ✓ Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management;
- ✓ Understand climate variability and change to enhance society's ability to plan and respond;
- ✓ Serve society's needs for weather and water information; and
- ✓ Support the Nation's commerce with safe, efficient, and environmentally sound transportation.

The purpose of this NWS Science and Technology (S&T) Infusion Plan (STIP) is to define S&T roadmaps supporting these goals and other NOAA priorities, while optimizing return on investment as judged by the socio-economic impact on the Nation. The STIP is a "living" plan and will be revised as key aspects change. This document outlines strategies and capabilities the NWS will pursue to provide the necessary S&T base to make needed performance improvements critical to its mission areas. Further details and plan updates are available on the NWS Office of Science and Technology web site **(www.weather.gov/ost)**.

Strategic Context and Vision

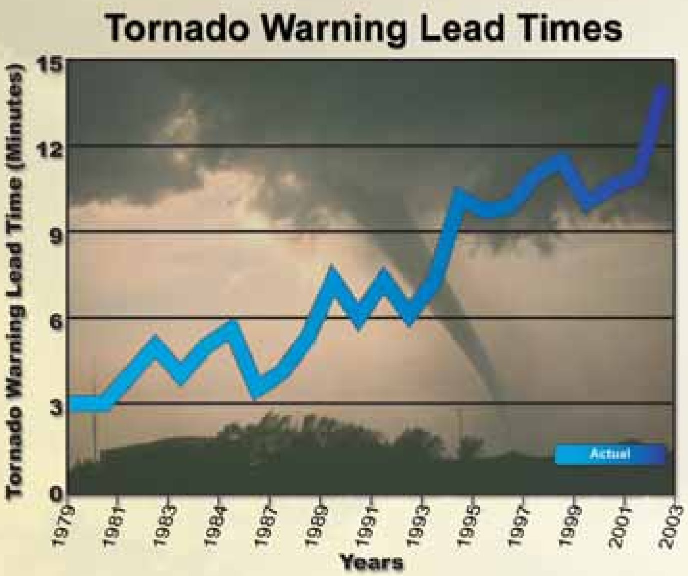
The NOAA Strategic Plan defines four S&T-dependent strategies to reach its goals. The agency uses these strategies as the process steps to collect, produce, deliver, sustain, and improve weather, water, climate, and related environmental information.

- The first step is to **Monitor and Observe** elements that define the Earth environment (space, atmosphere, land-surface, ocean, coastal, and inland water), archive these data, and make them available and accessible to users;
- The second step is to **Assess and Predict** the current and future state (from minutes to months and years) of the Earth environment by transforming observational data into forecast and warning products and information through data assimilation and numerical prediction models. This step also includes sustaining critical information technology (IT) supporting the end-to-end production and provision of NOAA products and services, from information collection to dissemination;
- The third step is to **Engage, Advise**, **and Inform** users of these observations, warnings, forecasts, and other information to promote appropriate responses to changing hazardous and routine environmental conditions; and
- The fourth step is to **Understand and Describe** the Earth system, develop new and improved observational systems, forecast models, and technologies, and demonstrate advances. This step encompasses research and technology advancements and workforce training necessary to support the other three steps in sustaining and improving existing product and service quality. It also includes long-term research aimed at increasing knowledge about the Earth system and anticipating changing social and economic needs that may require new products and services supporting NOAA's mission.

NOAA's Strategies

NOAA uses these strategies as process steps to collect, produce, deliver, sustain, and improve weather, water, climate, and related environmental information.

The quality of NWS products and services has improved over time as S&T has progressed in these four strategic areas. For example, deployments of the Weather Surveillance Radar-1988 Doppler (WSR-88D) network, geostationary- and polar-orbiting satellites, advanced data assimilation techniques and fine-resolution models on high-performance computers, and the Advanced Weather Interactive Processing System (AWIPS) have led to an increase in the yearly national average tornado warning lead time from 3 minutes in 1979 to 12 minutes in 2002, an increase in the yearly national average flash flood warning lead time from 8 minutes in 1987 to 53 minutes in 2002, and a decrease in the yearly average 72-hour hurricane track forecast error from 450 nautical miles in 1970 to 190 nautical miles in 2002.



Infusing new science and technology has improved national average tornado warning lead times (minutes).

Utilizing the Tropical Atmosphere/Ocean (TAO) buoy array in the central Pacific Ocean led to the 1997-1998 El Niño "event of the century" becoming the best monitored and the first ever predicted El Niño on record. Information formatting and dissemination have also improved and expanded - the NWS is in the process of making all of its forecasts accessible over the Internet in digital formats.

Emergency-management and other end-user responses to these improved forecasts and warnings result in lives saved and property damage reduced. For example, in a typical hurricane season, forecasts, warnings, and associated emergency responses save $3 billion.[3] In addition, economic sectors are becoming more sophisticated at using NOAA's environmental information to improve profit margins and environmental resource management. For instance, the energy sector's benefits include annual potential savings of $65 million by using NOAA climate station data.[4]

National implementation of the Advanced Hydrologic Prediction Service (AHPS) - hydrologic service improvements including better flood warnings and water resources forecasts - will contribute approximately $520 million per year in economic benefits to water resources users.[5] And, from 1998-2002, the total theoretical value of weather derivatives - financial contracts based on seasonal average temperatures, degree-days, or precipitation amounts - executed between parties amounted to nearly $12 billion.[6]

El Niños

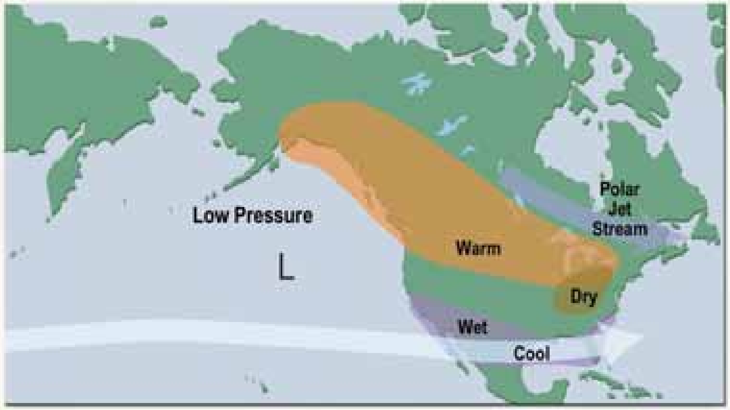
Droughts

Hurricanes

Floods

Despite these advancements, deaths and loss of property and commerce related to hazardous weather and floods still occur. In fact, America's vulnerability to weather and flooding is rising as more of the population moves into areas prone to these hazards and national and global economies become increasingly complex. Approximately 40 percent of Americans, about 100 million people, currently reside along our coasts and in other areas at high risk from natural disasters. On average, hurricanes, tornadoes, and other severe weather events and floods cause $11 billion in damage per year.[7] Furthermore, about one-third of the U.S. economy (about $3 trillion) is weather sensitive.[6] Industries directly affected by weather, including agriculture, construction, energy distribution, and outdoor recreation, account for nearly 10 percent of the gross domestic product.[8] Drought alone is estimated to result in average annual losses of between $6-8 billion across all sectors of the economy.[9]

While even perfect forecasts will not prevent all losses due to weather and floods, further forecast and warning improvements will lessen them. For example, the annual cost of electricity could decrease by at least $1 billion per year across the nation, if the accuracy of temperature forecasts improved by 1 degree Fahrenheit.[10] Better preparation, response, and mitigation could reduce the average annual cost of storm-related disasters by approximately 10 percent or $700 million per year.[11] Improved flash and river flood forecasts would save lives and an estimated $240 million per year in flood losses.[5] Worldwide agriculture benefits from better El Niño forecasts are at least $450 - $550 million per year.[12]



Common position of jet streams, storm tracks, and resulting weather patterns during an El Niño warm episode.

Reflecting this continuing national need for improved forecasts, warnings, and other environmental information, the 2003 NOAA and NWS Strategic Plans, and NWS Service Improvement Plan[13] focus efforts to:

- ✓ Increase the accuracy, lead times, and specificity of environmental forecasts and warnings;
- ✓ Increase the use and effectiveness of environmental information for planning and decision making; and
- ✓ Increase satisfaction with, and benefits from, NOAA environmental information and warning services.

The long-term (2025) S&T vision of the NWS is to provide the Nation with forecasts, warnings, and other environmental data, products, and information with lead times, specificities, and accuracy (*e.g., see pages 8 and 9*) meeting thresholds established by risk managers and by careful socio-economic research. Ultimate socio-economic outcomes include greatly reducing the loss of life and injury from weather and floods; enabling communities to take mitigating actions to save property well in advance of threatening conditions; and alerting economic and natural resource sectors about weather, water, and climate risks with sufficient lead time to avoid or limit impacts. To reach this level of service excellence requires visionary S&T supporting NWS operations.

Needs and Solutions

This section outlines S&T advances the NWS will pursue over the next decade to achieve NOAA strategic goals and move toward the realization of the NWS's long-term vision. To sustain performance improvement, the NWS must drive and keep pace with S&T advances in each of the four interlinked process steps supporting the production and provision of products and services, (1) Monitor and Observe, (2) Assess and Predict, (3) Engage, Advise, and Inform, and (4) Understand and Describe. The following S&T roadmap defines the a) purpose, b) current capability, c) vision, d) needs, e) solution

Monitor and Observe

a) Purpose: Defining the state of the Earth's environment is the first step in producing forecasts and warnings of hazardous weather and water conditions such as tornadoes, severe thunderstorms, flash and river floods, hurricanes, gales, winter storms, wildfire danger, tsunamis, and solar magnetic storms. Observations of temperature, wind, pressure, moisture, precipitation, and other parameters also are used to initialize complex data assimilation and modeling systems, produce real-time analyses and predictions ather, water, and climate conditions. vations also are fundamental to improving derstanding of the Earth's environment se they provide the geophysical data to models and forecasts, monitor and analyze ility and trends in weather and climate, and understand physical processes governing arth system.

urrent Capability: The NWS obtains ervations of Earth-system environmental ments over a range of spatial and temporal ales by using NOAA observational ystems and leveraging partner and ternational systems. These systems are ivided into four interrelated, but distinct ategories: space, atmosphere, land-surface d hydrology, and ocean observations.

Space observational systems measure incoming solar and outgoing terrestrial radiation to quantify the Earth's energy budget. The NWS uses surface- and satellite-based measurements to measure radiative and particle energy emanating from the sun. The most dramatic of these events are solar flares and coronal mass ejections. Space and solar sensors also measure changes at the Sun and in the Earth's magnetic field, ionosphere, and magnetosphere.

Atmosphere observational systems measure key atmospheric elements such as moisture, clouds, winds, temperature, pressure, precipitation, volcanic ash and other aerosols, and chemical constituents. These systems characterize key small- and large-scale weather and climate processes essential for predicting the weather and monitoring climate variability and change.

Land-surface and hydrology observational systems monitor the state of the Earth's surface by measuring elements such as precipitation type and amount, including rainfall and snowfall; surface skin temperature; land surface properties such as soil moisture, albedo, vegetation type, and stage of growth; snow depth; and river stage and volumetric rate of flow.

Ocean observational systems monitor the physical condition and processes of the oceans and the Nation's large bays and lakes. Measured elements include water temperature, sea level, wave height, current, salinity and conductivity, and near-ocean atmospheric conditions. Sea ice measurements record iceberg movement and ice concentration.

c) Vision: *Observations when and where needed.* Individual observation systems and networks are:

- ✓ Integrated into an enterprise architecture — providing a cost-effective, high-quality baseline capability of space- and surface-based systems and leveraged partner systems;
- ✓ Adaptable — easily increasing and expanding spatial and temporal data densities, and the number and type of measured elements to meet emerging needs;
- ✓ Extensible — quickly expanding to accommodate new missions; and
- ✓ Stable, continuous, and quality assured — providing consistent and continuous data for weather and climate applications.

d) Needs: Observational advances are essential to improve forecast and warning accuracy, specificities, and lead times. Data quality standards need to be established and followed to reduce analysis error. Higher space and time resolution measurements of critical environmental elements, such as water in all of its phases, are necessary to more properly define key phenomena and processes. Defining key phenomena and processes is especially important in the boundary layers of the atmosphere, oceans, and land, and in other "situationally-sensitive" regions. New measurements of elements such as air chemistry constituents, turbulence, cloud microphysics, and surface fluxes are required to enhance the suite of forecast and warning products. Improved data quality and timeliness with long-term continuity are necessary to improve forecasts and warnings, reduce observational and analysis error, and

> **"Earth observations can better the lives of ordinary people in every land. ... A more systematic, open, and timely sharing of existing Earth observations information would greatly improve responses to natural hazards or disasters. We would gain even more dramatic benefits if we put in place a comprehensive Earth observation system that will give us a complete picture of what is happening on our planet."**
>
> ***Secretary of State Colin Powell***
> *2003 Earth Observation Summit*

ensure a long-term climate record. Finally, the plethora of observational systems and networks need to be integrated into enterprise architectures to improve efficiency, and provide timely data access.

Satellites provide continuous views of the Earth for monitoring and observing weather, water, and climate.

Graphic courtesy of NASA.

e) Solution Strategy: Develop and sustain an integrated observing system that:

✓ Has a dynamic, cost-effective mix of measuring systems within an extensible enterprise architecture; and

✓ Supplies necessary observations to define the Earth system with sufficient resolution and quality.

Particular attention should be focused on improving observations in the Earth's transition zones among the atmosphere, ocean and land.

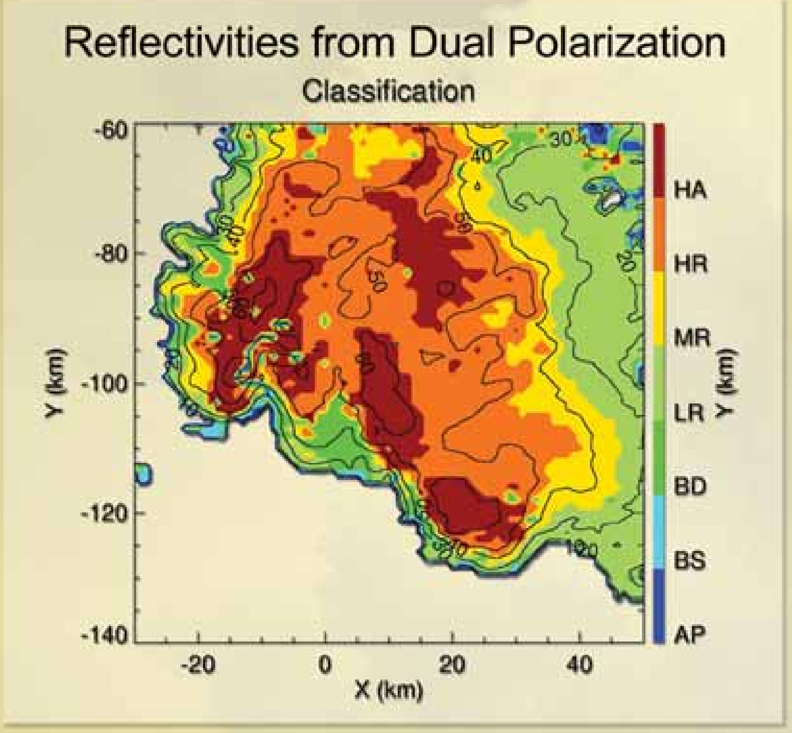
f) Objectives and Capability Improvements: This solution strategy will be implemented over the next decade by improving monitor and observe capabilities (*see Figure 1*) meeting the following objectives:

Objective 1: Increase the temporal, spatial, sensitivity, and energy spectrum resolution of observations to improve the depiction of critical phenomena and processes enabling more accurate and extended lead-time warnings and forecasts. Over the next decade, the NWS will have the benefit of improved observational resolution for a host of elements (*see Figure 1*). For example, one of the most important elements requiring improved resolution, and the objective of many sensor system upgrades, is water vapor. Improved detection of water vapor will be possible with the deployment of sensors on aircraft, expanded utilization of Geo-Positioning Satellite (GPS) signal processing, and with the deployment of the next generation of Geostationary Operational Environmental Satellite (GOES) satellites ("R" series). Improved water vapor observations will support forecast accuracy improvements in flash flood and aviation forecasts. Even with these advances, more resolution is required to fill gaps in the observing system and to detect subtle yet significant environmental processes and phenomena.

Objective 2: Obtain observations of new environmental elements to improve existing and enable new warning and forecast products. Insufficient observation and poor discrimination of critical elements increase forecast error. Over the next decade, NWS will expand access to observational systems to include new elements, as shown in *Figure 1*. For example, the WSR-88D has limited ability to distinguish between different types of weather and non-weather phenomena. With the addition of a dual-polarization capability to the WSR-88D in 2007, the radar will be able to discriminate among elements such as rain, snow, melting snow, and hail. Accurately identifying these weather types will improve precipitation forecasts, which in turn will improve flash flood warnings and river flow and stage forecasts. New observing systems are needed to measure land surface properties such as soil moisture and temperature, atmospheric electrostatic phenomena such as total lightning and static charge, cloud phase (liquid and ice mix), and air quality elements such as ozone, ozone pre-cursors (e.g., NOx and SOx), and particulate matter.

Objective 3: Improve timeliness, data quality, and long-term continuity of observations to reduce analysis and model initialization error; increase forecast accuracy; extend warning lead times; and maintain the climate record. Over the next decade, liness and quality with cquisition systems (*see* ades to the WSR-88D cquisition (ORDA) ;ather snap-shots of ites faster, directly re thunderstorm ng lead times.

Data quality is a key ement for forecasts, ally beyond three days, n small observational in model initial tions can grow into forecast errors. Data / is degraded when tainties exist in on, time, intensity of omena, or when obser- s do not define all onmental elements. adiosonde Program ng been a mainstay for ing atmospheric wind, rature, humidity, and re data. However, an nt problem of this n has been sensor on uncertainty, and ng wind speed error, sensor drifts away from its launch point. Beginning in 2005, the Radiosonde Replacement System (RRS) will address this issue by employing the Geo-Positioning System (GPS) to accurately determine the radiosonde's position during its ascent, thereby reducing position uncertainty and wind error, especially near the jet stream. This will directly improve both regional and global forecasts.



Reflectivities from dual polarization radar, demonstrating the enhanced ability to classify weather types. Color contours denote various phenomena: HA - hail, HR - heavy rain, MR - moderate rain, LR - light rain, BD - big rain drops, BS - birds and insects, AP - anomalous propagation.

Objective 4: Integrate multi-purpose observing systems and networks within an extensible enterprise architecture to meet cross-functional observational requirements cost-effectively and to provide more timely data access. NOAA is currently assessing its observing systems to ensure that they are optimized to reach their full potential. In support of this activity, an enterprise architecture is being developed to evaluate new requirements and assure new observing systems which:

- ✓ Provide the maximum value to NOAA;
- ✓ Build on current capabilities; and
- ✓ Operate efficiently within the NOAA enterprise architecture.

Examples of multi-purpose observing systems that will meet these objectives over the next decade are shown in *Figure 1*.

Assess and Predict

a) Purpose: Assessing and predicting weather, river, lake, ocean, space, and climate conditions is the heart of the forecast and warning production process. This activity transforms raw and processed observational data into many types of forecast and warning products, including those for severe weather, rain, winter storms, floods, temperature, ocean currents, and drought. These products are made available to NOAA partners and users such as resource managers, the commercial weather sector, the media, and the public - not only to reduce risk, but to take advantage of weather, water, and climate conditions. This step also includes sustaining critical Information Technology (IT) to support the entire end-to-en forecast and warning production process from i mation collection to dissemination.

b) Current Capability: Forecasts of Earth-sys environmental elements are produced for a rang spatial and temporal scales with three S&T capabil data assimilation and modeling, forecast preparati applications, and IT. The NWS uses data assimi tion and computer modeling systems to analyze observations; initialize and run numerical model process output for global, regional, hydrologic, oceanic, specialized - e.g., air quality - and probabil prediction. Diagnostic and statistical algorithms, decision assistance tools, and other forecast prepar applications help forecasters transform observatio raw model output, and other information into fore and warning products in textual, graphical, gridde and other formats. Information Technology sup ports the entire enterprise and consists of centr high performance and interactive computing syst AWIPS, and a telecommunications architecture.

c) Vision: *Integrated probabilistic environmental forecasts and information.* A prediction capability that is:

- ✓ Based on a common "Earth-system" model with coupled atmospheric, land, hydrologic, oceanic, and cryospheric components providing accurate weather, water, and climate prediction products;
- ✓ The basis for integrated environmental forecasts that span minutes to months and seasons, and new types of forecast products such as advanced air quality, water quality, coastal erosion, fish stock, and harmful algal bloom forecasts;
- ✓ Inclusive of advanced forecast preparation applications to support gridded forecast and warning product quality and preparation efficiency;

Needs and Solutions

d) Needs: Advanced data assimilation techniques are needed to improve the quality of analyses and model initialization, and to maximize the value of existing and new observational data sets. Better representation of cloud processes, topographic effects,
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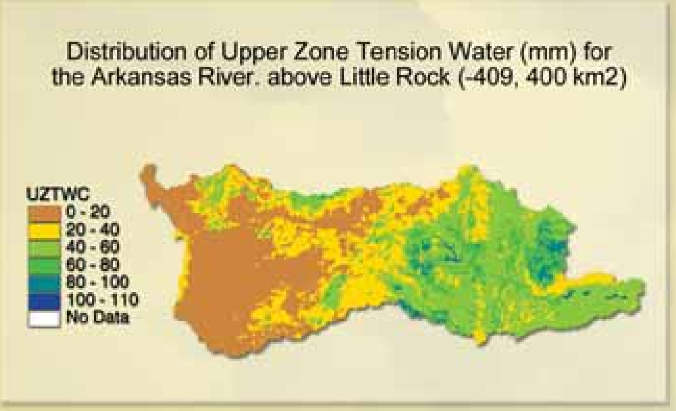
capabilities - are critical to support observations, data assimilation and modeling systems, forecast applications and product preparation tools, data visualization, communications, and dissemination systems.

e) Solution Strategy: Develop and sustain an integrated environmental prediction capability consisting of forecast and warning applications and tools built on a framework of dynamic, probabilistic, and other types of models. This will involve:

- ✓ Partnering in the development and improvement of community data assimilation and modeling systems;
- ✓ Developing and fully exploiting ensemble modeling systems, which optimally combine model resolution, the number of ensemble members, and model diversity, to produce probabilistic forecast guidance and forecast uncertainty measures of sufficient quality to support issuance of extended watch, warning, and forecast products;
- ✓ Developing improved objective interpretation and assessment of model output and forecasts;
- ✓ Developing forecast and warning applications, decision-assistance, and other tools within an interactive gridded forecast preparation architecture; and
- ✓ Developing and sustaining a reliable enterprise IT architecture capable of moving and processing large volumes of data with increased throughput speed to meet accuracy and timeliness demands for critical forecast and warning decisions.



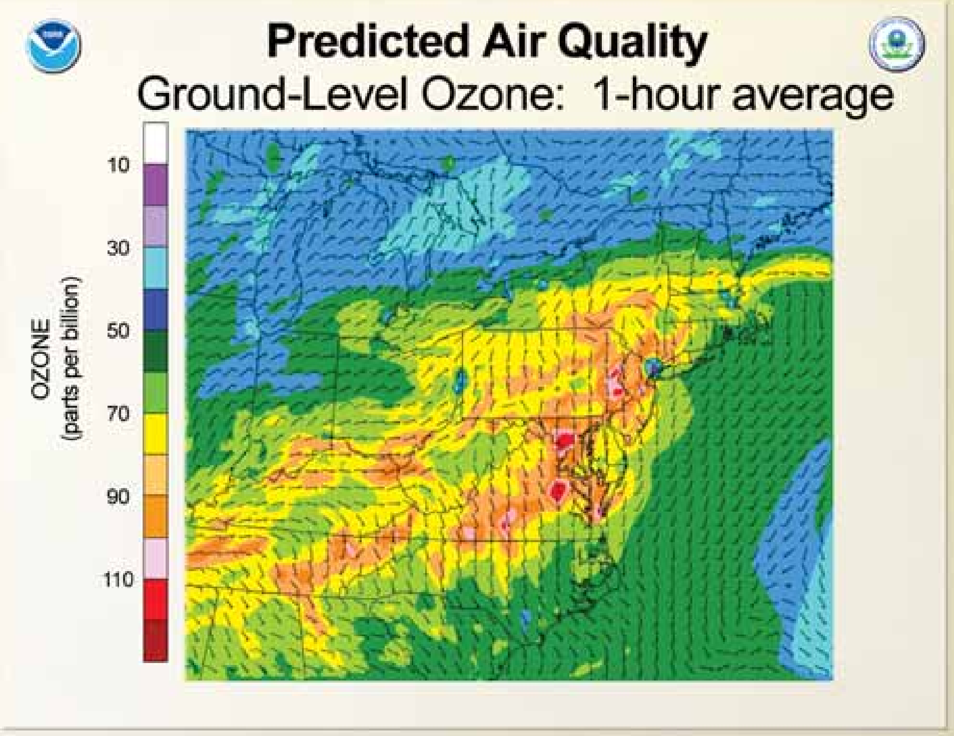
Simulated distribution of upper zone tension water (mm) for the Arkansas River drainage area above Little Rock. New science and technology is used to advance the ability of hydrologic models to meet diverse customer needs for flood warnings and water resource forecasts.

f) Objectives and Capability Improvements: This solution strategy will be implemented over the next decade by improving assess and predict capabilities (*see Figure 2*) meeting the following objectives:

Objective 1: Advance data assimilation techniques to improve model initial condition accuracy. Before a model can produce accurate predictions of the weather, ocean conditions, or some other future state of the Earth system, it must have accurate analyses of current conditions. Over the next decade, there will be a 10,000 fold increase in the amount of observational data available to improve model initial conditions as next generation satellites, radar technology, and other new sensor suites produce more frequent, higher spatial resolution, and new observations of the Earth system. With partners at the Joint Center for Satellite Data Assimilation and elsewhere, the NWS (*see Figure 2*) will develop algorithms to incorporate these new observations into advanced coupled air-ocean-land and four-dimensional data assimilation systems.

Objective 2: Improve and couple numerical modeling systems to adequately simulate weather, air quality, water, climate and other geophysical phenomena in common modeling systems. Over the next decade (*e.g., see Figure 2*), the NWS will implement advanced atmosphere, ocean and Great Lake prediction models, distributed hydrological models, and new models for airquality. Increasingly, these models will be based on common modeling architectures, which will be used by other operational agencies and the research community, enabling new physics algorithms and other research advances to be put into operations more quickly.

For example, the Weather Research and Forecast (WRF) common modeling system will include multiple dynamical cores and advanced physics, and will be able to be used at high spatial and temporal resolution or in ensemble mode. The WRF will become the basis for advanced hurricane predictions and other applications such as air quality prediction. The NWS also will be a partner in developing and implementing the Earth System Modeling Framework (ESMF), which will set the stage for new models that increasingly couple weather, water, and climate, and other Earth-state predictions in common Earth Modeling Systems.



Objective 3: Improve probabilistic prediction systems to quantify forecast uncertainty. Over the next decade (*see Figure 2*), the NWS will continue to establish and advance ensemble model prediction systems such as the Short Range Ensemble Forecast (SREF) and Global Ensemble to provide the basis for probabilistic forecasts and quantifying forecast uncertainty. Increasingly, these systems will be run at higher spatial and temporal resolutions and include more model members with different initial conditions, dynamics, and physics. New model output statistical techniques also will be developed and used to reduce model biases and further improve the quality of model output in capturing forecast variability.

Objective 4: Improve gridded forecast preparation applications to increase forecast and warning lead times, accuracy, location specificity, and enhance product formats. Over the next decade (*see Figure 2*), the NWS will advance automated monitoring systems - e.g., the Flash Flood Monitoring and Prediction (FFMP) application - into integrated warning and forecast monitoring and decision-support systems. Applications that incorporate new science and techniques, which interpret and assess model output and forecasts, also will be implemented for more efficient and accurate preparation of surface, three-dimensional, and eventually four-dimensional digital forecast grids.

Objective 5: Stay close to the leading edge of IT to increase system utility and functionality, and customer satisfaction. Over the next decade (*see Figure 2*), NWS will improve the performance, adaptability, and security of its IT systems. For example, AWIPS hardware supporting local forecasts and warnings will be refreshed every three years. The capacity of high performance central computing will be increased 80 fold to address numerical prediction and other requirements. Hardware, software and communication architectures will evolve to take advantage of technological advances and converge to emerging enterprise standards. Advances in the Internet and computational applications, such as grid computing, will continue to be leveraged and applied toward the NWS mission.

AWIPS Workstation

Engage, Advise, and Inform

a) Purpose: Engaging, advising, and informing people about warnings, forecasts, and other environmental information, enables them to take appropriate actions when hazards and other risks threaten. In addition to disseminating and otherwise making information available, other important components of engaging, advising, and informing are educational and community outreach activities, which explain the content of warnings, forecasts, other information, and safe

private customers employing various technologies to reach the maximum number of people. Hazardous weather and water forecasts, warnings, and other information are delivered as quickly as possible using "push" and "pull" dissemination technologies, which respectively send information and allow information to be retrieved.

Push (send) capabilities distribute, scheduled and non-scheduled warnings, forecasts, and information by a pre-determined priority. Warnings are given the highest priority. For example, NOAA Weather Radio is a "push" technology; it provides 24-hour access to weather information, including all-hazards information.

Pull (retrieve) capabilities make warnings, forecasts, and information available via data storage devices, for people to acquire as needed. The Internet is an example of a "pull" technology; it enables users to retrieve environmental information as needed from NOAA computer servers.

c) Vision: *Reach each person in the Nation.* An access and delivery system of environmental warnings, forecasts, and information to which people understand and react. The information is available to anyone, anywhere, promptly, and in formats easily interpreted.

d) Needs: Warnings are ineffective until those in harm's way take appropriate action. The quicker a warning is delivered, the more useful it is. Advanced, universally-accessible dissemination technologies are necessary to deliver environmental information for the protection of life and property. Universal access depends upon partnerships within communities to increase awareness and coverage.

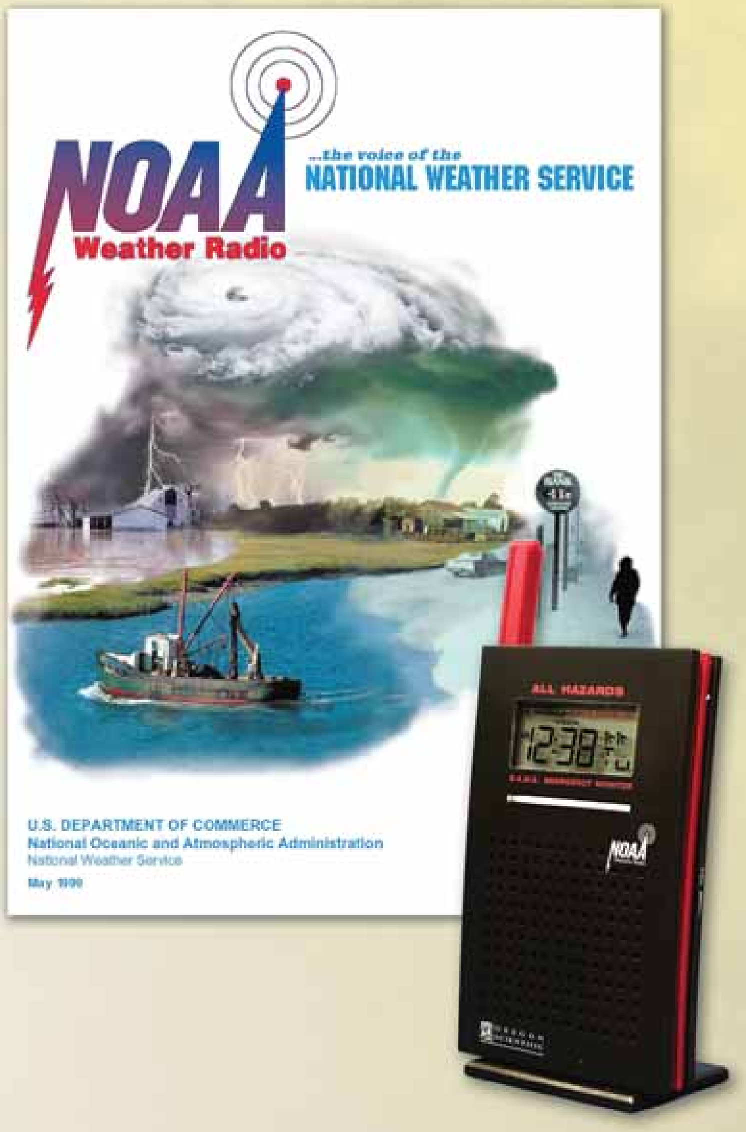
A comprehensive four-dimensional digital database with easy user access is needed to keep up with the ever increasing demand for environmental information. The database should contain atmospheric, oceanic, hydrologic, land, and space observations, analyses, and forecasts and seamlessly span the time scales associated with weather (up to approximately one week) and climate (beyond one week). Confidence measures and other uncertainty information, such as probabilities of exceeding a certain value, are needed for all forecast parameters and at any location, allowing users to make environmental decisions based on their level of risk tolerance. Information should be easy to access and extract in any format, including internationally-accepted standards. Users also need data-mining tools to probe the database and decision tools to exploit it.

e) Solution Strategy: Exploit emerging dissemination technologies to improve communication performance measured by operational availability, latency, customer satisfaction, and cost effectiveness. Make warnings and information available, via convenient methods and formats, to as many individuals as possible. Work with partners to develop a dissemination program that is integrated and adaptable to change.

f) Objectives and Capability Improvements: This solution strategy will be implemented over the next decade by improving engage, advise, and inform capabilities (*see Figure 3*) meeting the following objetives:

Objective 1: Improve performance to keep pace with the need for more data and information in various formats by maintaining adequate processing speed, appropriate latency, and cost effectiveness.

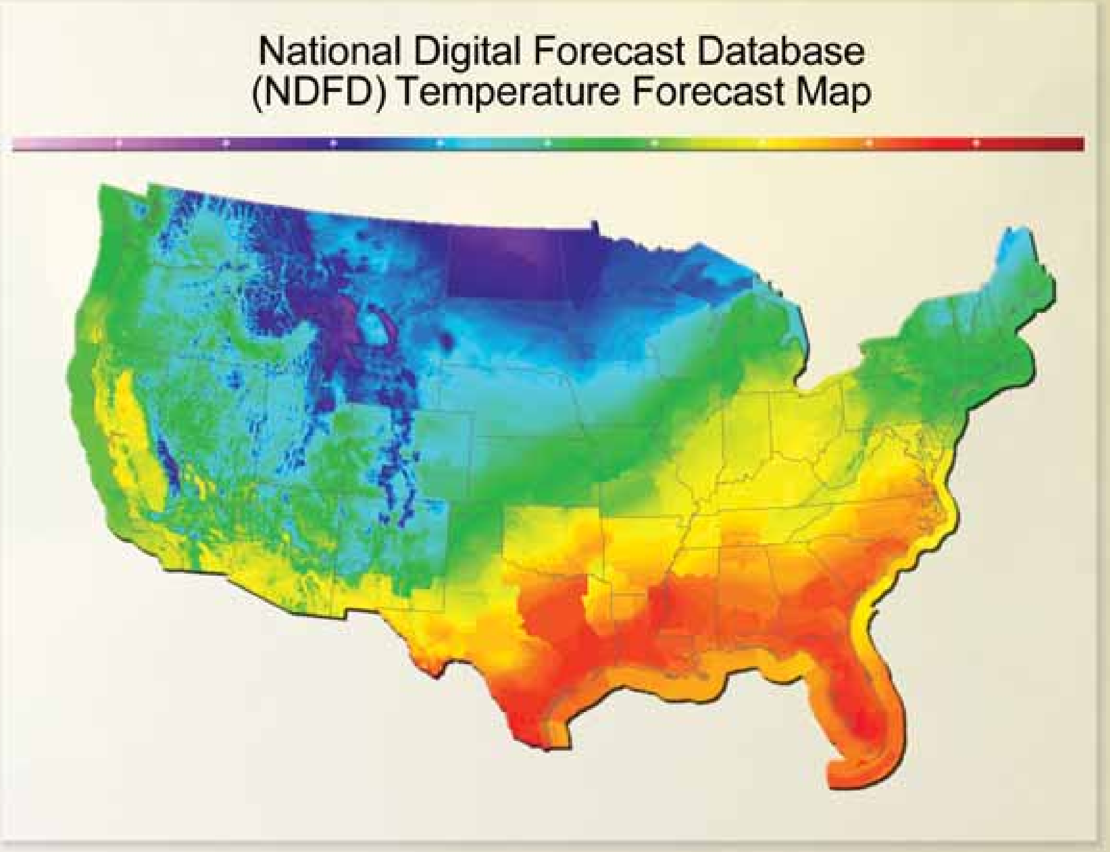
As science and technology continues to advance, more data sets, information, and higher resolution models will become available. Over the next decade (*see Figure 3*), NWS will make continuous hardware upgrades to existing systems to meet user demands for this data. Data compression techniques will allow more information to be transmitted by fully exploiting the communications infrastructure. Dissemination systems will process and deliver warnings and information in a timely manner that meet decision-makers' and end-users' requirements.



Objective 2: Expand content and coverage to provide the appropriate information to the proper audience when and where needed. Currently, there is no single dissemination technology or system that reaches all end users. Delivery and access to warnings, forecasts, and information vary largely across the Nation owing to available technologies and individual lifestyles. Over the next decade (*see Figure 3*), NWS will sustain and expand current dissemination systems such as NOAA Weather Radio. Multi-delivery and access methods will provide redundancy to ensuring that the maximum number of people can be warned, regardless of location.

Partnerships also will be pursued to create fully integrated hazard dissemination networks and to place environmental warnings, forecasts, and other information on televisions, handheld devices, and other emerging communication technologies. In addition, NWS will continue adding information content to the National Digital Forecast Database (NDFD) and exploit telecommunications advances to eventually make available a comprehensive, real-time, four-dimensional environmental information database of observations, model output, forecasts, warnings, and other information in internationally-accepted and other formats.

Objective 3: Implement enterprise information delivery and access systems to meet customer needs more quickly, efficiently, and cost effectively. Currently, various dissemination methods are used to provide services supporting specific customer needs. These individual systems are not able to keep pace with the increasing volumes of data and information available and requested in a timely, cost-effective manner. Over the next decade (*see Figure 3*), NWS will merge dissemination methods into an enterprise information delivery and access system that meets increasing and evolving customer needs for data and information.



The NDFD contains a seamless mosaic of NWS digital forecasts from NWS field offices working in collaboration with NWS National Centers for Environmental Prediction (NCEP). The database is available to all customers and partners - public and private - and allows them to create a wide range of their own text, graphic, and image products. This graphic depicts 24-hour forecast of maximum temperature (color contours in degrees Fahrenheit) generated from 5-km resolution data in the NDFD.

Understand and Describe

a) Purpose: Understanding and describing the Earth's environment through research, developing improved techniques and technologies to observe and predict environmental changes, and training the workforce how to use new science and technology are critical to sustaining and improving NWS products and services. The NWS depends on a pipeline of research and development (R&D) to meet its S&T needs in the monitor and observe, assess and predict, and

b) Current Capability: Research and Development, prototyping and pre-operational testing supporting the NWS is conducted within NOAA's laboratories, centers, joint institutes, testbeds, and forecast offices in collaboration with the academic community, other federal agencies, the private sector, and through programs including the U.S. Weather Research Program (USWRP), the Cooperative Science, Technology, and Applied Research (CSTAR) Program, Cooperative Program for Operational Meteorology, Education and Training (COMET), and the U.S. Climate Change Science Program (USCCP). Through these partnerships, NOAA leverages multi-agency and international investment to accomplish shared R&D objectives. Training is accomplished in classroom settings and through distance-learning modules.

c) Vision - *Advanced Analysis and Prediction of the Earth's Environment:* Critical physical processes linking weather, water, climate, and other environmental elements are understood and represented in numerical and statistical models ofthe Earth system. New observational and data assimilation techniques and technologies measure and analyze necessary parameters enabling these models to produce environmental predictions supporting forecasts, warnings, and other information with much improved lead times, details, and accuracies (*e.g., see pages 8 and 9*). New types of forecast information provide the Nation with accurate projections of how future weather, water, and climate conditions will impact the natural and built environment. These forecasts support ecological, resource management, public health, and other key socio-economic decisions, and all of this information is universally available in digital formats.

d) Needs: New techniques and technologies are needed to improve environmental forecasts and warning accuracies, specificities, and lead times. Observational deployment strategies need to be developed that cost-effectively meet NOAA's mission through integrated observing systems. New tools are needed to support gridded forecast preparation and user access. Improved understanding of predictability, weather and climate linkages, and statistical and ensemble models are needed to enable warnings and extended forecasts based on probabilistic forecasts. New understanding and models of processes and linkages among geophysical, chemical, biological, and anthropogenic systems are necessary to support new air and water quality forecasts, and environmental impact forecast products such as coastal erosion, fish stock, and harmful algal blooms. Research is also needed to anticipate changing social and economic needs that require new NOAA products and services. The workforce needs to be trained in new science and technologies that are being applied operationally to sustain service excellence.

e) SolutionStrategy: Conduct, direct, and leverage R&D leading to a better understanding of key processes governing the Earth's environment. Develop and test prototypes for new and improved observation systems and observing strategies; data assimilation; deterministic and probabilistic integrated Earth-system models; and forecast preparation and dissemination systems. Evaluate the socio-economic value of

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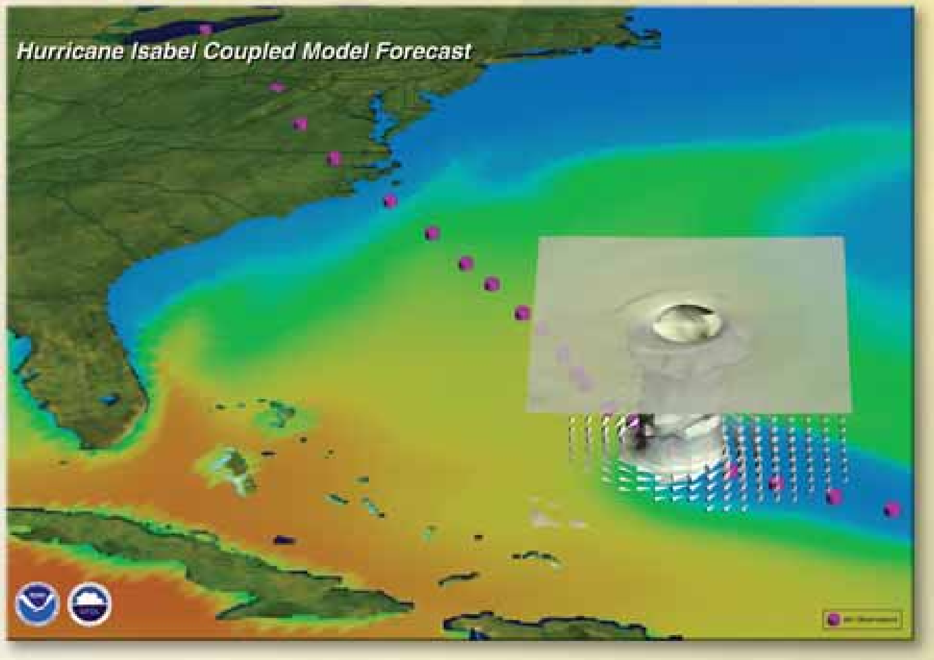
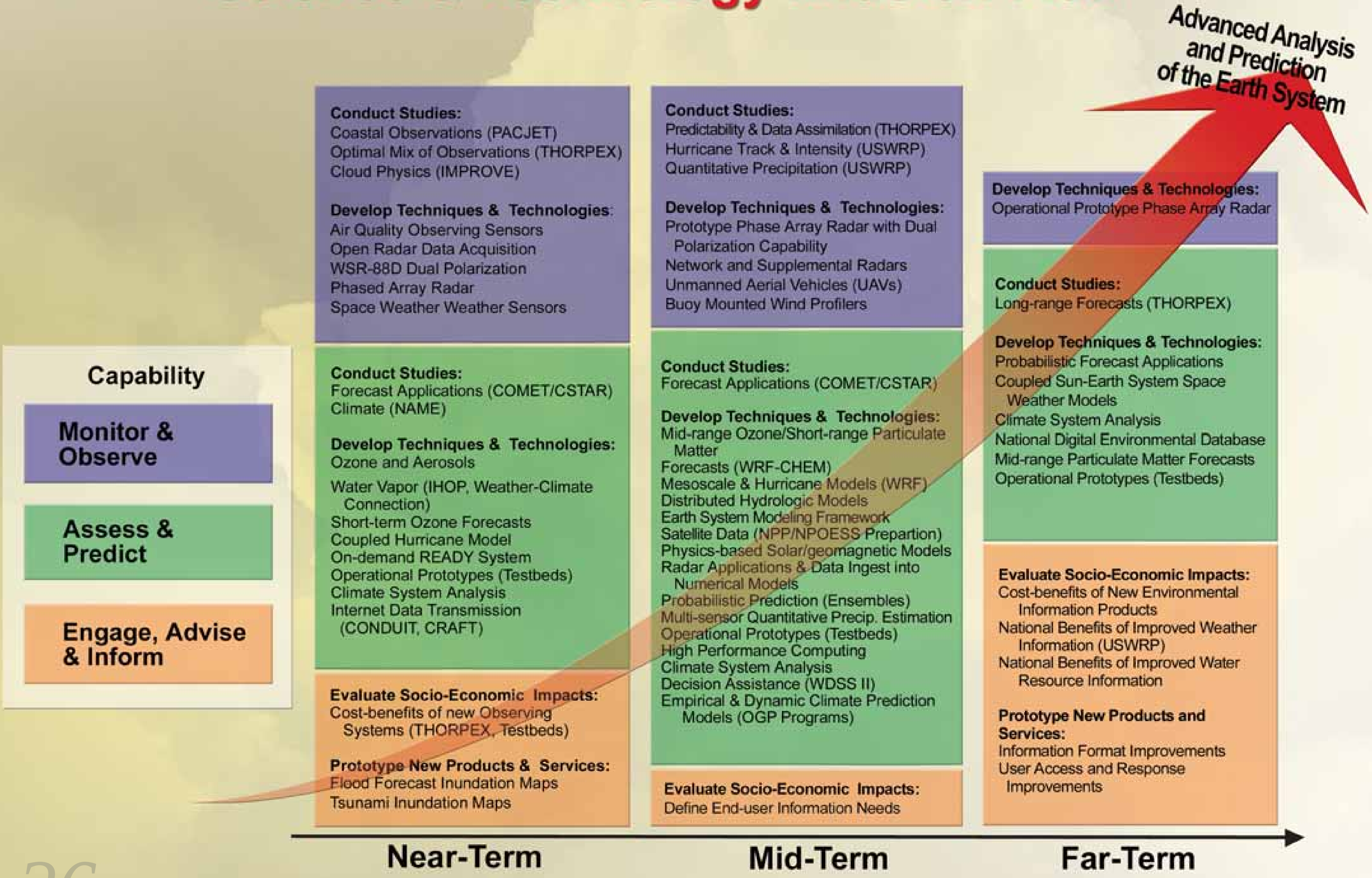


Three dimensional 99-hour forecast of Hurricane Isabel, valid at 1200 UTC September 15, 2003, generated from NOAA's coupled ocean-atmosphere hurricane model. Ocean temperatures (color contours), and the observed storm track in 6-hour increments (circles) are also indicated.

Figure 4: Understand & Describe Science & Technology Infusion Plan



Capability

🟪 **Monitor & Observe**

🟩 **Assess & Predict**

🟧 **Engage, Advise & Inform**

Near-Term

🟪

Conduct Studies:
Coastal Observations (PACJET)
Optimal Mix of Observations (THORPEX)
Cloud Physics (IMPROVE)

Develop Techniques & Technologies:
Air Quality Observing Sensors
Open Radar Data Acquisition
WSR-88D Dual Polarization
Phased Array Radar
Space Weather Weather Sensors

🟩

Conduct Studies:
Forecast Applications (COMET/CSTAR)
Climate (NAME)

Develop Techniques & Technologies:
Ozone and Aerosols
Water Vapor (IHOP, Weather-Climate Connection)
Short-term Ozone Forecasts
Coupled Hurricane Model
On-demand READY System
Operational Prototypes (Testbeds)
Climate System Analysis
Internet Data Transmission (CONDUIT, CRAFT)

🟧

Evaluate Socio-Economic Impacts:
Cost-benefits of new Observing Systems (THORPEX, Testbeds)

Prototype New Products & Services:
Flood Forecast Inundation Maps
Tsunami Inundation Maps

Mid-Term

🟪

Conduct Studies:
Predictability & Data Assimilation (THORPEX)
Hurricane Track & Intensity (USWRP)
Quantitative Precipitation (USWRP)

Develop Techniques & Technologies:
Prototype Phase Array Radar with Dual Polarization Capability
Network and Supplemental Radars
Unmanned Aerial Vehicles (UAVs)
Buoy Mounted Wind Profilers

🟩

Conduct Studies:
Forecast Applications (COMET/CSTAR)

Develop Techniques & Technologies:
Mid-range Ozone/Short-range Particulate Matter
Forecasts (WRF-CHEM)
Mesoscale & Hurricane Models (WRF)
Distributed Hydrologic Models
Earth System Modeling Framework
Satellite Data (NPP/NPOESS Prepartion)
Physics-based Solar/geomagnetic Models
Radar Applications & Data Ingest into Numerical Models
Probabilistic Prediction (Ensembles)
Multi-sensor Quantitative Precip. Estimation
Operational Prototypes (Testbeds)
High Performance Computing
Climate System Analysis
Decision Assistance (WDSS II)
Empirical & Dynamic Climate Prediction Models (OGP Programs)

🟧

Evaluate Socio-Economic Impacts:
Define End-user Information Needs

Far-Term

🟪

Develop Techniques & Technologies:
Operational Prototype Phase Array Radar

🟩

Conduct Studies:
Long-range Forecasts (THORPEX)

Develop Techniques & Technologies:
Probabilistic Forecast Applications
Coupled Sun-Earth System Space Weather Models
Climate System Analysis
National Digital Environmental Database
Mid-range Particulate Matter Forecasts
Operational Prototypes (Testbeds)

🟧

Evaluate Socio-Economic Impacts:
Cost-benefits of New Environmental Information Products
National Benefits of Improved Weather Information (USWRP)
National Benefits of Improved Water Resource Information

Prototype New Products and Services:
Information Format Improvements
User Access and Response Improvements

Advanced Analysis and Prediction of the Earth System

Objectives are in bold text (see text for definitions). Items listed beneath objectives are advances NWS will pursue to improve capabilities (denoted by color) over near-, mid-, and far-term time periods of the next decade. Items in parentheses denote specific programs (see acronym list on page 30).

decade (*see figure 4*), NOAA will advance observational, data assimilation and modeling systems, forecast applications and grid preparation tools, communications, dissemination systems, and information technology. For example, NOAA will develop multisensor precipitation estimation and radar detection of finescale storm structure, develop community forecast modeling systems, and advance observational and data assimilation techniques and systems. Many of these and other emerging techniques and technologies will be operationally prototyped and evaluated in testbeds, which will accelerate the transition to operations.

Objective 3: Evaluate user needs and socio-economic impacts of potential new products and services to meet the Nation's needs. Over the next decade (*see Figure 4*), NOAA will better understand the environmental information needs of our partners and users to reduce weather-related societal risk and enhance the Nation's economy.

Objective 4: Integrate user needs, operations, and research results to develop and test prototypes for new products and services. For example, over the next decade (*see Figure 4*) NOAA will assist water managers to more effectively allocate diminishing fresh water resources.

Objective 5: Sustain training to ensure the workforce remains highly skilled at applying operational S&T in the provision of products and services. Over the next decade, workforce training will be reviewed and refreshed periodically to in
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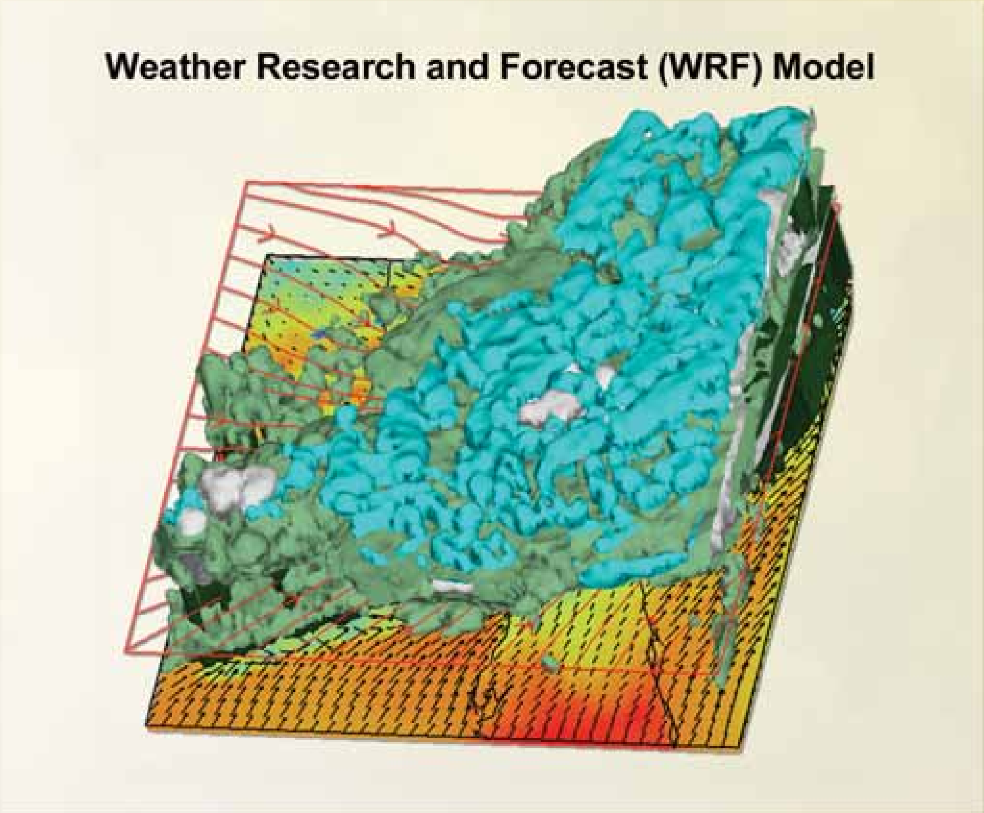

High resolution (5 km), experimental 12-hour forecast generated from the WRF model over Florida. Surface temperatures (color contours), surface winds (arrows), upper level streamlines, and clouds are shown.

Summary

Incorporating new S&T into operations has led to marked improvements of weather, water, and climate forecast and warning lead times, accuracy, and overall NWS product and service quality. In particular, improvements in tornado, flash flood, hurricane, winter storm, and other warnings and forecasts over the last decade have followed the implementation of new observing systems such as the WSR-88D, ASOS, and GOES; new data assimilation and modeling systems; forecast preparation applications; advanced processing and telecommunications systems such as the NCEP supercomputer and AWIPS; and requisite training of the workforce.

Over the next decade, these improvements in warnings and forecasts of environmental hazards and conditions must be sustained to meet the Nation's unmet needs for more informed decision making. Storms and floods continue to cause harm to people and property, and cost the economy billions of dollars every year. Many of these losses can be mitigated by supplying decision-makers and the public with even more accurate and extended lead-time weather, air quality, water, and climate forecasts and warnings.

The NOAA and NWS Strategic Plans respond to this continuing national need for improved information by calling for increased accuracy, lead time, and specificity of environmental forecasts and warnings; increased use and effectiveness of this information for planning and decision making; and increased satisfaction with, and benefits from, NOAA environmental information and warning services. To support the achievement of these goals, the NWS has developed this STIP. The plan defines objectives in four interlinked steps supporting the provision of products and services:

1. **Improve monitoring and observing the Earth's environment:**

   - ✓ Increase the temporal, spatial, sensitivity, and energy spectrum resolution of observations to improve the depiction of critical phenomena and processes enabling more accurate and extended-lead time warnings and forecasts;
   - ✓ Obtain observations of new environmental elements to improve existing products and make new ones possible;
   - ✓ Improve timeliness, data quality, and long-term continuity of observations to reduce observational, analysis, and model initialization error; increase forecast accuracy; extend warning lead times; and maintain the climate record; and
   - ✓ Integrate multi-purpose observing systems and networks within an extensible enterprise architecture to meet cross-functional observational requirements cost effectively and to provide more timely data access.

2. **Improve assessing and predicting the Earth's environment**:

    - ✓ Advance data assimilation techniques to improve the accuracy of model initial conditions;
    - ✓ Improve and couple numerical modeling systems to adequately simulate weather, air quality, water, climate, and other geophysical phenomena in common modeling systems;
    - ✓ Improve probabilistic prediction systems to quantify forecast uncertainty;
    - ✓ Improve gridded forecast preparation applications to increase forecast and warning lead times, accuracy, location specificity; and, enhance product information content and formats; and
    - ✓ Stay close to the leading edge of IT to increase system utility, functionality, and customer satisfaction.

3. **Improve engaging, advising, and informing the Nation:**

    - ✓ Improve performance to keep pace with the need for more data and information in various formats by maintaining adequate processing speed, appropriate latency, and cost effectiveness;
    - ✓ Expand content and coverage to provide the appropriate information to the proper audience when and where needed; and
    - ✓ Implement enterprise information delivery and access systems to meet customer needs more quickly, efficiently, and cost effectively.

4. **Improve understanding and describing the Earth's environment:**

    - ✓ Conduct and participate in process studies to provide new understanding of the Earth system, and the predictability of its processes;
    - ✓ Develop and leverage new techniques and technologies to sustain existing and support new products and services;
    - ✓ Evaluate user needs and socio-economic impacts of potential new products and services to meet the Nation's need;
    - ✓ Integrate user needs, operations, and research results to develop and test prototypes for new products and services; and
    - ✓ Sustain training to ensure the workforce remains highly skilled at applying operational S&T in the provision of products and services.

The STIP defines improvements the NWS will pursue with its partners over the next decade to meet these objectives and provide the necessary S&T base supporting its mission of protecting life and property, and supporting the socio-economic well-being of the Nation.

List of Acronyms

AHPS	Advanced Hydrologic Prediction Service
AIRS	Atmospheric Infrared Sounder
AMDAR	Aircraft Meteorological Data Relay
AQ	Air Quality
Argo	Deep Ocean Floating Buoy Array
ASOS	Automated Surface Observing System
AWIPS	Advanced Weather Interactive Processing System
C-GOOS	Coastal-Global Ocean Observing System
COMET	Cooperative Program for Operational Meteorology Education and Training
CONDUIT	Cooperative Opportunity for NCEP Data Using IDD Technology
COOP	Cooperative Observing Program
COOP-M	Modernized Cooperative Observing Program
CRAFT	Collaborative Radar Acquisition Field Test
CSI	Coastal Storms Initiative
CSTAR	Collaborative Science, Technology, and Applied Research Program
EPA	Environmental Protection Agency
EMWIN	Emergency Managers Weather Information Network
ESM	Earth System Model
ESMF	Earth System Modeling Framework
FAA	Federal Aviation Administration
FFMP	Flash Flood Monitoring and Prediction
FOS	Family Of Services
GIFTS	Geostationary Interferometric Fourier Transform Spectrometer
GFS	Global Forecast System
GODAS	Global Ocean Data Assimilation System
GOES	Geostationary Operational Environmental Satellites
GOES M	The Mth satellite in the GOES I-Q series
GOES R	The first satellite in GOES R series
GOOS	Global Ocean Observing System
GPS	Geo-Positioning System
HRW	High Resolution WRF
IDD	Internet Data Distribution
IFPS	Interactive Forecast Preparation System
IHOP	International H_2O Project
IMPROVE	Improvement of Microphysical Parameterizations Through Observational Verification Experiments
IMS	Internet Mapping Source
ISCS	International Satellite Communication System
IT	Information Technology
Jason-2	Oceanographic Surface Topography Mission Satellite #2/Radar Altimetry
L-1	Lagrangian Point 1
LIDAR	Light Detection and Ranging
MDCRS	Meteorological Data Collection and Reporting System
METOP-1	European Meteorological Satellite #1
N-AWIPS	NCEP AWIPS

Acronyms

NAME	North American Monsson Experiment
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NCF	Network Control Facility
NDFD	National Digital Forecast Database
NEXRAD	Next Generation Radar
NOAA	National Oceanic and Atmospheric Administration
NPN	NOAA Profiler Network
NPP	NPOESS Preparatory Project
NPOESS	National Polar-orbiting Operationa Environmental Satellite System
NSIP	NWS National Service Improvement Plan
NWR	NOAA Weather Radio
NWS	National Weather Service
NWSTG	National Weather Service Telecommunications Gateway
NWWS	NOAA Weather Wire Service
OGP	Office of Global Programs
ORDA	Open Systems-Radar Data Acquisition
PACJET	Pacific Land-falling Jets Experiment
PM	Particulate Matter
POES	Polar Operational Environmental Satellite
R&D	Research and Development
RAOB	Radiosonde Balloon
READY	Real-time Environmental Applications and Display System
RH	Relative Humidity
RRS	Radiosonde Replacement System
SAFESEAS	System on AWIPS for Forecasting and Evaluating Seas and Lakes
SBN	Satellite Broadcast Network
SCAN	System for Convection Analysis and Nowcasting
SOHO	Solar and Heliospheric Observatory Satellite
SREF	Short Range Ensemble Forecast
STIP	Science and Technology Infusion Plan
S&T	Science and Technology
SST	Sea Surface Temperatures
SXI	Solar X-Ray Instrument
TAMDAR	Tropospheric Airborne Meteorological Data Reporting
TDWR	Terminal Doppler Weather Radars
THORPEX	The Observation Research and Predictability Experiment
UAV	Unmanned Aerial Vehicle
USCCSP	U.S. Climate Change Science Program
USWRP	U.S. Weather Research Program
VOS	Voluntary Observing Ship
WRF	Weather Research and Forecasting
WDSS II	Warning Decision Support System- Integrated Information
WSR-88D	Weather Surveillance Radar-1988 Doppler
X-Band Radar	9.3 - 9.7 GHz Radar
3D	Three dimensional
3DVAR	Three-dimensional Variational Data Assimilation
4D	Four dimensional

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Concurrence

We, the Science and Technology Committee of the NWS Corporate Board, pledge that we are committed to working with the men and women of our agency, and with our science and technology partners to turn this plan into reality.

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