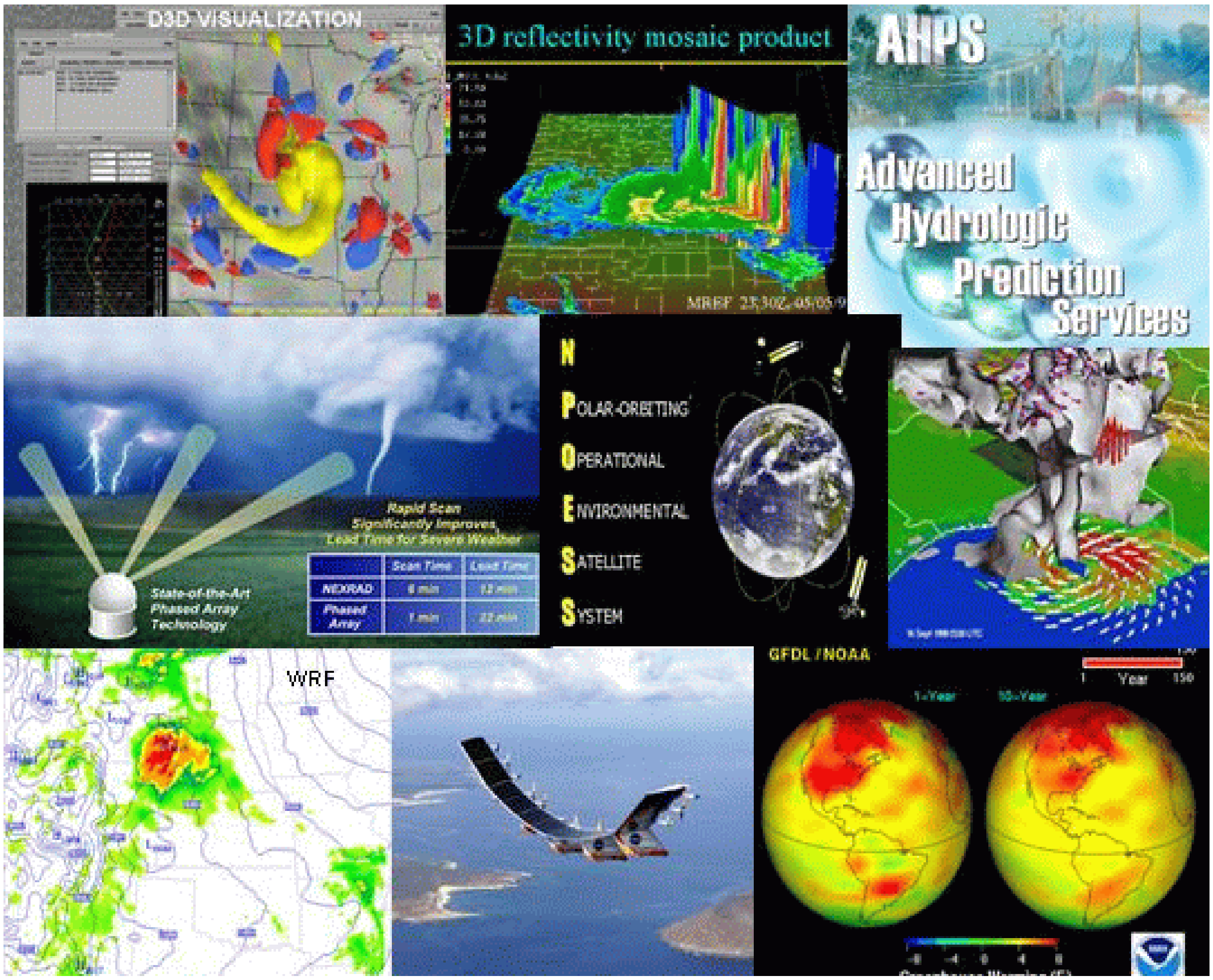
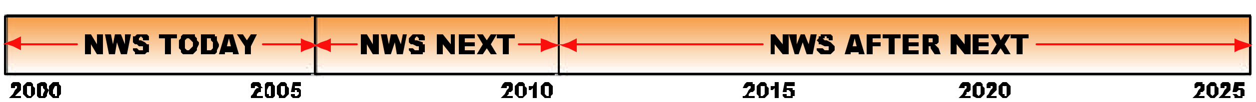
Draft: July 27, 2001

National Weather Service
Science and Technology Infusion Plan

A Roadmap to 2025





U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Office of Science and Technology
Silver Spring, Maryland

October 2001

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Preface

During the 1980's, the National Weather Service (NWS) embarked on a major modernization program, the Modernization and Associated Restructuring (MAR), to upgrade technological systems and restructure field operations. The MAR, officially completed in June, 1999, has led to significant improvements in NWS's operational products and services. As is the case with any service organization, the NWS can not rest on success. Since NWS services are science based, it must now prepare for the next several decades of science and technology (S&T) infusion. This infusion will build on the MAR and emphasize continuous implementation of S&T advancements into operations for maximum socio-economic benefit to the Nation.

The purpose of this Science and Technology Infusion Plan (STIP) is to provide an S&T guide by which NWS can strategically plan, focus and coordinate research and development, and operational implementation internally and with partners. Science and Technology Infusion *Planning* better describes the intent of the STIP because it will be a "living" plan revised as key aspects change. Version 1 focuses solely on S&T advancement targets stretching from today to the 2025 time frame, and the potential products and services these advances will enable. Follow-on versions of the plan will incorporate the influence of other factors shaping NWS S&T investment such as evolving customer needs, agency missions, operations concepts, etc., and also include more detailed implementation strategies.

The preparation of Version 1 of the plan has involved several sources of input and review from experts in the field, both within NWS and from the external science community. To date, these sources include:

- Written and verbal suggestions from NWS experts,
- Compilation of S&T plans and visions from existing NWS and National Academy of Sciences reports,
- A workshop involving the broader science community, and
- An NWS review forum.

After NWS Corporate Review, the STIP will undergo further refinement through:

- Presentation at professional meetings and in publications,
- A constituent / customer review forum, and

- Coordinating with Strategic, NWS System Architecture, Budget, Workforce, and other NWS, NOAA, and other planning efforts.

Many people and organizations were involved in preparing this document and thanks go to all of those who contributed. In particular, I thank the attendees of the NWS Next and After Next Workshop. In particular, I gratefully acknowledge the efforts of Susan Avery, Richard Hodur, David Rogers, Thomas Schlatter, William Turnbull, and Richard Wagoner, all non-NWS experts who provided much time and energy by leading portions of the Workshop in June, helping to revise the document in July, and who will present sectional overviews of the plan at August 2001 NWS Corporate Board meeting. Appreciation is also extended to the internal NWS reviewers: Vico Baer, Mickey Brown, Larry Dunn, Mark Jackson, Ed Johnson, Ken Johnson, Jim Kemper, Dan Mannarano, Ralph Petersen, Nick Scheller, Kevin Schrab, Dan Smith, Tim Sweeney, Fred Toepfer, and Michael Tomlinson. Thanks also in advance to the NWS Corporate Board for their input, especially during the Corporate Board meeting Finally and foremost, thanks goes to the Office of Science and Technology's (OST) Science Plans Branch. Paul Hirschberg led the development of the plan and authored the introductory sections of the document. Paula Davidson authored the Observations Section, and edited and integrated other technical sections of the plan. Sam Contorno co-authored the Enabling Technologies Section with Suzanne Lenihan, who also authored the Dissemination Section. Jeff McQueen authored the Data Assimilation and Numerical Prediction Section and Jin Huang authored the Fundamental Understanding Section. Our visiting scientist, John McGinley, wrote portions of the plan and participated in all aspects of the preparation of the document. Dave Helms, Jeff Savadel and Daniel Melendez also assisted. Dennis Staley organized the NWS Corporate Board Review of the plan. Finally, great appreciation is extended to Wendy Levine who while not under OST's employ, volunteered to author the Forecast Techniques and Product / Information Preparation Section of the plan.

Jack Hayes
Director, Office of Science and Technology
August 2001

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Executive Summary

Over the last 20 years of the twentieth century, National Weather Service (NWS) science and technology (S&T) infusion focused on the Modernization and Associated Restructuring (MAR), involving the implementation of major technological systems and restructuring of field operations. The S&T advances accompanying the MAR have led to operational improvements in warnings, forecasts, and other products and services reducing risk to society and the economy. With the MAR now complete, the NWS is planning for the S&T advances necessary to support improved product and service capabilities and organizational efficiency and productivity in the first decades of the twenty-first century.

In this S&T Infusion Plan (STIP), the challenge of planning NWS S&T infusion for the greatest socio-economic benefit of the Nation is approached first by defining an overarching vision for 2025: *There are no unanticipated weather, water, climate, or related environmental (WWCE) events impacting the Nation.* In support of this vision, *The NWS openly and freely provides the world's most accurate and highest quality WWCE data, products, and information in a seamless data base easy to access and use for any application or purpose.* Next, NWS S&T capabilities needed to reach this vision are identified from the present to 2025. In particular, three planning time frames, near- (NWS Today, circa 2005), mid- (NWS Next, circa 2010), and far-term (NWS After Next, circa 2011), are adopted for organizing discussion of current and target capabilities for major elements of the forecast and information-generation process: **observations**, **data assimilation and numerical prediction**, **forecast techniques and product/information preparation**, and **dissemination**. Also included are necessary advances in **enabling technologies** -- principally computing, communications, and data extraction or visualization and **fundamental understanding** of physical and chemical processes occurring in the atmosphere, hydrosphere, oceans, and land surface.

Today, the NWS provides weather, hydrological, and climate warning and forecast services to the public and other customers. Field forecasters integrate observations, output from various numerical prediction models enhanced with statistical techniques, and other types of guidance and decision assistance tools to produce forecasts and warnings for time-periods ranging from minutes (for severe weather) to seasonal and intra-annual (for anomalous temperature and precipitation). Satellite and other automated observing systems for surface conditions, rivers, streams, and lakes, atmospheric state, and the oceans, are supplemented with a variety of observations, such as those supplied by cooperative observers, ships, and in-flight avionics systems. Several times each day, observations are used to initialize regional- and global-scale numerical prediction models run centrally at the National Centers for Environmental Prediction. Week-2 forecasts are updated daily, and seasonal outlooks for general climate trends are generated on a monthly basis. These products, with accompanying automated model interpretation, are transmitted to forecast offices, where they are interactively displayed on AWIPS systems for use in developing forecasts and warnings. Local-scale models, such as workstation-Eta and others, are run experimentally at many WFOs. The Internet is used to transmit and display data and products on an auxiliary basis. Warnings and forecasts are disseminated to the public and private sectors over NOAA Weather Radio, and other electronic and print media. Increases of observation and product data streams are generated with ongoing improvements: more complete sampling; more accurate, more comprehensive (parameters, resolution, outlook length) prediction methods; advances in forecast techniques pose challenges for supporting computing and communications technologies.

By NWS Next, advances in computing power, communications, and other enabling technologies will provide the capabilities for more representative observations from a variety of new sources, for advances in numerical prediction, and in forecast techniques and product/information preparation. Advanced data assimilation techniques will make efficient use of the vastly expanded observational data, from satellite and other remote sensing platforms, in conjunction with in situ upper-air and surface measurements. Models will be run at ever finer resolutions for local, regional, and global applications; probabilistic forecasts for growing numbers of parameters will take advantage of amply populated ensembles. Adopting a common modeling framework will facilitate information sharing and connectivity among models for all spatial scales. Model output and interpretation tools will be provided to field forecasters in increasingly convenient formats for rapid interactive processing and advanced decision assistance. Dissemination to the public and other customers will rely on flexible alternative pathways to optimize accessibility and usefulness of both generic and specially-requested products.

By 2025, S&T advances will enable the NWS After Next to become more efficient and productive and provide seamless weather, water, climate, and related environmental information of greatly increased quality and quantity relative to today. A multi-dimensional data base will integrate observations, numerical prediction, climatological data, and human forecaster input, with accompanying uncertainty metrics for real-time, user-friendly access. More comprehensive observations will expand reliance on systems that adaptively target regions and features critical for reducing forecast uncertainty. Observational data will be ingested in common-framework numerical prediction systems that describe environmental processes operating over space and time scales ranging from meters and minutes to thousands of kilometers and years, for time periods nearing the limits of predictability. Ensembles, with sufficient numbers of members to represent adequately uncertainty in both initial conditions and models, will provide a basis for extended probabilistic forecasts. All information in the data base will be available to forecasters and other users. Accurate forecasts and warnings will be disseminated over multiple media, with sufficient lead times for mitigating actions. Advanced public and private-sector interactive data mining, decision aide, and visualization techniques will support customized interpretation and applications.

The STIP is a living document outlining target capabilities, which will necessarily be revised as key aspects change. From it will emanate cooperative action plans aimed at specific R&D-to- operational transitions. These action plans will focus on quick and efficient ways to perform critical elements of the infusion process, including testing and training. Finally, this S&T plan is one piece of an emerging integrated planning effort considering factors such as evolving customer needs, agency missions, budgetary, and organizational changes, etc., all affecting the NWS and influencing the S&T direction the agency takes over the next 25 years.

1.0 Introduction

Over the last 20 years of the twentieth century, National Weather Service (NWS) science technology (S&T) infusion focused on the Modernization and Associated Restructuring (MAR). Major elements of the MAR were the:

- Next Generation Doppler Radar Network (WSR-88D),
- Advanced Weather Interactive Processing System (AWIPS),
- Automated Surface Observations System (ASOS),
- Satellite Upgrades (e.g., GOES I-M),
- Central Computer Facility Upgrade, and the
- Restructuring of Field Operations (Weather Forecast Offices, River Forecast Centers, and the National Centers for Environmental Prediction).

The S&T advances accompanying the MAR have led to operational improvements in warnings, forecasts, and other products and services reducing risk to society and the economy. With the MAR now complete, the NWS is planning for the S&T advances necessary to support improved product and service quality and capabilities, and organizational productivity and efficiency in the first decades of the twenty-first century.

2.0 Setting and Purpose

The NWS Strategic Plan - Vision 2005 (hereafter referred to as NWS SP; NWS, 2000) and the associated Strategic Plan Implementation Guide (SPIG; NWS, 2001) lay the foundation for NWS entering the twenty-first century by building on the MAR. The purpose of this S&T Infusion Plan (STIP) is to extend the outlook by considering where anticipated S&T advances will enable its products and services to go by 2025[1]. Toward this end, the plan assumes the following from the National Research Council's *A Vision for the National Weather Service* (NRC Vision; NRC, 1999):

- There will be increasing uses of weather, water, climate, and related environmental information for safety and profitability;
- The science and technology communities will make enormous advances in the next 25 years; and
- The NWS will aggressively support and capitalize on these science and technology advances to increase the quality and value of weather, water, climate, and related environmental information to society and improve organizational efficiency and productivity.

[1] As noted by Dorman et al. (1999), such an extended outlook, of at least twenty years, provides guideposts for influencing emphases of current science advances that will enable the long-range evolution of NWS. While the length of outlook for maximum benefit is uncertain, the range is chosen to be far enough in the future that innovations, not current requirements, will be the key to significant progress.

This STIP provides a coherent roadmap integrated across S&T areas, by which the NWS can strategically plan, focus and coordinate research and development, testing, and transition to operations internally and with partners. The plan is based on a number of sources, which project the state of relevant S&T by 2025. In particular, the STIP integrates near- and long-term S&T plans and outlooks documented in the NWS SP, SPIG, Dorman et al. (1999; hereafter referred to as Dorman Report), NRC Vision, *The Atmospheric Sciences Entering the Twenty-First Century* (NRC, 1998), *Envisioning the Agenda for Water Resources Research in the Twenty-first Century* (NRC, 2001), and the Workshop on NWS Next and After Next (NWS, 2001). The STIP is a living document outlining S&T target capabilities, which will necessarily be revised as key aspects change. From it, more specific R&D to operational implementation action plans will be developed. In particular, these follow-on action plans will focus on critical elements of the infusion process such as quick and efficient testing and training. Finally, this S&T plan is one piece of an emerging integrated NWS planning effort considering factors such as evolving customer needs, agency missions, NWS System Architecture, and budgetary, workforce, and organizational changes, etc., which will affect the NWS and influence the S&T direction the agency takes over the next 25 years.

Background on the importance of technology infusion to the NWS is presented in Section 3. In Section 4, a vision of potential product and service capabilities, based on projected S&T advances, is presented. Section 5 describes current NWS technology baselines and the advancements necessary to reach the vision. The associated S&T roadmaps in Section 5 are presented for three time frames: near- (NWS Today), mid- (NWS Next), and far-term (NWS After Next). Finally, Section 6 outlines an implementation strategy.

3.0 Science and Technology Infusion

Science and technology infusion, especially for organizations such as the NWS which rely on cutting edge S&T, is necessary to sustain **relevancy** in:

- Product and Service Quality
- Process Efficiency and Productivity, and
- Customer Satisfaction

Dorman et al. (1999) define technology infusion as:

> *"the continuing, evolutionary process by which any organization or system maintains its health and improves its performance through the disciplined incorporation of new ideas, procedures, and capabilities."*

The NWS STIP lays the foundation for two key features of a successful technology infusion process, **evolution** and **discipline**. According to Dorman et al. (1999), managing **evolution** requires planning and assembling the resources necessary to implement the changes. The STIP will guide budget formulation and **disciplined** S&T implementation, following clearly articulated vision and goals for the evolving capabilities of the NWS. Prescient implementation of continuous S&T advances will also reduce, if not eliminate, the need for step-function improvements and attendant inefficiencies that follow periods of technological stagnation.

Since the NWS is a science-based service agency, the goal of its S&T infusion program must be to meet current and anticipated customer needs by balancing the "pull" of service requirements with the "push" of science while optimizing return on investment as judged by the socio-economic impact on the Nation. Service pull must dominate short-term planning and science push generally dominates long-term planning. Accordingly, three distinct, yet overlapping planning time frames suggested in the Dorman Report are adopted as the basis for this plan:

1. NWS Today (through 2005)
   - Period of continuous refreshment of the Modernized NWS
   - Planning for this period is primarily requirements driven -- more service pull than science push

2. NWS Next (circa 2010)
   - Technology infusion occurs through targeted improvements to MAR baseline: What will S&T allow for NWS operations by 2010?
   - Planning for this period is more balanced between service pull and science push

3. NWS After Next (circa 2025)
   - Focus is on innovation: What S&T breakthroughs will provide opportunities for improvements with major socio-economic benefits to the Nation?
   - Planning for this period is primarily S&T opportunities driven-- more science push than service pull[2]

In Section 4, planning for these three time frames is attacked by first establishing a vision for NWS in 2025. This vision is based on the promise of anticipated S&T advances and therefore, represents the upper-bound to what NWS can become. An S&T roadmap from NWS Today to Next and After Next is constructed in Section 5 with the understanding the vision will ultimately be bounded by customer-based performance measure goals, which maximize the positive impacts of weather, hydrological, climate and related environmental information for the Nation.

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[2] This statement is not intended to imply science "push" will dominate service "pull" when NWS reaches the After Next. Certainly by FY 2020 or so, planning for FY 2025 will be pull dominated. In this era, push will dominate planning for 2050.

4.0 NWS 2025: Potential Product and Service Capabilities Based on S&T Advances

The NWS overarching vision for environmental services in 2025 is:

There are no unanticipated weather, water, climate, or related environmental events impacting the Nation.

To support this vision:

The NWS openly and freely provides the world's most accurate and highest quality weather,water, climate, and related environmental data, forecast and warning products, and information. These are based on cutting-edge science and technology and are easy to obtain for any application or purpose.

In particular by 2025, the NWS (with partners) sustains a comprehensive digital data base of quality weather, water, climate, and other environmental information. The data base, seamlessly spanning time from past to future, domains from within the sea to the sun, and spatial scales from meters to thousands of kilometers includes:

- observations,
- analyses,
- forecasts,
- uncertainty information, and
- products and information such as outlooks, watches, and warnings.

The data are easy to access and extract in any format. Decision assistance and other data-mining tools allow users to interrogate and harness the data base. Private-sector software enables use of the data base for specific and tailored applications. The forecast data includes a wealth of high-resolution environmental parameters, range from minutes to decades, and are derived from dynamic combinations of single- and multi-model output, statistical tools, decision aides, and human forecasts with associated uncertainty metrics. Based on this information, probabilities of any forecast parameter exceeding any threshold value can be determined.

Various products, especially related to public safety, are disseminated from the data base by NWS over universally-accessible media and in formats users can easily interpret and use. In particular, for a specific time and location, Figure 4.1 illustrates how:

Long-range outlooks for hazards seamlessly become watches and watches become warnings as the forecast period decreases and the probability of occurrence exceeds critical thresholds.

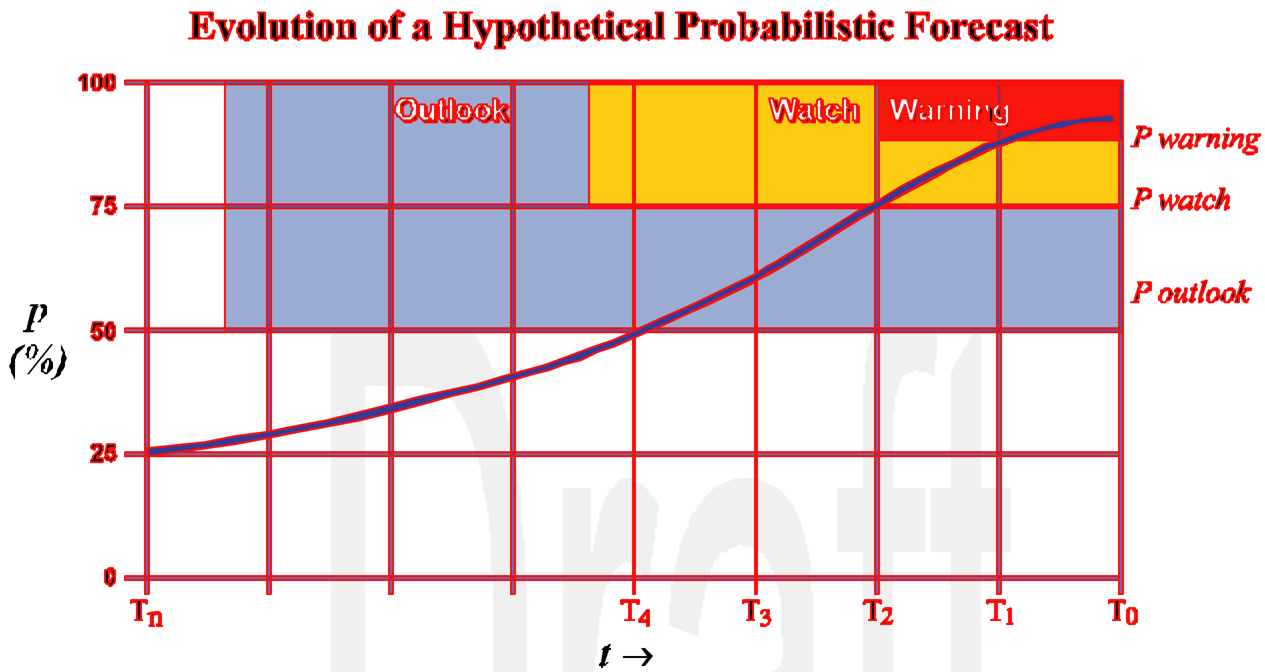

Fig. 4.1. Schematic evolution of a sequential series of probabilistic forecasts (heavy solid curve) for the occurrence of some hazardous event at forecast valid time (T_o). Any point along the curve is the probability (p) of the event occurring at T_o in a forecast initialized at time (t) preceding T_o. In this hypothetical example, the probability of the hazardous event occurring at T_o in a forecast generated at T_n is 25%; for the forecast initialized at the later time $T_{4,}$ the probability of the event occurring has risen to 5%; and by $T_{1,}$ the probability has risen to 90%. Shading indicates values of probability and time when an outlook, watch, or warning would be issued. As t approaches T_o and p increases past critical values $P_{outlook}$, P_{watch},, and $P_{warning}$, respectively, an outlook for the hazard would be issued, then the outlook would become a watch, and then the watch would become a warning. In this example, a hazard outlook would be issued near $t=T_4$, a watch near $t=T_2$, and a warning near $t=T_1$.

By 2025 NWS forecast and warning lead time, specificity, and accuracy meet goals (e.g., Table 4.1) established by risk managers and careful socio-economic research allowing those threatened by hazardous conditions to take mitigating actions well in advance of events. Loss of life and injury owing to *unforeseen* weather and floods are eliminated. Economic sectors that will be affected are alerted and warned with sufficient lead time to take avoidance action to eliminate or greatly limit cost impact. These breakthroughs provide the public and economic sectors quantum increases in preparing for and mitigating impacts of hazardous conditions.

Table 4.1. Potential NWS warning lead times and specificity goals for 2025[3]. All warning accuracies are greater than 90%.

Tornadoes: Warning lead time increases from an average of 12 minutes for counties in 2000 to as much as one hour for specific portions of counties in 2025. Allows residents in the path of a tornado enough time to take protective measures.

Severe Thunderstorms (non-tornadic): Warning lead time increases from an average of 18 minutes in 2000 for counties to as much as four hours for cities and towns in 2025. Allows those engaged in outdoor activities with ample time to take precautions before the first lightning strikes.

Flash Floods: Warning lead time increases from an average of 43 minutes for counties in 2000 to as much as 4 hours for specific portions of counties in 2025. Allows ample time for orderly evacuation. Emergency managers are able to use this timely information to take mitigating actions which reduce damage to homes and businesses.

River Floods: Average warning lead time increases up to four weeks for flood plains. Allows sufficient time to construct barriers to protect communities at risk.

Hurricanes: Warning lead time for landfall increases from an average of 20 hours in 2000 for 400 miles of coastline to three days and 200 miles of coastline in 2025. Provides emergency managers ample time to execute necessary evacuations in an orderly fashion at the right time. Reductions in overwarning saves billions of dollars in unnecessary preparations.

Winter Storms: Warning lead time increases from an average of nine hours for counties in 2000 to five days for specific portions of counties in 2025. Air and surface traffic are able to be rescheduled and rerouted. Snow removal teams can be positioned at the right places at the right times for rapidly restoring the Nation's roadways.

Low Ceiling and Visibility: Accurate warnings are issued an average of five hours in advance for specific airports, sections of road, and ports, in 2025. Provides aircraft, ships, and ground transportation enough time to reschedule and/or reroute to avoid hazardous conditions.

Non-Thunderstorm Turbulence and Icing: Accurate warnings are issued an average of five hours in advance along flight corridors, in 2025. Allows aircraft to reroute around dangerous areas.

Maritime Wind and Wave warnings: Accurate warnings are issued an average of five hours in advance for hazardous convective storms and an average of three days in advance for gales, and storms, in 2025. Allows commercial fishermen, other mariners, and port authorities to take appropriate safety measures, and recreational boaters to alter plans well before dangerous winds and waves develop.

Poor Air Quality: Accurate warnings are issued an average of five days in advance for metropolitan areas, in 2025. Alerts the elderly and other at-risk people to confine their outdoor activities. Power companies shift to alternative fuels that reduce problematic air quality.

Above ground weather warnings: Accurate warnings are issued for hazardous winds and frozen precipitation at all levels up to 2500', in 2025. Allows low-level air transportation and construction companies to reduce operating risks.

Space weather storms: Accurate warnings for geomagnetic storms are issued an average of up to five days

[3] Warnings are issued when the probability of occurrence reaches some critical threshold value at a specific location. While these lead times may challenge the limits of deterministic predictability for some phenomena, when viewed within the framework of useful probabilistic forecasts such lead times may be well within future capabilities.

in advance, and solar radiation storms as much as two days, in 2025. Allows electric power transmission is to be rerouted to eliminate surges in power delivered to customers.

In addition, more accurate, longer lead time forecasts and other information in the comprehensive data base improves capabilities for:

- **Better everyday decision making:** Not only from life-threatening tornadoes and floods, but also from other conditions that may impact everyday life and business such as temperature, winds, humidity, type and amount of precipitation, freezing, thawing, sunshine, cloud cover, and poor air quality. Planners of activities extremely sensitive to these events eliminate or minimize risk from unlikely, but potentially catastrophic events.

- **Longer-range preparation:** Forecasts and associated confidence levels are produced for long-range temperature and precipitation variability, and the frequencies and intensities of extratropical and tropical cyclones, thunderstorms, floods, drought, and other severe or extreme conditions, by region and by month. Coastal communities are able to build up shore and harbor breakwaters, reinforce coastal cliffs, and take other protective measures against more frequent and intense storms. Insurance companies and the weather derivatives industries reduce risk to themselves and their clients based on expected numbers of hurricanes making landfall next summer. Competing water demands for irrigation, fisheries, hydropower, are better managed. Farmers plant relatively low-yield, but highly drought-resistant corn, based on the three-month precipitation forecast.

- **Maximum exploitation of favorable conditions**: Energy resources are shifted from one region of the country to another based on probabilistic temperature, precipitation, river stage, and chemical weather forecasts. Prescribed burns are planned to take advantage of rains predicted for one or more weeks ahead to reduce the risk of escaped fires. Farmers decide to spray a highly effective, environmentally benign, but extremely water-sensitive pesticide over a two-day period based on a forecast for dry weather a week ahead of time. Airlines plan routes for transoceanic flights based on next week's jet stream pattern. Fishermen plan recreational outings and schedule commercial activities (including ocean routes and docking times) based on forecasts that include sea surface temperature, water levels, winds, and waves.

5.0 Roadmap

This section provides a 25-year roadmap (beginning with current NWS technology baselines) of envisioned S&T advances, which would technically enable NWS to reach the capabilities targeted in Section 4. Achieving these capabilities will require improvements in all aspects (categories) of producing and making available weather, hydrology, climate, and related environmental forecasts and information. These categories are: **observations**, **data assimilation and numerical prediction**, **forecast techniques and product/information preparation**, and **dissemination**. Advances in all of these categories will also depend on improvements in **enabling technologies** -- principally computing, communications, and data extraction or visualization and **fundamental understanding.**

Section 5.1 introduces the S&T roadmap with capsule overviews of current and target S&T capabilities in NWS Today, Next, and After-Next, - the way-points to 2025. In Sections 5.2 - 5.6, the capsule overviews are expanded into more specific capabilities for each category listed above. In particular, a summary listing of key advances for NWS over the next twenty-five years is provided for each category listed above, followed by a timetable summarizing current and target capabilities. Last, but not least, Section 5.7 describes the advances needed in the fundamental understanding of the atmosphere, ocean, waterways, land, and space environment to improve every step of the forecast and information-generation process.

5.1 Capsule Overview of NWS Today, Next, and After Next

NWS Today: Currently, the NWS provides weather, water, and climate services to the public and other customers. Forecasts and warnings are issued by field forecasters, located in 121 Weather Forecast Offices, 13 River Forecast Centers, 21 Center Weather Service Units, and seven National Centers. Forecasters use observations, output from various numerical prediction models enhanced with statistical techniques, and other types of guidance and decision assistance tools to produce forecasts and warnings for time-periods ranging from minutes (for severe weather) to seasonal and intra-annual (for anomalous temperature and precipitation). Satellite and other automated observing systems for surface conditions (e.g., ASOS), rivers and streams (USGS river and stream gauges), atmospheric state (WSR-88D, wind profilers, radiosondes), and oceans (moored and drifting buoys), are supplemented with a variety of observations, such as those supplied by cooperative observers, ships, and in-flight avionics systems. Several times each day, observations are used to initialize regional- and global-scale numerical prediction models run centrally at the National Centers for Environmental Prediction. Week-2 forecasts are updated daily, and seasonal outlooks for general climate trends are generated on a monthly basis. Experimental probabilistic forecasts are currently based on 23-member global and 20-member regional model ensembles. These products are transmitted to forecast offices via satellite broadcast, where they are interactively displayed on AWIPS systems for use in developing forecasts and warnings. Local-scale models, such as workstation-Eta and others, are run experimentally at many WFOs. The Internet is used to transmit and display data and products on an auxiliary basis. Forecasters, assisted by interactive forecast preparation tools, issue warnings and forecasts, which are disseminated to the public over NOAA Weather Radio, electronic, and print media. NWS has recently initiated efforts to make digital forecasts available in the National Digital Forecast Data base (NDFD).

NWS Next: Over the NWS Next time frame, improvements in computing power, communications, and other enabling technologies will accelerate advances in all areas of the forecast and information generation process. More representative observations will be available, from a variety of new sources (e.g. mesonet systems, new satellite sensors) for more effective warnings and for use in initializing numerical models. Advanced data assimilation techniques will make efficient use of the exploding amounts of satellite and other remotely-sensed data in conjunction with in situ and targeted upper-air, and surface-based measurements. Models will be run at ever finer resolutions with improved physics for local, regional, and global applications; probabilistic forecasts for growing numbers of parameters will be based on amply populated ensembles. A common modeling framework will facilitate information sharing and connectivity among models for all spatial scales. The NDFD will expand to include additional information and products. Comprehensive model output and interpretation tools will be provided to the field forecaster in increasingly convenient formats for rapid interactive and efficient processing, and advanced decision assistance techniques. Real-time verification will be available to continuously assess forecast and guidance products. Dissemination to the public and other customers will rely on flexible alternative pathways to optimize accessibility and usefulness of both generic and specially requested- products.

NWS After-Next: By 2025, S&T advances will enable the NWS After-Next to provide seamless weather, water, climate, and other environmental information of greatly increased quality and quantity relative to today. A multi-dimensional data base will integrate observations, numerical prediction, climatological data, and human forecaster input, with accompanying uncertainty metrics for real-time, user-friendly access. This system will support not only NWS forecast and warning services, but tailored data-mining by private-sector and other users. More comprehensive observations will expand reliance on systems that adaptively target regions and features critical for reducing forecast uncertainty. These data (including point observations and high-resolution profiles of the atmosphere and oceans, areal imaging of land and sea-surface and volume imaging of atmospheres and oceans, over representative time periods) will be ingested in common-framework numerical prediction systems that describe environmental processes operating over space and time scales ranging from meters and minutes to thousands of kilometers and years, for time periods nearing the limits of predictability. Ensembles, with sufficient numbers of members to represent adequately uncertainty in both initial conditions and models, will provide a basis for extended probabilistic forecasts. Accurate forecasts and warnings will be disseminated over multiple media, with sufficient lead times for mitigating actions. In addition, all of this information, including observations, model output, forecasts and warnings, and other information will be available to forecasters and other users at any time, for any location, and in consistent, and convenient formats. Advanced public and private sector interactive data mining, decision assistance, and visualization techniques will support customized interpretation and applications.

The anticipated S&T advances for NWS Today, Next, and After Next are detailed according to category beginning in Section 5.2. Before presenting these roadmaps, a scenario of a sequence of hypothetical weather-based business decisions by a cement company in 2024 is provided in the box below to illustrate how these advances will link together to improve products and services in the After Next.

In the fall of 2024, J&S Concrete, Inc. is planning to bid on a Federally-funded project to upgrade the nation's interstate highway system. This particular job will cover a 20-mile stretch of I-70 east of Bloomington, IL. and must be accomplished between November 5 – 9, 2025. Because their bottom line is heavily influenced by decisions surrounding weather, J&S runs Weather Risk Support Software (WRSS) developed by Micro Environmental Software, Inc. Using the infinite-bandwidth internet, WRSS extracts and processes data from the NWS digital data base (NDDB), consisting of all sorts of atmospheric, hydrologic, oceanic, and environmental observations, forecasts, and information, and displays information specifically tailored to J&S's needs on the company's virtual displays. Of particular interest to J&S, are accurate probabilistic weather forecasts, not only to help with tomorrow's crew deployment decisions, but as in this case, to help decide whether to bid on the interstate contract work for next year. These probabilistic forecasts are based on human quality-assured output from hybrid combinations of multi-scale ensemble prediction systems initialized with sophisticated suites of sensors observing scales of critical atmospheric motion and running on configurations of powerful computers.

During the last 25 years, the research community has made large gains in longer-range (climate) prediction. Understanding the links between the ocean and atmosphere has progressed to the point where useful seasonal to inter-annual outlooks are routine. With the NDDB's one-year weather forecast data as input to their business decision model, J&S project analysts determine their loss versus gain ratio including potential weather variability is small. Armed with this projection, J&S submits their contract bid.

In May 2025, J&S learns they have won the contract. Analysts must now do a project review and the potential weather variability grows in importance. The NDDB and WRSS indicate November 2025 will be wetter than normal. The expected flow extracted from the NDDB data is for a highly meridional pattern forced by interactions between the Pacific "El Nino" and the recently discovered Atlantic atmospheric-oceanic cycle called the "Moroccan". The J&S business model takes these wetter weather probabilities into account and recommends mitigation actions: acquisition of new fast drying concrete, rain gear for crews, tarps, new all terrain tires for trucks, etc. J&S is now at a higher risk level for job completion.

One week before the work is to begin, the weather is becoming the key factor. Crews, vehicles and material are being staged. Sophisticated high-resolution model output (as accurate at 7 days, as 4 days was at the turn of the century) sustains the NDDB over the 3 to 7 day time frame. On Nov 7th, a cold front is predicted to bring showers and thunderstorms, followed by brutally cold conditions and snow. In the J&S decision model, the cost/loss ratio has been exceeded by the NWS probabilities, telling J&S to postpone the tasks to be done on Nov 8 and 9. The costs for fines paid to the state DOT are far lower than the potential loss of having the crews, equipment, and material exposed to the elements.

After benign conditions on Nov 5 and 6, winds on the morning of Nov 7 are strong out of the south carrying abundant moisture. The J&S project manager saw the job completion risk factor rise overnight with the increasing probabilities of thunderstorms and precipitation. Early on the morning of the 7th, the evolving NDDB and WRSS models were predicting J&S risk thresholds would be exceeded by 1 P.M. The project manager informed the crews work would terminate at noon and be shut down until at least Nov 10th owing to sustained adverse weather. By mid-morning on the 7th, a dense network of government and private surface observing stations detects a gravity wave, which later initiates a powerful line of storms ahead of the front. Lines of convergence are detected just prior to the development by phased array radars. Data from the radars and human interpretation are fed into the NDDB. Short-range predictive models, which include explicit cloud physics and initialized in hot-start mode with advanced data assimilation techniques ingesting the phased array and multi-channel satellite data, allow accurate thunderstorm forecasts out many hours. With severe weather probabilities exceeding all J&S warning thresholds earlier than expected, the project manager's wireless decision display sounds an alert (along with NWS' public warning service) providing him two hours lead time to react to severe storms at the job site. The device also provides all mitigating actions necessary for employee safety and equipment protection. The project manager informs the crews to terminate work at 10 a.m., take appropriate mitigating actions, and seek shelter out of the work area by 11a.m.

5.2 Enabling Technologies

As part of the MAR effort, the NWS made significant upgrades in its infrastructure to support the quality, flow, display, and manipulation of data and information. Major components of these improvements were the development and deployment of the WSR-88D, ASOS, and AWIPS networks. In addition, enhancements to high-performance computing, communications and other enabling technologies have allowed the NWS to process newly available observational data with higher temporal and spatial density; run numerical prediction models at higher resolution and with more complex physical parameterizations; transfer information more rapidly and reliably to forecasters and users; and supply forecasters with interactive analysis and display capabilities. Regional servers play an active role to bring experimental data sets into an operational setting. A variety of NWS data, models and products can be accessed by internal and external users. Current and projected future NWS capabilities in these enabling technologies are summarized in Table 5.2.

Continuous enhancements to this modernized infrastructure must be made to avoid the need for future full-scale overhauls, implement advances in forecasting, and establish an integrated data base for storing/accessing all NWS information. However, an aggressive approach is essential for incorporating projected technological improvements into the NWS infrastructure and operations: not only those developed internally, but externally as well.

Over the NWS-Next and After-Next time frames, anticipated product and service improvements will rely heavily on keeping pace with increases in high performance computational capacity and communications. This will be necessary as increases in volume, resolution, and complexity of hydrometeorological and climate information outpace the capabilities of current systems before the advent of the NWS-Next time frame. Infrastructure to deliver training efficiently will be needed so that forecasters can quickly utilize the advancements. Using key advances in enabling technologies (see box) the NWS will be able to accomplish the following:

- domain-wide security;
- elimination of single points of failure in all systems;
- data on demand in a broadly accessible format;
- 100% global accessibility of NWS products and information by means of a multi-dimensional data base;
- flexible architecture and adaptable software;
- maintain NWS-wide standards; and
- rapid incorporation/deployment of new technologies NWS-wide.

Likewise, data extraction capabilities for forecasters and other users must be enhanced to make optimal use of enriched products and data sets. “Knowledge management” will become an important issue as forecasters become inundated with an increasing amount of varied and complex data and guidance products. The use of expert systems will assist forecasters in effectively and efficiently processing the information. In addition to operational improvements, the infusion of science and technology into the organization will address and improve the NWS business and administrative processes. This will allow the organization as a whole to be more efficient and productive.

Key advances in enabling technologies include:

- high performance computing;
- incorporation of computers as sophisticated information handling nodes in communications networks;
- use of a global Internet and the WWW for cost-effective transport of information, both internally and externally;
- expanding use of wireless and mobile technologies for both internal and external applications;
- use integrated data bases for all NWS information and products, and incorporating data extraction capabilities into all disseminating services;
- implementing microprocessors that add "intelligence" to the growing range of products and services; and
- fusion of audio, graphics, video, and digital communications through interchangeable, interconnected modes of transmissions (e.g. digital telephony and interactive video, wireless digital communications, and multimedia messaging).

Table 5.2 Summary of NWS Current and Future Enabling Technologies. Capabilities are shown in regular font if they appear current in multi-year NWS program lines; otherwise in italics.

Component	NWS Today	NWS Next	NWS After-Next
COMMUNI-CATIONS	SBN: 2 ½ channels AWIPS WAN: 1.5 Mbps max AWIPS LAN: Max 100 Mbps NWSTG: roughly 20 networks/ subscribers, backup facility -mainframe -point-to-point to IP-based -security -copper to fiber -upgrading circuits and routers -625K bulletins acquired/day -2000K bulletins transmitted/ day	*Expanded SBN* *WAN/LAN: Expanded operational network capabilities* *NWSTG-2,. At least double the volume, in half the time* *-distributed architecture* Wireless communications Video communications	*Advanced technology/ data on demand* *Further advances in data compression techniques*

Component	NWS Today	NWS Next	NWS After-Next
COMPUTING TECHNOLOGIES	NCEP Class IX/X supercomputers (FY05 requirement of 1.5 sust. tflps) AWIPS: Hybrid UNIX/LINUX	"Next" generation computing (minimum 300 sust. tflps) Operational network with continuous increasing in power	*"After next"computing*
INFORMATION EXTRACTION	AWIPS: 2-dimensional displays with time looping capabilities	Operational network: 3+-dimensional visualization with time looping capabilities	
NWS SYSTEM ARCHITECTURE	Architecture not standardized Integrated architecture within NWS	Integrated within larger external framework	
DATA FORMAT	GRIB1, GRIB2, BUFR RedBook Graphics, ASCII Text, GIF, TIF, ftp/http, ATM, frame relay, SHEF GINI	Fewer, standardized, adaptable formats supported for data base integration Advanced data compression techniques	
SECURITY	Ad hoc Initial use of Protective Kernel Interface and certificates to prevent spoofing of NWS information	Integrated into all technologies, products, and services Denial of service solved at the national network level Advanced Encryption	
SOFTWARE	Ad hoc	Modular code Modular model architectures Highly tuned Backwards compatibility	Highly adaptable
OTHER	Internet 2- limited use Limited data extraction capabilities (e.g., GIS)	Internet 2- standard for public Full suite of data extraction capabilities, Mobile operating network systems	Adaptive, dynamic, self-organizing networks

5.3 Observations

Currently, the NWS collects, archives, and ingests into models a suite of observations from ground-based sensors, river and stream gauges, WSR-88D Doppler radar, marine and atmospheric soundings from balloons, profilers, aircraft, and satellite, and other remote-sensing capabilities. Additional observations are available to field forecasters for severe weather warnings and routine forecasts. These include: cooperative observer-supplied temperature and precipitation, and severe weather; lightning; wind profiler data; mesonet observations in some localities; and incident observations at wildfires. Remotely sensed observations (both surface- and space-based) uniquely provide broad coverage required for longer forecasts, and detail needed for high-resolution forecasts and frequent updating. In situ observations provide directly measured "ground-truth" sampling which anchor remotely sensed observations and provide the basis for long range climate monitoring and prediction. In situ and remotely sensed data are archived at the National Climatic Data Center (NCDC) where they are available to researchers for retrospective study. Temperature, moisture, winds, pressure, precipitation, and cloud condition data are transmitted to the National Centers for Environmental Prediction (NCEP) for numerical weather prediction (NWP) model ingest and initialization. River and stream gauge, temperature, precipitation, radar estimated precipitation, and satellite precipitation estimate data are transmitted to the River Forecast Centers (RFCs) for hydrologic model ingest and initialization. A comprehensive listing of observations available from all federal agencies is maintained by the Office of the Federal Coordinator for Meteorology (OFCM, 2000).

NWS Today and NWS Next improvements (summarized in Table 5.3) focus on increasing sensor accuracy in representing environmental conditions. A principal focus of advanced sensor technologies for improved observations is better delineation and measurement of water in all phases in the atmosphere and in the hydrosphere (ground, streams, rivers, oceans). As an example, forecasts for severe weather rely heavily on observations that are currently too coarse to detect damaging small-scale convection; better delineation of planetary boundary-layer winds, clouds and moisture structure, and their changes with time will improve forecast accuracy and timeliness. This will be accomplished by expanding temporal and spatial coverage of observations of weather, water, and climate elements with a combination of in situ and remotely sensed measurements. Additional observations are also required to meet accuracy goals to further improve NWS analyzes and forecasts-- e.g., land surface moisture, turbulence, cloud properties, total lightning activity, fire and smoke properties, chemical data, and soundings of ocean temperature, salinity and currents-- in some cases via expanded use of partnerships, both internal and external to NOAA.

Projections in the NRC Vision for observing systems of the NWS After Next, include advances in sensor technologies for both direct sampling and remote sensing of environmental data and expanded use of data collected from mobile and situationally targeted adaptive platforms. Increased spectral coverage of satellite and other remote sensors will expand the types, and precision, of parameters monitored resulting in improved vertical temperature, wind, and moisture information. The advent of representative, real-time measurements of chemical species that have health and climate impact (e.g. atmospheric ozone, oxides of nitrogen and sulfur) will provide the basis for skillful forecasts of air quality. By this time frame, it is expected that the suite of observations will be available on a free and open, real-time basis, through the access to an integrated data base incorporating observations, analyses, forecasts and other products for North America. Observations in this data base will be updated in real-time as data are collected from in situ and remotely sensing platforms.

Well before the After Next, the NWS will be ready to exploit platforms and sensors of opportunity in the government and private sector. The ubiquitous growth of Global Positioning System (GPS) technology in all forms of consumer appliances and vehicles, an explosion of relatively inexpensive two-way wireless communications, and micro-circuitry of meteorological sensors such as temperature, pressure, and moisture will allow the NWS to gather data from all corners of the Earth at a fraction of the historical cost (e.g., a wireless mobile cooperative network built into consumer cell phones and Personal Digital Assistants (PDA)).

Currently, using commercial aircraft as a platform of opportunity (e.g., the Meteorological Data Collection and Receiving System (MDCRS) program) enables the NWS to gather thousands of mission critical data points in the atmosphere at a fraction of the cost of using government weather reconnaissance aircraft. Successful private sector and government collaboration like these must be reproduced many times over in the "After Next" time frame. This concept could be extended to the commercial satellites in Low Earth Orbit (LEO) which will be launched by the thousands over the next 25 years to enable broadband Internet for all parts of the globe. Partnerships with satellite communications companies will replicate the success of MDCRS by supporting the incremental costs of adding low power low weight environmental sensors to some of these communication LEO platforms. This will allow the NWS and end users such as cell phone customers, access to real-time high resolution imagery of the Earth from the very same communications satellite that completes their phone calls.

Key advances in observations include:

- increasing temporal and spatial coverage;
- better delineation of atmospheric moisture in all phases;
- increased use of remote sensors;
- increasing (situational) use of adaptive observing systems;
- increased focus on the planetary boundary layer;
- increased focus on oceans-to extend range of forecasts, develop time-series data record;
- increased measurement spectrum and interferometric and polarimetric methods; and
- wider range of parameters measured-- e.g., land surface moisture, and chemical data.

Table 5.3. Summary of NWS current and future observing capabilities. Capabilities are shown in regular font if they appear current in multi-year NWS program lines; otherwise in italics. Bold italics denotes potential non-NOAA systems.

Component	**NWS Today**	**NWS Next**	**NWS After-Next**
IN SITU	ASOS	Augment ASOS *Mobile observing systems*	
Surface-based (in situ, non-marine) observations:	River/stream gauges–height	*Lake surface temperatures*	*Chemical weather data*
	Coop observer network, with rainfall, stream gauges, temperature data	Upgrade coop network completed: soil moisture/ temperature data added	*Real-time coop network*
	Incident observations (e.g. wildfire, oil spills)	*Extend use and data ingest from mesonet observing systems*	
Marine observations (in situ)			
Surface:	Fixed and drifting buoys; ARGO floats		***Integrated global observing system***
	Wind profilers (coastal)	Wind profilers (buoy-mounted)	
	CMAN stations	*Buoy sensor advances for reliable long-term monitoring of winds, waves, currents, salinity tsunamis, air-sea flux*	*Advanced instrumentation on commercial ships (MDCRS for the sea)*
	Ship-borne obs.: temperature, winds, waves, current, salinity		
Subsurface:	Ocean profilers: temperature, current, salinity sensors	*Increased density and frequency of profiles*	
Upper Air: (In situ)	Radiosondes	GPS-radiosondes	*Stratospheric balloons*
	MDCRS; *increasing use of WVSS*	Expanded MDCRS	*UAV-dropsondes over oceans*
		Broaden operational use of UAVs, driftsondes	

Component	NWS Today	NWS Next	NWS After-Next
REMOTE SENSING **Surface-based (remote) sensing**:			
Radar	WSR-88D: Open architecture (rainfall estimates for hydrologic forecasts) FAA ARSR-4, ASR-9, 11, TDWR	Dual polarization ***X-band radars*** (fill gaps in 88D coverage) ***CODAR*** (shore-based HF radar for mapping currents)	*Phased array, polarimetric and multi-channel* ***Dense arrays: X-band***
Other radars, lidars, etc.	Wind Profilers *Boundary-Layer profilers* National Lightning Detection Network (C-G) TRMM Lightning Imager Sensor (LIS)	*Expanded wind-profiler network* *AIRS, RASS, GIFTS profiles of moisture, winds, radiance* *Moisture profiles from ground-based GPS receivers.* *Solid-state acoustic profilers (e.g. RASS) for PBL over oceans*	*Increasing sensor spectra: microwave radiometers, acoustic sensors, lidars* *Acoustic techniques for sub-surface oceanic currents, salinity*
Multi-System: Satellite Combined: geostationary, polar-orbiting, LEO, constellations Other research satellites	Emphasis: optical/IR measurement of temperature (T), SSTs, precipitable water, winds, cloud coverage, cloud radiance, radiative energy flux	*Sensor advances: radio occultation and limb soundings, multispectral obs.*	*Increasing multispectral (with high spectral discrimination) data: e.g. microwave, lidar, acoustic sensors* *Tomographic atmospheric imaging.* *Satellite systems: central with orbiting companions for wide-aperture sensing* *Other orbits: MEO, Molniya, L1, L2, satellites*

Component	NWS Today	NWS Next	NWS After-Next
Polar-orbiting (POES)	Emphasis– vertical resolution, geographic coverage for radiometric T and WV	NPOESS Preparatory Project	NPOESS deployed *Wind profilers (e.g. Doppler lidar)*
Geostationary (GOES)	Emphasis: Tropics and mid-latitude imaging- Visible/ IR wavelengths: imaging cloud and WV, precipitable water, atmospheric stability, precipitation estimates Microwave sensors: Soil moisture Radiometric msmts: Radiative flux, evaporative flux, T WV	GOES-R+ Series *Satellite constellations for better coverage and calibration.* Multispectral precipitation estimates	*Active microwave observations*
ADAPTIVE OBSERVATIONS	Situational use: e.g. hurricane flights, winter dropsondes in East Pacific, snow survey flights	*Broader program of targeted obs-- e.g. UAVs, dropsondes in regular operational use*	*Network of mobile met-sensors* *Satellite observations--programmable, adaptive* *UAVs with active sensors (e.g. microwave radiometers)*
OTHER non-NOAA SYSTEMS	NASA EOS satellites DMSP observations ***Integration of local and mesonet observing systems--e.g. highway sensors, RAWS*** ***Commercial radar data***	***Platforms of opportunity: vehicle-mounted sensors*** *Total Lightning from GEOs*	***Chemical weather monitors***

5.4 Data Assimilation and Numerical Prediction

NWS currently employs a three-dimensional variational (3DVAR) approach to initialize its suite of regional- and global-scale numerical prediction models. Variational data assimilation is primarily performed at NCEP and the RFCs (for hydrologic models), where most of the real-time satellite, radar and national observing network data can be ingested in numerical prediction models. At NCEP, an experimental data assimilation system is running daily for land surfaces over the conterminous United States (CONUS) that insures self-consistent analyses of temperature and moisture for the surface, soil and vegetation or canopy. For ocean observations, a variational assimilation system is being tested in the ocean and climate models. Future developments in data assimilation will include improving the treatment of error statistics, data quality control and new forward assimilation models that are necessary for handling the expected exponential increases in observational data noted above.

Today NWS employs fourteen separate forecast modeling frameworks: climate (AGCM & SFM), global (MRF), regional (Eta, RUC, RSM) as well as oceanic (COFS), specialized (GFDL Hurricane model), land-surface (NOAH), threats and dispersion (HYSPLIT) systems, and several hydrologic models. NWS RFCs use the NWS River Forecast System (NWSRFS), a spatially lumped conceptual approach for modeling current soil moisture and stream flow conditions on the streams and rivers for low flows, floods and navigation. Oceanic models are currently run for the West Atlantic for 48-hour forecasts. NWS modeling systems and planned evolution are shown in Figure 5.4-1. Atmospheric model resolutions range from 200 to 10 km horizontally, with approximately 40-60 vertical levels through the troposphere, and up to 25 levels in the boundary layer. Ensemble prediction techniques are used for time periods ranging from one day out to seasons. In the NWS Today time frame, computational resource limitations may well impose tradeoffs among model resolution increases, advanced assimilation approaches, and increasing numbers of ensemble members. Features that are resolved at these various scales, and principal model applications, are listed in Table 5.4-1 for each model in the NWS suite. Local-scale models, such as workstation-Eta (WS-Eta), are run experimentally at many WFOs. The models are not linked, except that the larger-scale atmospheric models provide initialization and boundary conditions to drive the finer-scale and oceanic, hurricane, hydrologic and dispersion models. Within the NWS regional and local weather models, there is limited coupling of atmospheric and land modules; the NWS hurricane model incorporates limited atmospheric--oceanic coupling. For the short-range (0-72 hrs), ensemble techniques are run routinely for evaluation purposes. Table 5.4-2 summarizes NWS current and future modeling capabilities.

During the NWS Next time frame, model resolution will increase, and atmospheric models and data assimilation systems will be fully coupled with those for land, ocean, sea ice, and land surface systems. The greatest immediate impact of this coupling on forecast accuracy is expected to be at the climate and global scales, where the feedbacks are especially significant. The first four-dimensional (space-time) variational data assimilation systems will be implemented. While coupling will provide improved representation of surface physics processes, increased accuracy will also require a more complete inclusion of turbulence, cloud, precipitation and radiation physics. An explosion of new remotely sensed data should be available which will require advanced assimilation techniques for ingest in operational numerical prediction models. In concert with the new data access, improved and more efficient techniques to evaluate a future observing system's impact on model simulations (OSSE) will also be developed. A new, common modeling framework, named the Weather Research and Forecast (WRF) system, will resolve regional and local-scale phenomena, such as non-hydrostatic circulations and convective processes. These features are critical for improving forecasts for precipitation type/amount and severe weather, for example. Computing power would be large enough to run high resolution models on demand for rapidly evolving atmospheric conditions, at least locally, by this time. Additional examples, listed in Table 5.4-1, indicate where implementing the WRF system and upgrades for increased resolution will drive improvements in forecast accuracy with better treatment of local- and regional-scale phenomena. By this time, dynamic stochastic techniques may be mature enough for use in adaptive parameterization of some physical processes (e.g. cloud micro-physical processes). Extending the use of common modeling infrastructures should reduce the number of NWS forecast models to six. As part of the WRF framework, the first operational models to predict air quality for short-term, national and regional applications are

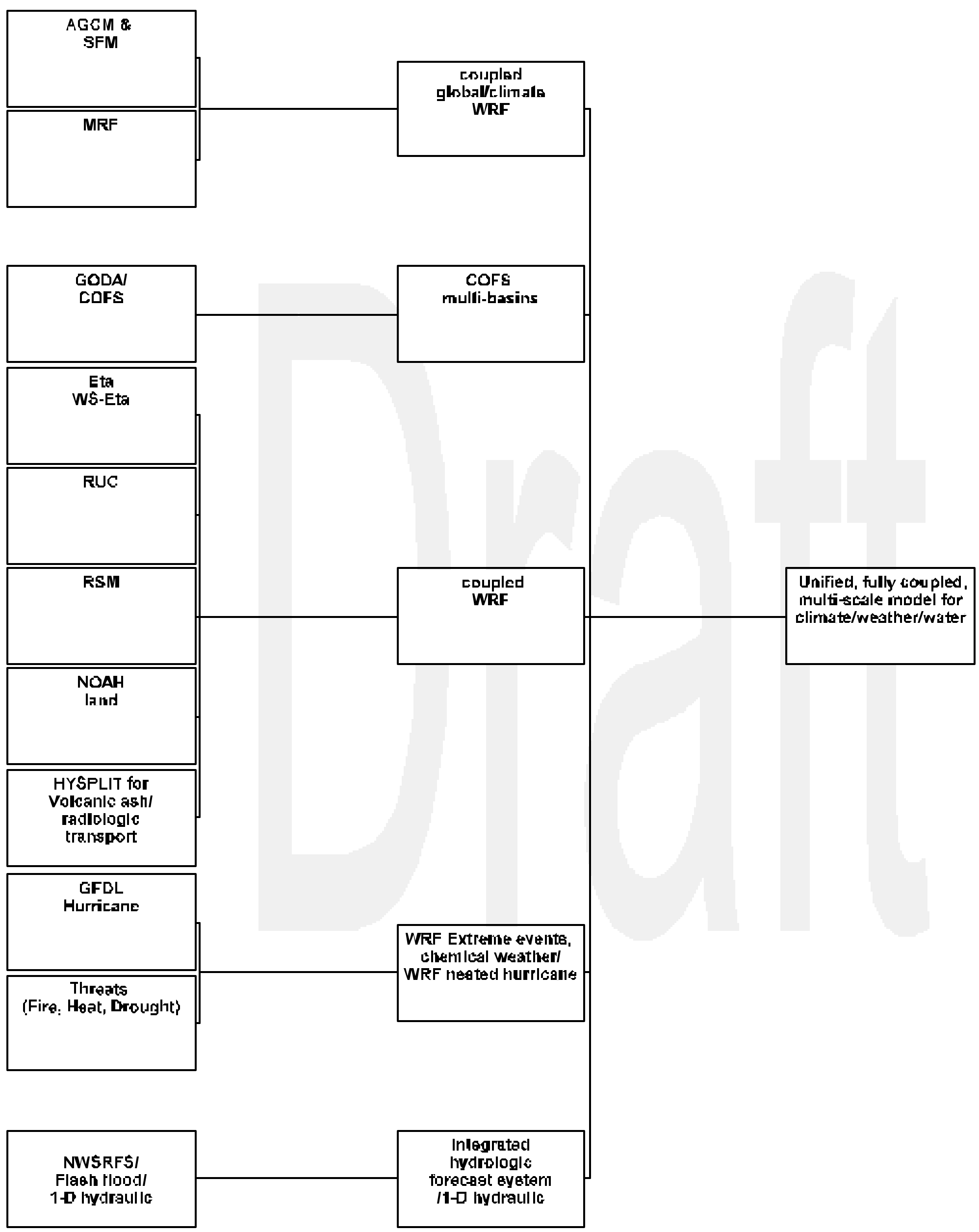

Figure 5.4.1. Expected progression of NWS numerical models

Table 5.4-1. Summary of NWS current and future data assimilation and numerical prediction capabilities. Capabilities are shown in regular font if they appear current in multi-year NWS program lines; otherwise in italics.

Scale	**Spatial Extent**	**Phenomena resolved**	**Applicable Model** **NWS Today 6 NWS Next**
Climate	Global/ regional	2 week/seasonal/ interannual prediction of anomalies; phase shift of climate modes (e.g. ENSO, PDO, AO); flood/ drought, environmental threats	AGCM, SFM 6 WRF Global
Global	Global	Medium to long-range planetary wave prediction	MRF 6 WRF Global
Oceanic	200 km - Global	Currents, eddies, waves, coastal water-level	COFS 6 WRF / coupled ocean model
Regional	200km-2000 km	Short-range synoptic-scale fronts, low pressure	Eta, RUC, RSM 6 WRF
Local	20 km-200 km 2-20 km < 2 km	Gravity waves, short-range land-water breezes, hurricanes, convection, complex terrain, fire weather, turbulence, storm-scale processes	WS-Eta, Hurricane 6 WRF
Hydrologic	1 km -2000 km	River, stream flow and floods Flash floods (site specific) River hydraulics	NWSRFS 6 Integrated HFS NWSRFS 6Integrated HFS 1-D unsteady flow hydraulic routing 6 improved routing
Land	20 km -Global	Short-range out to seasonal/ interannual soil, vegetation conditions	NOAH 6 WRF
Dispersion	<2 km -2000 km	Volcanic ash, smoke, air quality, radiological transport, deposition	HYSPLIT 6 WRF
Global Ensembles	200 km -Global	Short-range out to seasonal/ interannual synoptic-scale prediction of threats, droughts, ENSO	RSM/Eta 6 WRF and international center models

anticipated in this time frame as well. Increases in model resolution and in the tractable number of ensemble members will boost accuracy in short- and medium-range predictions (daily to weekly to seasonal), while providing reliable forecast uncertainties at all ranges. More general use of ensemble methods is anticipated, such as for storm-scale events, hydrological simulations, and for developing variational assimilation error covariances. The first operational integrated Hydrologic Prediction Systems (HPS) will be introduced to predict river and stream flow as well as runoff in the watershed. This physically based distributed model integrates snow and runoff. Experience with such operational numerical prediction systems will be the basis for establishing operational, fully coupled hydrologic-atmospheric operational models, in the NWS After-Next time frame.

In the NWS After-Next period, integration into a single multi-scale model will significantly enhance opportunities to incorporate atmospheric-land-hydrologic-ocean-sea ice coupling on all scales. Improvements in coupling on the regional and local-scales will be facilitated with a comprehensive common modeling system that includes environmental processes operating over time-scales ranging from hours to decades, and from sub-kilometer to global distances. New remotely sensed data will be available which will require additional advanced assimilation techniques for ingest in operational numerical prediction models. Such data could include micro-scale phenomena (e.g.: turbulence, cloud microphysics, surface fluxes). Techniques to perform assimilation in fully-coupled systems will be developed in this time-frame. Hydrological models will be fully coupled with atmospheric land-surface models to provide more complete predictions of watershed basins and their interactions with the atmosphere. Variations in flux and reactivity of atmospheric constituents will be fully incorporated in atmospheric models. Advances in computational science and technology will support deterministic and richly-populated ensemble predictions at times that approach limits of predictability, for spatial scales horizontally of 1-10
km and vertically to meters through the boundary layer. Increased reliance on ensemble predictions and better understanding of physical processes will increase reliability of climate predictions for longer time-scales. Multiple-scale phenomena will be described and predicted with flexible, adaptive high-resolution capabilities. High-resolution local models will
incorporate phenomena at the urban-scale (down to tens of meters), including chemical weather processes and fire propagation. All model output from these prediction systems will be available km and vertically to meters through the boundary layer. Increased reliance on ensemble predictions and better understanding of physical processes will increase reliability of climate predictions for longer time-scales. Multiple-scale phenomena will be described and predicted with flexible, adaptive high-resolution capabilities. High-resolution local models will in the data base. By this time, models will be run on demand in a distributed or central fashion, with concurrent increases in computational and telecommunications power.

Over the next 25 years, fundamental challenges will be addressed that cover all aspects of atmospheric, ocean, sea-ice and land surface data assimilation and numerical forecast modeling. Concomitant advances in enabling science and technologies (increased understanding of environmental processes and capacity, speed and efficiency in observations, communications and computation) will be necessary.

Key advances in data assimilation and numerical prediction model development include:

- data assimilation for the exponential increase in observations of the atmosphere/ land/ surface/ ocean system; necessitating data quality control, and improved forward models;
- development of common modeling infra-structures for the climate and weather systems;
- physically based hydrologic forecast models;
- improved models for the atmosphere, including dramatic improvement of model physics and numerical treatments, incorporation of chemical weather phenomena (especially for air quality and fire weather), and relevant, comprehensive verification algorithms;
- similar improvements in and full coupling among models for land surface, hydrologic, oceanic, and atmospheric systems; and
- improved ensemble forecast techniques.

Table 5.4-2. Summary of NWS current and future. Capabilities are shown in regular font if they appear current in multi-year NWS program lines; otherwise in italics.

Component	**NWS Today**	**NWS Next**	**NWS After-Next**
Data Assimilation	3DVAR; background error covariance estimation	Advanced assimilation (e.g.: 4DVAR); improved QC and forward models; land-atmosphere coupling; expanded base of ingested observations for additional physics	*Fully coupled advanced assimilation; expanded ingest–new observations for detailed physics
Physics	2nd order closure PBL, bulk radiation, 5 species cloud microphysics, parameterized convection, coarse land surface coupling, similarity theory surface layer	2nd order closure PBL including urban effects, 20 species cloud microphysics, explicit convection, local radiation parameterizations, interactive ocean effects, advanced in-canopy land sfc processes, dynamically adaptive physics	Explicit turbulence, aerosol interactions with cloud and radiation process, advanced surface physics thru full coupling with biological, hydrologic, ocean models
Climate	**AGCM** & **SFM** 14 day (200km) coupled to ocean models Statistical tools	**Common** regional and global WRF climate model infra-structure coupled* (single-tier)	***Fully coupled** inter-annual and global change physics
Global	**MRF** (80 km)	WRF global medium range coupled* (30 km)	Fully coupled (10 km)
Ocean	**COFS** Atlantic, Alaska (20 km) **GFDL** hurricane coupled to ocean model (10k)	**COFS** multi-basins (5 km) WRF **Nested hurricane** (8 km)	Fully coupled global (10 km) Fully coupled regional (1km)
Regional	**Eta** (22 km), **RUC** (20 km), **RSM** (40 km)	**WRF** coupled (6 km)	Fully coupled (1 km)
Local	WS-Eta and Threats (10 km)	WRF coupled (2 km)	Fully coupled (100's m)
Land	**NOAH/LDAS**	Coupled Global (30 km) and WRF coupled regional (10 km)	Fully coupled regional (1 km)
Hydrologic	**NWS RFS–** lumped conceptual runoff, physically based snow and channel models. Lumped parameter estimation (a priori) Site specific **flash flood** model 1-D unsteady flow **hydraulic** routing	A **Integrated HFS** with distributed parameter estimation (a priori) 1-D **hydraulic** routing including ice jams and channel losses	Fully coupled LSM (1 km) 2-D hydraulic models
Other Hazards	**HYSPLIT** -- volcanic ash and radiological dispersion; **threats** (fire, heat index, drought)	*WRF Air quality* (multiple species) WRF Threats, Fire weather	*Coupled hazards-atm-land-ocean*

Component	NWS Today	NWS Next	NWS After-Next
Ensemble	Global (MRF 200 km) Regional(Eta/RSM 48 km) Hydrologic (ESPADP)	Global–common global(60 km) Regional--WRF (22 km) Hydrologic – integrated HFS, simple hydrologic models New: Local–WRF (10 km) New: Oceans, hazards	Multi-centers global (10 km) Hydrologic - LSM (1 km)

** Coupled = Interactive land-atmosphere-ocean-sea-ice systems. Fully coupled integrates hydrologic modules*

5.5 Forecast Techniques and Product/Information Preparation

The NWS Today makes widespread use of a variety of scientific techniques to support the task of forecasting and product preparation. Statistical forecasts are generated using multiple linear regression (Model Output Statistics - MOS) and provide valuable forecast guidance throughout NWS. The utility of MOS forecasts will continue to be improved with increases in the number of cycles and elements forecast. Other probabilistic techniques with expanding use in NWS Today include ensembles and elementary techniques for precipitation and temperature forecasting. These probabilistic/statistical techniques are allowing NWS to begin issuing probabilistic forecasts including probabilistic quantitative precipitation forecasts (PQPF), probabilistic river stage forecasts, and probabilistic winter weather guidance and products. In addition, current operational monthly and seasonal climate forecasts are based on both statistical tools and numerical models.

Decision assistance techniques have become a staple in most forecast offices for monitoring incoming data and alerting forecasters of the existence of critical weather areas. Fuzzy logic and neural network applications are being applied to the identification and forecasting of hazardous conditions, with most such output in the “experimental” stage at this time. Specific packages for NWS Today include the System for Convection Analysis and Nowcasting (SCAN), including AutoNowcaster capability; System on AWIPS for Forecasting and Evaluating SEas and lAkeS (SAFESEAS), and numerous aviation applications based on hybrid forecasting techniques.

A wide array of interpretive, diagnostic, and predictive techniques are becoming available to support the forecast process in NWS Today, including Advanced Hydrologic Prediction Services (AHPS), extratropical wave forecast techniques, automated tsunami forecast techniques, probabilistic flood forecast and inundation mapping, and quantitative precipitation estimation techniques. AHPS is designed to take advantage of the growing skill in short- to long-range weather and climate forecasts to produce hydrologic forecasts with lead times of a few days to several months. It will provide river forecasts that not only account for precipitation already on the ground but also will probabilistically account for estimates of future precipitation.

Interactive support for operational forecast product preparation has recently been initiated. The Interactive Forecast Preparation System (IFPS) supports the current suite of NWS text forecast products and will provide the infrastructure, as the product suite evolves, to include more graphic and digital products. Throughout NWS Today, improvements will continue to be made to IFPS to add additional capabilities that enhance the utility of the software and address workload issues associated with this new methodology of forecast product preparation. Within the next five years, the National Digital Forecast Data base (NDFD) will provide users with gridded forecasts from across the country. National verification procedures will be expanded and improved to verify additional products and most of the forecast elements within these products.

During the NWS Next and After-Next time frames, improvements in the accuracy of numerical model output, combined with increased sophistication in decision assistance techniques, will enable forecasters to enjoy greater reliance on automated output. Probabilistic and statistical techniques will continue to improve. Use of ensembles will be expanded. Statistical techniques will employ more advanced algorithms, incorporating non-linear regression and eventually operations research/decision theory, and will provide guidance support for more probabilistic forecasts. Improvements in the fundamental understanding of climate variability will provide more statistical tools for climate forecasts. Improved probabilistic forecasting techniques will enable NWS to produce a greater number of probabilistic forecasts, such as probabilistic river stage forecasts, severe weather warnings and forecasts of the severity of large-scale winter storms. Confidence metrics will be specified for all forecast parameters. Dramatic improvements in decision assistance techniques will continue, with advanced hybrid forecasting systems making use of neural network output and fuzzy logic. These intelligent weather systems (IWS)[4] will provide support for all service program areas and long-range forecasts. Specific packages will include advanced versions of the national airspace products now being issued by the Aviation Weather Center (AWC), THOR for support of aviation and public interests, IWS-based decision models for improved hurricane track and intensity forecasts, and the DiCAST point-forecast technique that will be applied to long-range and seasonal forecasts. The array of interpretive, diagnostic, and predictive techniques available to support the forecast process in NWS Next and After-Next will expand, including beach/coastal erosion forecast techniques, integrated distributed river and flash flood models, dispersion modeling and a national boundary detection program. Quantitative precipitation estimates will employ new techniques for incorporating dual-polarized radar and other new remotely sensed data, and uncertainty specification will be provided through ensemble analysis. The NDFD will evolve to include observations and expanding suites of forecast information.

In the NWS After-Next period, a single integrated multi-dimensional data base[5] will be the primary repository/access point for all NWS weather, water, and climate, and related environmental information. This will contain, for the first time, an integrated record of observations, numerical prediction, human forecaster, and statistically- otherwise processed data with accompanying uncertainty metrics. Advanced extraction algorithms will mine the information so that NWS can provide analyses, forecast, and warning products and services, and make available its wealth of information in

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4 Following NCAR's definition, Intelligent Weather Systems (IWS) are forecast systems that use fuzzy logic as a mathematical integrator of diverse types of weather data to derive the best estimate of a single weather parameter defined for a specific time and location.

5 The multi-dimensional data base will contain, for specified time/location, standard-grid data, specific-point data, and specific event or phenomenological data.

user-friendly formats. Research in social sciences and communications will help shape the most useful products for our users. For specific decision making and other tailored applications, organizations or individuals will use private-sector services, software, and other customized tools to interrogate and mine the data base.

Verification/validation capabilities will be improved to provide quantitative parallel measurements of model, human, and hybrid post-processing technique forecast performance using advanced methods at high time/space resolution. Results will be used to determine the optimum synthesis of forecast inputs to populate the multi-dimensional digital data base and to measure the impact of continued technology infusion on NWS products, services, and information.

Key advances in forecast techniques and product/information preparation include:

- hybrid forecasting, which combines observations, mesoscale NWP guidance, numerical modeling, climatology and human input in expert systems that use rule-based or fuzzy logic;
- probabilistic forecasting, providing information on the uncertainty/reliability of forecasts;
- production of a multi-dimensional data base integrating easy-to-access observation, model and forecast information;
- distributed hydrological forecast techniques; and
- new artificial intelligence/decision assistance techniques.

Table 5.5. Summary of NWS current and future forecast techniques and product/information preparation capabilities. Capabilities are shown in regular font if they appear current in multi-year NWS program lines; otherwise in italics.

Component	NWS Today	NWS Next	NWS After-Next
Decision Assistance	Hydrometeorological data monitoring and alert Elementary hybrid systems Elementary neural networks and fuzzy logic Initial prognostic capabilities Specific packages: SCAN, AutoNowcaster, numerous aviation products, SAFESEAS	Increased use of neural networks, fuzzy logic, hybrid systems Increased prognostic output *IWS* *NWS gridded output to support user's decision assistance tools* Specific packages: THOR, advanced national airspace products, *DiCAST*	*Advanced hybrid forecasting systems use neural net output* *Support provided for all service program areas and long-range forecasts*
Forecast Preparation Systems	By 2005: IFPS supports all program areas; smart tools and initialization; elementary "model interpretation" tools (blend models, adjust thresholds); supports inter-site coordination and site backup; supports OCONUS sites	IFPS focus on interactive "model interpretation" (blend models, adjust thresholds) and other new techniques Tools integrate data on dams and current conditions, GIS maps, and techniques for preparing warnings and guidance on dam failures.	*Expert systems identify which model/models to initialize forecast* *Advanced preparation tools (e.g. meteorologically consistent 4-D editing/ adjustment of model fields)* *"Smart" analysis and visualization tools*

Component	NWS Today	NWS Next	NWS After-Next
Probabilistic Forecasting/ Statistical Techniques	MOS based on multi-linear regression: run on AVN, MRF and Eta models; 4 cycles; increased elements forecasted; use of ensembles; gridded output	*Statistical techniques adjust MOS values to any location* *New techniques (non-linear regression, neural nets)*	*Output forecasts based on operations research, decision theory, and other techniques* *Dynamic MOS*
	Limited use of ensembles	Expanded use of ensembles	
	Elementary techniques for precipitation and temperature forecasting	*Probabilistic forecasting techniques improved; used for temperature extremes*	*Advanced use of probability theory for severe weather to long range forecasts*
	PQPF; probabilistic river stage forecasts; probabilistic winter weather guidance and products	Risk-based flash flood products	
	ESP: QPF uncertainty, deterministic parameters, model and initial conditions; simple bias adjustment	ESP: integrated parameter, model and initial condition uncertainty; stochastic bias adjustment in post-processor	ESP: multi-model ensembles with integrated bias removal
	Climate forecast statistical tools (CCA; OCN; CAS; ENSO composites)	More tools based on diagnosing climate modes; improved coupled models	Climate: multi-model ensembles
Other Interpretative/ Diagnostic/ Predictive Techniques	AHPS expansion		
	Probabilistic flood forecast and inundation mapping	Integrated distributed river and flash flood forecasts	
	QPE - deterministic multisensor, bias correction of radar, merged with gauge and satellite estimates	QPE - dual polarized radar estimates; uncertainty specification by ensemble analysis	QPE - linkage with local-scale models; incorporation of new remotely sensed data
	Extratropical wave forecasts	*Beach/coastal erosion forecasts*	
	Automated tsunami forecast techniques		*National boundary detection program*

Component	NWS Today	NWS Next	NWS After-Next
Products	alphanumeric, graphics, images 3-dimensional national digital forecast data base (gridded forecasts) “Push” paradigm Forecasts of extremes; drought and flood; ENSO forecast; seasonal hurricane forecast; heat index; seasonal fire forecast; UV index	Increasing reliance on digital gridded output 4-dimensional national digital forecast data base (gridded forecasts) Flood forecast mapping *Surface transportation forecasts; Route forecasts (driving or air)* *Probabilistic forecasts (weather, water, climate) in a common format* *Uncertainty and accuracy information in many NWS products* *Regional impact of climate extremes*	Multi-dimensional national digital forecast data base - *user-interrogation/“pull” paradigm* *Digital data base includes: synthesized best estimate from combined human, model, and post-processing system; confidence metrics; accuracy and uncertainty for all parameters* *Grid point information stored as FL membership value* *Chemical forecasts (e.g., ozone); water quality* *Phase shift of climate modes*
Verification	National verification procedures expanded and improved to verify additional products/ elements	National system verifies all forecast/ warning products and forecast elements Verification of gridded forecasts Data assessment and verification system for numerical model forecasts *Advanced methods provide quantitative parallel measures of model, human, and hybrid post-processing technique forecast performance at high time/space resolution.*	*Include impact of technology infusion on products/ services* *Verification/validation capabilities determine optimum combination of inputs to populate multi-dimensional data base*

5.6 Dissemination

At present, dissemination of NWS data and products to external users is limited to electronic (satellite and radio, cable-phone, Internet and Intranet) and print (newspapers) media. Principal dissemination pathways are shown schematically in Figure 5.6. Several networks are fed from the NWS Telecommunications Gateway, with subsequent transmission either by satellite broadcast systems: Emergency Managers Weather Information Network (EMWIN), International Satellite Communication Service (ISCS), and World Area Forecast System (WAFS); or over the Internet: Interactive Weather Information Network (IWIN), Internet Weather Source (IWS), and the Radar Product Service (RPS). NOAA Weather Radio (NWR) is a national network of radio stations that continuously broadcast information provided by NWS field forecasters with automated voice technology. NOAA Weather Wire Service (NWWS) sends data through dedicated uplink sites to a commercial satellite for external distribution. The AWIPS Local Data Acquisition and Dissemination (LDAD) system transmits data from observing sites to field forecast offices. From field offices, LDAD data are transmitted via the WAN and commercial satellite to other users, both within and outside the NWS, and by other means to designated customers. These networks serve different purposes and clients but also provide some redundancy necessary for backing up critical systems.

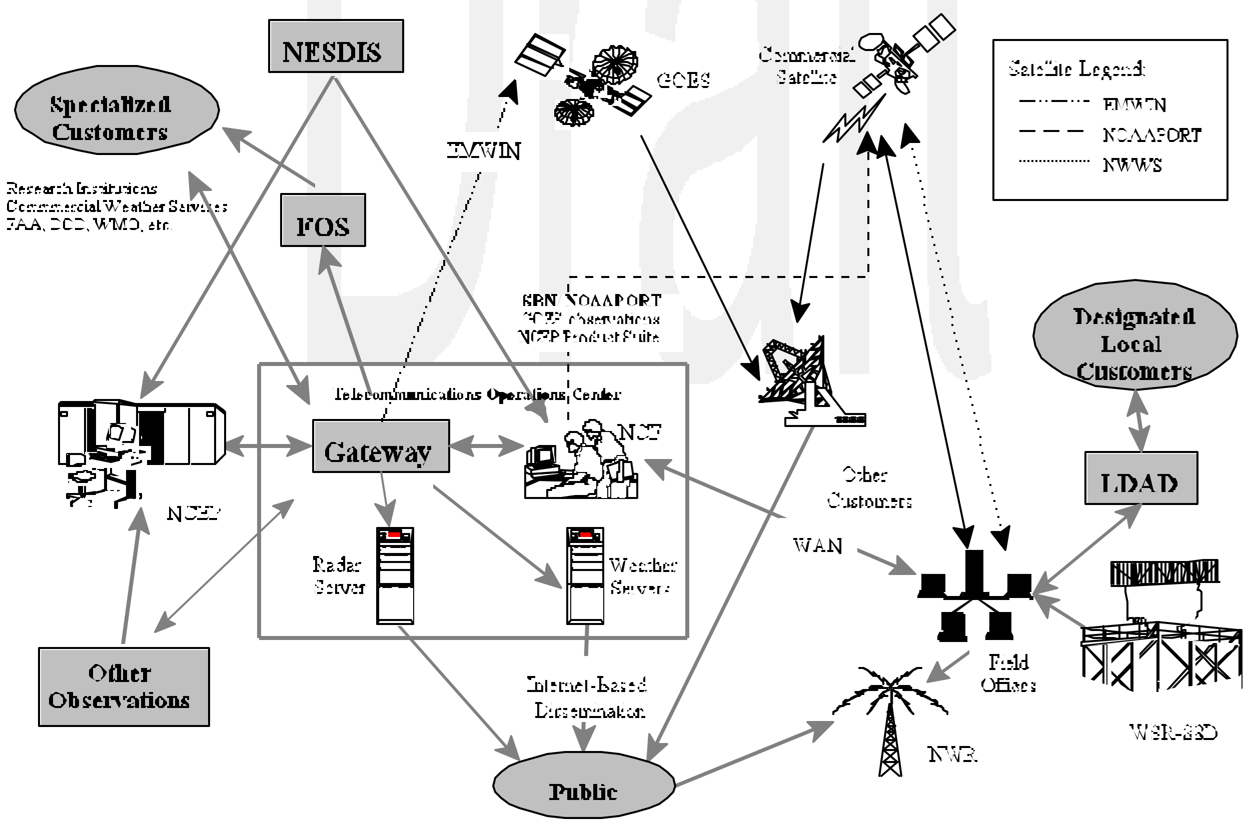

Figure 5.6: Current NWS dissemination network

In the near future, dissemination will expand to include emerging wireless technologies such as cell phones, pagers, and personal data assistants. Wireless technology, which now can network a house or office, will expand so that neighborhoods, communities, and eventually the entire nation will be connected via wireless hubs. More products will be integrated by way of the Internet. Advances in visualization technologies will be aimed at augmenting text-only products with graphical representations.

An important goal for 2025 is to foster global ubiquity of access to any type of NWS data regardless of time or location, using the smallest devices. This will require both national and international efforts and willingness to share data. Analysis of current and future networks will reduce duplicate capabilities and ensure information is streamlined while still providing redundancy. NWS will support innovative dissemination media, such as integrated information, communication, and entertainment (ICE) systems, with its complete suite of products and data.

Over the next 25 years, the NWS will continue efforts to improve the accessibility and availability of a seamless suite of weather, water, climate, and related environmental products. This can be achieved with progressive modification of dissemination technologies to parallel concurrent advances in newer and faster technologies.

Key advances in dissemination include:

- more aggressive use of Internet, Next-Generation Internet, and Follow-on Internet dissemination;
- integrating networks, both nationally and worldwide;
- evaluating duplicate systems for possible merger; and
- emphasizing exploration, planning and implementation of revolutionary technologies.

Table 5.6. Summary of NWS current and future forecast techniques and product/information preparation capabilities. Capabilities are shown in regular font if they appear current in multi-year NWS program lines; otherwise in italics.

Component	NWS Today	NWS Next	NWS After-Next
BROADCAST			
NWR	NWR - audio VHF Increase coverage from 85-90% to 95% Audio Broadcast over internet; total availability Direct Broadcast Satellite Convert NWR to multilingual formats Digital data transmission All Hazards - Emergency managers access Performance enhancements	Digital Radio with smart receivers 100% US coverage Convert NWR to multilingual formats 100% coverage of high risk areas Direct Broadcast Satellite	*Automatic Atmosphere Observing System* *Possible DBS (with video) system for NWR* *Text transmission to host additional data streams*
NOAAPORT	Multiple data types continuously increasing *Increase number of dedicated SBN channels*	Continuous increase of products	

Component	**NWS Today**	**NWS Next**	**NWS After-Next**
NWWS	20 NWS uplink sites in the field Fully deployed and operational CONUS; also partial OCONUS coverage Text format Graphic format implemented Internet capability	Integrated systems: redundancy without duplication Digital Broadcast Satellite	
EMWIN	Western Hemisphere and South Pacific Text and graphic	Integrated systems: redundancy without duplication GOES N/Q series GRIB products with GOES R series ((Enabling)) Increase bandwidth ((Enabling))	
OTHER SATELLITE PATHWAYS: ISCS (WAFS and RMTN)	>90 sites in 83 countries; two-thirds world coverage 38.4Kbps to 64Kbps X.25 format to TCP/IP Backup: SADIS Tailored suite of products	Bandwidth expansion or unlimited availability	Audio and video capabilities
INTERNET: IWIN, IWS, RPS	Limited data availability Internet 2- private RPS: html and ftp format	*Internet 2: public access* XML for automated page parsing Wireless 3G 300 Kbps - 2Mbps, 4G 5-10Mbps	Global ubiquity

Component	NWS Today	NWS Next	NWS After-Next
OTHER DISSEMINATION PATHWAYS: FOS	6 services: PPS, DDS, IDS, HRS, SAS, and RPS-multicast Increase of products Migration to TCP/IP and multicast	Increase of products	
LDAD	EMDS (Emergency Managers Decision System) Experimental use of fax-modem		
TOC Center NCF NWSTG	IT hardware enhancements every 3 years Multiple Circuits (see enabling)	(Transition to a modular architecture) Increase spatial density Transmit more products and more frequent updates More efficient end-to-end process	

5.7 Fundamental Understanding

Advances in the fundamental understanding of physical and chemical processes and variability of the atmosphere, oceans, inland water systems, and in the upper-layers of the land surface will be critical for refining and improving all elements of the forecast process. Much effort has been made to identify knowledge needed to achieve progress in forecast accuracy and to increase forecast lead times, most recently in the NRC report, *The Atmospheric Sciences Entering the Twenty-First Century* (1998), and *Envisioning the Agenda for Water Resources Research in the Twenty-first Century* (2001). Many research goals adopted by USWRP, USGCRP and NOAA research are relevant for supporting the vision and goals in this plan. The following summarizes what have already been projected to be high-impact areas.

Weather

- Improve water vapor observation and develop a quantitative description of water vapor in the atmosphere.
- Improve understanding and models of cloud physics.
- Improve understanding and models of physical processes at land-surfaces.

- Develop and verify a capability to predict the influence of small-scale atmospheric physical processes on large scale phenomena.
- Improve data assimilation methods.
- Improve nowcasting techniques.
- Develop adjoint techniques, which target specific regions of the atmosphere for special observations that will lead to greatly reduced forecast error.
- Advance models of tropical cyclone motion and intensity, especially with improvements in treatment of the physics of tropical cyclone motion and intensity changes; interactions with the upper ocean layers, and delineation of optimal combinations of measurement systems for hurricane forecasting.
- Provide information for benign, but economically important weather.
- New observing system and new instrumentation development.

Climate

- Improve understanding of the roles of ocean and land systems.
- Link weather and climate to improve the predictive capability of extremes.
- Understand the relative importance of internal atmospheric variability and interaction with slowly varying phenomena in the ocean and land.
- Improve understanding of air-sea interaction (fluxes of heat, momentum and moisture).
- Understand variability and predictability of climate modes (ENSO, PDO, AO, NAO and etc)
- Improve predictive skill for tropical processes.
- Understand tropical/mid-latitude connection and mid-latitude/polar connection within the atmosphere as well as through the coupled atmosphere-ocean-land system.
- Understand hydrologic impacts in climate variability.

Hydrology

- Understand processes that control the water cycle and improve prediction of the hydrologic cycle over a range of time scales and on a regional basis.
- Improve understanding of the interactions among the hydrological cycle and meteorological, climatological and other phenomena, to increase skill in predicting regional water supply and hydrological extremes.
- Improve the techniques in hydrologic data assimilation, hydrologic probabilistic verification and ensemble streamflow forecasts.
- Quantify uncertainty of river forecasts based on forecast probability information.
- Understand and predict the frequency and cause of floods and droughts.

Maritime

- Improve coastal ocean observations, assimilation, and model-based marine forecasting.
- Improve understanding of estuarine and ocean chemistry.

Upper-Atmosphere and Space Weather

- Identify and quantify stratospheric processes that affect climate and the biosphere, including the effects of ozone-depleting chemicals, volcanic emissions, and solar variability.
- Increase emphasis on space "weather," the short-term variability of the near-Earth space environment that has important effects on satellite performance, human health in space, communication systems and power grid operation.
- Evaluate changes in the middle and upper atmosphere in response to natural and anthropogenic influences that have significant effects on the lower atmosphere.
- Assess effects of solar variability on the global climate system, which may be significant but must be differentiated from other natural influences and from climate effects associated with human activity.

Air Quality

- Develop advanced predictive models and verification methods for atmospheric chemistry and air quality.

Other

- Improve understanding of operational environmental forecast process.
- Improve understanding of predictability of water quality.
- Improve understanding of interdependence of social science and natural science.
- Improve understanding of societal and economic impacts of weather, climate and hydrologic forecasts.
- Improve understanding of the interactions of physical and biological systems.
- Document the chemical climatology and meteorology of the atmosphere through the development of monitoring networks.
- Understand the environmentally important atmospheric species and the chemical, physical, and biological processes and interactions that couple them.
- Assess the consequences of land use change and other environmental manipulations that cause significant changes in regional climate and hydrology.

6.0 Implementation Strategy

The 2000 NRC Report, *From Research to Operations in Weather Satellites and Numerical Weather Prediction (REF, 2000)*, use the phrase "Crossing the Valley of Death" to describe the fundamental challenge of transitioning R&D to operations. This report and the Dorman Report among others, identify the following keys to successful infusion programs:

- Stimulate and reward innovation.
- Examine a wide spectrum of alternatives.
- Incorporate the concept of (test-bed) demonstration throughout the insertion process.
- Foster teaming across R&D and operational organizations.
- Develop and maintain appropriate transition plans.
- Ensure adequate resource provision.
- Keep the focus on the customer.
- Optimize return on investment as judged by socio-economic impacts on the Nation.
- Establish education and training to fully implant technological gain.

To succeed in these activities and to meet the aggressive S&T implementation targets outlined in this plan will require NWS, NOAA, and their R&D partners to collaborate closely. Toward this end, an umbrella NOAA S&T infusion program will drive efficient "end-to-end" R&D to operational implementations, and training necessary to reach STIP goals. The vision of this program is to:

Ensure science and technology implemented in NWS operations are the best in the world, maximizing return on investment, and minimizing transition time and cost.

A unified effort to focus the research and operational communities on transitioning S&T to the operational sector will be critical. At the basic research level national funding agencies must be encouraged to support research with a track toward operations. During development an outreach effort is needed to identify and steer work toward operational needs. Having demonstrated feasability, S&T efforts need to be rigorously tested in an organized and adaptable test bed process. The final jump to operations will involve both the operational and research sectors. Implementation must be preceded by a thorough training and education program. These responsibilities will require a team approach to budgeting, facilities, and long term management and planning. The STIP will provide the basis for four fundamental aspects of the program: Teamwork, Budget/Oversight, Architecture, and Investment Planning.

1) Teamwork: A Partnership among NOAA and external (including international) organizations, with the following technology insertion roles:

NWS:
- Identifies operational S&T shortfalls
- Evaluates S&T opportunities
- Tests and validates new S&T
- Inserts proven new S&T into operations

- Leads planning and budgeting for S&T insertion into operations
- Develops forecast and warning operations processes based on new S&T
- Implements education and training for new S&T

NESDIS:
- Identifies satellite user requirements
- Defines space-based observations and applications to meet user needs
- Develops new innovative uses of current satellite systems and defines future systems
- Leads planning and budgeting for satellites and satellite product R&D

OAR:
- Does/finds best R&D
- Identifies S&T opportunities
- Responds to NWS operational S&T shortfalls
- Collaborates/assists in S&T testing and validation
- Collaborates/assists in S&T insertion into operations
- Consults on documentation and maintenance of operations S&T capability
- Leads planning and budgeting for R&D
- Provides expertise for training and education

U. S. Weather Research Program, U.S. Global Climate Research Program, UCAR/NCAR, universities, non-NOAA laboratories, other partners:
- Identifies S&T opportunities
- Performs basic to applied R&D
- Collaborates/assists in S&T testing and validation
- Participates in technology insertion
- Serves as a resource for training and education

2) Budget/ Oversight: A joint budget formulation and oversight process, consisting of:

- Prioritizing investments according to:
  - current/anticipated customer and service needs and requirements,
  - cost/benefits,
  - areas of mutual partner interest, and
  - emerging opportunities
  - leveraging related projects

- Developing coordinated multi-partner implementation plans with milestones and deliverables;

- Securing resources for priority items through coordinated direction of base resources and/or joint budget initiatives covering end-to-end R&D to implementation costs; or identifying on-going outside activity and partnering, and

! Overseeing the test bed process: testing, validation and transitions.

3) Architecture: A National Testbed structure supporting:

! observational,
! numerical prediction,
! forecast applications and preparation

themes with hardware, software, communications, operating systems, data streams, etc. that are identical/compatible with operational units; where new S&T is developed, tested, and when mature, transitioned to NWS.

4) Investment Plan: A comprehensive and integrated plan(s) from R&D to operational implementation.

7.0 References

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Appendix A
Acronyms

3DVAR	Three-Dimensional Variational Data Assimilation
4DVAR	Four-Dimensional Variational Data Assimilation
AGCM	Advanced Global Climate Model
AHPS	Advanced Hydrologic Prediction Services
AIRS	Atmospheric Infrared Sounder
AMBER	Areal Mean Basin Estimated Rainfall
AO	Arctic Oscillation
ASOS	Automated Surface Observing System
ATM	Asynchronous Transfer Mode
AVN	Aviation numerical forecast model (run from the MRF)
AWIPS	Advanced Weather Interactive Processing System
BUFR	Binary Universal File Record
CAS	Constructed Analog with Soil Moisture
CCA	Canonical Correlation Analysis
LDAS	Climate Land Data Assimilation System
CMAN	Coastal-Marine Automated Network
CODAR	COastal raDAR
COFS	Coastal Ocean Forecasting System
CONUS	Conterminous United States
DBS	Digital Broadcast System
DDS	Domestic Data Service
Di-CAST	Dynamic Intelligent Forecast
EDAS	Eta Data Assimilation System
EMDS	Emergency Managers Decision System
EMWIN	Emergency Managers Weather Information Network
ENSO	El Niño Southern Oscillation
ESP	Ensemble Streamflow Prediction
ESPADP	ESP Analysis and Display Program
FDDA	Four Dimensional Data Assimilation
FOS	NWS Family of Services
GCM	Global Climate Model
GEO	Geosynchronous Earth Orbiting
GDAS	Global Data Assimilation System

GFDL	Geophysical Fluids Dynamics Laboratory
GIFTS	Global Infrared Far-Infrared Telemetry System
GINI	GOES Ingest NOAAPORT Interface
GIS	Geographical Information System
GODAE	Global Ocean Data Assimilation Experiment
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GRIB	Gridded Binary
HMD	Hydrometeorological discussion
HPC	Hydrometeorological Prediction Center
HRS	High Resolution Data Service
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectories model
IASI	Infrared Atmospheric Sounding Interferometer
ICE	Information, Communications and Entertainment system
IDS	International Data Service
IFPS	Interactive Forecast Preparation System
IHFS	Intergrated Hydrologic Forecast System
IIDA	Integrated Icing Detection Algorithm
IIFA	Integrated Icing Forecast Algorithm
ISCS	International Satellite Communication Service
IWIN	Interactive Weather Information Network
IWS	Internet Weather Source
JCSDA	Joint Center for Satellite Data Assimilation
LAMP	Local AWIPS MOS Program
LEO	Low Earth Orbit
LDAD	Local Data Acquisition and Dissemination
LDAS	Land Data Assimilation System
LSM	Land Surface Model
MAR	Modernization and Restructuring
MDCRS	Meteorological Data Collection and Receiving System
MJO	Maden-Julian Oscillation
MOD	Model on Demand
MODIS	Moderate Resolution Imaging Spectrometer
MOS	Model Output Statistics
MRF	Medium-Range Forecast model
NAO	North Atlantic Oscillation
NASA	National Aeronautic and Space Administration
NCAR	National Center for Atmospheric Research

NCEP	National Centers for Environmental Prediction
NCF	Network Control Facility
NCDC	National Climate Data Center
NCWF	National Convective Weather Forecast
NDFD	National Digital Forecast Data base
NGM	Nested Grid Model
NOAA	National Oceanic and Atmospheric Administration
NOAH	NCEP, Oregon State University, Air Force and Office of Hydrology land-surface model
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRC	National Research Council
NSP	NWS Strategic Plan
NWP	Numerical Weather Prediction
NWR	NOAA Weather Radio
NWS	National Weather Service
NWSRFS	NWS River Forecast System
NWSTG	NWS Telecommunication Gateway
NWWS	NOAA Weather Wire Service
OCN	Optimal Climate Normals
OCONUS	Outside Conterminous United States
OFCM	Office of the Federal Coordinator for Meteorology
OSSE	Observing System Simulation Experiments
PDA	Personal Digital Assistant
PDO	Pacific Decadal Oscillation
PMEL	Pacific Marine Environmental Library
PNA	Pacific/North American
PoP	Probability of Precipitation
PPS	Public Product Service
PQPF	Probabilistic Quantitative Precipitation Forecast
QPE	Quantitative Precipitation Estimation
QPF	Quantitative Precipitation Forecast
QTF	Quantitative Temperature Forecasts
RAWS	Remote Automatic Weather Station
RASS	Radio Acoustic Sensor System
RBG	RedBook Graphics
RCM	Regional Climate Model
RFC	River Forecast Center
RMTN	Region IV Meteorological Telecommunication Network
RPS	Radar Product Service

RSM	Regional Spectral Model
RUC	Rapid Update Cycle
SADIS	Satellite Distribution System
SAS	Server Access Service
SAFESEAS	System on AWIPS for Forecasting and Evaluating SEas and lAkeS
SCAN	System for Convection Analysis and Nowcasting
SEUS	Snow Estimation and Updating System
SFM	Seasonal Forecast Model
SHEF	Standard Hydrometeorological Exchange Format
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SMLR	Screening Multiple Linear Regression
SPIG	Strategic Plan Implementation Guide
SST	Sea Surface Temperature
THOR	Thunderstorm Operational Research (Project
TIP	Technology Infusion Plan
TITAN	Thunderstorm Identification, Tracking, Analysis and Nowcasting
TOC	Telecommunication Operations Center
TRMM	Tropical Rainfall Measuring Mission
UAV	Unmanned Aerial Vehicle
UV	Ultraviolet
VAFTAD	Volcanic Ash Forecasts Trajectories & Atmospheric Dispersion model
WAFS	World Area Forecast System
WFO	Weather Forecast Office
WHFS	Weather Forecast Office Hydrologic Forecast System
WRF	Weather Research and Forecast system
WSR-88D	Weather Surveillance Radar 1988 (Doppler)
WVSS	Water Vapor Sensing System
WWW	World Wide Web