NOAA Earth System Research Laboratory

Physical Sciences Division

Strategic Plan
2011-2015

Executive Summary

The Physical Sciences Division (PSD) provides NOAA with the essential core capability to conduct physical science research across time and space scales. In so doing, PSD advances NOAA's abilities to observe, understand and improve the prediction of the behavior of atmosphere, ocean, cryosphere, hydrosphere, land, and related impacts on global-to-local and climate-to-weather scales. The research infrastructure within PSD provides the foundation for executing focused observational programs, analyzing physical processes and improving their representation in numerical models, and developing diagnostic and predictive tools required to advance climate, weather and water science. To identify user needs for science-based information, PSD works closely with its internal partners and a broad external user community. For example, PSD interacts and collaborates extensively with external user groups through the NOAA Regional Integrated Sciences and Assessments (RISA) and National Integrated Drought Information System (NIDIS) programs, and through NOAA's Hydrometeorology Testbed (HMT).

Addressing major technical and practical challenges related to climate, weather and water science requires the ability to develop innovative new tools and methods. PSD scientists, engineers, state-of-the-art observing and analysis tools and outreach experts represent primary capabilities for innovation in these areas, and are a bridge to serving a broad range of needs across NOAA. As illustrated by PSD's strong roles in the Western Water Assessment, NIDIS and HMT, water resources applications are an important crosscutting theme in PSD, with emphasis on extremes, from too little to too much water, particularly in climate sensitive regions of the country. Within NOAA, PSD collaborates to transfer its research advances across Line Offices and Programs and contributes to the evaluation and development of NOAA mission requirements.

In support of NOAA's mission, PSD research over the period FY11-15 will focus on five major strategic goals: 1) Improve observations and understanding of Earth system processes; 2) Integrate climate, weather and water research; 3) Understand, attribute and predict extremes in a variable and changing climate; 4) Advance understanding of regional processes and develop applications related to climate variability and change; and 5) Conduct research and develop prototypes to improve NOAA environmental information and services.

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1. Introduction

This document provides a strategic plan for the period 2011-2015 for the Physical Sciences Division (PSD) of the NOAA Earth System Research Laboratory (ESRL). This plan supports core missions of NOAA, OAR, and ESRL, and is developed within the context of broader national priorities.

PSD research primarily addresses NOAA's Mission Goals "to understand climate variability and change to enhance society's ability to plan and respond" and "to serve society's needs for weather and water information." PSD supports NOAA through its role within the Office of Oceanic and Atmospheric Research, which has as its mission "To conduct environmental research, provide scientific information and research leadership, and transfer research into products and services to help NOAA meet the evolving economic, social, and environmental needs of the Nation." PSD provides the primary focus for physical sciences research within ESRL, whose mission is to observe, understand and predict the Earth system through research that advances NOAA's environmental information and services from minutes to millennia on global-to-local scales.

Within ESRL, PSD's mission is **"to conduct weather and climate research to observe and understand Earth's physical environment, and to improve weather and climate predictions on global-to-local scales."** PSD has unique strengths within NOAA in physical sciences research linking climate, weather and water. This provides a strong science foundation for developing, prototyping and improving NOAA products and services in these mission-critical areas. To ensure the development of useful and usable NOAA products, PSD works closely with partners both within and outside NOAA. Within NOAA, PSD scientists collaborate with the National Weather Service to improve flood forecasts and climate monitoring and predictions. PSD also collaborates extensively with external partners to develop new capabilities in climate services as, for example, with the University of Colorado in the Western Water Assessment project and in developing a National Integrated Drought Information System in collaboration with numerous federal, state and local agencies, tribes, and other partners.

The rapidly changing environment under which this plan has been developed poses special challenges as well as unique opportunities. Over the past year a new Administration has been elected and NOAA has come under new leadership. Revised strategic plans are being developed within NOAA and, in a broader context, in national and international science programs. The daunting challenges of a changing climate, and consequent needs for climate information, are being recognized within and beyond the federal government. The needs for a national climate service, and specifically for the development of a climate service within NOAA, have become increasingly evident. At this time, NOAA is devoting a very high level of effort to establishing a new climate service, although the full organizational implications are uncertain.

What is perhaps more certain is that PSD can play a major role in shaping and developing future climate services, building from its long history of involvement, commitment, and successful innovations in this area. At the same time, PSD's exceptional capabilities in observing and understanding physical processes across weather and climate time scales – including the fundamental connections between weather and climate - provide a strong scientific underpinning for future NOAA services. These same capabilities will be crucial to advancing understanding, analysis and prediction of the Earth system through addressing science challenges related to coupling between various system components (atmosphere, ocean, land surface, and sea ice). PSD also has unique strengths in water-related research that extend from observations and process understanding to modeling, predictions, and experimental service delivery. This end-to-end capability provides significant opportunities to develop and evaluate approaches to address urgent societal needs for improved information on phenomena such as extreme floods and droughts.

This document summarizes key drivers and outlines PSD strategic goals that will take advantage of PSD strengths and capabilities to help address NOAA and national priorities. The strategic goals also play an important role in effectively integrating PSD's research across its branches.

2. Overview of Research Strategy and Goals

Several factors help guide PSD in developing its research strategy. These include; 1) NOAA's Mission Goals; 2) Needs of existing and emerging NOAA services; 3) National and international research priorities; 4) National imperatives for science-based information, and 5) Emerging research areas that have the potential for major scientific advances and/or service improvements. In addition, assessments of PSD capabilities and expertise, especially areas where PSD may provide unique contributions, are crucial in determining its strategic priorities.

NOAA's Mission Goals

NOAA's Mission is "To understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs." In order to achieve its Mission, NOAA has established five strategic goals. PSD research primarily supports two of these goals:

- Understand climate variability and change to enhance society's ability to plan and respond
- Serve society's needs for weather and water information

These goals will be referred to as the "Climate Goal" and the "Weather and Water Goal", respectively.

Within the Climate Goal, PSD has focused, and will continue to focus, most of its efforts within the Climate Research and Modeling (CRM) Program and the Climate Observations and Monitoring (COM) Program, especially in advancing capabilities to understand climate processes and developing new capabilities in climate analysis and attribution. The great majority of research conducted in the Climate Analysis Branch (PSD1) and a significant part of the research conducted in the Weather and Climate Physics Branch (PSD3) focus on core science objectives related to these areas. At the same time, PSD climate research crosscuts all major program elements, including the Climate Services Development (CSD) Program. For example, there are deep science connections between climate observations and climate modeling in the areas of climate analysis, reanalysis and attribution. PSD scientists are working across COM and CRM programs in order to advance NOAA capabilities in these important areas. This work is leading to the development of a new climate service capability on attribution. PSD scientists are also contributing strongly to the NOAA 5-year research plan objective to enhance NOAA's decision support tools for emerging climate services as, for example, related to drought and water resources management.

Within the Weather and Water Goal, PSD has substantial involvement in several programs, including the Integrated Water Forecasting Program, the Air Quality Program, and the Science and Technology Infusion Program (STIP). PSD2 has a particularly strong focus on research to improve weather forecast and warning accuracy and lead times for extreme precipitation events, as well as to improve water resources forecasting capabilities, key science objectives identified in the 2008-2012 NOAA 5-year research plan. These areas will continue as high priorities for PSD research over the next five years. PSD scientists also support NOAA efforts to develop and improve air quality forecasts. All of these activities support broader NOAA services, with PSD scientists playing a leading role in transitioning research advances into the NWS through the STIP.

While NOAA has defined Climate Goals and Weather and Water Goals separately, PSD scientists have long emphasized the strong connections between weather and climate, as well as the role of water as an integrator across time scales. Further, societal needs for environmental information –and for the services that NOAA will provide – extend across time scales, with no clear demarcation separating weather from climate. Accordingly, PSD has emphasized, and will continue to emphasize, the connections between climate, weather and water as core drivers for its future research strategy.

The FY09-14 NOAA Strategic Plan provides the current context for the development of the PSD strategic plan. However, NOAA is currently in the process of developing a new Next Generation Strategic Plan (NGSP). The NGSP is yet to be finalized; however, an early draft version suggests that PSD is well positioned to make major contributions toward NOAA's proposed future goals, especially related to climate adaptation and mitigation and supporting a more weather-ready nation.

Needs of existing and emerging NOAA services

PSD conducts purposeful research to support NOAA's abilities to meet evolving national needs. This approach has been, and will continue to be, at the heart of PSD's research strategy. It is also central to supporting OAR's mission, which is to conduct environmental research, provide scientific information and research leadership, and transfer research into products and services to help NOAA meet evolving national economic, social, and environmental needs.

PSD research contributes to building the strong science foundation that underpins NOAA services. Perhaps less appreciated, but vitally important, research is also essential to building connections between fundamental science and the services that NOAA ultimately provides. PSD has a strong history of helping to build these science-service connections. Two important attributes for research to build effective services are *responsiveness* – understanding current user needs, including needs of existing services – and *innovation* – anticipating future needs, including for services that may not yet exist. PSD's research strategy focuses on appropriately balancing responsiveness and innovation, that is, between "user pull" and "research push".

A long-standing driver for PSD priorities is identification of major gap areas of NOAA services that PSD research may help to address. Even prior to PSD's formation, the Director of Environmental Technology Laboratory, ETL (now PSD Director) and the Director of the Climate Diagnostics Center, CDC (now PSD Deputy Director) identified a critical gap in NOAA services between short-term weather forecasts and seasonal and longer-term climate outlooks. They worked together to create a joint research initiative, the "Weather-Climate Connection", to conduct research that would help address this major gap in NOAA's capabilities. This work continues today, and in many ways provides the overarching research theme for PSD.

Analysis of gaps in NOAA science and services also identified inadequacies in NOAA's research related to water services. Prior to PSD's formation, significant science capabilities existed in the former ETL and CDC to initiate a more coordinated approach to improving NOAA's water services, especially related to high-impacts events such as floods and droughts. Following formation of PSD, addressing this gap has become a major part of PSD's strategy, and is now the primary research focus for one of the branches (PSD2). This will continue to be a major research priority for PSD, recognizing the important role of water as an integrator across weather and climate.

For the foreseeable future, a crucial driver for PSD research will be the emergence and development of NOAA and national climate services. As this strategic plan is being prepared, a NOAA Climate Service (NCS) has been proposed but is yet to be congressionally approved. Under NOAA's proposal, PSD would be located organizationally within the NCS. PSD and its predecessor organizations, particularly CDC, have a long history of involvement in research related to climate services, with special strengths at regional scales. Indeed, much of CDC's research dating to the mid-1990s and continuing today in PSD1 has been focused on developing a strong scientific foundation and experimental services that would be required to meet future NOAA climate service needs. This has produced a large body of work, for example, on understanding the predictability of the climate system, improving NOAA's intraseasonal-to-interannual climate predictions, and developing useful and usable climate products, for example, to support decision-making related to water resource management, as in the Western Water Assessment and the National Integrated Drought Information System. As another example, research to develop an attribution service capability that has emerged as a NOAA priority, and for which PSD has had leadership, also addresses a critical climate service gap between descriptions of past and current conditions and climate outlooks and projections for future conditions. As in the past, PSD plans to pursue a strategy that balances responsiveness to needs of existing climate, weather and water services with innovation of new capabilities in anticipation of future service needs.

National and international research priorities

NOAA's Mission Goals and current and emerging services requirements are the primary drivers for PSD's research. However, this research also occurs within the context of broader national and international science activities. PSD recognizes these relationships and, as able, supports these national and international programs. Major programs whose priorities influence PSD's strategies include the U.S. Global Change Research Program (USGCRP) and World Climate Research Programme (WCRP) for climate, and the U.S. Weather Research Program (USWRP) and World Weather Research Programme (WWRP) for weather. PSD scientists have contributed to the Intergovernmental Panel on Climate Change (IPCC), and are likely to do so in the future. PSD scientists are also involved at higher levels in several large national and international efforts, for example, serving as chairs, co-chairs, or members of committees or working groups or in other significant capacities. These service contributions will continue over the next five years.

The full scope of PSD connections to national and international science programs and research priorities will not be discussed here. However, it is useful to note some larger-scale directions. First, a growing body of research indicates that over time artificial distinctions will be removed between weather and climate, as we begin to move toward a more unified understanding of phenomena and processes across time scales. A major priority of the WWRP, The Observations, Research and Prediction Experiment (THORPEX) has as its primary objective to accelerate improvement in forecasts of high-impact weather on time scales from one day to two weeks. The WCRP Coordinated Observation and Prediction of the Earth System (COPES) Program emphasizes the need for seamless predictions on time scales from weeks to centuries in advance. The most important requirement recognized in the World Modelling Summit for Climate Prediction is for improvements in predictions of the statistics of regional weather variations. Within the U.S., the USGCRP has identified as a key research question the relationships between climate variations and change and extreme events such as droughts, floods, wildfires, heat waves and hurricanes. Addressing these fundamental challenges will require a more unified approach than in the past to understanding connections between weather and climate. PSD is well positioned to contribute its scientific and technical expertise in this important direction.

Second, there is growing recognition of the importance of considering problems in weather and climate within the context of a more fully integrated Earth system that includes atmosphere, ocean, sea ice, land surface and biological components. Indeed, it is likely that some of the most important challenges posed by climate change, such as estimating the risk of rapid or accelerated changes in climate and attendant impacts, will require significant advances in understanding the couplings between various Earth system components. PSD is also well positioned to contribute to this important area of research.

In addition to the above drivers, national imperatives for science-based information and emerging research areas with high potential for advances influence PSD's research strategy. For example, national needs for improved science information to anticipate and prepare for droughts have driven, and will continue to drive, PSD research to improve capabilities in drought monitoring and prediction. Imperatives for improved science-based information to support climate change adaptation will increasingly influence climate research priorities, especially for improved information at regional scales. National needs for greater energy security and efficiency will require improved environmental information across weather and climate time scales. Rapid changes in the Arctic are impacting many sectors, including transportation, energy, and the environment, with major implications for NOAA's mission in environmental and marine stewardship, as well as national defense and international policy. PSD research strengths and scientific capabilities can play important roles in addressing these urgent national issues.

Finally, a significant part of PSD's strategy will be to continue to allow flexibility for both the development of, and response to, major new science advances, whether from inside or outside PSD. As one example, an important research advance within PSD over the past several years – the demonstration of the capability to construct high-quality reanalyses from only surface pressure data – has led to a much broader, international effort to produce historical reanalyses that extend back for periods well over one century. This initial research advance is, in turn, now influencing PSD's strategy and research priorities over the next five years.

PSD Strategic Goals

In consideration of the drivers discussed above, PSD's research mission and its core capabilities and strengths, PSD identifies the following five major strategic goals as its major research directions over the period 2011-15:

Goal 1: Improve observations and understanding of Earth system processes.

Goal 2: Integrate climate, weather and water research.

Goal 3: Understand, attribute and predict extremes in a variable and changing climate.

Goal 4: Advance understanding of regional processes and develop applications related to climate variability and change.

Goal 5: Conduct research and develop prototypes to improve NOAA environmental information and services.

Summaries of science objectives for each branch addressing these PSD major strategic goals are provided in the next section.

3. Branch Plans

a) Climate Analysis Branch (PSD1)

Research Overview

Climate Analysis Branch (CAB) research advances national capabilities to describe, understand, and assess the predictability of climate variations and change on time scales ranging from a few weeks to a century. These capabilities are essential to creating effective and credible national climate services. PSD1 has particular scientific expertise in innovating and applying climate diagnostic methods to identify the causes and assess the potential predictability of high-impact climate phenomena such as droughts, floods, El Niño-Southern Oscillation, and decadal-to-centennial climate variations and change. PSD1 scientists also have significant expertise in data assimilation methods, which are used to develop reanalysis data sets for numerous research uses, for model diagnostic analyses, for improving weather and climate predictions, as well as for an increasing range of practical applications.

Creating an effective climate service requires the ability to identify current public and decision-maker needs for climate information as well to anticipate future needs. To help guide research priorities related to climate services, PSD1 works closely with many partners, including the Western Water Assessment (WWA) and National Integrated Drought Information System (NIDIS). These partnerships provide an invaluable means for assessing current needs and anticipating future needs for NOAA climate products and services, leading to more efficient and effective development of NOAA services.

PSD1 research is organized under three primary themes: 1) Intraseasonal to Interannual Climate Research, 2) Decadal to Centennial Climate Research, and 3) Experimental Climate Services. The first theme addresses critical gaps in NOAA mission capabilities connecting weather and climate. An important research priority is improving understanding of how extreme events such as droughts and floods may be affected by a changing climate (PSD Goals 1 and 4). CAB's second theme focuses on understanding causes and assessing the potential predictability of decadal-to-centennial climate variations and trends. Such information is required to evaluate longer-term adaptation and mitigation alternatives (PSD Goals 2, 3, 5). The third theme focuses on identifying current and future requirements for a NOAA Climate Service. This work includes sustained stakeholder interactions that are required to identify, develop and evaluate experimental climate products. The ultimate objective of this theme is to improve the value of the climate information that NOAA provides (PSD Goals 3 and 5).

An emerging PSD1 research priority that crosscuts all themes is the development of a climate attribution capability that will translate improved understanding of the causes of climate variations and change into decision support products that will inform policy development and resource management. This activity is intended to move NOAA beyond descriptions of climate conditions toward physical explanations of why such conditions occur, and to identify the related implications for future conditions in a changing climate.

PSD1 will continue to emphasize research that transforms improved understanding of climate variations and change into products that are useful for decision-making and risk management, in support of the development of a NOAA Climate Service. In order to achieve this goal, PSD1 will focus on the following primary research objectives over the period 2011-15.

CAB-1: Advance Intraseasonal to Interannual Predictive Capabilities

(Supports PSD Goals 1 ,2, 3 and 4)

This objective will focus on developing quantitative, probabilistic experimental precipitation and temperature forecasts with improved skill over present-day products. An important aspect of this work will continue to be to improve understanding and modeling of key phenomena, such as the El Niño-Southern Oscillation and other major modes of climate variability. One area of modeling emphasis will be to develop super-ensemble prediction schemes that combine dynamical and empirical modeling approaches. A second focus area will assess the feasibility of using large hindcast datasets to correct systematic model biases to improve forecast skill. PSD1 scientists will extend and apply reforecast methods to develop improved threat assessments for high-impact weather and climate events, and assess the potential predictability of hydrologic extremes in a changing climate at watershed scales. Modeling and diagnostic research within PSD1 will be coordinated with observational and processes research in PSD2 to accelerate advances in this area. Another area of research will focus on the development of hybrid methods that apply numerical and statistical modeling methods to advance skill in weather and climate predictions. A significant part of this work will be performed in collaboration with NCEP (CPC and EMC) and other partners (e.g., NASA GMAO).

CAB-2: Improve Representation of Tropical Dynamics in Models

(Supports PSD Goals 1, 2, 3, and, 4)

Research to achieve this objective will focus on increasing understanding of the Madden-Julian Oscillation (MJO) and other equatorial atmospheric modes and phenomena, and translating this new understanding into improved predictions and climate model simulations. To accelerate advances in this area, dynamical, diagnostic and modeling expertise in PSD1 will be coordinated with PSD3 research in observations and processes in air-sea fluxes, clouds and precipitation focused in the tropics, such as the upcoming DYNAMO field program. Tropical heating and convection represent major sources for potential predictability at subseasonal to seasonal time scales. However, at present accurate representation of these phenomena disappears within a few days in model simulations. Significant potential exists to advance skill in medium range and seasonal predictions through improved simulations of the tropical heating and the MJO in ocean-atmosphere coupled models. Research in this area will include detailed analyses of current capabilities of atmospheric models to simulate tropical heating and climate variability, applications of statistical methods to identify model deficiencies, and impact evaluations obtained through sensitivity tests of model physical parameterization schemes.

CAB-3: Assess the Causes and Potential Predictability of Decadal Climate Variations *(supports PSD Goals 1, 3, 4, 5)*

The overarching science objective is to support development of new NOAA and national predictive capabilities on multi-year to multi-decadal time scales. The ultimate goal is to provide society with an improved ability to plan for and adaptively manage high-impact climate phenomena such as droughts, floods, temperature extremes, rapid Arctic change, and changing ocean conditions that profoundly impact coastal and marine resources. This is an emerging research area, with major unknowns, both on the causes of the decadal variations and the extent to which such variations may be predictable. Research in this area will involve significant partnerships, both externally and internally with NOAA, with one important NOAA partner being GFDL. Within PSD1, one major research focus will be to assess how probability distributions for the location, frequency and intensity of extreme events are influenced by decadal variability and climate change. Evaluations will be performed of models developed within and outside NOAA to determine effects of model changes on representations of decadal variations and change, including effects on high impact phenomena listed above. Areas of applied research will include refining capabilities to identify the most critical areas of tropical sea surface temperature (SST) change that regulate global climate change, to investigate the causes of model errors in representing tropical SST variations on all time scales through detailed diagnosis of the local and remote SST feedbacks in models and observations, and to investigate the impact of erroneous air-sea coupling around the globe on model simulations and forecasts. The resulting reductions in model error and better characterization of inherent uncertainties in decadal to century projections are needed to predict extreme events in a changing climate and thus increase confidence in regional impacts. Research will also focus on how best to separate natural decadal variability from anthropogenically forced changes through a variety of strategies examining the predictable part of externally and internally forced decadal variability.

CAB-4: Extend Historical Reanalyses and Contribute to the Development of an Integrated Earth System Analysis capability *(Supports PSD Goals 1, 3, 4, 5)*

Over the past five years, PSD has led pioneering efforts to back-extend atmospheric reanalyses to periods prior to the modern radiosonde era. This unique effort now provides a continuous atmospheric reanalysis record of winds, temperatures and numerous other meteorological variables extending back to the late 19th century. Developing this capability and its derivate products have involved, and will continue to involve, extensive partnerships within NOAA (e.g., NCDC), and numerous national and international organizations. Over the next five years, to support decision-making user requirements for reanalysis data sets will be incorporated into the design and implementation efforts. Future improvements will include assimilating more land and marine observations back to the early 19th century, including incorporating newly recovered data from the Southern Hemisphere and Arctic. Next generation reanalyses will be performed at higher resolution with updated models, improved methods for assimilating additional surface variables (e.g., winds, temperatures, tropical cyclone positions), using a multi-model ensemble approach, and including better representation of forcing uncertainties (e.g., ensemble of SSTs and Sea Ice, CO2, solar forcings). PSD1 will also contribute its research expertise and experience in reanalysis and data assimilation to supporting the national climate science priority of building a national Integrated Earth System Analysis (IESA) capability that includes coupled cryosphere-ocean-land-atmosphere-chemistry components. Major NOAA and national partners in this effort will include NOAA/NCEP/EMC and NCDC, and NASA/GMAO.

CAB-5: Establish a Climate Attribution Capability for the NOAA Climate Service

(Supports PSD Goals 1- 5)

This science objective is to develop a new core capability in climate attribution in support of the NOAA Climate Service. The aim is to produce a comprehensive suite of routine, systematic explanations of the causes of observed climate variations and change at national to regional scales (e.g., U.S. annual surface temperature and precipitation; U.S. extreme events and major climate anomalies such as drought, cold outbreaks, heat waves, floods, intensity of the hurricane season, and apparent abrupt regional changes). In coordination with NCEP and other NOAA partners, this activity will also produce regular assessments of the performance of NOAA climate predictions, including scientific interpretations of the causes for skill variations in U.S. seasonal temperature and precipitation outlooks, ocean predictions, and drought outlooks. The goal here is to incorporate the new knowledge on the causes for evolving climate conditions into a capability to improve the performance of climate predictions for seasonal to decadal time scales, and to increase the regional specificity of climate change projections.

CAB-6: Develop and Prototype Products for NOAA Climate Services

(Supports PSD Goals 2, 5)

Research under this objective will develop and evaluate experimental climate products to be provided by NOAA for use in policy development, resource management and to inform public and private sector decisions. Focus areas will include experimental products related to drought (onset, termination, duration, and severity) in support of the NOAA-led National Integrated Drought Information System (NIDIS), flood risks, and ocean conditions that impact living marine resources. One research focus will be on the use of models to understand and predict how physical changes in the climate systems may impact living marine resources and ecosystems. A long-term goal is to develop new predictive capabilities, products and services that can be effectively incorporated into the plans and decisions for natural and built resource management. As part of this effort, major emphasis will be placed on developing and evaluating climate information products and services at the spatial and temporal scales relevant for decision-making. Applied research on how to downscale, and how far to downscale climate information, while ensuring the results are scientifically defensible - rather than simply helping decision makers do the wrong thing more precisely - will be a high priority. PSD will work with partners across NOAA to develop a process to transform experimental products and services into products and services meeting reliability criteria for transition to use in an operational setting. This process requires an ongoing engagement between PSD scientists and operational service partners to continuously evaluate and, as needed, improve products and services once they have been implemented operationally. These processes are necessary to ensure continual infusion of research advances into NOAA operational products and services, so as to ensure that NOAA products and stewardship responsibilities are based upon the best available science. Evaluations and enhancements of the resulting experimental climate information products and services will be achieved through sustained partnerships with a diverse network of users who are engaged in an iterative process to assess usability and to ensure their information needs are being met.

b) Water Cycle Branch (PSD2)

The Water Cycle Branch (WCB) brings together expertise on research quality observations and basic atmospheric physics. These capabilities are used to develop the process understanding and regional monitoring systems necessary to simulate and track climate changes, particularly in terms of extreme events involving the water cycle. Research extends across time scales, from real time monitoring to predictions to projections, and emphasizes extreme precipitation. The Branch conducts rigorous scientific research that is published through peer-review and engineering developments that are documented through patents and technical reports, some of which are connected to industry through a long-standing Cooperative Research and Development Agreement.

The WCB has extensive experience with the design and use of regional networks of ground-based and airborne remote sensors, conventional in-situ observations and satellite data. The WCB maintains and deploys many research-quality instruments, including 15 wind profilers with radio acoustic sounding systems (RASSs) and surface stations, GPS-met receivers, sodars, 5 vertically pointing S-band radars, 2 FMCW snow-level radars, 3 scanning radars (X and C-bands), flux and soil moisture systems, ceilometers, GPS sounding systems and other equipment. Engineering advances focus on adapting equipment for use in extreme environments and on improving automation, reliability and cost-effectiveness.

A key example of the Water Cycle Branch capabilities and scientific contributions is the study of atmospheric rivers (ARs), which are narrow regions (relative to their planetary scale role; averaging 400 km wide) of the atmosphere where conditions are warm, moist and the winds are strong. ARs conduct >90% of the meridional water vapor transport in the midlatitudes and thus are critical in the global water cycle. WCB research has uniquely observed ARs, compared the findings with numerical models, and developed an automated monitoring and detection capability that combines satellite and ground-based remote sensing. Research has found that ARs are responsible for most of the extreme precipitation events on the US West Coast, and also provide 30-50% of the annual water supply in the region. These findings have led to field studies and diagnostics that link AR behavior to tropical forcing via the MJO, teleconnections, ENSO and air-sea interactions. New methods based on these findings are being used to evaluate the efficacy of downscaled climate projections of extreme precipitation and water supply and to establish long-term monitoring capabilities in the form of atmospheric river observatories that can provide unique information for extreme event predictions as well as create the ability to detect climate trends in water vapor transport and associated extreme precipitation events. Using data from the atmospheric river observatories, and high-resolution weather forecast models, a prototype decision support tool known as the Coastal Atmospheric River Monitoring and Early Warning System has been developed and is being demonstrated through the NOAA Hydrometeorology Testbed (HMT).

WCB provides key leadership elements of the NOAA HMT (hmt.noaa.gov), which is a "bridging" effort across OAR labs, across NOAA Line Offices and across Agencies. It has catalyzed research on key scientific and technical challenges related to extreme precipitation, provides independent evaluations of related forecast performance and prototypes new methods for testing and possible implementation in forecast operations. Where suitable, HMT assists in the transition of new methods and tools into long-term operations.

The following represent primary science objectives for WCB over the period FY11-15.

WCB-1: Advance hydrometeorological sciences and services through HMT

(Supports PSD Goals 1- 5)

The Hydrometeorology Testbed (HMT) focuses on research and on accelerating the infusion of new observing technologies and strategies, precipitation forecast model improvements, and new science of precipitation from the research community into forecasting operations of the National Weather Service (NWS) and into the emerging NOAA Climate Service (NCS). The development of HMT was led by PSD's Water Cycle Branch, and has grown to include participation from several NOAA laboratories, universities, agencies and NWS offices. In addition to leadership, PSD brings scientific and technological capabilities to bear on problems related to complex terrain precipitation, from state-of-the-art measurement systems, to diagnostic tools, to the development of new performance metrics focused on extreme precipitation and linkages to users of NOAA scientific and predictive products. (The relationship between NOAA's Strategic Plan, Research Plan and performance measures is described in detail in an Appendix, which is excerpted from the HMT Implementation Plan.)

Results from prototyping in the west have led to the implementation of key findings partly through support from the California Department of Water Resources, and range from deployment of new observing systems and modeling methods to the creation of a decision support tool for extreme precipitation forecasting in the region. A common theme of this implementation is better monitoring (for weather and climate) and prediction of atmospheric rivers and their affects on extreme precipitation. Also, NOAA program planning has included implementation of key additional capabilities in the out years as part of the "100% requirement." In addition, new performance measures focused on extreme precipitation and on snow level are being developed, and have the potential to transform NOAA's services by measuring forecasts in ways heretofore never conducted. Also, working closely with the Office of Hydrologic Development, a new performance measure for river flood warning lead time is being adopted by the NWS and will firmly establish the formal mission requirements to better predict extreme precipitation and incorporate these findings into hydrologic predictions.

HMT is contributing to NOAA's role in providing input into the Nation's Integrated Water Resources Science and Services (IWRSS) through the development of regional pilot studies and creation of key new methods that will be incorporated into the "Federal Toolbox" that IWRSS is proposing to establish. As key science questions remain on orographic precipitation, atmospheric rivers, snow and complex terrain, a significant "legacy" research effort will be maintained in the region, with a focus on extreme precipitation and runoff. This legacy will include work with the California Energy Commission and the Scripps Institute of Oceanography on evaluating the causes of uncertainty in climate projections of both water supply and flooding in the region. This multi-year project is called "CalWater" and has engendered involvement from multiple federal and state agencies to address this key socioeconomic challenge.

Lessons learned from HMT-West are being applied in the development of the next regional implementation of HMT, which is in the Southeast U.S. Findings from the PSD-led user requirements workshop and science-planning workshop will be completed in FY10. Establishment of HMT-SE has already begun through efforts of partners in the region and through coordination with NASA and NSF. A primary goal is to conduct major field efforts in FY13, in close coordination with NASA, regional investigators, and other partners. These efforts will address challenges of extreme precipitation in a region that differs substantially from the HMT-West domain, in terms of the mesoscale processes that produce extreme precipitation and the forecast challenges represented by these events. Unlike the west coast states, extreme precipitation events in the Southeast can occur in the warm season as well as in the cool season. HMT-Southeast will serve as a primary site for validation of and hydrologic studies for the NASA-led Global Precipitation Measurement (GPM) Mission.

HMT follows several steps in developing and carrying out its scientific, technological and service improvement objectives, with a focus on extreme precipitation:
Step 1: Understand both the state of the science and the major gaps in predictive services and related requirements.
Step 2: Identify and understand the underlying physical processes and the current predictive system.
Step 3: Develop methods to better monitor and predict key physical processes, and to baseline and assess the performance of current and new forecast products.
Step 4: Prototype tools for potential use in future predictive systems and for use by policy makers.
Step 5: Implement long-term capabilities for "operational" use in partnership with regional agencies, NWS and NCS.

WCB-2: Develop a HydroClimate Testbed (HCT) and associated "Extreme Precipitation Portal" (XPP) using lessons from HMT and NIDIS

(Supports PSD goals 1-5)

Whereas HMT focuses on studies and regional demonstrations that seek to understand key hydrometeorological processes that occur on shorter time and finer spatial scales, the WCB, in conjunction with the other branches in PSD, is working towards the development of a Hydro-Climate Testbed (HCT). The HCT will draw on the lessons learned and science derived from HMT and NIDIS and focus on conducting long-term observations and diagnostic studies, over larger basins (such as the Colorado River Basin) bridging weather and climate time scales. The HCT infrastructure will support diagnostic studies and the evaluation of large-scale climate models.

Planning has identified the development, demonstration and evaluation of a prototype Extreme Precipitation Portal (XPP), and its required scientific inputs, to meet key needs across Climate and Weather time scales as a priority. Accurate information on extreme precipitation events, past, present and future, is crucial for water supply and infrastructure planning and mitigation, but uncertainties are large. The focus is on the development and delivery of state-of-the-art information on high-impact, extreme precipitation events to support decision-making. This will build upon and integrate real time monitoring, long-term observations, diagnostic studies, and process understanding to deliver information products and services bridging weather and climate time scales. HCT will also focus on the transferability of lessons learned in the first phase of pilot studies to other regions, and on transitioning relevant HMT research findings into a NOAA Hydroclimate Testbed, which builds on and extends HMT time scales, and helps to address emergent extreme event issues in climate and ecosystems that have a high societal impact (due to either too much or too little water).

The Extreme Precipitation Portal (XPP) will be an interoperable (across users/agencies) tool focused on extreme precipitation observations, forecasts and climate projections. The XPP will provide extreme precipitation information services on time scales spanning weather and climate. The requirements for such system are being established through HMT and IWRSS, and are reflected in new formal or prototype performance measures for river flood warning lead time, extreme precipitation forecasting, snow level, and emerging climate services measures. It will be built so the outputs plug into the predictive system for precipitation and into the Community Hydrologic Prediction System (CHPS). This will include a component that is being developed for the California Department of Water Resources Enhanced Flood Response and Emergency Preparedness (EFREP) Program and NOAA that consists of a decision support tool (DST) to help forecasters better predict extreme events on the watershed scale (timing, location and intensity). Currently, quantitative precipitation forecasts (QPFs) are biased very low for the big events, partly because when an extreme event is predicted but does not occur (i.e., a false alarm), there are serious consequences as well. The goal of the "Forecasting DST" is to reduce the low bias in extreme QPF events without increasing the false alarms.

The DST will build, in part, on a number of research results on ARs that were produced by HMT and its precursors. Scientific findings and new monitoring and forecast aids developed in HMT-West, which identified thresholds for IWV and upslope winds that distinguish conditions that can generate extreme orographic precipitation in the region, from conditions that do not, will be a foundation of this tool. Additional concepts and tools will be incorporated into the XPP as they are discovered, prototyped and demonstrated in HCT and HMT activities.

Users of NOAA's precipitation products have also clearly indicated that lead-time on extreme events is needed for effective mitigation of impacts (e.g., reservoir operators can take actions). This demands significant improvements from 1 day to 14 days lead time, and also seasonally. Past findings relating MJO and ENSO conditions to these events, including the role of atmospheric rivers, will be explored and findings will be incorporated into the Forecasting DST. Key advances in reforecasting and ensemble prediction are also being pursued jointly with PSD1, NCEP, GSD and the Developmental Testbed Center (DTC). These hold significant promise. The EPP would be targeted to become a key tool in the "Federal Toolbox" that IWRSS is proposing to establish. Plans are under development to create an IWRSS/HMT pilot study on the Russian River of California, in close cooperation with the USGS, ACE and the Sonoma County Water Agency, which will help advance these objectives. Lessons from the NIDIS Drought Portal will also inform this effort.

WCB-3: Develop, deploy, and operate state-of-the-art observations for water cycle research and HMT prototyping

(Supports PSD goals 1-4)

The WCB engineering team develops and deploys new state-of-the-art sensors and sensor combinations to fill gaps in research observations that are needed to better monitor or understand water cycle processes. Data derived from these sensors are used by PSD scientists to address outstanding scientific and practical questions related to key physical processes. PSD scientists and managers also use these data to develop and implement plans that shape and take advantage of this research. The WCB deploys ground-based remote sensors to measure wind and temperature profiles, precipitation distribution, precipitation microphysics, boundary layer processes, snow level, water vapor transport, air pollution transport, and to detect and monitor key water cycle phenomena, such as atmospheric rivers. In-situ instruments are also deployed to measure rainfall rates and accumulations, snowfall amounts, surface meteorology, soil moisture, and stream levels.

The WCB's engineering team has deployed instruments at some of the most remote locations and extreme environments on Earth ranging from both the North and South Poles to the jungles of Thailand, bottom of the Grand Canyon, on board ships, ocean buoys, as well as aboard manned and unmanned aircraft. The engineering team develops new instruments, builds instruments, deploys instrumented networks, and maintains these networks during various research field campaigns. Datasets from these field campaigns are collected and archived in near real time. Scientists use these datasets to develop new tools and algorithms to gain a better understanding of water cycle processes and to provide operational forecasters and other end users with value-added information to improve their services.

An example of the WCB engineering expertise is in the development of a new portable S-band frequency-modulated, continuous-wave (FM-CW) snow-level radar. During past HMT deployments, California Weather and River Forecast Offices have found the value of snow-level measurements for verifying snow-level forecasts, for example, because flooding in mountain valleys strongly depends on how much of the mountain basin is exposed to rain versus snow. The measured snow levels were determined by an award-winning automated algorithm developed by WCB scientists that works with vertically pointing radars deployed for HMT. As part of a project to establish a legacy for HMT in California, the State of California Department of Water Resources (DWR) contracted with the WCB to develop an inexpensive snow-level radar. The WCB has successfully designed and prototyped an S-band FM-CW radar for this project and deployed the first two production units as part of a network of ten; each radar will be located at a key reservoir throughout the State. PSD will also maintain the network and deliver the data to the appropriate California Data Center.

The WCB will continue to study water cycle processes under a changing climate. Some research questions to address include how warmer sea-surface temperatures will impact the turbulent fluxes of water from the oceans, which provide a source of energy for oceanic storms that eventually may make landfall. How will atmospheric circulations distribute this water vapor regionally and globally? What role will climate change play in the complex cloud and mesoscale processes that produce precipitation? Once the water is on the ground in the form of rain or snow, what is the role of soil moisture in controlling the impacts of precipitation on the hydrologic system? The WCB will use its arsenal of observing capabilities to address these questions and use their engineering expertise and ingenuity to design new sensors and instruments to fill observation gaps. The WCB will continue to interact with other branches in PSD to gain a better understanding of the intricate connections between climate, weather and water.

c) Weather and Climate Physics Branch (PSD3)

The Weather and Climate Physics (WCP) Branch focuses on improving understanding of the drivers, feedbacks and mechanisms of weather and climate-relevant physical processes. To achieve this goal, observations and unique observing instruments are developed and applied to study air-sea, air-land, and air-ice interactions, including the effects of clouds, turbulence, radiation, boundary layer structures and multiscale interactions. Results are applied in air quality studies, physical algorithm development, understanding climate change processes, and improving weather and climate models and predictions.

The Branch is administratively divided into three teams: a Polar (Arctic) climate team, a boundary-layer processes team, and a multi-scale interactions team. This is a somewhat artificial division, because many PSD3 scientists participate actively in multiple areas.

The **Polar (Arctic) team** advances understanding of mechanisms controlling Arctic climate, including providing detailed measurements of properties of clouds, atmospheric and surface radiation, aerosols, and other observations required to interpret causes of observed polar weather and climate variations and change. Detailed measurements are taken with instruments such as radar, lidar and radiometers to better characterize key physical processes and identify long-term trends in this relatively poorly observed part of the world. This team supports the NOAA Atmospheric Observatories component of the U.S. Study of Environmental Arctic Change (SEARCH) program for which NOAA is among the lead agencies. The group has particularly strong intra-NOAA, interagency, University and international linkages. Polar team scientists work closely with GMD, CSD, GSD and PMEL; act as principal investigators /panel chairs on a number of DOE and NSF supported Arctic observation and modeling projects; operate data collection programs in 6 of the 8 Arctic countries and observations in the Arctic Ocean; and provide support for contracts with U.S. universities. The group leads an International consortium of Arctic observatories (www.iasoa.org) that is developing the foundation for what could be an Arctic component of a ground-based, observational network for the NOAA Climate Service.

The **Boundary-Layer Processes** team advances understanding of surface and boundary-layer processes in order to improve predictions, modeling and analysis of climate, weather and water in support of NOAA’s mission. This team combines field work with numerical modeling to improve weather and climate predictions. The field work is based on several technologies originally developed in PSD (e.g., wind profiler networks and seagoing cloud radars) where PSD has great strengths in understanding the technologies and their application to atmospheric physics problems. Modeling research focuses on improving community regional/mesoscale models such as WRF and previously MM5. PSD3 has developed its own versions of these models by incorporating advanced parameterizations (e.g., 2-moment microphysics or sea spray fluxes) to attack regional or unique problems, e.g., in extreme environments such as hurricanes. The team has a strong history in boundary-layer and mesoscale aspects of air pollution, coupling of cloud-microphysics to radiation, and applying observations to test and improve models.

The **Multiscale Interactions team** connects the interactions of geophysical processes occurring on different spatial and temporal scales. Using theoretical and experimental methods, the multiscale interactions group investigates small-scale oceanic and atmospheric processes and their effects on global-scale geosystems. The team is also involved in developing remote sensing techniques for processes of different scales in the ocean and atmosphere. The team consists of a diverse group of scientists with research experience in academic, industrial, and military applications. This group is involved in the measurement and theoretical understanding of small-scale, rapidly varying processes that impact larger scale atmospheric and oceanic motions. A goal of this team is to describe multiscale interactions using stochastic techniques that may be employed in weather and climate models.

The following represent primary science objectives for the WCP branch for FY11-15.

WCP-1: Advance understanding of key Arctic processes that impact the region's weather and climate and determine teleconnections with other regions. (Supports PSD goals 1, 4 and 5).

In December of 2008 President Bush signed in law a U.S. Arctic Policy. The document states:
"It is the policy of the United States to:

Meet national security and homeland security needs relevant to the Arctic region;
Protect the Arctic environment and conserve its biological resources;
Ensure that natural resource management and economic development in the region are environmentally sustainable;
Strengthen institutions for cooperation among the eight Arctic nations (the United States, Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, and Sweden);
Involve the Arctic's indigenous communities in decisions that affect them; and
Enhance scientific monitoring and research into local, regional, and global environmental issues."

One of the results of the development of the formal U.S. Arctic Policy is a substantially invigorated Interagency Arctic Research Policy Committee which is charged with developing a comprehensive U.S. research plan. Presciently, the efforts of WCP-1 have been organized now for over 6 years around the concept of a pan-Arctic Observatory system. This system has tremendous potential to be an important component in a larger system supporting both the infrastructure of an Arctic Observing network as well as the system science approach that will be necessary to support the mission directed science that will be necessary to support the research components of the U.S. Arctic Policy.

It is anticipated that the sustained atmospheric information products produced by the Atmospheric Observatory System will be essential for developing a predictive understanding of in a number of areas, for example changes in; Arctic sea ice (including impacts on shipping and national security), permafrost (including carbon and methane storage), glacier mass balances (including sea level rises) and coastal erosion (including impacts on Arctic communities). The science questions driving these long-term observational activities involve cloud processes, carbon cycle gases, precipitation distributions, atmospheric circulation, aerosol concentrations, pollution transport pathways, surface temperatures, and evolution of ozone/UV impacts on the surface.

Specific 2011-2015 objectives are to:

- Extend measurements of process level cloud and other atmospheric properties around the Arctic, with major new observations programs being implemented at Summit, Greenland and Tiksi, Russia to complement programs in Barrow, Alaska and Alert/Eureka Canada.
- Integration of NOAA activities into an integrated Interagency U.S. Arctic Observing Network plan that will constitute the U.S. contribution to the International Sustained Arctic Observing Network.
- Provide leadership on organization of an international consortium of flagship observatories in the Arctic region that are operated by the respective Arctic countries, including not only land stations, but also the long-term Russian ice stations.
- Continue and initiate the development of climate critical long-term monitoring data sets to track Arctic changes and provide a system capable of providing alerts on annual and biannual time scales.
- Utilize data on an on-going basis to study the clouds, aerosols, the Arctic boundary layer, and the atmosphere-surface exchange systems in the Arctic using observations and models to better understand key processes and improve representations in regional weather and climate models.

WCP-2*:* Improve the characterization, understanding, and capability to predict boundary layer structure and phenomena through application of expertise in remote sensing, boundary layer physics, and numerical modeling.

(Supports PSD Goals 1- 5)

Important phenomena and applications sensitive to boundary layer structure and processes include: hurricane intensity, which is controlled in part by the fluxes of heat, moisture, and momentum into and through the boundary layer; the initiation of summertime convection, which is often triggered within the boundary layer; the transport and diffusion of pollutants and hazardous chemical or biological materials; visibility; aviation safety; accurate depiction of the diurnal variation of surface temperatures in weather and climate models; boundary layer clouds such as marine stratus, and their effect on the climate system; and all weather-driven forms of renewable energy such as wind, solar, and wave energy. Because of the importance of boundary layer processes and challenges that remain in their observation, understanding and prediction, the recent National Research Council Report *Observing Weather and Climate From the Ground Up* highlighted the need to improve the nation's capability to observe and predict the atmospheric boundary layer to advance weather predictions and climate analysis.

Current focus areas of PSD boundary layer research are:

Boundary Layer Characterization. Remote sensors offer the best tool for observing the turbulent boundary layer. PSD applies these sensors to better understand the climatology of boundary layer depth and structure, including seasonal variations and regional differences in areas of complex terrain. These observations are being used to evaluate both weather and climate models. PSD will use new high-resolution wind profiling radars to study the stable boundary layer, including the low-level jet and its impact on wind energy. This research will contribute directly toward achieving PSD Goals 3 and 5.

Hurricane Intensity, Sea-Spray, and Wave Interaction. Hurricane's energy originates from the fluxes of heat and moisture at the sea surface. Although hurricane track forecasts have significantly increased in skill over the past two decades, hurricane intensity forecasts have improved little. PSD scientists have developed new parameterization schemes that simulate the effect of evaporating sea-spray on the fluxes of heat and moisture in high-wind speed conditions, and the impacts of breaking waves on generating the spray droplets. PSD is collaborating with NWS/NCEP and university scientists to implement and evaluate a sea-spray parameterization in NOAA's operational hurricane forecast model. This research will contribute directly toward achieving PSD Goals 3 and 1.

Air Quality. PSD will continue its efforts to improve understanding of boundary layer processes affecting air quality. This includes determining the effects of boundary layer structure on ozone and aerosol particulate matter (PM2.5) concentrations. PSD will participate in the CalNex 2010 field study, which will occur in the summer of 2010 and include all regions of California. PSD will help deploy instruments, analyze observations, and evaluate NOAA and Canadian operational air quality forecast models. This research will contribute directly toward achieving PSD Goals 3 and 1, and will also address Goal 5.

Renewable Energy. Weather-driven renewable energy is an emerging research priority for the PSD Boundary Layer Team. Discussions with the energy industry and with DOE have made it clear that improving our ability to forecast wind and solar energy production on all times scales from minutes to decades is essential for the design and operation of an effective national energy system that depends on weather-driven renewable energy. PSD (with other components of NOAA) has had extensive discussions with DOE on research paths that could lead to improved forecasts of wind energy. PSD is currently helping plan a joint DOE/NOAA observational and modeling pilot program to improve operational forecasts of winds at the wind turbine level. This research will contribute directly toward achieving PSD Goal 3 but also to Goals 1, 2, and 5.

Oceanic Boundary Layers: Recent work in spectral cloud microphysics and the acquisition of the PSD W-band radar greatly increases our potential for advances in this area. Future projects include the DYNAMO study of Madden Julian Oscillation in the Indian Ocean in 2011/2012. This research will contribute directly toward achieving PSD Goals 1, 2, and 4.

Specific science objectives for FY11-15 are to:

- Initiate a new program on weather-dependent renewable energy and its links to the weather-climate connection.
- Expand the existing hurricane research program (under HFIP) into boundary-layer and cloud microphysics representations in HWRF. This will build on expanded observational and modeling capabilities.

- Develop a coordinated PSD-wide investigation of tropical boundary layer variability drawing on analysis efforts in PSD1, atmospheric river efforts at PSD2, and the planned DYNAMO MJO field program.
- Deploy seagoing flux and cloud observing system (jointly with Polar team) on future Arctic icebreaker field program to investigate boundary layer cloud and aerosol interactions over the Arctic ice pack.
- Deploy instruments, analyze observations, and evaluate models for the CalNex 2010 air quality field program.

Additional information is available at: http://www.esrl.noaa.gov/research/themes/pbl/

WCP-3: Work toward a unified theoretical framework for geophysical scale interactions, including physically based descriptions of stochastic variability for use in climate analysis and prediction systems.

(Supports PSD goals 1-4)

Accurate description and forecasting of the climate system requires quantitative understanding of how small-scale, rapidly varying physical processes affect the evolution of global climate. Practical use of numerical climate models requires that some scales be unresolved in such models, but the cumulative effects of these unresolved processes on the climate scales of interest must not be neglected. An accurate stochastic representation of a physical system requires detailed knowledge of the system's statistics and how they are generated.

The multiscale interactions group participates in every step of this enormous process. The process starts with the development and operation of observational techniques, continues through the theoretical understanding of small-scale, rapidly varying meteorological phenomena such as turbulence and oceanic surface waves, uses this understanding to develop stochastic descriptions of them, and leads to numerical implementation of stochastic parameterizations in numerical models. These efforts are directly related to Goal 2, integrating water, weather and climate research, in that weather-climate interactions, most of which involve water, are target subjects. For example, given the importance of tropical cyclones to the water budget, research leading to the development of better simulations of hurricanes in regional models can be expected also to lead to an improved description of tropical hydrology in global models.

Research in this area supports PSD Goal 1, improving observations and understanding of Earth system processes. A major objective in this area is to contribute to both experimental and theoretical aspects of stochastic weather and climate descriptions. Observational tools that will be investigated and applied include the use of GPS technology and acoustic tomography; theoretical aspects include the theory of stochastic wave propagation. Goal 4, advancing understanding of regional processes and developing applications related to climate variability will be addressed by utilizing results from PSD's other goals to provide experimental forecasts of climate variables such as sea surface temperature, and analyzing the forecast errors. Additional information is provided at the following websites:
http://www.esrl.noaa.gov/psd/psd3/multi/ocean/
http://www.esrl.noaa.gov/psd/psd3/multi/remote/
http://www.esrl.noaa.gov/psd/forecasts/sstlim/

Specific scientific objectives for 2011-2015 are

- Continue development of satellite and remote sensing techniques for observing stochastic weather processes affecting climate.
- Advance understanding of rapidly varying physical processes pertinent to air-sea interactions and their effects on climate.
- Collaborate with scientists in PSD and elsewhere to utilize stochastic theory and state of the art numerical techniques for the improvement of probabilistic climate forecasts.

WCP-4: Develop a unified physically-based parameterization of air-sea fluxes of meteorological, trace gas, and particle fluxes.

(Supports PSD Goals 1 and 3)

PSD is a world leader in both flux observing technology and in parameterization. Here we need to maintain our leadership through the NOAA COARE flux algorithm suite and collaborations in advancing observing methods with several university groups. Specific Objectives 2011-2015 are to:

- Initiate new field program (joint with U. Hawaii, U. Connecticut, and LDEO) to obtain direct gas transfer (CO2, DMS, CO, and acetone) observations at high winds. Expand the suite of observed forcing parameters (wave properties, bubbles) to improve physical basis of the NOAA COARE gas transfer algorithm.
- Work with NCDC and the WCRP/CLIVAR Working Group on Numerical Experimentation to provide a major analysis of air-sea fluxes from NWP models. This will draw on the SURFA archive of NWP fluxes (hosted at NCDC) and buoy and ship observations from NOAA's Office of Climate Observations program.
- Initiate new field program (joint with LDEO and UNSW) to obtain direct sea spray observations at high winds. Expand the suite of observed forcing parameters (wave properties, bubbles) to improve physical basis of the NOAA COARE sea spray algorithm. This is in parallel with the P-3 observations objective below.

WCP-5: Advance observing technology in boundary-layer and air-surface interaction to promote Branch goals, emphasizing innovative remote sensing and highly advanced direct turbulence observation methods.

(Supports PSD Goals 1-4)

PSD maintains a strategic capability in technology development principally in the area of remote sensing of the boundary layers and cloud/precipitation radars. Such technologies are closely linked to our research efforts in hydrometeorological and dynamical processes. PSD3 will continue to work toward development of innovative concepts for observing geophysical phenomena. This effort will draw on the unique theoretical strengths of the multiscale team. Specific objectives for FY11-15 are to:

- Develop and deploy a new ocean-surface interaction capability for NOAA P-3 research aircraft. This instrument suite will include the scanning radar altimeter – WSRA (ocean wave spectra); high speed digital imagery (wave breaking statistics); the PSD W-band Doppler radar (sea spray and cloud microphysics profiles); GPS bistatic radar (hurricane surge and surface roughness). These observations will promote development of sea spray and flux parameterizations plus provide direct observations for future surge model and wave model evaluations (part of HFIP strategic plan).
- Develop a new FM-CW space-array antennae wind profiling radar that will be able to provide ultra-high vertical resolution wind profiles and be able to operate in high-clutter urban and forested environments.
- Explore acoustic tomography methods to determine area-averaged surface fluxes.
- Perform a feasibility study of ocean acoustic method to retrieve high spatial resolution hurricane surface wind fields.
- Work with WHOI to investigate possible uses of PSD2 and PSD3 technologies (wind profiler, flux sensors) for Ocean Initiative buoys.

WCP-6: Continue to Advance the capabilities of the Boulder Atmospheric Observatory as a world class Climate, Weather, and Water monitoring facility.

(Supports PSD Goals 1, 2, 3 and 5)

PSD is responsible for maintaining the Boulder Atmospheric Observatory (BAO). Operational for over 35 years, it not only supports research within NOAA (GMD, CSD, and PSD), but scientific interests throughout the world's universities and private corporations. As the centerpiece of the BAO facility, the 300m instrumented tower with a profiling instrument carriage provides an unparalleled resource for studying the planetary boundary layer, developing and testing remote sensors, and understanding regional air quality.

- Provide scientists with a platform for testing new remote and in situ sensors.
- Help explore acoustic tomography methods to determine area-averaged surface fluxes.
- Work with CSD to resolve the vertical chemical structure and aerosol growth in relationship to anthropogenic pollutants at a mid-continental site.
- Work with GMD to sample CO_2 and related gases in the continental boundary layer as part of the NOAA ESRL Tall Tower Network.
- Continue to collect surface radiation flux measurements with GMD as part of the Baseline Surface Radiation Network (BSRN) promoted by the World Climate Research Program.
- Serve as a resource to the renewable energy community for both wind and solar energy.

4. Information Technology Strategic Plan

The mission of PSD's Information Technology group is *to provide the scientific and administrative staff of PSD with the IT infrastructure necessary to fulfill the mission of ESRL PSD.*

Aside from the maintenance and daily operations of the servers, desktop computers, storage, communications devices and printers that make up the core of PSD's IT infrastructure, the IT group provides assistance and support to the research staff in areas such as:

- Data acquisition, control, and analysis
- Graphics Display
- High Performance Computing (Modeling)
- Internet-based Information Delivery
- Other (field program support, IT procurement and property management)

The PSD computing environment consists of a mixture of machines specialized for diverse research activities. This includes interactive Windows and Macintosh desktop-based computer systems for daily use and smaller compute jobs, as well as batch-oriented Linux servers and Intel clusters for large memory jobs or large CPU time, multi-processor model computations. Network connections are 1 GB/S between server computers and to each user. Approximately 100 terabytes of network accessible, managed storage is available for user home and data file systems. Mission critical data is backed up centrally on an enterprise-class tape library, and a copy of all backed-up files is stored off-site each month. Self-serve tape drives allow ad-hoc ,user driven backup of special purpose data as necessary. Two large format plotter/printers and several high-end graphics workstations provide production facilities for conference posters and other materials suitable for publication.

Although PSD is a research organization and, therefore, is not funded nor staffed for 24x7 operations, all central systems have UPS power and building emergency power backup, with planned availability 24x7. Operations after hours and on weekends are on a "best effort" basis. All critical systems have either a failover capability or a backup system, so interactive computing and critical services are always normally available. Remote access is available via a VPN. A wireless 802.11b/g network allows roaming internet access throughout the building

Year-to-Year Operations

On a FY basis, PSD IT prepares an annual operating budget for continuing operations and technical refresh through the year. IT follows an annual cycle when it comes to major software subscriptions (Microsoft Windows and Office subscriptions, and user level CAL's for Enterprise-level Microsoft services, Redhat Linux, MATLAB, IDL, NAG & IMSL are some of our major costs) & multi-function printer/copier leases.

For hardware refresh, PSD IT attempts to maintain a 3 year schedule on desktop PC and Macintosh computers, and a nominal 5 year refresh cycle on backend storage and computer servers. That means in a "normal" budgeting year we expect to replace 1/3 of the desktop systems and 1/5 of the backend systems. Of course, being subject to the vagaries of the Federal Government Budget cycle as well as the additional uncertainties of budgeting within an R&D enterprise, those objectives gets adjusted from year to year, typically near the end of the fiscal year.

For any additional infrastructure upgrades and / or IT services growth, PSD IT attempts to follow a rough 3 year cycle of focus:

FY 0: Backup/Storage
FY +1: Compute & Print server
FY +2: Network, Security, & Cluster computing

In recent years increased backup and storage requirements have almost outpaced our ability to grow, so we've had to make major backup and/or storage upgrades for the past few years running. We have managed, in addition, to acquire new compute servers to replace our aging Sun Solaris Compute and Web servers with more modern, Intel-based hardware running the Redhat Linux OS.

Our cluster computing capabilities have suffered as a result, however, and are becoming increasingly high in our refresh priorities. At present, PSD runs 2 compute clusters for larger programming jobs: an 88 core Intel cluster with 44 nodes, each consisting of 2 2.2 Ghz single core Intel Xeon processors and 1 GByte of RAM per processor; and a 32 core Intel cluster consisting of 4 nodes, each with 8 2.66 Ghz cores and 16 GBytes of RAM. A 3rd "cluster" consists of our desktop Macintosh machines which are loosely clustered through running Sun Grid Engine software and are available for spare-cycle batch computing in the evenings.

Factors influencing our strategic direction

1. The continued growth of demand for storage

Our overarching strategy is to go where the science asks us to go. Over the past few years as data from new observing systems and from advanced high performance computing capabilities has increased dramatically, the number one demand, as expressed through the PSD Computer Users Advisory Committee (CUAC), has been storage growth, which we've accomplished to the extent available within our budget. We see no end to the growth in storage demands. In fact, current forecasts project both demand and the growth of demand to increase over the next 5 years. The PSD Web and Data Administration team anticipates demand for ~100 additional TBytes of storage alone for dataset storage and dissemination, not including new, in-house created demand. Much of this is driven by the increasing availability and production of increasingly finer scaled observational datasets - the Hydrometeorological Testbed (HMT) – products forecast to produced over the next 4 years, as well as finer scaled weather and climate forecast and analysis products – for instance, the 20th Century Reanalysis project.

2. Continued IT Security concerns

Unfortunately, IT security has been a growth industry over the past 30 years, and will continue to be so in the future. The nature of the threat has changed, and with it, so must the nature of our response. In the 1970's and 80's, the main threat was "hackers," individuals who, for lack of a better outlet, broke into computer systems simply to prove it could be done. With the advent first of the World Wide Web, and then e-business, and finally e-government, the nature of the threat has evolved to more organized criminal enterprises attempting to extort money and, more recently to countries and organized political entities waging cyber-warfare. Such efforts are conducted by organizations, not individuals, and by organizations that are comparatively well-funded, extremely disciplined, and professional in their approach.

As the nature of the threat has changed, so must our response. It's no longer enough to require passwords and have a simple firewall protecting the system. IT security now requires "defense in depth" with multiple layers of security for individual systems, and a policy of "least required privileges." i.e. in the past, users were given permission to do anything there wasn't a good reason to disallow, whereas now, users are given permission to only do things there is a good reason to allow (i.e., what is required to get the job done).

3. Need to "Green" IT

With increasing emphasis being given globally, nationally, and locally to climate change issues and to carbon footprints and carbon neutrality, it is only fitting that PSD should make every attempt possible to lower the carbon footprint of its IT operations. Increasing emphasis is being given to "green" IT across the industry. Servers and storage systems are being designed with lower power and cooling requirements, and desktop computers are increasingly being supplied with low-power hibernation and sleep options and "wake-on-LAN" capability that allows machines to be virtually off at night, but powered back up as needed for backup and security scanning/patching.

4. Web 2.0 technologies and increasing ubiquity of "social networking"

PSD maintains several active and well-visited Web sites, including the main PSD site at http://www.esrl.noaa.gov/psd/, with over 10,000 pages of publicly-accessible content. The site includes organizational structure and mission information, current PSD research directions and results, comprehensive climate datasets, and interactive tools for accessing data sets and real-time or quasi real-time information on ongoing field activities and research missions.

PSD also uses a number of Web 2.0 tools to communicate both internally and externally. Internally, PSD maintains IT documentation for end-users on an internal wiki, and another wiki describes Web server configuration and procedures for scientists who contribute to PSD's external Web pages. Externally, some projects are using password-protected blogs to communicate key project information to collaborators from NOAA and other agencies. Some PSD scientists have experimented with using Facebook pages for their projects to attract a new generation of scientists, much as NOAA's chief administrator, Dr. Jane Lubchenco, is already doing to communicate her activities.

5. A flat, or at most very slightly increasing, IT budget on a per user basis.

Table 1 represents PSD IT costs on an FY basis since the inception of PSD as part of ESRL in FY05. With the exception of FY05 (which involved the purchase of an Enterprise class tape library) and FY06 (partially the result of the larger expenditures the year prior), IT budgets on a per user basis have been flat or slightly increasing over the life of PSD. We expect this trend to continue, although IT security costs and requirements continue to increase, as do storage and network bandwidth requirements. The net result is a requirement to do more with the same amount of resources each year.

FY	IT Costs / User
05	$ 15,775.87
06	$ 9,837.76
07	$13,167.12
08	$ 12,579.51
09	$ 13,394.36
10 (est)	$ 13,208.63

Table 1. PSD IT Costs per user

PSD IT strategic goals

Given the above external and internal influences, PSD IT proposes five strategic goals for FY11-15:

1. **Continue "business as usual" while simplifying and standardizing architectures as much as possible, and replacing aging infrastructure with "greener," less power hungry components as budgets allow.**

The combination of flat budgets with increased requirements can only mean one thing – a requirement to simplify administration and maintenance of infrastructure so that less labor is needed for support on a per user or per desktop basis. To this end PSD IT has standardized on an architecture of Redhat Enterprise Linux on our backend servers, and a choice of either the Windows OS or Macintosh OS on the user's desktop. We have eliminated redundant Web and FTP servers between PSD1 (the former CDC) and PSD2&3 (the former ETL), regularized and standardized our network architecture, DNS and license servers, and are in the process of standardizing our backup systems across the division.

We will strive to continue to drive IT costs down or hold them constant on a per user basis by continuing to seek standardized solutions and architectures across the IT infrastructure as possible, as well as seeking common solutions with other ESRL divisions and organizations within the DSRC, as practical.

The combination of increased storage, processing, and security requirements, flat budget, and a desire to "green" IT systems also necessitates moving to more modern, less power and cooling hungry infrastructure elements as quickly as possible. PSD IT has for the most part eliminated all CRT monitors (power and cooling intensive) in its server rooms and on desktops and replaced them with more modern, power efficient LED displays. We have replaced all our aging Solaris servers with more modern Linux-based Dell Servers, and replaced 2 racks worth of aging storage with more efficient RAID arrays. We have been phasing out our power-hungry PowerPC desktop Macintosh computers with more efficient Intel-based Macs, and expect to complete that process in FY10.

Prime for replacement in the next few years is our aging cluster in PSD-South, built in the late 1990's. The cluster consists of 44 nodes, each consisting of 2 2.2 GhZ Xeon processors with 1 GB of RAM each. With today's multi-core chips, a more powerful cluster could be built using just 4 nodes, each with 4 quad core processors, with considerably less power and cooling required.

2. Increase security while retaining flexibility and accessibility

As mentioned previously, IT security is an ever-present and ever-growing concern in today's networked world. PSD IT must strive to continue to increase our IT security posture in the face of growing and changing threats, while at the same time preserving an open and flexible IT environment to invite collaboration within PSD, across ESRL divisions, with other NOAA labs, and even with external entities wherever possible. Potential means of both increasing our security while decreasing the burden on individual researchers include:

- Implementing single sign-on and centralized authentication mechanisms across PSD IT resources wherever possible.
- Implementing two-factor authentication with NOAA CAC cards, or some other token if necessary.
- Implement Network-Access-Control software to allow laptops and field equipment to be more easily plugged into the network when returning from travels without constituting a threat to the rest of the network.

3. Increase both the manageability and scalability of our storage pool by migrating towards a single, iSCSI-based SAN for all PSD requirements (common Dataset storage, web services, linux-user home directories and adjunct storage for desktops).

In keeping with (1) above, PSD IT has been migrating it's ad-hoc and disparate storage solutions for Windows and Macintosh desktops, Web and FTP servers, and Linux home directories away from direct-attach and NAS based solutions to a more homogenous, standardized architecture of an iSCSI-based SAN storage pool provisioned and configured to serve the multiple storage needs listed above.

Implementing a common storage pool across all of PSD in this way increases flexibility and manageability of the storage pool, and should drive costs down on a per/megabyte basis.

4. Provide for ease of discovery and easier interpretation of online datasets through increasingly detailed metadata based on appropriate standards.

As datasets get larger and more complex, issues of cataloging and managing the information contained therein to allow easy discovery and proper interpretation become more important.

Appropriately detailed Metadata based on internationally recognized standards allows easier data discovery and manipulation. Modern web-based protocols such as OPeNDAP and libraries such as THREDDS rely on good metadata. As new climate and weather services are developed, cataloging both the data and web page(s) providing access to that service will become increasingly important.

5. Investigate and encourage the use of Web 2.0 and social media, where not in conflict with NOAA policy, for the communication and dissemination of research results.

PSD IT is cognizant of the fact that it is a support organization for a scientific research establishment, whose very raison d'être is, in some part, the communication and dissemination of information. Thus, despite the ever-increasing IT security requirements thrust upon us, we must find new and more effective ways of presenting PSD's science to the rest of the research community, NOAA, and the general public. PSD has had considerable success, and garnered considerable attention, with its web presence and suite of interactive tools designed to allow the online analysis of certain climate datasets. We have also had some limited success to date with using Blogs for communication tools during research campaigns. However, the pace of technological change and innovation in web-based services and presentation continues unabated, and in order to remain at the forefront of web and internet-based publication of research results, PSD must investigate, and to the extent not prohibited by DOC and NOAA policies, make use of new technologies and capabilities as they become available.

APPENDIX A: HMT in the Framework of NOAA's Strategic Plan and Performance Measures

(Excerpted from the FY2009 HMT Implementation Plan)

Key Societal Needs

Water is a vital resource that touches every life, every day. Thus it is almost a paradox that both too much water and too little water can be extraordinarily costly, and even deadly.

- "Water is the next oil." Managing a key natural resource (and a valuable commodity) requires advanced monitoring and predictive capabilities to reduce conflict between many competing demands, from fisheries, to agriculture, human consumption and many other uses
- On average, flooding causes more loss of life than other weather-related natural hazards, a significant fraction of which can be mitigated through more accurate forecasts and warnings
- Whether the problem is too little, or too much water, the societal impacts are profound

A National Priority has Emerged on Water Resources Information

Water resources problems are significant and getting bigger, and have created demand for NOAA and other agencies to coordinate and accelerate efforts to address these challenges. Excerpts from a briefing by NOAA Deputy Undersecretary Mary Glackin at the interagency meeting "Collaborating for a Sustainable Water Resources Future" (August 2009), include:

- Climate change and variability are dramatically impacting water availability and quality
- Socio-economic impacts of floods and droughts are escalating
- Population growth and economic development are stressing water supplies
- Increasing global demand for food and energy are causing unprecedented pressure on water resources and aquatic ecosystems
- Seamless integration of information and capabilities, and enhanced levels of collaboration, are required to address these challenges
- Each Federal water agency has an important role

NOAA's Mission

NOAA's mission is to

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

The NOAA Mission Goal that is addressed most directly by HMT is to

> *"Serve Society's Needs for Weather and Water Information"* (Weather and Water)

Weather and Water's Performance Objectives

The Weather and Water formal performance objectives that are addressed most directly by HMT are

- Increase development, application, and transition of advanced science and technology to operations and services
- Increase lead time and accuracy for weather and water warnings and forecasts
- Improve predictability of the onset, duration, and impact of hazardous and severe weather and water events

Additional Weather and Water formal performance objectives addressed by HMT are

- Reduce uncertainty associated with weather and water decision tools and assessments
- Increase application and accessibility of weather and water information as the foundation for creating and leveraging public (i.e., federal, state, local, tribal), private and academic partnerships
- Increase coordination of weather and water information and services with integration of local, regional, and global observation systems
- Enhance environmental literacy and improve understanding, value and use of weather and water information services

Weather and Water Research Areas within NOAA's Five-Year Research Plan FY2008–FY2012

- Improve weather forecast and warning accuracy and amount of lead time
- Improve water resources forecasting capabilities
- Improve NOAA's understanding and forecast capability in coasts, estuaries, and oceans

NOAA Mission Requirements/Program Objectives Addressed by HMT (from Program Charters)

Mission requirements related to the Integrated Water Forecasting (IWF) Program:

- NOAA's Role: Provide accurate and reliable water forecasts (*where, when, and how much), including*
    - Precipitation
    - Flash Flood
    - River flood
    - Estuarine water level and storm surge

Program objectives for IWF (from NEC decisional briefing December 2008) addressed by HMT:

- Advance and integrate observing systems for water resources
- Reduce 1-7 day river forecast errors by 50% and quantify uncertainty
- Provide seamless suite of summit-to-sea high resolution water quantity and quality forecasts
- Provide flood inundation forecast maps for 100% of high-impact river and coastal communities
- Couple modeling systems for rivers, lakes and estuaries

Mission requirements related to the Weather and Water Science, Technology & Infusion Program:

- Advance NOAA mission-oriented scientific understanding
- Advance NOAA mission oriented technology development
- Infuse new science and technology into NOAA forecast operations

Performance Measures

Table 1.1 lists the current, applicable Government Performance Requirements Act (GPRA) measures (from NOAA's Annual Operating Plan) and demonstration GPRA measures under development. The major R&D activity areas required to improve forecast and warning services (technical guidance from the HMT Management Council, informed by the HMT Advisory Panel and Project Manager) are also listed.

Table 1.1
GPRA and Demonstration Performance Measures for Forecasts and Warnings Addressed by HMT

Type	Forecast or warning	Statistical form	Issuing offices	Major R&D activities required
GPRA	1 inch precipitation	Threat score	NCEP HPC	A, F, G
GPRA	River flood warning	Lead time, accuracy	RFCs, WFOs	A, B, C, D, F, G
Demo	Extreme precipitation	POD/FAR/CSI/MAE	NCEP, RFCs	A, B, E, F, G
Demo	Snow level	Altitude error	RFCs	A, D, F

HMT's Major Activity Areas for R&D and Service Improvements

A	Quantitative precipitation forecasting (QPF)
B	Quantitative precipitation estimation (QPE)
C	Snow information (snow level and snow on ground)
D	Hydrology (flooding, soil moisture, runoff and streamflow)
E	Debris flow
F	Verification
G	Forecaster decision support tools

HMT Links Science and Technology Advances

HMT links science and technology (S&T) advances and NWS forecast improvements by fostering mission-oriented R&D and infusion of advances into operations. This section is from the draft "Capstone" document supporting the "NWS S&T Roadmap" currently under development.

A core challenge for S&T is how to measure science and technology research performance, including both the underlying advances needed in S&T to enable future breakthroughs in NOAA's services, as well as the near-term incremental improvements that typically build on existing operational tools. Key constraints should be recognized in establishing appropriate measures, i.e., S&T advances are a foundation of NOAA's service improvements, yet are often not initially measurable in the "service" GPRA scores. Improving "service" GPRA scores requires "service" programs to adopt new methods, yet this may have a cost and require services to let go of existing methods. Thus a balance must be struck: while research suggests fast improvements in GPRA scores may be possible, operational goals must be reasonably achievable or the risk of failure is increased. Standard measures of scientific and technical staff productivity include patents and formal publications that do not directly link to service improvements, and yet are critical to career advancement and are standards of productivity used broadly in the S&T community.

To strike this balance, a mix of the following approaches in measuring progress on implementation of the S&T Roadmap is recommended:

i. Internal measures suitable for state-of-the-art science & technology development; i.e., measure the innovation that underpins future breakthrough advances (the S&T "push")
ii. "Infusion-oriented" measures, including testbed demonstrations of proposed new GPRA measures
iii. Internal measures in "service" programs tracking implementation of infusion; i.e., measure the services' "pull" for science and technology
iv. Internal measures tracking the rate at which innovation is assimilated into forecast operations and the rate at which outdated forecast tools are discontinued

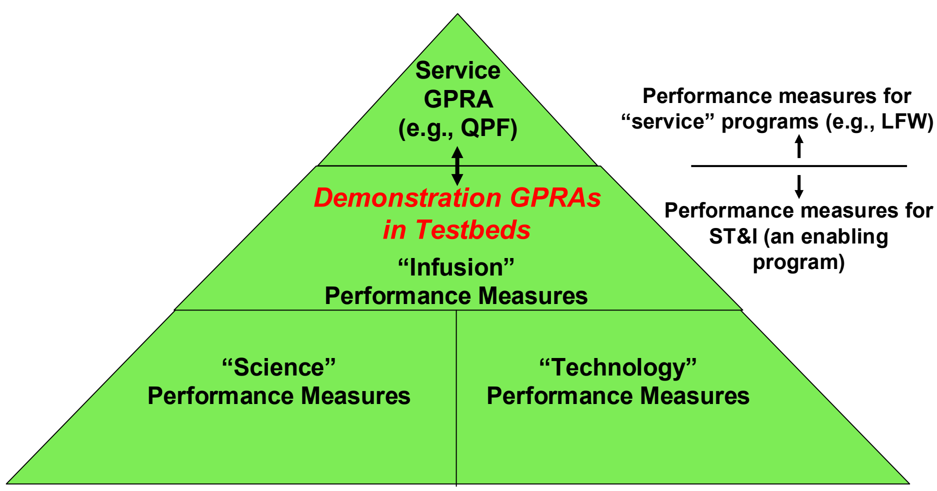

Figure 1.1 A graphical depiction of the relationship between S&T performance measures, the transitional demonstration (or stretch) measures, and formal GPRA metrics.

The overall concept is to use "demonstration" GPRA measures (i.e., "stretch" versions of current goals and entirely new goals) to measure potential service improvements and appropriate measures of science and technology progress (Figure 1.1). Key elements of this strategy are:

- Internal "stretch" GPRA score goals can be set higher in testbeds than in full operations
- Adoption of new methods for full operations requires proof of concept
- Proof of concept can be demonstrated by limiting tests to small areas, times, and tools
- By limiting the scope of tests, the costs can be kept within reasonable bounds
- Researchers and forecasters jointly define strategies to demonstrate impacts on the suitable "Demonstration GPRA" goal (e.g., QPF) during the tests
- If tests show regional improvement, extend results nationally with follow-up testing