A CLIMATE SERVICE IN NOAA

Connecting Climate Science to Decision Making

Vision and Strategic Framework

Contents

Purpose of this document

This Vision and Strategic Framework describes how NOAA proposes to respond to society's growing need for climate services. It describes the vision for a Climate Service line office and outlines the best approach to achieving that vision. The document outlines how the Climate Service can achieve new strategic goals related to the delivery and development of reliable, timely, and authoritative climate science and services to enable a climate-resilient society to grow and prosper.

Executive Summary

Every place on Earth is sensitive to changes in climate and weather. Up to one-third of the U.S. gross domestic product depends on accurate weather and climate information.[1] The local-to-global-scale impacts of climate variability and change have fueled a growing public demand for *climate services*—easily accessible and timely scientific data and information about climate that helps people make informed decisions in their lives, businesses, and communities.

For decades, the National Oceanic and Atmospheric Administration (NOAA) and its partners have been providing climate information that is essential to many aspects of policy, planning, and decision-making. Climate observations, monitoring, modeling, and predictions—underpinned by the best available science—provide the foundation for today's climate services. Important new questions are arising about how the nation can best prepare for anticipated changes in climate in context with changing economic, ecological, and social conditions.

As public and private sectors increasingly grapple with complex climate-sensitive decisions, NOAA and its partners in the U.S. Department of Commerce (DOC), the private sector, academia, and other federal agencies will improve the effectiveness of its climate services to meet growing public demand for science that informs, but does not prescribe, decision-making.

In February 2010 the U.S. DOC and NOAA announced their intent to establish a Climate Service to fulfill society's growing needs for climate information and services. The climate service will combine NOAA's world-class climate monitoring and modeling capabilities with a scalable new partnership for sharing knowledge, increasing public understanding, and building professional capacity at all levels of society. NOAA expects the Climate Service to participate vigorously in Federal interagency partnerships, which are vital to fulfilling the demand for climate services, as each agency has unique and complementary strengths. Recognizing the unique roles of various agencies, a Climate Service in NOAA would be well positioned to *connect climate science to decision making*.

Climate Service Vision

By providing science and services, the Climate Service envisions an informed society capable of anticipating and responding to climate and its impacts.

To achieve this vision, the Climate Service mission is to…

Improve understanding and prediction of changes in climate and inform a climate-resilient society by:

- Monitoring climate trends, conducting research, and developing models to strengthen our knowledge of the changing climate and its impacts on our physical, economic, and societal systems
- Providing authoritative and timely information products and services about climate change, climate variability, and impacts
- Informing decision-making and management at the local, state, regional, national, and international levels

The Climate Service delivers products and services in collaboration with public, private, and academic partners to maximize social, economic, and environmental benefits.

[1] Dutton, J.A., 2002: Opportunities and Priorities in a New Era for Weather and Climate Services. *Bulletin of the American Meteorological Society*, 83, 1303-1311.

The establishment of the Climate Service is also an explicit recognition of the historic opportunity to support a new category of economic innovation: entrepreneurs, as well as established businesses, that will seek to specialize in the provision of services and products based on environmental and climate data. This private climate service industry is central to the success of the Climate Service. Similar to the development of the private industry around weather information, the Department of Commerce expects that as better climate information is made available to the public, entrepreneurs in the private sector would find opportunities to tailor information to meet the unique needs of manufacturers, farmers, retailers, wholesalers, planners, resource managers, and others for advice on how to adapt their business or community development plans to a changing climate.

The Climate Service will work collaboratively with partners, including those in the DOC,[2] and decision makers in the public and private sectors to achieve four interdependent strategic objectives. The Climate Service objectives are from NOAA's Next Generation Strategic Plan (NGSP): [3]

1. Improved scientific understanding of the changing climate system and its impacts
2. Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions
3. Mitigation and adaptation efforts supported by sustained, reliable, and timely climate services
4. A climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions

To meet these objectives, the Climate Service will draw from NOAA's four existing climate core capabilities:

1. *Observing Systems, Data Stewardship, and Climate Monitoring.* NOAA collects, preserves, and analyzes the global environmental record for continuous climate monitoring and for developing periodic assessments in support of climate services. This readily accessible long-term archive serves the nation's need for trusted climate-related data and information about the current and changing state of the climate system. This capability provides the foundation for understanding the climate system; for identifying and monitoring regional to global scale trends; for helping to characterize scientific uncertainties; for tracking and quantifying of climate forcings, feedbacks, and their impacts; and for evaluating Earth system models.
2. *Understanding and Modeling.* NOAA advances the understanding of climate variability and change, and informs climate-sensitive decisions. This capability focuses on developing a comprehensive understanding and description of current and future states of the climate system. Analysis and modeling activities include process studies to advance

[2] The Department of Commerce includes the climate-relevant agencies such as the International Trade Agency, the National Institute of Standards and Technology, the Economic Development Administration, and the Census Bureau. These agencies offer considerable expertise and capability related to business and socio-economic issues.

[3] NOAA's *Next Generation Strategic Plan* (final draft Version 5.0, October 2010).

predictability and assess model performance, applications of climate models to diagnosis and explain climate processes, identification and interpretation of changes in climate forcings, feedbacks and their impacts at global to regional scales, and characterizations of the uncertainties in capabilities to measure and predict climate variability, change, and impacts.

3. *Predictions and Projections.* NOAA climate predictions and projections provide information on timescales from weeks to centuries. Development of climate system predictions and projections focuses on improved reliability, content, and delivery to support public and private sector preparedness, precautionary responses, adaptation, and other climate-sensitive decisions. Ongoing assessments of the performance of climate predictions and projections helps users understand skill and confidence and guides internal development efforts. Experimental analysis and translation tools will be developed with our stakeholders to transform model predictions and projections into useful phenomenological information at the spatial and temporal scales where people live, work, and manage resources.
4. *Integrated Service Development and Decision Support.* NOAA provides local to regional to global decision makers with timely and relevant climate information. NOAA supports partnerships to facilitate scientists and decision makers developing a shared understanding of changing and varying climate conditions and using those insights to inform adaptation decisions and climate policy. NOAA delivers data and information streams from which climate service providers can develop decision-support tools and other applications. NOAA also provides effective communication and education based on an interactive dialog with the public. An ongoing process of user engagement and needs assessments are used to ensure an appropriate mix of usable climate information products and services are being provided.

The four core capabilities provide the foundation for the services the Climate Service and its partners will deliver. The basic climate services currently provided by NOAA will grow and evolve through the sustaining and strengthening of the Climate Service core capabilities. Since many sectors and regions served through the NOAA's existing core capabilities are strongly linked to missions of other federal agencies, the Climate Service will continue to work with federal, state, tribal, and local partners to ensure the best possible set of climate services are delivered to the nation.

Additionally, the Climate Service will direct investments to new services that address strategically important climate-related societal challenges. New Climate Service services will also strengthen elements of the existing core capabilities, thus benefitting all other services, sectors, and regions. For each of the selected societal challenges, NOAA has mission responsibility, expertise, established partnerships, considerable demand from stakeholders interested in adaptation and mitigation, a proven track record in providing services, and identified resources.

The Climate Service will initially focus on four societal challenges:

1. *Climate Impacts on Water Resources.* The Climate Service will improve the nation's capacity to manage its water resources. Effective water resource management is critical

to numerous economic, social, and environmental sectors in a changing climate. For example, investments in many types of infrastructure are sensitive to altered temperature and changes in precipitation runoff, timing, volume, and location. The expected outcome is a coordinated and authoritative early warning information system that provides actionable and cost-effective guidance for the nation's water managers from local water districts to federal water agencies.

2. *Coasts and Climate Resilience.* The Climate Service will characterize the physical processes of climate variability and change that affect coastal regions and communities such as local sea-level rise and inundation. The Climate Service will also promote public understanding of the potential impacts that sea-level rise has on communities and ecosystems. The expected outcome is that decision makers have access to the best available information and are proficient in applying that information in ways that reduce risks and vulnerabilities in their communities.
3. *Sustainability of Marine Ecosystems.* The Climate Service will enhance resource managers' access to, and application of, the best available information to manage large marine ecosystems in a changing climate. The expected outcome is that federal, state, tribal, and local fisheries resource managers prepare for, and respond to, the impacts of climate on large marine ecosystems through improved understanding of how climate can alter ocean circulation and composition, and how changes in ocean properties impact living marine resources.
4. *Changes in the Extremes of Weather and Climate.* The Climate Service will provide the best available information to help the public, resource managers, and policy makers anticipate, prepare for, and adapt to ongoing changes in weather and climate extremes and their impacts. The expected outcome is the development and delivery of information to prepare for and adapt to weather and climate extremes—including changes in frequency, intensity, seasonality, and geographical distribution—on an ongoing basis.

Effective management of the Climate Service will be necessary to ensure that the best available climate information is delivered to support public and private

Example Activities: Sea Level Rise and Coastal Flooding Impacts

Coastal communities and planners have a vast exposure to the potential effects of climate variability and change. Their needs for climate services require NOAA to integrate multiple capabilities – observing, modeling, prediction, and decision support – and multiple scientific disciplines – climatology, meteorology, oceanography, economics, and social science. The Climate Service will provide an integrating foundation to bring together these capabilities and disciplines in service of the decision makers.

NOAA's Sea Level Rise and Coastal Flooding Impacts Viewer is one example of the first steps towards an integrated tool. It provides simulations of sea level rise at local landmarks, communicates the uncertainty of mapped sea levels, models potential marsh migration, overlays social and economic data, and examines how tidal flooding will become more frequent.

In addition, the Climate Service will be well positioned to investigate critical and complex issues such as effects of weather and climate extremes on coastal communities and ecosystems.

sector policy, planning, and decision-making. Making the Climate Service work well will require management principles, business practices, and partnerships designed to integrate NOAA's climate assets in support of adaptation and mitigation decision-making. Strong leadership will help create a unified Climate Service, able to deliver accessible, authoritative climate science and services necessary to help the country adapt to climate variations and changes and mitigate undesirable changes. A continuous process of evaluation and feedback from stakeholders will ensure that the Climate Service delivers state-of-the-art information that empowers individuals and governments at local, state, regional, tribal, and national levels to anticipate and to respond to climate and its impacts.

The nation's need for climate services exceeds the scope of any individual organization or agency. Accordingly, a strong framework of partnerships is key to success of the Climate Service. The Climate Service will bring together diverse scientific and service communities, including other parts of NOAA, federal, state, tribal and local agencies, cooperative institutes and other academic partners, the private sector, non-governmental agencies, and the international community.

Figure ES.1 illustrates the Climate Service strategic framework and the interactions between climate-related societal concerns, the Climate Service core capabilities and partners, the basic climate services, and the initial societal challenges. Research and service are a vital part of all four capabilities but play differing roles in each capability. As climate science is a developing field, the Climate Service views climate research itself as a product. The role of research in the Climate Service is to add to the scientific knowledge base and its practical application, thereby supporting the development of new products, new services and new industries.

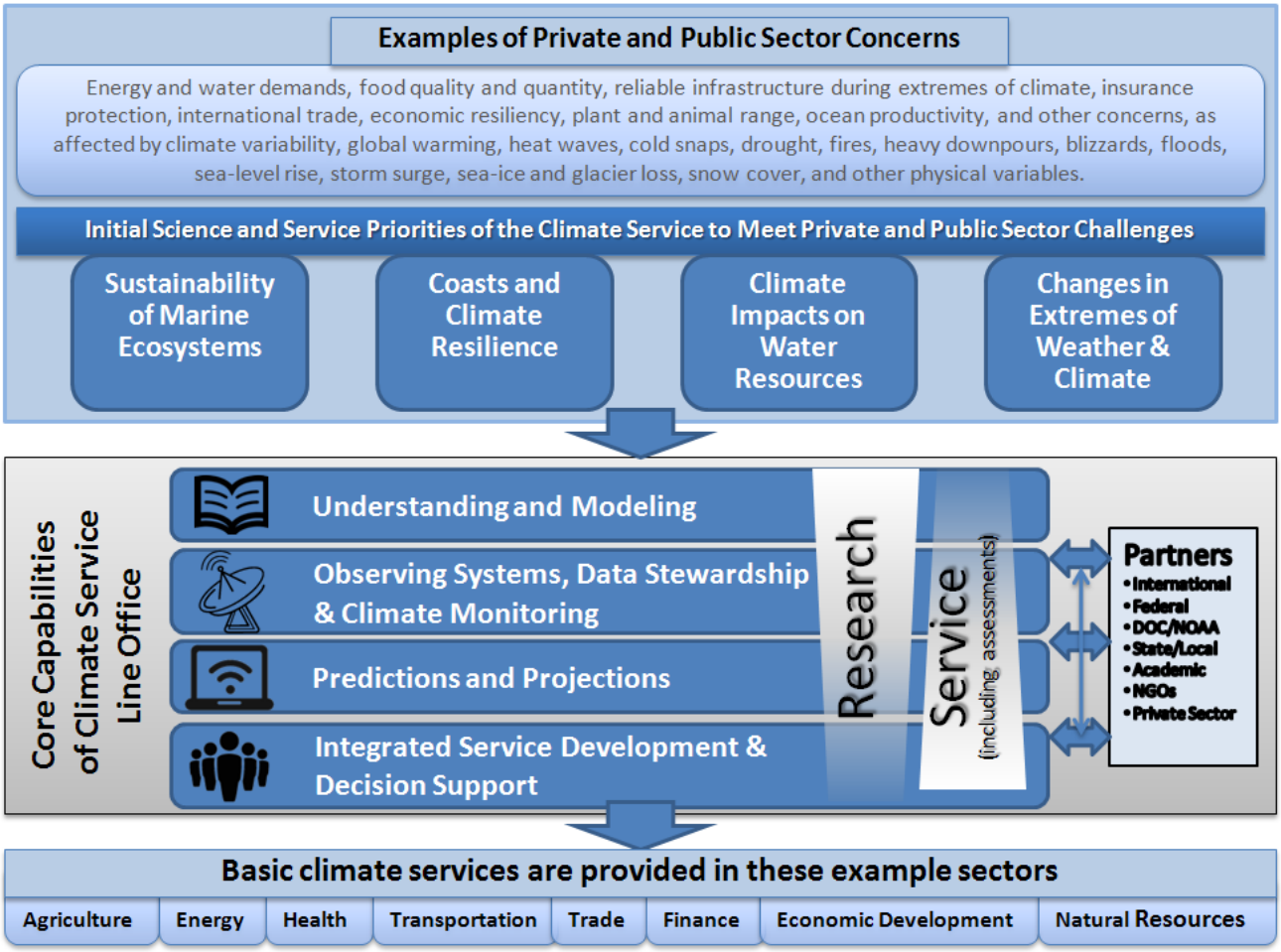

Figure ES.1. Climate Service Core Capabilities Address Societal Challenges. Societal concerns inform the four core capabilities. Partners from across the broader climate community both contribute to and benefit from the core capabilities. Research and service are a vital part of all four capabilities but play differing roles in each capability. The core capabilities support basic services in a variety of sectors. The core capabilities also support the initial four societal challenges, which receive expanded focus.

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Chapter 1: Importance of a Climate Service in NOAA

The Need for a Climate Service

Every place on Earth is sensitive to changes and variations in climate and weather. Up to one-third of the U.S. gross domestic product depends on accurate weather and climate information.[4] The local-to-global-scale impacts of climate variability and change have fueled a growing public demand for *climate services*—easily accessible and timely scientific data and information about climate that helps people make informed decisions in their lives, businesses, and communities. The Climate Service will foster the growth of a climate service enterprise including private sector providers. This has similarities to the growth of the weather service enterprise, in which a strong private sector component builds off of NOAA's National Weather Service (NWS) to provide important national and international weather services. Similarly the Climate Service would enable new national and international climate services to help elevate U.S. status as an international leader.

People are not indiscriminant seekers of information; rather, they seek sources they consider to be trustworthy, relevant, and easy to use. Just as Americans have come to rely upon authoritative and official forecasts from NWS, they also want authoritative and official information about climate on many scales, from local to global, monthly to decadal. Decision makers, in particular, seek an agency that can serve as an "honest broker" of accurate, reliable climate information that will help them evaluate options for avoiding unwanted changes in climate and the adverse impacts of unanticipated climate variation and change.

> **Climate Services**
>
> "A mechanism to identify, produce, and deliver authoritative and timely information about climate variations and trends and their impacts on built, social-human, and natural systems on regional, national, and global scales to support decision making."
> (NRC, 2009)

For decades, NOAA and its partners have been providing climate information that is essential to many aspects of decision-making.[5] Climate observations, monitoring, modeling, and predictions—underpinned by the best available science—provide the foundation for today's climate services. However, society's need for climate information and services has grown greater than the climate services that NOAA and its partners can provide today[6]. Thus, several scientific and policy organizations have called for the establishment of U.S. climate services to provide timely and authoritative information on climate and its impacts, at multiple time scales and geographic areas, and tailored to the decision-making needs of information users.[7]

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[4] Dutton, J.A., 2002: Opportunities and Priorities in a New Era for Weather and Climate Services. *Bulletin of the American Meteorological Society*, 83, 1303-1311.

5 See http://www.economics.noaa.gov/ for a thorough and up-to-date discussion of the economics and social benefits of NOAA Data and Services.

[6] NRC (V. Ramanathan Chair), 2009: Restructuring Federal Climate Research to Meet the Challenges of Climate Change. The National Academies Press, Washington, DC, 13.

[7] Miles, E.L., A.K. Snover, L.C. Whitley Binder, E.S. Sarachik, P.W. Mote, and N. Mantua. 2006: An Approach to Designing a National Climate Service. *Proceedings of the National Academy of Sciences* 103(52), 19,617-19,623. National Academy of Public Administration, 2010: Building Strong for Tomorrow: Recommendations for the Organizational Design of the NOAA Climate Service.

As public and private sectors grapple with complex climate-sensitive decisions, NOAA must work with its partners in DOC, the private sector, academia, and other federal agencies to improve the collective ability to develop and deliver climate services that meet the nation's expanding needs. Important new questions are arising about how the nation can best prepare for changes in climate in context with changing economic, ecological, and social conditions. The Climate Service will help address these growing concerns.

Benefits of a Climate Service in NOAA

Establishing the Climate Service will ensure that the best available climate science is effectively communicated with the public and used to develop and evaluate mitigation and adaptation strategies. The Climate Service will strive to inform decision makers as they seek to minimize undesired economic and environmental impacts of climate variability and change. Benefits of a Climate Service will include:

1. Cities, tribes, and states will have a primary and authoritative source of information on the likelihood of heat waves, storm surges, and other climate extremes (and related impacts such as poor air quality and flooding) to help them address vulnerabilities and develop adaptation plans.
2. Coastal communities will become more resilient as Climate Service services enhance state and local policy and planning. These services will include integrating local sea-level trends with global sea-level projections, for example, and assessing the risk of coastal inundation from changes in storm intensity and frequency.
3. Natural resource management agencies will use Climate Service information to make more informed adaptation decisions in the fulfillment of requirements to protect ecosystems and species.
4. More durable, resilient, and cost-effective water systems, dams, runways, roads, and bridges will result from Climate Service collaborations with infrastructure planners.
5. The Climate Service will help national security decision makers identify areas of potential near-term upheaval and long-term conflict in response to changes in food and water availability, climate-related health issues, sea-level rise, and other climate impacts.
6. The Climate Service information will help local, state, tribal, federal, and international government agencies manage pollution emissions to mitigate climate change and improve air quality, resulting in improvements for public health, transportation, and energy sectors.
7. Climate-sensitive decisions will be informed by relevant, accurate Climate Service information communicated at all levels of society at which decisions are being made to optimize investment strategies for energy and transportation, to enhance the economy, to create jobs, and to avoid job losses.
8. Scientists involved in climate studies will have a strengthened knowledge base with improved coherency between research, observations, modeling, and other disciplines.
9. The United States public will be more climate-literate with an increased ability to plan for and respond to climate and its impacts.

Vision for the Climate Service

NOAA has unique capabilities and experience in atmospheric and oceanographic science and services,[8] and decades of successful engagement with governmental, academic, and private sector partners. The Climate Service seeks to combine the agency's world-class climate science, technical, service, and communication capabilities into one line office focused on meeting demands for climate services. A first step will be to integrate existing capabilities and experience with climate-relevant science and services. Subsequently, NOAA will be better prepared to develop the necessary synergies with other agencies and climate service providers to form a new and greater whole, better able to meet the climate challenges facing the nation.

NOAA through the NWS already provides a unique service to the nation related to the weather forecasting enterprise. Weather forecasts demand a relentless real-time operation that draws upon well-established science and operational protocols. The Climate Service will draw upon NWS's experience and best practices to meet the new demands for services related to the longer time horizons of climate variations and changes.

Climate Service Vision

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The Climate Service delivers products and services in collaboration with public, private, and academic partners to maximize social, economic, and environmental benefits.

Features of the Climate Service and Critical Challenges

NOAA will work collaboratively with partners, including those in DOC,[9] and decision makers in the public and private sectors to achieve four interdependent strategic objectives consistent with NOAA's *Next Generation Strategic Plan* (NGSP):[10]

1. Improved understanding of the changing climate system and its impacts
2. Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions
3. Mitigation and adaptation choices supported by sustained, reliable, and timely climate services
4. A climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions

[8] Includes meteorological and oceanographic services and data stewardship, sustained observations and monitoring, state-of-the-art models for prediction and projection, process understanding, analysis, attribution research linking climate causes and effects, and national and international assessments.

[9] The Department of Commerce includes the climate-relevant agencies such as the International Trade Agency, the National Institute of Standards and Technology, the Economic Development Administration, and the Census Bureau. These agencies offer considerable expertise and capability related to business and socio-economic issues.

[10] NOAA's *Next Generation Strategic Plan* (final draft Version 5.0, October 2010).

To meet these objectives, the Climate Service will draw from four existing Core Capabilities—Observing Systems, Data Stewardship, and Climate Monitoring; Understanding and Modeling; Predictions and Projections; and Integrated Service Development and Decision Support (Chapter 2 and Appendix A)—and will focus initially on four vital societal challenges: Climate Impacts on Water Resources, Coasts and Climate Resilience, Sustainability of Marine Ecosystems, and Changes in the Extremes of Weather and Climate (Chapter 2 and Appendix B).

The Climate Service will be defined by the successful management of the four interdependent core capabilities. Without the solid base they provide, unacceptable uncertainties will persist, assessments will stagnate, services will wither, and public understanding will remain fragmented. Without strong scientific services and assessments that build upon each other, policy-related decisions will not be based on scientific knowledge and public climate literacy will be unlikely to improve. Organizations and decision makers will not be able to access the best available scientific information and will incur the high risks and costs associated with poorly informed choices. If public understanding does not improve, critical public debates will be ill-informed, adverse economic and environmental impacts from climate variability and change will continue to grow, and opportunities to stimulate commerce may go unrealized.

Risks to NOAA's organization and mission from the establishment and implementation of the Climate Service must be evaluated alongside clear benefits. The requirements for the new climate service must be designed to maintain investments in research to ensure continued success of strong science foundation that will be the building blocks for next generation services. NOAA is committed to standing up a well-balanced Climate Service that is equally committed to excellence in services for society and excellence in science. NOAA has ready examples of a healthy co-existence of science and services, so the agency understands the principles and best practices needed to protect and promote both. For example, NOAA's climate monitoring capability uses the best science available to transform observations into Climate Data Records (CDRs) that measure changes of climate over multiple decades. This information is provided in various forms to diverse users: the general public, academic researchers, the private sector, governmental policymakers, and non-governmental organizations (NGOs).

The Climate Service budget will be managed in a manner that is consistent with the practices of other NOAA line offices, and based on the principles that long-term investments must be protected against the pressures of short term payoffs. The Climate Service budget will reflect this strategy each year. While the Climate Service organization can provide an effective base level of science and services without increased resources, NOAA can only incrementally advance *both* science and services with existing resources. NOAA anticipates beginning the process of forming the Climate Service by emphasizing science and service in four key climate-related challenges facing society today (Chapter 2 and Appendix B).

Key Principles

Combining NOAA's resources into a well-integrated, more focused climate service is a critical first step toward achieving the agency's four interdependent strategic objectives. In addition, the Climate Service recognizes the need for some new approaches and commits to a set of principles and outcomes including:

1. **Strong internal and external partnerships** including the provision of a regular set of climate information from which other climate service providers can tailor new products to users
2. **Science and service synergies through a National Climate Service Enterprise**, including the collaborative development and evaluation of products and guidance of future science and services
3. **Expanded engagement through assessment services**, including a collaborative, participatory process of user engagement in the identification of needs and an assessment approach that includes sustained stakeholder engagement and dialog rather than periodic report writing
4. **Enhanced traceability, credibility, and transparency**
5. **A cultural change:** integrated end-to-end priorities implemented through new business practices

1. Strong Internal and External Partnerships

No one agency or community can provide all of the climate services that the nation needs, and the Climate Service requires an organizational framework that fosters sustained dialog with diverse scientific and service communities. These communities include DOC; other parts of NOAA; federal, tribal, state, and local agencies; academic partners; private industry, non-governmental organizations, and the international community. Chapter 3 describes how the Climate Service will work with each sector, ensuring that emerging scientific findings are transformed into high-quality products responsive to user needs.

2. Science and Service Synergies through a National Climate Service Enterprise[11]

In general climate science and services are still in their infancy compared to, for example, weather science and services. The Climate Service will evolve iteratively, incorporating vigorous research investigations and discovery, and considering new processes, user requirements, and user feedback. Weather services are driven by necessarily fast information transmission and the sheer quantity of forecasts, watches, and warnings. Integrating emerging science into these demanding mission-critical operations requires a deliberate approach. Because climate services will often have a longer time horizon, new and emerging science can be more readily used in climate services. Additionally, the inclusion of robust science within the Climate Service provides a means to share new advances in climate science beyond the science community. Such a service increases in value over time.

[11] The "National Climate Service Enterprise" is used as shorthand in reference to the emerging interagency and private-sector investment in climate services

An effective Climate Service will adopt an approach of "co-production of knowledge" with decision makers.[12] The intent of "co-production" is climate science that informs, but does not prescribe, decision-making. Similarly, decision-making should inform climate science, but not prescribe research priorities. The Climate Service must balance this 'user pull' and 'science push.' Rapidly growing demand for climate services will challenge the Climate Service to expand its products and research information to address user needs. It is also important to recognize that science and research can sometimes identify needs that are not yet known (such as anticipating the emergence of new risks). The Climate Service will cultivate its capacity to align user needs with emerging new science—and vice-versa. Connecting research findings to decisions will require knowledge of climate science and business acumen.

Examples of co-production of knowledge that NOAA has participated in or contributed to include:

- The use-inspired research by the NOAA-supported Regional Integrated Sciences and Assessments (RISAs) that is guided by user information needs
- The partnership approach of producers and users of information within the National Integrated Drought Information System (NIDIS) to develop and deliver drought services
- The collaborative, participatory process of user engagement within Pacific Climate Information System (PaCIS) to foster the use of climate information in decision-making
- The discovery of the depletion of stratospheric ozone and the provision of joint stakeholder and NOAA inspired products and information to solve the problem
- The continuous, interactive dialogue among federal agencies, the academic community, and Water Utility Climate Alliance (WUCA) to develop actionable information for adapting to climate change

The fundamental goal of the Climate Service will be to directly connect the best and most relevant climate science to user decisions. Methods and vehicles to do this will include assessments, ongoing engagement, and science itself, including predictions,[13] projections,[14] and attribution studies (research into the causes of observed variations and changes, including extreme events.)

The rapidly evolving nature of climate science combined with an emphasis on providing information for climate-sensitive decision-making at international, national, tribal, and local levels requires that extra care be taken to ensure the Climate Service's climate information is trustworthy, relevant, and timely. Climate Service science and assessments will be based on clear

[12] Ostrom, E., 1999: Crossing the Great Divide: Coproduction, synergy, and development. In: *Polycentric governance and development: Readings from the workshop in political theory and policy analysis* [McGinnis, M.D. (ed.)]. University of Michigan Press, Ann Arbor, MI, 346–374.

[13] A climate prediction is the result of an attempt to produce a most likely description or estimate of the actual evolution of the climate in the future (ranging from seasons to centuries).

[14] A projection is the anticipated response of the climate system to emission or concentration scenarios of greenhouse gases and particles, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions to emphasize that climate projections depend upon the emission, concentration, and radiative forcing scenario used, which are based on assumptions, concerning, for example, future socioeconomic and technological developments, which may or may not be realized and are therefore subject to substantial uncertainty.

and up-to-date scientific principles, assumptions, methods, models, and data. The science, projections, and predictions will be consistently reviewed and revised as new observations, new knowledge about processes, newer models, and updated analyses become available. Each of these steps will take user needs into account.

3. Expanded Engagement through Assessment Services

Climate Science Assessments comprehensively summarize the knowledge gathered from many studies and disciplines into authoritative overviews of climate variability, climate change, and climate impacts. Science assessments characterize uncertainties based on documented information and identify gaps in understanding to help prioritize future research and service development efforts. Because the assessment process exemplifies the synergy between science and service, the Climate Service will use assessments to inform policy advisors, community planners, and decision makers, as well as its own research agenda. The Climate Service will focus on two types of Climate Science Assessments:

1. National and International Assessments
2. Problem-Focused Assessments

The Climate Service will only participate in Climate Science Assessments that have standards in place which meet or exceed those of Information Quality Act.[15]

A third type of assessment—Stakeholder Needs Assessments—will help ensure that the Climate Service science and services are brought to bear on relevant problems and questions. For example, Needs Assessments will be used by the Climate Service to help frame problem and policy-relevant issues that connect to the Climate Service core capabilities.

Together, these three types of assessments serve as powerful tools to guide the design of high-quality regional service products, and will frame dialogues among Climate Service scientists and service providers and regional users.

The Climate Service will include climate service users and private sector partners in the framing of the assessments, thus seeding a network that is grounded in the Climate Service's sustained engagement across geographical regions and societal sectors. These services will be important for delivering scientific support and information from scientific assessments that can be used to help meet user demands. Where user demands cannot be met, the need for new science or additional services will be evaluated and appropriate priorities established. The Climate Service portfolio prioritization framework is discussed in more detail in Chapter 3 (Figure 3.1).

[15] Information Quality Act, sometimes referred to as the Data Quality Act, was enacted in December 2000 as Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (P.L. 106-554). The act required the Office of Management and Budget to issue guidance to federal agencies designed to ensure the "quality, objectivity, utility, and integrity" of information disseminated to the public. Requires agencies to take three actions (to the extent permitted by law): (1) have a peer review conducted on all "influential scientific information" that the agency intends to disseminate (changed from "significant regulatory information" in the proposed bulletin); (2) have all "highly influential scientific assessments" peer reviewed according to more specific and demanding standards; and (3) indicate what "influential" and "highly influential" information the agency plans to peer review in the future.

The Climate Service's assessments will be developed with the intention of being an integral contribution to broader national and international assessment strategies, such as those implemented by the U.S. Global Change Research Program (USGCRP), the World Meteorological Organization (WMO), the United Nations Environmental Programme (UNEP), and the Intergovernmental Panel on Climate Change (IPCC).

Assessments are described further in Chapter 2, section D.

4. Enhanced Traceability, Credibility, and Transparency

Through strength in research, the Climate Service will aim to grow the body of scientific knowledge about climate variability and change, including the determination and quantification of uncertainties and confidence intervals. Because the Climate Service will use and tailor new science to address applications and user needs, the Climate Service will ensure its data, information, and services meet the highest standards of scientific excellence. This mandates careful quality assurance, including:

- Rigorous and internationally-recognized procedures for calibration and validation of observation and monitoring systems
- Transparent peer-review procedures for articles, documents, and assessment reports
- Quantification and accurate communication of uncertainty in model outputs
- Accessible metadata documenting the quality of data products and services

The Climate Service will identify—and make public—the teams responsible for the quality assurance of particular products, to ensure that its services are trustworthy, relevant, well-described, and easily accessible.

5. Creating a Culture for Success in the Climate Service

To create a new culture of shared learning that values the co-production of knowledge, advances scientific understanding of climate, and delivers relevant, usable services, the Climate Service will need to adopt new business practices that:

- Promote ongoing and sustained engagement with policy advisors, community planners, and decision makers
- Provide for the rapid infusion of research findings into products and services
- Nurture the growth of science and service within a single organization as complementary rather than competing activities
- Balance what users want and what is justifiable scientifically
- Recognize science and research as valuable services in their own rights
- Value communication and education as both a contribution to services and to research
- Link research to decision-making as an alternative to the more traditional research–to-operations paradigm
- Incorporate a fast-track review process for information products to meet the time-dependent information needs of decision makers
- Leverage innovative internet-based tools to enhance communication and collaboration with stakeholders.

These practices are discussed in greater detail in Chapter 3.

Chapter 2: Strategic Framework

A. Overview

In February 2010, DOC and NOAA announced the intent to create a climate service line office in NOAA dedicated to bringing together the agency's strong climate science and service delivery capabilities. The implementation of the Climate Service will directly support NOAA's vision of "an informed society that uses a comprehensive understanding of the role of the oceans, coasts, and atmosphere in the global ecosystem to make the best social and economic decisions." The Climate Service will contribute to NOAA's mission "to understand and anticipate changes in Earth's environment, and conserve and manage coastal and marine resources to meet our nation's economic, social, and environmental needs."

To support the agency's mission, the Climate Service will sustain and advance the following set of core capabilities, described in section B below:[16]

1. Observing Systems, Data Stewardship, and Climate Monitoring
2. Understanding and Modeling
3. Predictions and Projections
4. Integrated Service Development and Decision Support

The Climate Service will initially draw on those capabilities to focus on four societal challenges with broad economic reach.[17] These challenges, detailed in section C, represent critical climate issues at the core of NOAA's science, service, and stewardship mission and mandates:

1. Climate Impacts on Water Resources
2. Coasts and Climate Resilience
3. Sustainability of Marine Ecosystems
4. Changes in the Extremes of Weather and Climate

In these focus areas, NOAA has clear mission responsibility, expertise, considerable demand from stakeholders interested in adaptation and mitigation, a proven track record in providing services, and identified resources.

The Climate Service will draw from existing core capabilities to address specific problems and will support development of new climate services necessary to meet these societal challenges. Committing to meet these societal challenges will enable the Climate Service to prototype end-to-end service development, to work with a range of partners and users, and will help the Climate Service identify weaknesses or gaps in core capabilities. These four foci will very likely evolve, depending on future resources, the breadth of the National Climate Service Enterprise (see footnote 11), and maturing stakeholder priorities.

The climate products and services currently provided by NOAA will continue to evolve. As the sectors and regions served through the agency's existing core capabilities are strongly linked to

[16] Appendix A details core capabilities.
[17] Appendix B details four key societal challenges.

missions of other federal agencies, the Climate Service will continue to work with partners such as the USGCRP and its member agencies to optimize climate services delivered to the nation. Additionally, investing in new services for the four societal challenges described above will improve services for other sectors and regions, since each of those challenges overlaps with needs in other sectors and regions.

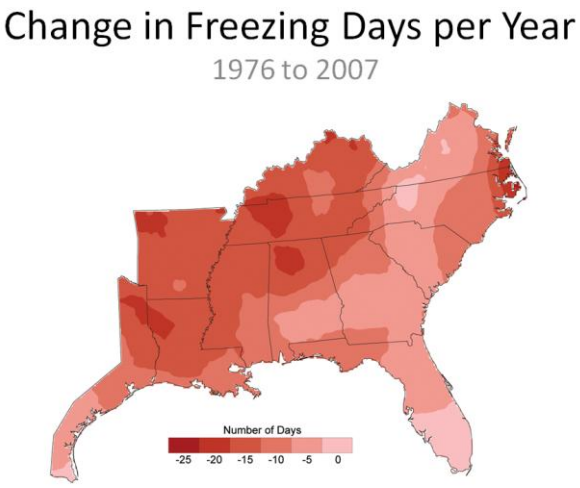
Most of these societal challenges focus on adapting to variations and changes in climate and climate impacts. To help users make informed adaptation decisions, The Climate Service will provide basic information that is timely, relevant, authoritative, and easy to access and use. The Climate Service will ensure that both the science and the communication of that science meet the needs of specific users (such as decision makers, community planners, resource managers, and the public) so that infrastructure, ecosystems, human health, and welfare can be effectively managed. From changes in short-term extreme events (such as hurricanes) to long-term climate variability and change (such as longer growing seasons), the Climate Service will provide information to help our nation realize the benefits of implementing the most appropriate adaptation and mitigation strategies. Assessments, described in section D below, will be a key vehicle for these services.

This chapter describes Climate Service's four core capabilities, four societal challenges, and how they support each other. It also describes how effective assessments will serve as critical integrating vehicles.

Example Activity: Growing Seasons

Since the mid-1970s, observations show that the number of days per year in which the temperature falls below freezing has declined by four to seven days over much of the Southeast. Some areas, such as western Louisiana, have experienced more than 20 fewer freezing days. These observations inspire climate-related questions: Will these trends continue, accelerate, or change direction? How will next year's freeze-free period compare to these trends?

The Climate Service will work to deliver the most authoritative and useful information for decision making relevant to agricultural, horticultural, and other related sectors.



B. Climate Service Core Capabilities

NOAA has diverse and deep experience in connecting users with environmental information through weather, climate, ocean, fishery, and satellite services. This expertise will form the foundation for implementing the Climate Service. The Climate Service will continue to use a variety of internal and external mechanisms to invest in climate science and services programs, and to partner with other agencies' science and service programs. NOAA's current and near-future investments in climate science and services will be managed in the context of Climate Service's four core capabilities.

Existing core capabilities are distributed among the NOAA line offices; are located in laboratories, centers, field offices, and programs; depend on strong and continuing partnerships with federal, tribal, and state agencies, the academic community, and the private sector; and rely on international collaboration and formal agreements. The Climate Service core capabilities create both a strong foundation and the future building blocks that will enable NOAA to meet the growing societal demands for climate services. Appendix A provides an overview of the four Climate Service core capabilities.

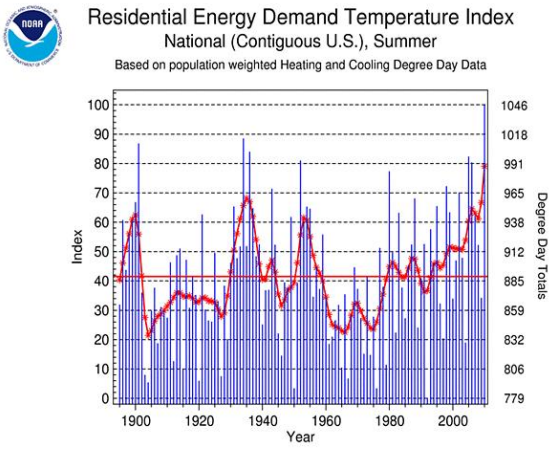
Basic Climate Services

Users expect the Climate Service to provide a basic level of climate information to support a broad range of decision-making. This basic level of information will also feed the development—by others, including the private sector—of value-added services and products tailored for specific applications. In providing a basic service, the Climate Service will produce and deliver authoritative, timely, and usable "primary-level" climate information.[18] This easily accessible, single source of information can serve a variety of needs, including regional-to-national decision-making and statutory compliance. Enhancements in the types and quality of the basic service information and products will depend on the rate and extent to which Climate Service core capabilities advance in support of the four identified key societal challenges, and through other strengthening mechanisms. Enhancements will be dependent on innovative management, science and services, and fiscal responsibility. In sectors such as energy, transportation, agriculture, health, insurance, construction, tourism, and national security, the Climate Service will depend on other federal agencies and the private sector to take the lead and to define the climate impacts and information needs, and to determine how to best produce appropriate information to meet those needs. The Climate Service will leverage advanced information technology in all core capabilities; from high performance computing for climate modeling, advanced informatics for data management, archive, and access; to novel application software and social networking tools for communication, education and

Example Activity: Residential Energy Demand

The energy sector has a significant exposure to climate variability and change. Energy production utilities make decisions about their business based on weather and climate information on the scales of minutes to decades. NOAA has a history of providing timely and reliable support to the energy sector.

An example is NOAA's Residential Energy Demand Temperature Index. This is an index based on population-weighted heating and cooling degree day data that is closely related to the demand for certain specific types of energy usage in the contiguous US.



[18] This is climate information that is generic in nature. It is not tailored for specific decisions of any individual business, but is generally considered the building blocks for assessments and decision-support tools developed by individual businesses, other sectors, or selectively developed by the Climate Service.

stakeholder engagement. The Climate Service will continue to strive to provide the basic climate information for all sectors where NOAA plays a supporting role (Table 2.1 highlights examples).

Table 2.1. Continued Support. The Climate Service will continue NOAA's support of other agencies and complimentary capabilities, by providing climate services critical to those agencies' missions. For example, DOE, NASA, and EPA have responsibilities and/or capabilities regarding carbon monitoring and emissions, renewable energy, and seasonal energy use. The Climate Service will support those missions with greenhouse gas monitoring, seasonal climate forecasts, and more.

Issue	Key Federal Agencies	Examples of Existing NOAA Products and Services
Energy: • Renewable energy development • Seasonal energy use • Carbon emissions issues	DOE, NASA, EPA	• Seasonal climate forecasts • Climatology information for wind and solar energy infrastructure planning • Precipitation and water resource information for hydroelectric energy • Greenhouse gas monitoring
Transportation: • Impacts of a changing climate • Infrastructure • Transportation corridors	DOT, FAA	• Navigation charts • Climatology of significant meteorology for major airports • Real-time tides and currents for safe navigation of ports • Aviation sector planning and support • Surface airport climatology
Agriculture: • Crop yields • Drought and flood information • Seasonal crop forecast • Forest management	USDA, USGS, USFS	• Precipitation and temperature forecasts and observations • Drought monitoring and forecasts • Climate normals
Health: • Environmental stressors • Oceans and human health	HHS, EPA	• Observations and understanding of air quality processes • Extreme weather forecasts and predictions

In addition, a much broader range of sectors will benefit from investments to strengthen core capabilities and advance service delivery in support of the four identified key societal challenges. For example, to deal with challenges involving water resources and climate extremes, the Climate Service will develop products designed to inform adaptation options for a broad range of sectors, from health to agriculture. Adapting effectively to a changing and varying climate requires information about numerous aspects of the state of climate. Understanding adaptation choices for a specific time in the future requires understanding the path taken to get there. Such

information is not only useful to assess the cost effectiveness of adaptation options, but also the impact of various mitigation strategies and scenarios.

The Climate Service will assist its partners and stakeholders in evaluating the diverse portfolio of climate information available to support adaptation and mitigation. The Climate Service will also help facilitate capacity building to improve the ability of its partners and stakeholders to appropriately use, interpret, and communicate the climate information being produced for adaptation and mitigation. The Climate Service basic level of service will evolve in response to consumer feedback, clarification of agency roles through the formation of a National Climate Service Enterprise (see footnote 11), lessons learned within the societal challenges, changes in national priorities, and new climate data.

C. Four Societal Challenges

The Climate Service will expand NOAA's current focus on information and services in four climate-related challenges to society. The challenges selected represent a spectrum of needs for which NOAA can develop and deliver services. The societal challenges focus on providing information necessary to make informed decisions for effective adaptation actions and other climate-sensitive decisions.

1. *Climate Impacts on Water Resources.* The Climate Service will improve the nation's capacity to manage its water resources. Effective water resource management is critical to numerous economic, social, and environmental sectors in a changing climate. For example, investments in many types of infrastructure are sensitive to altered temperature and changes in precipitation runoff, timing, volume, and location. The expected outcome is a coordinated and authoritative early warning information system that provides actionable and cost-effective guidance for the nation's water managers from local water districts to federal water agencies. To address this water resources challenge, NOAA will build on experiences gained in developing the National Integrated Drought Information System (NIDIS). Methodologies developed through the Hydroclimate Testbed and the National Weather Service, especially the River Forecast Centers, will contribute to the Climate Service's abilities to anticipate, prepare for, and adapt to drought and flooding events on climate time scales.

2. *Coasts and Climate Resilience.* The Climate Service will characterize the physical processes driving local sea-level rise and inundation affecting coastal regions and communities. The Climate Service will also promote public understanding of the potential impacts that sea-level rise has on communities and ecosystems. The expected outcome is that decision makers will have access to the best available information and will be proficient in applying that information to reduce risks and vulnerabilities in their communities. Addressing this challenge is a natural extension of work performed by the National Ocean Service, and specifically its Coastal Services Center, to support decision-making efforts that involve adapting to and mitigating the impacts of local sea-level rise and inundation, and the work performed by the NWS in helping communities adapt to sea-level rise by issuing various coastal watch and warning products.

3. *Sustainability of Marine Ecosystems.* The Climate Service will enhance resource managers' access to, and application of, the best available information to manage marine ecosystems in a changing climate. The expected outcome is that federal, tribal, state, and local fisheries resource managers prepare for, and respond to, the impacts of climate on marine ecosystems through improved understanding of how climate can alter ocean circulation and composition, and how changes in ocean properties affect living marine resources. Providing information and services to address this challenge builds on the core mission of the National Marine Fisheries Service by integrating climate information into the management of marine ecosystems. One example of this work is NOAA's ongoing development of experimental services for the California Current System.

4. *Changes in the Extremes of Weather and Climate.* The Climate Service will enhance the ability of resource managers, policy makers, and the public to apply the best information to anticipate, prepare for, and adapt to ongoing changes in climate extremes and their impacts. The expected outcome is the development and delivery of information to prepare for and adapt to climate extremes—including changes in frequency, intensity, seasonality, and geographical distribution—on an ongoing basis. Activities that address this challenge will be closely coordinated with efforts led by the National Weather Service to encourage public awareness of, and preparedness for, near-term extreme events.

Though these societal challenges will provide initial focus and integration to the Climate Service activities, it is important to recognize that science and research can sometimes identify needs that are not yet known. Two examples are the discovery of the stratospheric ozone hole and ocean acidification through absorption of atmospheric carbon. NOAA's annual planning methodology allows emerging science to guide the prioritization of activities.

The Climate Service recognizes that it could play a strong role in developing scientifically-grounded estimates of the costs of climate impacts on water resources, climate impacts on coasts, climate impacts on marine ecosystems, and the effectives of changes in extremes, which would inform future iterations of interagency assessments on the social costs of adaptation and mitigation options.

Though the four societal challenges deal with different aspects of the climate system and some are relevant to specific geographic regions, information requirements for each challenge are not independent. Efforts to address all four challenges will benefit from cross-fertilization during development of enhanced services and effective delivery methods. Table 2.2 summarizes the relationship of the four Climate Service societal challenges to external drivers, mission responsibilities, existing capabilities, new demands for services, and new resources.

Appendix B describes the four societal challenges in more detail.

Table 2.2. Societal Challenges. Four societal challenges, NOAA's responsibility for each, current capabilities, demand, budget, and external drivers.

Challenge > Criteria ∇	Climate Impacts on Water Resources	Coasts and Climate Resilience	Sustainability of Marine Ecosystem	Changes in the Extremes of Weather and Climate
NOAA mission responsibility	• Freshwater supply (DOC) • NIDIS leadership	• Stewardship • DOC trust resources	• DOC trust resources	• USGCRP lead in synthesis and assessment products
Existing capabilities to address challenges	• Observations • Analysis • Modeling • Predictions • Projections • Service delivery • NIDIS	• Observations • Analysis • Modeling • Predictions • Projections • Service delivery	• Observations • Analysis • Modeling • Service delivery • Projections • Predictions	• Observations • Analysis • Modeling • Predictions • Projections
Primary contribution	Adaptation	Adaptation	Adaptation	Adaptation
Demand for services or user need	• NIDIS • HMT–(tools for water in a changing climate) • Flood	• Primary internal partner: NOS	• Primary internal partner: NMFS	• Built and natural resource management for current and future risk
New resources in President's FY11 budget	• NIDIS • Water resources research to operations, Earth system modeling • Assessment services • Climate Data Records (CDR) • NOAA Climate Services Portal	• Preparing coastal communities for climate hazards • Earth system modeling • Assessment services • CDR • NOAA Climate Services Portal	• Global ocean observing system • Integrated ocean acidification • Earth system modeling • Assessment services • NOAA Climate Services Portal	• Earth system modeling • Assessment services • CDR • NOAA Climate Services Portal
External drivers (assessments requiring climate services)	• IPCC Climate Change and Water Tech paper • GCCIs Report	• IPCC AR4 • CCSP SAP 3.3 • Coastal sensitivity to sea-level rise	• IPCC AR4 • CCSP SAP 4.3	• CCSP SAP 3.3 • IPCC Extreme Events Climate Change Adaptation Tech Report • GCCI

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D. The Importance of Assessments

Scientific understanding is the foundation of the Climate Service and will provide essential information for adaptation and mitigation decisions across the country. NOAA currently has strong core capabilities (observing systems, models, and integrated services) that will enable Climate Service to deliver effective climate services. In coordination with our partners, the Climate Service will continue building capacity to better identify and deliver climate information that supports informed adaptation and mitigation policy. A key part of that effort will be Climate Service engagement in three types of climate assessments.

Climate Adaptation

"...one of the actions society can take to respond to the climate challenge…

Adaptation refers to changes made to better respond to present or future climatic and other environmental conditions, thereby reducing harm or taking advantage of opportunities."

Global Climate Change Impacts Report pp 10-11

National and International Climate Science Assessments

These are deliberative and focus on a broad set of peer-reviewed and open-source material. The primary goal is to assess the state of knowledge in areas of climate science relevant to climate change adaptation and mitigation. These assessments tend to take a substantial amount of time to complete because of the thorough review process. National and International Climate Science Assessments generally address problems and issues of broad interest (such as issues that affect large regions, including the entire globe) and are often of national and international policy relevance. The Climate Service will develop its core capabilities with the intent to play a leading role in these assessments and operate in partnership with national and international experts and stakeholders.

Problem-Focused Climate Science Assessments

These assessments are often time-sensitive and address climate-sensitive specific issues demanding decisions at the local and regional levels. Problem-Focused Climate Science Assessments often use National and International Climate Science Assessments as a starting point, but generally require additional analyses, reprocessing, interpretation, and information to focus more tightly on a specific problem. One example of a Problem-Focused Climate Science Assessment is the rapid evaluation of recent changes and trends in extreme climate events, and their impacts. Of particular interest is whether or not recent changes and trends portend future conditions that will impact specific aspects of a region's infrastructure, ecosystems, or economics. In the Climate Service, this kind of assessment can lead to the development of easy-to-use decision-support tools and the timely flow of data and information to support such tools. These tools may be developed internally in some instances where they closely relate to the NOAA mission, but are likely to be more frequently developed by the external stakeholders. When the tools are developed externally, the role of the Climate Service will be to provide transparent, official, regular, and authoritative information for these products. Although the demand for information is often more severely time-constrained compared to National and International Climate Science Assessments, it is important that Problem-Focused Climate Science Assessments give due attention to maintaining the standards of the Information Quality Act, including transparency, openness, and reproducibility.

Needs Assessments

The Climate Service will engage policy advisors and decision makers in Needs Assessments. The goal of this needs assessment process is to conduct a systematic investigation of decision-maker needs in order to identify aspects of individual knowledge, skill, interest, attitude and/or abilities relevant to climate and climate issues. The Climate Service will conduct needs assessments processes to determine decision-maker needs, wants, and develop requirements for new climate-related products and services. Conducting a needs assessments process is done on an ongoing basis to continue to evaluate stakeholder needs for information, products, and services. These assessments can include stakeholder analysis, surveys, interviews, workshops/focus groups, cost-benefit analysis, content analysis, and/or non-market valuation.

Needs Assessments can lead to targeted new products and services, including decision-support products for addressing climate risk and vulnerability at local and regional levels. Needs Assessment methods are based on current social science techniques for determining needs and vulnerability, and follow the concepts of transparency, openness, and reproducibility. In addition to helping define needs for decision-makers, the results can be used to serve as one input to help frame National and International Climate Science Assessments. Needs Assessments are key inputs to help define the problem when the Climate Service has responsibility for participating in a Problem-Focused Climate Science Assessment, based on a response to a decision-maker described need.

The Climate Service's assessment program, an extension of NOAA's current involvement in assessments, will help clarify the nature and causes of current and expected climate impacts. This is part of an overall effort to understand the nation's vulnerability to climate variability and change, and to inform climate adaptation and mitigation strategies at all levels, through continuous engagement. The Climate Service's three types of assessments will help local and regional decision makers understand their options for adaptation in the context of probable changes and variations in climate; will enable institutions and economic sectors to understand predictions and projections of climate variability and change and its impacts; and will inform international discussions of mitigation and adaptation. The Climate Service's assessments will benefit from continued scientific advances and will also help guide the Climate Service in sustaining and strengthening basic services through investment in core capabilities and new services focused on specific societal challenges.

E. The Intersection of Core Capabilities and Societal Challenges

Development of new climate services for the four described societal challenges will depend upon the identification and subsequent closure of gaps across the Climate Service's four core capabilities. Within the implementation process for each Climate Service societal challenge, NOAA's scientists, NOAA's partners, and decision makers will engage in a deliberate assessment process to inform and guide how the Climate Service sets priorities and allocates resources. While this process is in the formative stages for most aspects of the four Climate Service societal challenges, it is already possible to identify examples of the types of information gaps that the core capabilities will need to help close. Listed below are listed current strengths and the expansions necessary to support the four societal challenges, organized by core capability.

Observations, Monitoring, and Data Stewardship

A broad spectrum of direct and indirect observations, monitoring, and data stewardship core capabilities will be required to support the four Climate Service societal challenges.

Water Resources

- Improved long-term hydro-climate observations to quantify exchange processes with sufficient density at watershed scales to allow closure of the water budget and evaluation of climate model fidelity
- Enhanced understanding of tropical dynamical processes influencing the export of moisture to constrain predictive models and for early warning monitoring
- Better resolved socio-economic and related data analysis for quantitative estimates of impacts

Coastal Resilience

- New high-quality observations of trends in local and global sea level
- Improved high-resolution climatologies in key environmental variables such as wind intensity, extreme wave and high seas, heavy rains, and storm tracks
- New sea-level predictions that include operational analyses of sea-surface altimetry and estimates of ocean temperature-related components of sea-level rise
- Higher-resolution coastal Digital Elevation Models
- Augmentation of the tide and stream gauge network through connection to state networks and more gauges

Marine Ecosystem Sustainability

- More targeted observations of atmospheric, and physical and biogeochemical oceanographic, parameters on spatial and temporal scales that affect organisms
- Maintenance and expansion of existing Climate Data Records to include chemical and biological properties
- New and sustained water mass surveys, ARGO floats, and cruise surveys
- Coastal survey and open-ocean acidification monitoring

Climate Extremes

- Improved extreme event monitoring products to ensure a climate quality record
- Expanded observation networks to support development of process understanding and the assessment of the predictability of extremes
- Higher-resolution spatial and temporal monitoring to characterize extremes at regional scales

Understanding and Modeling

Process and modeling studies will advance understanding and predictive capabilities—especially at regional scales—to support climate-sensitive decision-making in each of the four societal challenge areas.

Water Resources

- Better process understanding and modeling of relationship of changes in climate forcings and feedbacks on regional precipitation, runoff, and drought

- Improved process understanding of the influence of the tropical ocean on extratropical predictability of precipitation and temperature extremes
- Improved simulations of watershed-scale processes that affect runoff and water supply; short-term, multiyear, and decadal droughts; and drought duration, severity, and terminations

Coastal Resilience

- Better process understanding and modeling of the relationship of changes in climate forcings and feedbacks on local and global sea level, wind intensity, high seas, heavy rains, tropical cyclone intensity
- Improved understanding of the sensitivity of global and local sea level changes to cryosphere dynamics

Marine Ecosystem Sustainability

- Better process understanding and modeling of the relationship of changes in climate forcings and feedbacks on physical ocean properties (temperature, salinity, currents, eddies, fronts, stratification, upwelling) and chemical ocean properties (carbon, pCO_2, pH, nutrients) at spatial scales relevant for the management of large marine ecosystems
- Development of a better understanding of the mechanistic links between climate and marine ecosystems that provide insights into how climate variability and change impacts propagate up and down the food chain and cause imbalances in marine food chains.

Climate Extremes

- Enhanced understanding of key physical processes involving the coupled atmosphere-ocean system that modulate extreme events on regional, national, and global scales
- Better understanding of the opportunities and limits to predictability of extreme events across the full range of spatial and temporal scales in which climate-sensitive decisions are made.

Predictions and Projections

Implementation of advances in climate modeling will enhance prediction and projection capabilities —especially at regional scales and for phenomena of particular interest to stakeholders—to support climate-sensitive decision-making in each of the four key societal challenge areas. To adequately assess confidence and skill, all four societal challenges will benefit from a broad suite of ensemble reanalysis and reforecasts of past conditions, and projection and prediction of future conditions.

Water Resources

- Implementation of improved climate model representation, predictions, and projections of watershed-scale processes that affect runoff and water supply; short-term, multiyear, and decadal droughts; and drought duration, severity, and terminations
- More skillful sub-seasonal predictions to multidecadal projections of low-latitude sea-surface conditions that influence extratropical hydrologic conditions

Coastal Resilience

- Application of advances in climate models to predict and project local and global sea level, wind intensity, high seas, heavy rains, tropical cyclone intensity
- New capabilities to either run inundation models offline or coupled to global climate projection models
- Enhanced practices for linking models from global-to-local scales with a distributed network of academic and private modelers

Marine Ecosystem Sustainability

- Skillful predictions and projections of physical ocean properties (temperature, salinity, currents, eddies, fronts, stratification, upwelling) and chemical ocean properties (carbon, pCO2, pH, nutrients) at spatial scales relevant for the management of large marine ecosystems

Climate Extremes

- Implementation of advances in climate modeling to predict and project regional climate extremes with confidence
- More skillful sub-seasonal predictions to multi-decadal projections of sea-surface conditions that influence likelihood of extreme events
- Advanced analysis and translation tools to transform model predictions and projections into useful information on likelihood of extreme events across timescales

Integrated Service Development and Decision Support

The National Climate Service Enterprise (see footnote 11) already brings together and strengthens internal NOAA and external partner regional activities and provides the institutional foundation for the Climate Service regional program. Through its core capabilities, NOAA already contributes to elements of all four societal challenges, with emphasis currently on water resources, extremes, and research on impact mitigation. NOAA is already a key contributor to National and International Climate Science Assessments (through IPCC and other global bodies), and these directly and indirectly address all four societal challenges. NOAA and affiliated partners also currently conduct regional and sector-specific Problem-Focused Assessments, which when connected to user defined needs through the needs assessment process, can help inform decisions to address social challenges such as water resources, infrastructure investments, resource management, etc. Both types of assessment activities enable systematic and ongoing evaluation of vulnerability to climate variability and change. As described earlier, needs assessments will be a key vehicle for Climate Service to uncover decision-maker needs in order to prioritize product and service development to meet those needs and to deliver integrated services and decision support.

In areas that are witnessing strong changes in climate and other factors, old infrastructures are vulnerable and new investments can be informed by the risk analysis in climate science assessments. Needs assessments would be used to determine decision-maker and policy-maker needs/wants in order to minimize climate-related risks to their own capacity to adapt to regional-scale changes and to take advantage of new opportunities.

The Climate Service also will contribute to existing programs designed to improve access to useful and usable NOAA climate data products and services, enhance overall national climate literacy through educational programs and strategic partnerships, provide technical training on Climate Service products and services, leverage innovative internet-based technologies for enhanced communication and collaboration with stakeholders, and expand the cadre of individuals skilled in understanding the societal consequences of changing climate conditions and the scientific and technical capabilities that they have at their disposal.

The Climate Service will need to ensure that core capabilities provide a basic set of information needed by NOAA to address the four societal challenges and its external partners for those and other sectoral needs (e.g., energy, health, transportation and agriculture). Climate Service success will depend on effective coordination of its internal activities, a balanced portfolio that supports both near term and long-term payoffs, robust partnerships across NOAA and externally, and rigorous evaluation of internal performance and external service delivery. These are discussed further in Chapter 3.

Chapter 3: Managing for Success

Overview

Effective management of the Climate Service will be necessary to ensure that the best available climate information is delivered to support public and private sector policy, planning, understanding, and decision-making. Making the Climate Service work well will require management principles, business practices, and partnerships designed to integrate NOAA's climate assets in support of adaptation and mitigation decision-making. Strong leadership is critical to creating a unified Climate Service that is able to deliver accessible, authoritative climate science and services. The business practices, partnerships, and ongoing evaluation processes described below provide a solid management foundation upon which the Climate Service will deliver its climate science and services. The future implementation of the Climate Service will address recommendations in several recent National Academy of Sciences reports (Appendix C), and will align with NOAA's Next Generation Strategic Plan (Appendix D).

Research to Decision Making

In contrast to the traditional "Research to Operations" approach, the Climate Services proposes to extend the value chain from research through operations to decision relevance.

The key to a coherent and traceable connection from climate science and research to decision making is the stakeholder engagement which takes place in the Integrated Service Development and Decision Support core capability. The Climate Service will ensure that stakeholder needs are clearly understood and documented so that they can inform the products, services and research priorities. Similarly, as research uncovers unanticipated results, the same communication chain will serve to inform users about the latest findings and their implications.

Management Principles

It will be imperative that the Climate Service continue to protect and maintain its research and observation strengths. At the same time, the Climate Service will continue to build upon its service development and decision support. As resources allow, the Climate Service will expand climate service delivery to better meet societal challenges. The goal is a balance of science and service to meet the needs of society by providing climate information that is accurate, usable, understandable, relevant to decision-making, and trustworthy.

Cognizant of its fiscal responsibility, the Climate Service will manage its portfolio in a transparent manner. The Climate Service will assess competing investment opportunities in terms of mission relevance, benefits, costs, and risks. The portfolio management processes seeks an optimized portfolio of investments covering the spectrum of near-term to long-term payoffs, near-term to long-term readiness, and a balance among the Climate Service core capabilities.

The Climate Service will use a decision-making framework for prioritizing the portfolio of Climate Service activities that balances feasibility of activities and fit within the Climate Service mission with the potential level of impact (Figure 3.1). Programs and projects that a) fit well within the mission and are feasible and b) address large potential impacts will be higher priority (upper right quadrant, Figure 3.1). Programs and projects that a) fit poorly within the mission or are difficult to achieve and b) deal with small potential impacts are lower priority (lower left quadrant). Extensive stakeholder engagement will be needed to prioritize other programs and projects (upper left and lower right quadrants). Throughout the prioritization process, and

regardless of quadrant, stakeholder engagement continues to be an important part of the decision-making framework.

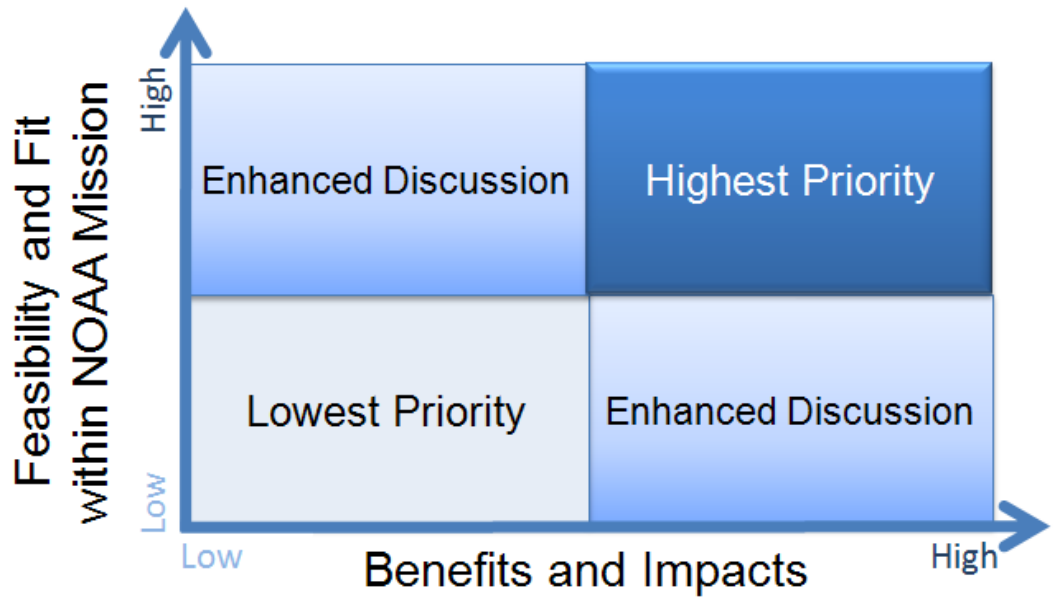


Figure 3.1. Climate Service portfolio prioritization framework. The Climate Service will use a portfolio management approach to set priorities and manage expectations. Potential service offerings will be assessed relative to their benefits to and impact on stakeholders, society, or the environment; their fit with NOAA's mission; and their feasibility.

This prioritization framework holds for strategic decision-making (e.g. evaluating ongoing changes to societal challenge focus areas) as well as for operational decision-making (e.g. the scope and focus of needs assessments). The Climate Service will harmonize user expectations with what NOAA is uniquely capable of delivering.

Business Practices

Maximizing the Climate Service's effectiveness will require new ways of doing business that encourage communication and collaboration both within and across organizational lines. The Climate Service will need to develop the tools to execute the formal operational responsibilities of a NOAA line office, yet at the same time be responsive enough to conduct the science needed for effective decision-making. As the Climate Service provides improved climate information, stakeholders' capabilities and skills will evolve and their needs will change—and the Climate Service will respond with advances in core capabilities.

Successful integration across the Climate Service will require internal business practices to manage the four core capabilities in ways that strengthen each while promoting improved effectiveness and efficiency. The previous chapter describes two integrating approaches the Climate Service will use: assessment and societal challenges. The integrating nature of climate

assessments will require engaging all four core capabilities by identifying and filling gaps in observations and monitoring, understanding and modeling, predictions and projections, and service delivery to meet information needs. Likewise, successfully addressing the end-to-end requirements of the four Climate Service societal challenges will require strong interactions among four core capabilities, thus promoting cross-fertilization.

The Climate Service implementation approach will require business practices that maximize collaboration with the other NOAA line organizations. The partnering and sharing of resources with NWS to provide early warning across climate timescales illustrates how the Climate Service expects to collaborate across NOAA. The Climate Service and NWS will work closely together to ensure that NOAA's delivery of services across temporal and spatial scales is transparent to users. The Climate Service will have primary responsibilities at longer timescales, NWS will have primary responsibilities at shorter timescales, and responsibilities will be shared at intermediate climate timescales.

For example, when dealing with extreme events, NWS will provide forecast and warning information to support preparedness in the form of precautionary responses and actions (e.g., non-permanent actions to prepare for threats such as a tornado, flood, or hurricane). The Climate Service will assume responsibility to provide information to guide adaptation (e.g., investment in infrastructure to deal with to changes in the frequency and intensity of extreme events). NWS and the Climate Service will work together to provide information when preparedness and adaptation meet or overlap (e.g., a dry spell that evolves into a drought, or shifts in the likelihood of extreme events).

The Climate Service will use effective partnerships as the foundation to develop business practices to foster communication, collaboration, and engagement with organizations that are external to NOAA. The business practices will be codified in formal agreements such as the 2010 Memorandum of Understanding between the U.S. Department of the Interior and DOC to coordinate and cooperate in climate-related activities involving science, services, mitigation, adaptation, education, and communication.

Partnerships

The Climate Service requires an organizational framework that brings together diverse scientific and service communities, including other parts of NOAA, federal, state, tribal and local agencies, cooperative institutes and other academic partners, the private sector, non-governmental organizations, and the international community. While it is impossible to identify all potential partners and collaborative activities, the Climate Service will be able to build on existing regional, federal, and international agreements and activities, and will employ a full range of formal and informal agreements with partners, ranging from memoranda of understanding, competitive grants, contracts, and cooperative research and development agreements to formal interagency and international processes.

How to Engage with the Climate Service

NOAA provides a diverse set of mechanisms through which partners can engage in collaboration and coordination of climate service activities.

- Federal Agency partners can engage through the mechanism of the Interagency Working Groups of the USGCRP, and by implementing a Memorandum of Understanding with NOAA/DOC directly.
- State, tribal and local agencies and State Climatologists can engage via the Regional Climate Service Directors and Regional Climate Centers, and through interagency cooperative initiatives.
- Stakeholders and users can engage through portals and National Data, Information and Prediction Centers.
- Private sector partners can engage in many ways, including through the Department of Commerce, through customer service in the Integrated Service Development and Decision Support core capability, and through the Small Business Innovation Research program.
- Academic partners can engage through CI's, RISA's and NOAA's grant programs.

Among the core capabilities, the Climate Service anticipates that much of the observations and monitoring will be achieved working with internal partners across all of NOAA, partners in academia, and private sector partners. Much of the Climate Service understanding and modeling core capability will be achieved as collaborative research with internal NOAA partners (e.g., OAR), USGCRP federal agencies, and academic researchers. The predictions and projections core capability will be a multiagency activity that includes internal NOAA partners in NWS and OAR, USGCRP federal agencies, academic partners, and international collaboration under the auspices of groups such as WMO and the IPCC. The integrated services core capability will be with partners across all of NOAA as well as other federal, state, and local agencies, the academic community, nongovernmental organizations, and emerging capabilities in the private sector.

Among the societal challenges, the Climate Service anticipates that much of the coast resilience work will be done in partnership with internal NOAA partners (e.g. NOS and NMFS), other federal, state, and local agencies, and nongovernmental organizations, much of the water resources work will be in partnership with USGCRP and resource management federal agencies, internal partners in NWS, with contributions from state and local agencies, academic partners, and the private sector, while much of the marine ecosystems work will be done with internal partners in NMFS and NOS with significant contributions from federal, state and local resource management agencies.

NOAA

Addressing challenges of fundamental societal and environmental importance in which climate plays a significant role will require that the Climate Service leverage the wealth of expertise and

capabilities across NOAA. For example, addressing challenges in water resources and climate extremes will require strong partnerships with the NWS, NESDIS, and OAR. Addressing climate challenges involving the oceans and coasts will require strong partnerships with NOS, NMFS, NWS, NESDIS, and OAR. The consequences of these partnerships will be an agency that delivers skillful, relevant, and timely monitoring and prediction products that span weather and climate time scales and the ocean-atmosphere system.

Several actions will serve to assure sound business practices involving coordination of climate-related activities across the agency:

1. The Climate Service will establish memoranda of agreement (MOAs) with other line offices to address critical line office dependencies by delineating roles and responsibilities of each organization.
2. The Climate Service will provide a management and oversight function for intra-agency execution. Laboratory and center Directors from other line offices will have a formal report-out in their performance plans to the Director of the Climate Service, commensurate with the level of resources invested by the Climate Service in their laboratory or center.
3. The Climate Service will identify within its annual operating plan specific cross-line office engagements, the role of Climate Service (lead or supporting), and contributing and/or supporting programs, and Climate Service will systematically track and report on the execution and performance of these activities.

While implementing the approach, the Climate Service will work with the other line organizations to build capacity in shared priorities across the agency. This approach naturally leads to joint annual operating plans between the Climate Service and other line organizations, and to NOAA-wide evaluation of execution. With better agency-wide coordination, NOAA will be able to respond more rapidly and effectively to unforeseen or emergent situations (such as NOAA's rapid response to the Deepwater Horizon oil spill).

Department of Commerce

The Climate Service will partner with DOC bureaus to provide information products and services to foster, serve, and promote the nation's economic development and technological advancement. This joint endeavor will focus initially on enhancing the availability and usefulness of current NOAA climate products and services. The Climate Service will work closely with other bureaus to ensure that emerging scientific insights are transformed into high-quality products responsive to user needs. The Climate Service will leverage the capabilities of social and economic scientists within DOC in order to quickly bring to bear complimentary state-of-the-art science on climate-related societal challenges.

Collaborative efforts addressing shared interests could include:

- Investigating the influence of past, current, and future climate on the U.S. economy, on regional economic development, and on the rest of the world economy (in partnership with the DOC's Economic Development Agency)
- Interpreting the influence of climate on the nation's changing demographics (in

partnership with the Census Bureau)

- Facilitating the growth of a green economy by understanding and meeting the climate information needs of specialized businesses and the public sector (in partnership with the DOC's Economic Development Agency)
- Providing information on the impacts of a changing climate on the global business environment and U.S. competitiveness (in partnership with DOC's International Trade Agency)
- Collaborate with interagency efforts regarding assessment of social and economic impact of climate change adaptation and mitigation options (in partnership with multiple DOC bureaus)
- Reducing the vulnerability of U.S. infrastructure to extreme events on climate timescales (with the NOAA-National Institute of Standards and Technology [NIST] "Disaster Resilient Communities" cooperative initiative)
- Improve observing system accuracy in collaboration with NIST to ensure the basis for internationally-recognized measurements critical to global climate organizations.

The Climate Service will work with other NOAA line offices to stimulate innovation and discovery and promote the nation's economic growth by providing access to state-of-the-art scientific, technical, engineering, and business-related information, presented in a climate-relevant context. The Climate Service will also work with departmental leadership to explore mechanisms to advance the DOC-wide goal and collaborative framework for understanding the climate needs of U.S. commercial interests and for providing reliable, high-quality products and services to address those needs.

The Department of Commerce is formulating an engagement plan to work with its interagency partners, the academic community, and the private sector towards the establishment of broader national services. The objectives of the Department's engagement plan are to:

1. Increase collaboration with the private, public, and academic partners through an intentional and systematic process that achieves the goal of providing science-based foundational information products and services
2. Develop and deliver climate services to inform decision-making, investments, and management at the local, state, regional, national, and international levels in order to promote a more climate resilient economy and society
3. Support a new category of economic innovation and growth that spurs entrepreneurs and other businesses in the provision of services and products based on environmental and climate data

Federal Agencies

Many federal agencies have specific and complementary strengths related to critical climate science and service issues, forming the basis for a federal National Climate Service Enterprise capability. While the details of this larger National Climate Service Enterprise are yet to be defined, NOAA will work with its interagency partners towards the establishment of broader national services. Formal, bilateral agreements will clarify roles and responsibilities and reduce unnecessary duplication. Already, the DOC has signed a Memorandum of Understanding with the Department of Interior, and is advancing similar relationships with other agencies.

NOAA agrees with the National Academy of Public Administration report[19] that

> "*The Panel recommends that the Administration strengthen and expand interagency coordination structures tasked with aligning Executive Branch climate resources. Specifically, the Panel recommends that the President empower a senior interagency group – led at the White House and convened at the Deputy Secretary or Secretary level – to provide the President annually with a strategic plan for management of federal climate research and service deliver.*"

The Climate Service plans to strong support such interagency coordination. For example, NOAA will provide leadership for the Subcommittee on Global Change Research and its working groups to facilitate cooperation and collaboration among the climate services activities of the agencies of the USGCRP. NOAA will also participate in other Administration-led climate activities, as appropriate, such as the Interagency Climate Change Adaptation Task Force, and the Executive Office of the President's Climate and Information Service Roundtable.

International

Climate science and service is a global enterprise. The Climate Service relies upon engagement with international partners in critical areas such as observations and monitoring, research, modeling, and risk management. Current NOAA climate activities are coordinated with international partners through a variety of international governing organizations, primarily in conjunction with the United Nations. The Climate Service will continue and strengthen NOAA's participation in international climate frameworks, assessments, and policy support, including: the Global Framework for Climate Services, the World Climate Research Program, the Global Climate Observing System, the World Meteorological Organization, the Intergovernmental Oceanographic Commission, the International Council of Science, the International Ozone Assessment, and the Intergovernmental Panel on Climate Change.

Academic Community

Climate science involves diverse expertise and is evolving rapidly, so the Climate Service will have strong partnerships with the academic community to ensure the highest-quality research, operations, and services. The academic community helps educate and train the next generation of NOAA's (and the nation's) scientific workforce. The Climate Service will deliver educational programs to K-12 students, as part of efforts to promote a climate-literate public. The Climate Service will support career development through continuation and strengthening of postdoctoral and graduate fellowship programs in climate science and services. Academic partnerships will be supported by research grants and contracts, institutional awards, and cooperative agreements. The Climate Service will need to coordinate with the Office of Oceanic and Atmospheric Research and NESDIS to determine the roles of joint and cooperative institutes and Sea Grant College Programs.

[19] National Academy of Public Administration, 2010: Building Strong for Tomorrow: Recommendations for the Organizational Design of the NOAA Climate Service.

Private Sector

The Climate Service is committed to the growth of public-private partnerships and capabilities to promote a National Climate Service Enterprise, recognizing that cooperation, not competition, is the best way to meet the diverse needs of society. To ensure coordination with the private sector, the Climate Service will not significantly change existing information dissemination or introduce new services without carefully considering the views and capabilities of all parties. Climate Service is committed to equity and will not use taxpayer funds to provide climate services to any one entity unless these services can also be provided to other entities.[20]

The Climate Service will encourage and foster growth of a private-sector climate industry to meet specialized business and public sector needs. To support the private sector, the Climate Service will:

- Identify key industries and industry leaders to engage in region-specific climate partnership discussions.
- Participate in a newly-formed Interagency Roundtable on climate services.
- Encourage the academic and private sectors—through the Small Business Innovation Research program—to advance value-added products and potential services
- Use Cooperative Research and Development Agreements to help speed the commercialization of federally developed technology
- Procure supplies and services through contracts
- Engage the private sector in discussions on emerging concerns and issues, such as through the American Meteorological Society's Commission on the Weather and Climate Enterprise
- Ensure that the private sector has full access to existing and new information with openness and transparency in practices, methods, products, product developments, and testing
- Develop web services with easy access to basic information needed by a broad set of private sector users

Non-Governmental Organizations, Tribal, State, and Local Government

Most adaptation to a changing climate will occur at regional-to-local levels. Many tribal, state, and local governments are already making climate adaptation decisions for their jurisdictions. Non-governmental organizations (NGO) represent additional partners and capacity. The Climate Service will work in partnership with networks of state and tribal agencies, emergency management agencies, and other water and natural resource agencies, as well as the NGO community, to share lessons learned and provide a common scientific foundation for adaptation and mitigation planning. The Climate Service will use Intergovernmental Personnel Agreements with state and tribal agencies, local government, or NGOs to bring in external knowledge and

[20] NOAA Policy on Partnerships in the Provision of Environmental Information (Partnership Policy) NAO 216-112; Special Studies Authority, 15 U.S.C. 1525 permits DOC to receive funds for the purpose of making special studies on matters within the authority of the Department upon the request of any person, firm, organization, whether public or private; Joint Project Authority (JPA), 15 U.S.C. '1525 (second paragraph), permits DOC operating units to enter into projects with nonprofit, research or public organizations (such as state and local governments) if the project is of mutual interest to the parties and the costs of the project are apportioned equitably.

skills when important, especially when communicating climate-related information for adaptation and mitigation. The Climate Service will not meet all information needs for regional- and local-level decision makers. The broader National Climate Service Enterprise will be necessary to address myriad regional and local problems—by designing the highest-quality regional service products, engaging in a multi-way dialog between the Climate Service and local to regional users, and ensuring that Climate Service science is responsive to those needs.

Fee-for-Service

The Climate Service will comply with President Obama's Memorandum on Transparency and Open Government (January 21, 2009): "to increase accountability, promote informed participation by the public, and create economic opportunity, each agency shall take prompt steps to expand access to information by making it available online in open formats." Government data have no copyright protection. The private sector is free to create innovative applications for specialized users, and will do so with full support from the Climate Service.

Fee-for-service payment structures have not been successful, nationally or internationally, when the price is prohibitively high. In the past, some countries chose to charge large fees for their basic atmospheric data or data products (such as model output), and it can be argued that many saw diminished use of their data over time as the customer bases eroded. A recent book on the availability of spatial and environmental data in the European Union describes the subject in detail.[21]

Fees have been reduced or eliminated in many countries. For example, the European Centre for Medium Range Weather Forecasts (ECMWF) is privately funded and charges for products and services. Despite collaboration with the much more accessible United Kingdom Meteorological Office, ECMWF has found it difficult and costly to leverage its renowned scientific expertise on many climatological issues. In the United States, distribution of Landsat satellite data was privatized and data were unaffordable for most research and development. The effects included reduced use of Landsat data and the failure to develop value-added applications. Fee-for-access to data has been used by NOAA Data Centers to recoup the cost of delivery of data. In 1984, the National Environmental Satellite, Data and Information Service granted the authority for its centers to provide free information and data within a limited user base. In 1990, NOAA expanded the data access policy to allow the National Data Centers to provide free data access to users to the extent resources permit. In accordance with the President's goal to make government information more available to the public, the centers will continue to reduce the fee-for-access to products, within the bounds of legal and fiscal limits. For these reasons, the Climate Service does not favor any expansion of its current fee-for-service policy.

[21] Janssen, Katleen. 2010 *The availability of spatial and environmental data in the EU. At the crossroads between public and economic interests (Energy and Environmental Law and Policy Series).* Kluwer Law International.

Evaluation of Progress

The overall principles, objectives, challenges, and expected outcomes described in this Vision and Framework will be used to evaluate the Climate Service. Evaluating the pathways to success of the Climate Service will focus on both internal performance and external impact of effectively communicating research and information products in the support of adaptation and mitigation policy, planning, and decision-making as described in the previous chapters. Evaluation results will help inform the ongoing The Climate Service priority-setting process and annual planning and budget allocation. A robust evaluation plan will help to improve and evolve programs, laboratories, and centers; and to document success stories and challenges. The evaluation process will assess the quality and "health" of the research, science, information, and services performed and provided by the Climate Service.

Evaluation Criteria

The Barron Report (2008) and the NRC report *Thinking Strategically* (2005) have provided a basis for developing the evaluation criteria listed below.[22] These evaluation criteria will be supplemented as appropriate depending on the entity being evaluated:

- Is the Climate Service strengthening climate science and climate services?
- Are the Climate Service information products robust, trustworthy, authoritative, effective, relevant, and timely?
- Are the interdependencies among the four Climate Service core capabilities—Observing Systems, Data Stewardship, and Climate Monitoring; Understanding and Modeling; Predictions and Projections; and Integrated Service Development and Decision Support—managed in ways that strengthen each while promoting improved effectiveness and efficiency?
- Do the Climate Service core capabilities meet the needs of the societal challenge areas?
    - Climate Impacts on Water Resources
    - Coasts and Climate Resilience
    - Sustainability of Marine Ecosystems
    - Changes in the Extremes of Weather and Climate
- Are the Climate Services's data products and services aligned with the space and time scales needed by users to inform decision-making?
- Are there effective, two-way interfaces for climate services such that the development of products and access to them are transparent to users and partners?
- Is the Climate Services's climate research being effectively transitioned to products, applications, and decision-support services?
- Does the Climate Service promote new avenues of research and discovery that result in new and useful products or services?
- Does the Climate Service develop and maintain effective international, national, and regional partnerships both internal and external to NOAA?

[22] *The Barron Report* is a review of NOAA's climate services, July 15, 2008. The Metrics section of the Barron Report draws heavily upon the NRC report, *Thinking Strategically: The Appropriate Use of Metrics for the Climate Change Science Program.* In addition, the 2007 NRC report *Evaluating Progress of the U.S. Climate Change Science Program: Methods and Preliminary Results* has been a valuable resource.

- Does the Climate Service incorporate and use capabilities across NOAA and the broader climate community to develop and deliver climate services?
- Does the Climate Service use management and engagement approaches that embody shared learning and joint problem solving?
- Does the Climate Service foster a broad and diverse community of engaged users?

There are multiple organizational factors that determine success in addressing the individual societal challenges and the core capabilities with related basic services. The following functional capabilities and capacities will be routinely evaluated to ensure the Climate Service has the resources it needs to achieve its mission goals:

- The organization maximizes execution ability and flexibility
- There are adequate resources (such as investment capital, infrastructure, instrumentation, and computation capability)
- Personnel have the right expertise in specific research fields, policy, management, extension, training, or capacity building
- The Climate Service fosters advancements in the state of knowledge of climate science
- The Climate Service ensures the availability of information, capabilities in service, and synergies with partners at other agencies and academia

Evaluation Approaches and Strategies

Evaluation of the Climate Service will be accomplished using different approaches tailored to the basic and directed services the Climate Service will provide. The full value of the Climate Service can only be assessed across the full suite of core capabilities, sectors served, and societal challenges addressed. Thus, no single scoring tool or report is likely to provide adequate information about the success of the Climate Service. The Climate Service evaluation process will be ongoing, with different levels of review conducted on annual and multi-year schedules. The evaluation process will establish baselines using existing information and methods such as program evaluation guidance, strategic logic model assessments, and performance management methods.

Elements of a successful Climate Service evaluation program include:

- Key planning and implementation documents to guide Climate Service implementation execution and to describe the desired outcomes (e.g., the NOAA Strategic Plan, this Climate Service Vision and Strategic Framework, and the Climate Service Annual Operating Plan)
- Models outlining and linking inputs, actions, outcomes, gaps, and critical issues
- Formal reviews conducted on a regular schedule with consistent criteria and objectives to assess how the Climate Service has performed relative to peer science and service agencies
- Performance measures and milestones

The Climate Service evaluations will be performed by a broad cross section of independent external groups (Science Advisory Board, User Advisory Councils and affiliated working groups), the USGCRP, internal groups such as NOAA leadership (NOAA, the Climate Service

leadership itself, and other line offices), program and project managers, Climate Service evaluation staff, and surveys of stakeholders and NOAA employees. The Working Groups of the Science Advisory Board will play important roles in advising and reviewing the directions and quality of the science being conducted and delivered by the Climate Service. Accountability will be built into senior executive service performance plans and staff performance plans throughout the organization. Evaluations will be both objective and subjective, incorporating expert analyses and peer review. The Climate Service will strive to have dedicated competencies, capabilities, and capacities to build and execute an evaluation system that includes collection of data to support the analyses and a suite of metrics that spans activities, outputs, and outcomes.

Performance measures will be an important component of an evaluation system used to address the needs of White House Office of Management and Budget, DOC leadership, and NOAA leadership, as well as for program management to monitor and improve the programs. Performance measures will be an important part of the budget process; easy-to-understand measures with an outcome orientation are critical to communicating the overall intent of the program. It will be useful to have a broad set of performance measures that address multiple levels of the Climate Service and that reflect different types of measures (outcome, output, efficiency). An initial set of high-level measures, Government Performance and Results Act (GPRA) measures, are currently in the process of review for implementation within NOAA. Non-GPRA measures will also be used in evaluating the Climate Service. Following is a brief overview of how services will be assessed.

Basic Services

The basic services provided through the four core capabilities will be examined using a diverse set of evaluation tools and criteria. Performance measures will serve as an important tool to evaluate the pathways of success in the basic services. These criteria and metrics must capture both the intent to strengthen science as well as service. Areas that will be evaluated in each of the four core capabilities are provided below, derived, in part, from the National Research Council's Thinking Strategically report (2005).[23] These areas will be supplemented and tailored as the evaluation process matures.

Observing Systems, Data Stewardship, and Climate Monitoring

- Measurable progress toward achieving robust climate observing systems and accurate climate data
- Identification of uncertainties, increased understanding of uncertainties, quantification, and systematic reduction of uncertainties
- Tracking of broadly accessible results such as data and information and new and applicable measurement techniques
- Production of scientific assessments to provide the state of the science and guide new research directions

[23] *The Barron Report* is a review of NOAA's climate services, July 15, 2008. The Metrics section of the *Barron Report* draws heavily upon the 2005 NRC report, *Thinking Strategically: The Appropriate Use of Metrics for the Climate Change Science Program.*

- Measurable peer-review information such as number of publications, citations, and associated metrics to assess the quality and use of Climate Service science and research within peer review communities

Understanding and Modeling

- Measureable improvement in climate model representation of hydrologic, coastal, maritime and extreme events processes.
- Enhanced understanding and development of new modeling capabilities for identifying, quantifying and interpreting the impact of changes in climate forcings and feedbacks
- Identification of uncertainties, increased understanding of uncertainties, quantification and systematic reduction of prediction and projection uncertainties
- Measurable peer-review information such as number publications, citations, and associated metrics to assess the quality and use of the Climate Service science and research within peer communities
- Tracking of peer-reviewed and broadly accessible results such as:
    - quantification of important phenomena or processes
    - well-described and demonstrated relationships aimed at improving understanding of processes or enabling forecasting and prediction
- Assimilation of scientific assessments to guide new research directions

Predictions and Projections

- Measureable improvement in climate model performance and implementation of high-spatial-resolution modeling applications, especially for changes in the likelihood of extremes.
- Measurable progress toward consistent and reliable climate predictions and projections
- Measurable peer-review information such as number publications and associated metrics to assess the quality and use of the Climate Service predictions and projections within the applications community
- Tracking of peer-reviewed and broadly accessible results such as:
    - predictions and projections of important phenomena or processes
    - Experimental analysis and translation tools to transform model predictions and projections into regional information
- Contributions to scientific assessments to describe the state of the science

Integrated Service Development and Decision Support

- Increased confidence in the ability to use the Climate Service's basic services and climate information for the public and private good
- Needs Assessments to ensure an appropriate mix of products and services are being provided and to inform requirements for the Observing Systems and Understanding and Modeling basic services
- Useable information for stakeholders provided through assessment services, selected decision-support tools, new products, and increased capacity to use them in decisions

The Integrated Service Development and Decision Support core capability will be evaluated on how well it builds on and helps deliver the information and products from the Observing Systems, Data Stewardship, and Climate Monitoring and Understanding and Modeling basic services. The Integrated Service Development and Decision Support function will be evaluated in part on its role as the integrating bridge between the Climate Service basic services and how that information will be used to address the Climate Service societal challenges: Climate Impacts on Water Resources; Coasts and Climate Resilience; Sustainability of Marine Ecosystems; Changes in the Extremes of Weather and Climate; and Informing Climate Policy Options. This core capability will entail more engagement with user groups and partner organizations. While performance measures will be used to evaluate Integrated Service Development and Decision Support, other approaches to engage user feedback to evaluate the Climate Service services will include:

- NOAA's Science Advisory Board's Working Groups will be relied upon. For example, the Environmental Information Services Working Group (EISWG), which has been established by NOAA to examine communications among the various public, private, and academic entities engaged in weather and climate information matters. EISWG will focus on evaluating the Climate Service engagement with the private sector.
- The Quality of Relationship method, which uses indicators such as awareness, trust, satisfaction, and usability to determine the percent improvement in the quality of the relationship NOAA has with the users of its climate information and services. The Quality of Relationship will be used to evaluate the Climate Service effectiveness in the communication of climate information for decision-making, and the building of partnerships with public and private sector entities.
- The Kellogg evaluation rubric based on the seven characteristics identified in the Kellogg Commission Report: responsiveness, respect for partners, academic neutrality, accessibility, integration, coordination, and resource partnerships needed for effective engagement. The Kellogg evaluation rubric will be used to assess how well the Climate Service is engaging their constituents.
- Evaluation of effectiveness of operating agreements between the Climate Service and its partners (including other line offices, cooperative institutes, the Sea Grant Program, the Coastal Services Center, the National Centers for Environmental Prediction, Atlantic Marine Oceanographic Laboratory, the Pacific Marine Environmental Laboratory, and others).
- Leadership and support to the Department of Commerce's Climate Services Business Roundtable discussion.

New Directed Services: Societal Challenges

The information requirements to support adaptation and mitigation among the Climate Service societal challenges are interdependent and will therefore benefit from integration of enhanced service development and delivery efforts. The Climate Service will evaluate the integration of the basic services delivery and core capabilities advancements to support new services, and how well the balance of the two is addressing the societal challenges. The evaluation of Climate Service integration will examine aspects such as the resourcing of basic services compared to new services to address the societal challenges; and how well the Climate Service organization is

coordinating internally to optimize integration to deliver new services more efficiently. The success of addressing each societal challenge will be evaluated based on the goals, requirements, and desired outcomes explained in Chapter 2. A key evaluation question will be, "How much progress has the Climate Service made in achieving the overall desired outcomes for the societal challenges?" Select outcomes are summarized below:

Climate Impacts on Water Resources

- The nation's water managers, from local water districts to federal water agencies, have a coordinated and authoritative early warning information system that provides actionable and cost-effective guidance.

Coasts and Climate Resilience

- The nation's decision makers for coastal communities have access to and apply the best available information to address planning for community risk and vulnerability associated with local sea-level change and coastal inundation.

Sustainability of Marine Ecosystems

- Federal, tribal, state, and local fisheries resource managers prepare for and respond to the impacts of climate on large marine ecosystems through improved understanding of how changes in climate can alter ocean circulation and composition, and how such changes in ocean properties impact living marine resources.

Changes in the Extremes of Weather and Climate

- Information to prepare for and adapt to climate extremes—including changes in frequency, intensity, seasonality, and geographical distribution—is communicated on an ongoing basis for society to make informed decisions.

The Climate Service has planned for a robust set of management practices—from portfolio prioritization through partnerships to evaluation—to manage for success. The critical and increasing societal demands for trusted climate services will require exceptional management discipline. The Climate Service will continue to seek out and apply best practices in management—from other NOAA line offices, other federal agencies, and partners in the private sector—to support a climate service in NOAA.

Appendix A: Core Capabilities

Core Capability 1: Observing Systems, Data Stewardship, and Monitoring

Goal

To measure, capture, preserve, and provide easy access to the historical record of the global environment for continuous climate monitoring and periodic assessments in support of climate services, improved understanding of climate variability and change, and better anticipation of future climate.

Overall Outcome

Users of the Climate Service will obtain easy and timely access to the nation's trusted data and information about the current state of the climate system in context with the past.

Requirements

The Climate Service is committed to:

- Sustaining satellite and *in situ* observations of the atmosphere and its composition, the oceans, and the Arctic to measure the previously established Global Climate Observing System (GCOS) Essential Climate Variables and to meet established Climate Monitoring Principles. Providing necessary support to facilitate the other Climate Service core capabilities
- Providing a long-term climate data archive and public access to data from observations of the atmosphere and its composition, the oceans, the Arctic, and also complementary geophysical parameters (such as bathymetry, Earth's geoid, solar output, and volcanic emissions) for users that span all levels of government and public and private sectors. These data will be interoperable with data from other agencies and are used to inform a broad spectrum of decisions.
- Stewardship of the climate record for the GCOS Essential Climate Variables from the satellite and *in situ* observations to maintain the integrity, continuity, trust, and timely availability of the data
- Analyzing and reporting to the public on the state of the climate system and its components through two types of assessments related to observed changes—National and International and Problem-Focused—consistent with Information Quality Act standards
- Enhanced observing and monitoring of regional sources, sinks, and impacts of greenhouse gas and aerosols
- Assessing, characterizing and communicating the level of uncertainty associated with the data
- Addressing known societal challenges of significant concern early in the formation of the Climate Service by using appropriate, open, and transparent data, analyses, monitoring, and assessment techniques. For example, instituting a national network of soil moisture observations and cross-agency cooperation to proactively address Climate Impacts on Water Resources (one of the Climate Service's initial four societal challenges)

Establishing Priorities

Independent of resource considerations (increases or decreases), there is a need to sustain satellite and in situ observations of the atmosphere and its composition, the oceans, and the Arctic, and climate-related terrestrial observations. There is an inherent value in documenting the climate record. Maintenance of such a core capability does not imply business as usual, but will account for technology change and observing system evolution under the GCOS and U.S. Global Change Research Program (USGCRP) Climate Monitoring Principles.

Recognizing that observing, data, and climate monitoring systems rarely, if ever, are built de novo, but rather are the legacies of research or service programs, priorities for managing this core capability can readily be identified:

- The need to produce or maintain a Climate Data Record of GCOS Essential Climate Variables (both in situ and remotely-sensed), with special priority for long-term homogeneous data records
- The preservation and stewardship of data and information
- Easy access to data, information, and model output, including projections, reforecasts, and reanalyses of past weather and climate.
- Initiation and preservation of a high-quality climate record that can be used for reference
- Support for internationally agreed upon goals and plans (such as the World Climate Research Program [WCRP], GCOS and the Global Ocean Observing System [GOOS])
- Support for national and international climate assessments and climate attribution
- Demonstrated support for climate prediction
- Demonstrated support for climate service delivery and integration

In considering support for components of the climate observing system, the following criteria will be used to set priorities, with special consideration given to requirements in the four societal challenge areas:

- Observations needed to produce or maintain a Climate Data Record of a GCOS Essential Climate Variable. A Climate Data Record is a long, calibrated, and homogeneous dataset of a given parameter, with associated metadata, that is preserved in accordance with the USGCRP Climate Monitoring Principles. It is implicit that preserving a long-term record would take precedence over initiating a new one. Reference observing systems, particularly those *in situ* observing systems that could be used to bridge gaps or discontinuities that may appear in the satellite data record over the next 10–20 years, are of particular interest.
- Observations needed to support a new research or service effort. Observations to support thematic issues related to the Climate Service four societal challenges should receive priority.
- Observations supporting internationally agreed-upon goals and plans (of WCRP, IPCC, GCOS, and GOOS), because NOAA operates many of its activities as a partner and in agreements with the international community.
- Observations that provide demonstrated support for prediction. The Tropical Atmosphere-Ocean (TAO) array network would be one example of such a system.

- Observations to quantify global and regional climate forcing by greenhouse gases, aerosols, and black carbon, linking emission sources with their regional impacts
- Observations that provide demonstrated support for services. Existing practitioners of climate services, for example NOAA's Regional Climate Centers, are some of the strongest supporters of the U.S. Climate Reference Network and U.S. Historical Climatology Network, as well as various regional surface networks.
- Observations that provide critical support for climate assessments. For example, the Total Solar Irradiance Sensor record does not have a broad stakeholder constituency but a consistent solar record is essential for distinguishing a natural vs. human-induced climate signal.

A variety of national and international efforts have provided recommendations on future satellite measurements and to some extent an integrated view of NOAA's overall observations requirements. In consideration of national, state, international, and private sector capabilities, the Climate Service will take guidance from these documents as it develops observations requirements. In addition, the Climate Service priorities will also be influenced by feasibility, which in turn comes from a close examination of the ability of current models to deliver regional climate information at appropriate time and space scales, and at a level of predictability necessary to support partner agency, private, and public sector needs. The principal models used include climate system models and regional-scale models using initialized and boundary condition modes. As part of the modeling activity to determine the priorities for observations, tools employed will include climate Observing System Simulation Experiments (OSSEs) based upon classical weather systems, which can be used to evaluate the impact of adding or removing observations.

Thus, the Climate Service observations requirements, including sustaining observations to support regional climate information delivery, will be identified through integrated evaluation of expert assessments and objective experiments. The Climate Service priorities for observing systems will be further evaluated in context with other capabilities and practices including those of other agencies. Preference will be given where the Climate Service had a unique role or where clear synergies are evident.

Existing Capabilities

Observing Systems. NOAA currently maintains most of the nation's sustained climate observing networks, including NOAA satellites and research and operational *in situ* networks for integrated atmospheric and oceanic observations. Some key examples of these capabilities are below.

The Atmospheric Baseline Observatories conduct long-term measurements of atmospheric gases, particles, and solar radiation, which continue the world's longest time series of atmospheric data. These data supply information on the state and recovery of the ozone layer, and allow us to monitor global carbon dioxide and other trace gases impacting the global climate. Similarly, the Arctic Atmospheric Observatory is establishing long-term intensive measurements of clouds, radiation, particles, surface energy fluxes, and chemistry in three different Arctic climate regimes to better understand the mechanisms that drive climate.

The main thrust of the U.S. GCOS atmospheric program is focused on the implementation of reference quality upper air and surface observing systems (and their related data management activities) in order to address a number of critical scientific gaps in climate observing that have been identified in numerous studies and reports. As a key contribution to the atmospheric portion of GCOS, considerable work is being done with respect to developing the GCOS Reference Upper Air Network (GRUAN) which will consist of 30-40 sites worldwide in order to take climate quality observations of water vapor measurements (a key climate variable) in the upper atmosphere. Another key contribution to GCOS, the U.S. Climate Reference Network (USCRN) consists of 114 high-quality climate surface observing stations in the continental United States designed for the express purpose of detecting the national signal of climate change. This network is expanding into Alaska with an additional 29 stations. The Regional U.S. Historical Climate Network (RUSHCN), which is currently being fielded in the Southwest and West, will substantially improve the quality of data for long-term and regional climate analyses over the current USHCN network of sites.

NOAA provides the major U.S. contribution to the Global Ocean Observing System (GOOS) with links to the coastal component of the system. This international observation system is designed to measure a set of core variables (such as ocean temperature, surface winds, salinity, sea level, carbon dioxide) to provide the information needed to effectively plan for and respond to climate variability and change. Additionally, the GOOS includes Arctic observations as part of the U.S. contribution to the International Arctic Observing Network. Each of these elements brings unique strengths and limitations to build a greater whole. For example, the network of Argo Profiling Floats measure the ocean's heat content, which is directly related to our changing climate and is reflected in sea-level change. The entire system must go forward together; none of the elements can do the job by itself. The GOOS will need to be sustained and expanded to meet additional requirements for measurements of the deep ocean, and key chemical and biological variables.

Data Stewardship. NOAA currently provides data with best-practice scientific stewardship. NOAA maintains the permanent archive of weather, geophysical, climate (including paleoclimate), and oceanographic data through its National Data Centers. In recent years, these centers have been challenged by dramatic growth in data types, volume, and complexity as well as increased heterogeneity of the data and information. There has also been an increasing demand for data exchange, integration, and interdisciplinary use. The Climate Service will meet these challenges by implementing community standard protocols for data archive, data discovery, and access, fully utilizing the data centers' Comprehensive Large-Array data Stewardship System (CLASS) for long-term preservation and easy access to the large volumes of data, and by leveraging new technologies. In addition, the Climate Data Modernization Program digitizes paper archives to transform these observations into more useful and accessible digital media. Over the next decade, millions of observations will be preserved digitally to meet the needs of the scientific and business communities. These stewardship strategies, technologies, and protocols will be implemented in partnership with relevant NOAA partners, federal partners through the USGCRP, international partners, state agencies, academia, and the private sector.

Monitoring. Enabled by carefully stewarded observations, the Climate Service will build on current efforts to monitor, analyze, document, and provide data and information on the changing

state of the climate and its impacts, and to enhance attribution, assessment, modeling, and predictive understanding. Critical to this effort is the production of continuous Climate Data Records (CDR), which involves the transformation of raw observational data into unified and coherent long-term environmental observations and products, including the 30-year global satellite record.

NOAA publishes monthly and annual *State of the Climate* reports that provide national and global assessments of Essential Climate Variables, from temperature and precipitation to extreme events such as droughts, wildfires, hurricanes, and tornadoes. NOAA also monitors key large-scale climate patterns such as the El Niño-Southern Oscillation and the North Atlantic Oscillation.

NOAA produces high-quality ocean products that document the impact of climate on the oceans including estimates of the warming of the ocean (heat content), and evaluation of sea-surface height data from Jason-2 satellite—including sea-surface height anomaly and basic statistics of mean, missing values, and extreme values. NOAA also publishes a suite of *in situ* data from the GOOS including ocean color products from multiple satellite platforms for various types of applications. Long-term trends in sea-surface temperature are monitored by NOAA through the operational assembly and production of the Extended Reconstruction Sea-Surface Temperature record, which provides estimates of global sea-surface temperatures from 1855 to present. Higher-resolution measurements of sea-surface temperature suitable for regional monitoring are produced with the Optimally Interpolated Sea Surface product, which relies on satellite measurements available from 1981-present.

NOAA conducts real-time monitoring of climate and assesses the origins of major climate anomalies. NOAA synthesizes these data for international science assessments, including the WMO/UNEP Scientific Assessments of Ozone Depletion, and the IPCC climate assessments, which have played and will continue to play major roles in national and international policy decisions. NOAA has also played a primary role in the USGCRP and the U.S. Climate Change Science Program (CCSP), has lead several of the CCSP synthesis and assessment products, including *Global Climate Change Impacts in the United States,*[24] and the annual *State of the Climate* assessment.

NOAA currently provides global distributions, trends, and fluxes for some greenhouse gases, aerosols, black carbon, and other climate-forcing agents. NOAA engages science and decision makers in observations and monitoring of atmosphere composition through Ozone science and assessments, Carbon Tracker, the CalNex study in California to simultaneously address climate and air quality, and participation in international assessments such as IPCC, WMO/UNEP, and CCSP/USGCRP assessments. NOAA has also organized and participated in multi-agency, interdisciplinary workshops in the observing and monitoring of climate forcings and atmospheric ozone.

[24] Karl, T.R., J.M. Melillo, and T.C. Peterson (eds.), 2009: *Global Climate Change Impacts in the United States*. Cambridge University Press, 188 pp.

What the Climate Service Will Do

The Climate Service will sustain and work with partners to expand the comprehensive nature of the observing system and monitoring capability, which includes the refresh of measurement approaches using technological advances with compliance of the climate monitoring principles.

The Climate Service will provide full and open access to data, information, and service for NOAA, other agencies, and both the public and private sectors for climate-related decision support and other purposes.

The Climate Service will archive and steward data from operational satellites from NOAA and its partners, and assemble these data to create multi-decadal measurement records of many essential climate variables including sea-surface temperature, clouds, water vapor, and other parameters as the basis for determining the origins and impacts of climate variability and change. The Climate Service will partner with NESDIS and NASA to prepare for the stewardship of data from upcoming operational satellite systems.

The Climate Service will continue to support the acquisition, deployment, and operation of the climate sensors that were de-manifested from the prior NPOESS program. The data and measurements from these sensors will be integrated with the core Climate Service climate monitoring capabilities.

The Climate Service will engage the satellite research community through a competitive grants program to capture and deliver its expertise in the construction of CDRs, archiving the data and code necessary for their production, developing the capacity to produce these products operationally and routinely within NOAA, and planning to maintain the continuity of CDRs across future observing systems.

The Climate Service will build on existing capabilities to observe and monitor impacts of human-induced atmosphere forcing of the climate through improved quality and spatial coverage of observations to monitor global and regional trends in greenhouse gases, stratospheric ozone and ozone-depleting substances that affect the recovery of the ozone layer, aerosols, including air pollution, dust, and black carbon.

The launch of the Earth radiation budget sensors on satellite platforms will permit the Climate Service to build new monitoring products for better quantifying Earth's radiation budget, which can be used to diagnose changes in Earth's climate system as well as to discover the processes at work, and thus to improve predictions of changes in precipitation and surface temperature patterns.

Incoming solar radiation is a major driver of Earth's climate system, and the deployment of a solar irradiance monitor will allow the Climate Service to detect minute spectral changes in the solar output and will enable the continuity of this important base measurement which is used in predictive climate models.

The Climate Service will expand its portfolio of CDRs to include measurements that describe multi-decadal measurements of precipitation, outgoing Earth radiation, ice cover, land surface temperature, aerosols, sea-surface winds, and other key parameters that enable climate

monitoring and assessments activities. CDRs are defined as time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. The Climate Service will also sustain and enhance its existing collection of Climate Data Records and plan for the continuity of these records in the future.

The Climate Service will employ the CLASS to meet its archive storage needs through its multi-node distributed architecture. The Climate Service will leverage CLASS' capabilities to provide user-defined search and access to data. These data services will extend beyond the Climate Service and will address all of NOAA's data archive needs.

How the Climate Service Will Do It

For its ocean observations program, the Climate Service will continue to leverage international partnerships under the Global Ocean Observing System, contributing roughly 50 percent of global *in situ* observing system assets. For this contribution, NOAA will use the capabilities of the academic community, the NOAA oceanographic laboratories, and the National Ocean Service to provide the baseline measurements of Essential Climate Variables of the ocean.

NOAA Data Centers will work with other agency organizations to ensure archiving or redundancy of archive for some climate data. The Climate Service policy is that data should be archived at centers with expertise in the data type archived. For example, a non-NOAA archive for atmospheric trace gases exists through the Carbon Dioxide Information and Analysis Center (CDIAC) at Oak Ridge National Laboratory. The National Center for Atmospheric Research also archives and provides access for data, such as the International Comprehensive Ocean-Atmosphere Data Set (ICOADS), which is also archived at NCDC.

NOAA is currently partnering with NASA on the climate elements of the National Polar-orbiting Operational Environment Satellite System (NPOESS) Preparatory Project (NPP) and the Joint Polar Satellite System (JPSS), and has engaged NASA personnel and their expertise through its CDR program. The Climate Service will build upon existing NOAA agreements with the space agencies of Japan (Japan Aerospace Exploratory Agency [JAXA]) and the European Union (European Space Agency [ESA]) to share data and products from their satellite observing systems (e.g., Global Change Observations Mission, Operational Meteorology Satellite System [MetOp]).

The Climate Service will work more closely with user communities. For example, standard 30-year climate "normals" are produced every 10 years, but the user community has asked for more products. In Webinars and other communications stakeholders asked NOAA to produce averages based on different periods other than the standard 30-year normal (also called Dynamic Normals). The Drought Portal is another example where NOAA provides comprehensive access to topically focused monitoring tools and forecasts for stakeholders and decision makers in a "one-stop shopping" concept.

The Regional U.S. Historical Climatology Network (RUSHCN) will be implemented to provide high-quality data for monitoring regional climate change. It is designed to provide data in support of climate monitoring activities following the GCOS Monitoring Principles using redundancy in instruments and pristine siting requirements to ensure the data are of the highest

quality possible, and eliminating the need for advanced data processing currently required to remove biases from historical observations.

Successful programs like the Climate Database Modernization Program will continue to provide service across NOAA.

Better instrumentation will be deployed to observe and quantify the role of feedbacks in the climate system including man-made greenhouse gases, water vapor and clouds, and of their effects on global and regional climate sensitivity.

Data and Information Standards

To carry out its mission, NOAA must be able to successfully integrate model outputs and other data and information from all of its discipline-specific areas to help us understand and address the complexity of many environmental problems. With the large and growing data volumes from satellites, model, and *in situ* platforms, and with the large and growing complexity of data types, the rapid exchange of data and information can only be accomplished through the adoption of international standards for the management of data and model output.

The Climate Service will optimize available resources by using national and internationally agreed-upon standards for purposes of long-term preservation, stewardship, and to promote ease of access and interoperability of various data sources, such as satellites, *in situ* observations, and model outputs. Further, NOAA supports the national U.S. Global Earth Observation System and the international Global Earth Observation System of Systems (GEOSS) by conforming to standards that allow inter-comparison of NOAA's model outputs with other participating Group of Earth Observation (GEO) countries.

Current Practices

Within the U.S. numerical modeling community, three primary data formats are used across government agencies and academic institutions: Gridded Binary, Hierarchical Data Format (HDF), and Network Common Data Form (NetCDF). Of these three, HDF and NetCDF dominate the satellite community. The *in situ* observing communities use a more disparate collection of formats, but in recent years they have begun converging on NetCDF as the file format of choice.

Data format alone is insufficient to ensure ease of access, interoperability, and long-term preservation, all of which require standardized metadata (information about the data). At the file level, the use of the Climate and Forecast convention for NetCDF has become widespread, and for collections of data the Content Standard for Digital Geospatial Metadata from the Federal Geospatial Data Committee is mandated for use across the U.S. government. That standard is now being migrated to the

Examples of standards currently used by NOAA and other federal agencies

Standards for access to data and products

- OGC's CSW, WMS, WCS, and SOS
- OPeNDAP
- Simple Object Access Protocol (SOAP)
- Web Services Description Language (WSDL)

Data format standards

- GRIB
- HDF
- NetCDF

Metadata and preservation standards

- FGDC, ISO 19115-2, ISO 19119
- OAIS-RM (ISO 14721)
- CF

International Standards Organization (ISO) 19115-2 for geospatial metadata and ISO 19119 for geospatial data services. Specific data access and discovery standards in wide use now include the Open-source Project for a Network Data Access Protocol (OPeNDAP), and the suite of Open Geospatial Consortium (OGC) standards—including the Catalog Service for the Web (CSW), Web Coverage Service (WCS), Web Mapping Service (WMS), and Sensor Observation Service (SOS). To ensure that the full value of data and information is realized over the long term, the NOAA Data Centers and many other U.S. government archives have also begun conforming to the Open Archival Information System Reference Model (OAIS-RM, ISO 14721), the international standard for digital archives.

NOAA's Data Centers are already adopting and migrating to these (and other) standards for representing scientific data as steps toward increasing interoperability and preservation (see box). In addition, NOAA ensures its data and products are collected and managed in accordance with policies, procedures, and standards that support and enhance integration and conform to NOAA Administrative Order 212-15.

Future Priorities

The future priorities for the Climate Service will be to more broadly and comprehensively implement the services currently in use across a wider range of its data and information holdings. Broader and more universal adoption of these standards requires additional effort within NOAA and in consultation and collaboration with the external community of data providers and data consumers.

In addition, the Climate Service will provide the tools and services that translate data into information that can be used by our extensive stakeholder community. The vision for the Climate Service is to provide easy access to data through its Climate Portal (www.climate.gov) and other venues such as data.gov; provide interoperability among data and systems by building on national and international standards; and take advantage of online tools developed for users that are readily available to decode, plot, and perform advanced scientific analyses. This vision will be met by:

- Using web-based technologies to translate formats and protocols that simplify the exchange and integration of large amounts of data over the Internet
- Supporting new visualization technologies and web-based mapping services as well as technical documentation of the data and models, including source code
- Using best practices established by the data and modeling communities
- Being cognizant of emerging standards

Core Capability 2: Understanding and Modeling

Goals

The Climate Service will improve our understanding and modeling of the Earth System and its response to a broad range of forcings and feedbacks. Fundamental advances in understanding and modeling will be required to develop credible projections and predictions at regional scales of the impacts of climate variability and change.

Overall Outcome

The Climate Service will provide a comprehensive understanding, diagnosis, and description of the current and future state of the Earth system at global to regional scales, with assessed uncertainties, impacts, and attribution of observed changes.

Requirements

The need to advance understanding of climate variability and change and their impact on the Earth system, improve climate predictions and projections globally and regionally, and better inform adaptation and mitigation strategies is urgent. These strategies must be informed by a solid scientific understanding of the Earth System. And yet key scientific uncertainties limit scientists' ability to understand and predict changes in the climate system. This is particularly true for monthly-to-decadal timescales and at the regional and local levels, which are highly relevant to planning and decision making. Research on the interplay between weather and climate, for instance, is necessary to understand how a variable and changing climate may affect the distribution and occurrence of high-impact weather events like hurricanes, floods, droughts, and adverse air quality.

On decadal-to-centennial timescales, research is needed to better quantify the relationship between increases in atmospheric greenhouse gases and potential impacts like regional changes in sea level, heat waves, and droughts. More broadly, uncertainties in the many factors responsible for forcing climate variability and change, along with those in the physical and biogeochemical feedbacks that may amplify or reduce the forcing, need to be better quantified. Research is required to understand how changes in the global ocean circulation affect the climate system with subsequent impacts on coastal regions, including sea level rise, ocean acidification, living marine resources, and water resources at large-watershed scales. Improved understanding of climate change and variability will depend on sustaining and advancing climate observing systems and platforms that monitor the state of the climate system as well as improving the representation of physical and chemical processes in numerical and statistical models operating at regional scales

The above requirements motivate the following research foci that will advance our understanding of the Earth System and provide an improved basis for confidence in understanding key oceanic, atmospheric, hydrologic, biogeochemical, and socioeconomic components of the climate system and impacts:

- Ocean processes and phenomena with decadal time scales that offer prospects for forecasting climate at these ranges will be studied, with a particular focus on the Atlantic Meridional Overturning Circulation and its relationship to anomalies in sea surface temperature that may impact regional climate predictions. On the short climate time

scales, better understanding of tropical convection will be gained through field measurement campaigns like one dealing with the subseasonal Madden-Julian Oscillation. In general, enhanced understanding and prediction of low-latitude sea surface conditions are critical to advance extratropical predictions of precipitation, temperature, and extreme events

- Improvements to NOAA's CarbonTracker tool will allow more confident assessments of the sources and sinks of carbon dioxide and provide a more reliable basis for comparing satellite measurements of greenhouse gases with those from the in situ network and for calculating the annual Greenhouse Gas Index.
- An improved understanding of the global distribution and trends of greenhouse gases, aerosols, water vapor, ozone, and ozone-depleting gases will enhance interpretations and explanations of the rates and mechanisms changes in climate and the recovery of the ozone layer.
- An enhanced understanding will be developed for the role of changes in external forcings and feedbacks in the modulation of high-impact regional climate conditions. A primary focus will be on how this understanding can advance the prediction of regional climate extremes like floods, droughts, heat waves, and the extent to which such events can be attributed to natural and/or human influences and adverse air quality. This advanced process understanding will be critical to evaluate and assess progress in climate model representations of these processes and their impact on regional climate.
- Improvements will be sought in forecasting water resources and associated estimates of precipitation, evaporation, and runoff at the scale of large watersheds over intraseasonal to decadal time scales. Use of testbeds will accelerate improvement in climate model representations of watershed-scale processes that affect runoff and water supply.
- Because of the expectation that the polar regions of the Earth will experience an amplified response to climate variability and change, efforts will be enhanced to explore the physical and chemical processes governing the local energy balance as well as the understanding and modeling of the teleconnections between polar regions and the tropics and extratropics.
- The atmospheric boundary layer mediates the exchange of heat, momentum, moisture, and chemical constituents between Earth's surface and the free atmosphere. Efforts will be focused on improved representation of the exchange processes that need to be included in Earth system models applied to a broad range of phenomena like wind-driven upwelling in the ocean affecting marine ecosystems, terrestrial ecosystem responses to changed temperature and moisture regimes, and the changed energy balance in the Arctic affecting sea ice formation and permafrost melting.
- Physical and chemical mechanisms operating at decadal time scales will be elucidated and will motivate the improvement and validation of numerical and statistical models that can inform future climate-sensitive decisions.

Existing Capabilities

NOAA works on process-level understanding of climate forcing mechanisms and interactions in a variable and changing climate system, and develops predictive understanding of climate variability and change on time scales of weeks to a century, and on geographic scales from global to regional. NOAA applies this knowledge in the development, testing, and evaluation of

coupled Earth system models. The agency's research includes quantifying, with uncertainty ranges, the impacts and roles of natural variability and climate forcing by greenhouse gases, aerosols, clouds, land use (and their interactions), as well as influences of a changing climate on atmospheric constituents and oceanic composition.

NOAA conducts process-oriented research, and model experiments to investigate climate forcing and response functions in the atmosphere. These local-to-global scale studies involve long-term atmospheric composition monitoring, intense field campaigns to establish forcing mechanisms and physical processes, data analyses, rapid information synthesis, and assessments. Such information allows nations, tribes, regions, states, and local governments to make climate-sensitive decisions while improving air quality, managing water resources more effectively, and anticipating extreme event . It provides national, as well as state- and regional-scale information on climate forcings and their impacts that informs options to simultaneously improve air quality and manage greenhouse gas and aerosol emissions.

Specific long-term programs of note are:

- Quantification of greenhouse gases and aerosols as climate forcings now, in the past, and in the future based on longterm monitoring of key species such as carbon dioxide, methane, nitrous oxide, ozone, and halocarbon gases as well as aerosols. Many of these measurements were started in the 1950s and 1960s. Assimilation of these data into models, for example CarbonTracker [25], enables estimation of sources and sinks for key climate changing agents.
- Understanding and interpreting patterns of the global and regional concentrations and trends in ozone depleting substances and their substitutes, as well as changes in the stratospheric ozone depletion and the recovery of the ozone layer in response to the Montreal Protocol.
- Maintaining a world-class capability in observing, diagnosing, parameterizing and modeling the planetary boundary layer over the oceans, land, and cryosphere. Such a capability has been applied extensively over the last forty years to improve modeling of air quality, better characterize air-sea fluxes of heat, moisture, momentum, and trace gases in climate models, and more recently to quantify the controls of the energy budget of the Arctic critical to changes in sea ice and the melting of the Arctic permafrost.
- Carrying out fundamental studies of extreme events in the hydrological cycle affecting lives and property as well as providing for the co-management of fisheries, energy generation, and agriculture. This has also involved identifying major organizing features in the atmospheric circulation that may yield future improvements in predictability.
- Fundamental advances in reanalysis and diagnoses of the global climate system necessary to explain current anomalies in the context of systematic changes, to illuminate the global interconnection of major circulation changes in the atmosphere and ocean, and to identify

[25] A system that calculates carbon dioxide uptake and release at the Earth's surface over time using model predictions of atmospheric carbon dioxide and compared with the observed atmospheric carbon dioxide mole fractions.

critical scientific advances that will be needed to develop future information products and services.

- Maintaining a global network of observatories that support shorter-term intensive process studies while maintaining a long-term climate record – a network that has been recently augmented in the sparsely observed Russian Arctic
- Development of an experimental decadal climate prediction system with large ensembles of hindcasts to evaluate the basis for making forecasts of climate variability and change for the next one-to-three decades.

The Climate Service will provide research and analyses of short-term climate from weeks to a few decades. The research focuses on basic processes, such as Madden-Julian (30-60 day) atmospheric oscillations, monsoons, air-sea-land interactions, seasonal variations, the El Niño-Southern Oscillation, and the persistence or re-emergence of multiyear to decade ocean conditions. The analyses focus on key details of the initial state of the ocean, land, and atmosphere as sources for prediction. Multi-model ensemble and statistics-based predictions and projections are developed and tested to advance probabilistic climate outlook products in support of early warning, preparedness, adaptation, and mitigation. Field experiments and diagnostic studies are carried out to identify features in the climate system that may lead to improved predictive skill at regional scales and at short climate time scales.

The Climate Service will focus on near-term understanding and modeling capabilities to address key climate questions (priority societal challenges) identified by the Climate Service, including water, coasts, marine ecosystems, extreme events, and human influences. Future activities will also include coordinated efforts in labs, field campaigns, and modeling to advance understanding of the influence of various components of the climate system on variability, change, and extremes, and to transition advances in research into improved global climate models. Climate Service research will continue to be critical to assess global and regional climate sensitivity, regional predictability, decadal predictability, predictability of extreme events, and associated impacts. Partnerships will be required with the private sector, other public sector agencies, academic organizations, and various international partners in order to deliver authoritative and timely information.

What Climate Service Will Do

The Climate Service will provide information on process understanding, abundances of greenhouse gases, and analysis of the predictability of the global-to-regional climate and Earth system and its change. In the near term (Fiscal Years 2011–2015) process studies and modeling will be used to address scientific questions such as the interplay between air pollution and climate change due to short-lived species, and the predictability of hydrologic extremes and high impact weather and climate events. In the medium term, coordinated efforts in laboratory, field, and modeling to advance understanding of the role of clouds, aerosols that affect clouds and precipitation, organic aerosols that come from biogenic emissions, water vapor impacts on climate variability and hydrologic extremes, and to transition research advances into global climate models, operational seasonal and regional forecast models, and support climate-sensitive decisions. This research is critical for improved estimates of global and regional climate sensitivity and impacts, as well as climate adaptation strategies.

Some objectives for improving the understanding and modeling capabilities include:

- Simulations and analyses that include field observations applied to the understanding, attribution and quantification of extreme events such as heavy precipitation, drought, excessive runoff, heatwaves, and hurricanes in the context of climate change.
    - Such analyses will engage NOAA's global field observation network that extends from pole to pole and utilizes airborne, ship-borne, and space-based observatories, and exploit newly developed reanalysis and data assimilation methods.
    - Target geographical regions of the Earth either sensitive to amplified responses to external forcing (such as the polar regions) and as sources of distant circulation changes (such as the Indian Ocean).
- Advancing our capability to provide regional downscaling of climate models and their evaluation necessary to establish guidelines for their application:
    - Documenting the role of oceanic STT patterns on regional temperature and precipitation anomalies.
    - Systematic and rigorous evaluation of current/commonly available downscaling products.
    - Development and utilization of observational and modeling testbeds to advance downscaling science.
- Improved understanding of:
    - Global and regional trends in stratospheric ozone and ozone-depleting substances including determination of the recovery of the ozone layer and climate impacts in the lower atmosphere
    - Regional greenhouse gas variations in the United States in support of the North American Carbon Program
    - The role and quantification of the boundary layer and surface exchange processes in closing the CO_2 budget using models such as CarbonTracker and NOAA's Tall Tower network
    - The integrated impact of greenhouse gases, aerosols, clouds, water vapor and associated feedbacks on global climate, regional impacts, and extreme events
    - Trends in net solar radiation (a bottom line in climate forcing) at the surface characterizing the 'dimming' or 'brightening' of the Earth's surface, their potential linkages to aerosols and clouds, and associated global to regional climate impacts
    - Upper tropospheric and lower stratospheric water vapor based on more accurate measurements of low concentrations
    - The water vapor transport and distribution to quantify the global radiation balance
    - Particles—including air pollution, dust, and black carbon—impacting climate and air quality in the U.S. and Arctic
    - Changing cloud fraction and composition in polar regions affecting surface energy budgets and ice melt
    - The processes linking emissions, chemistry, transport, transformation, and deposition of key short-lived species in the atmosphere (such as black carbon and organic aerosols), including quantification of the uncertainties

    - The behavior of deep ocean heat content to given the impact on sea level rise, current trends, and projections of SLR
    - How the trajectory of changes in the Arctic will impact climate and climate predictability on timescales from weeks to centuries
    - The mechanisms and feedbacks modulating deepwater formation and meridional overturning circulation influencing multidecadal climate trends and regional conditions
    - The opportunities for and limits to predictability of climate at seasonal, annual and decadal timescales
- Leadership in national and international assessments (such as the U.S. National Climate Assessment [2013] and the IPCC Fifth Assessment Report [2013]) providing the scientific basis for decisions and choices made by industry, government, and the public relating to climate change, air-quality improvement, and ozone-layer protection
- Improvements in the understanding of the ocean circulation and its biogeochemistry yielding better ocean models and leading to improved:
    - Understanding of uptake of carbon in the oceans
    - Linkages between global oceans and the coasts
    - Linkages between physical oceanography and marine ecosystems
- Improvements in strategies for using climate and hydroclimate test-beds and multi-model ensembles, and statistical methods to advance:
    - Diagnosis and analysis of high impact climate events from weeks to a few years with a focus on the initial state of the ocean, land and atmosphere
    - The sustainability of terrestrial ecosystems in changing climate regimes (e.g., temperature and precipitation)
    - Understanding and modeling of hydroclimate processes by developing observational and modeling testbed approaches (Hydroclimate Testbed)

How the Climate Service Will Do It

The Climate Service will carry out this work with a broad array of partners. Academic partners will be integral to this effort through their participation in grant-sponsored work or Cooperative Institutes to fill capability and expertise gaps in NOAA. Other federal laboratories will take up specific tasks that are within their expertise.

The work of many federal agencies will help NOAA by providing science information to NOAA or, as customers, use the information produced by NOAA. They include agencies such as NASA and the National Science Foundation for augmenting science expertise, U.S. Environmental Protection Agency for being a partner in strategic development of climate services and as receivers of information for regulatory use. State agencies that deal with climate and air-quality issues will partner with NOAA in developing such information and in using NOAA's unique measurement and analytic capabilities. Partnerships with international agencies such as WMO, WCRP, International Geosphere-Biosphere Programme, and UNEP will provide mechanisms to link with the international communities and to share data, monitoring, research, and modeling capabilities.

Core Capability 3: Predictions and Projections

Goals

To provide credible and authoritative predictions and projections of global to regional climate conditions for decision support on timescales from weeks to centuries.

Overall Outcome

The Climate Service will support public and private sector preparedness, precautionary responses, adaptation, and other climate-sensitive decisions by providing global predictions and projections and regional climate information at the spatial and temporal scales where people live and work, where our nation's infrastructure is built, where trust coastal and marine resources and other natural resources are managed, and where renewable energy is produced.

Requirements

NOAA requires a prediction and projection capability for past, present and future states of the climate to support preparedness, adaptation and other climate-sensitive decisions. A climate and earth system modeling capacity is needed that spans the spatial and temporal scales of climate variability, change, and extreme events. An integrated climate predictions and projections capability is needed to implement state-of-the-art approaches to provide the "best available" climate information at global to regional scales to provide early warning across timescales and to inform decision making. Specific requirements include:

- **Climate and earth system modeling capability**
  - Refine, implement and evaluate climate and coupled Earth system model predictions and projections of past, present, and future states of the climate system.
  - Improve data assimilation and enhance boundary layer exchange processes in earth system reanalysis models to include greenhouse gases and other climate forcing agents and to resolve atmospheric boundary layer processes that mediate the exchange of heat, momentum, moisture, and chemical constituents between Earth's surface and the free atmosphere
- **Climate predictions and projections**
  - Reliable climate predictions, projections and associated uncertainties from global climate models run at high spatial and temporal resolution to inform climate-sensitive decisions.
  - Development of prediction techniques for regional climate information to inform preparedness, precautionary responses, adaptation, and other climate-sensitive decisions
  - Estimates and explanations in the uncertainty in climate predictions and projections across spatial and temporal scales.

To meet these requirements the Climate Service will focus on a suite of activities that contribute to implementation of a next generation climate and earth system modeling capability and to advancing the reliability of climate predictions and projections:

- Improve simulations of the Earth System using more robust models to better predict and project climate across timescales
- Increase understanding of the decadal predictability of the unforced and forced climate system
- Develop progressively higher-resolution coupled climate and atmosphere modeling and employ nested regional modeling to provide spatially resolved climate information
- Develop an integrated earth system analysis system for climate that captures or incorporates a broad range of phenomena such as wind-driven upwelling in the ocean, terrestrial ecosystem responses, biogeochemical cycles and the impact of sea ice and permafrost melting on high latitude energy balances
- Provide improved predictions and projections of water resources and associated estimates of precipitation, evaporation, and runoff at the scale of large watersheds over intraseasonal to century time scales
- Improve the reliability of climate forecasts and projections across timescales through the development of multi-model ensemble prediction systems, improving operational data assimilation schemes, and correcting systematic errors in numerical prediction models.
- Implement a coastal sea level prediction system to provide intraseasonal and seasonal predictions of regional coastal inundation
- Improve the representation, evaluation, and prediction of the roles of marine and terrestrial ecosystems in climate predictions and projections by more fully incorporating biogeochemical cycling into earth system models
- Enhance representation of sea ice related processes within the operational and next generation forecast systems augmented by improvements in the assimilation of satellite data to improve daily to weekly sea ice forecasting capabilities

Existing Capabilities

NOAA predicts and projects the response of the climate system to natural forcings, human-to forcing functions in the atmosphere.

The Climate Service will develop and maintain fully coupled global Earth system models used to make short-term (weeks to seasons) predictions based on the initial state of the total Earth system, as well as longer-term (decades to centuries) projections due to natural and human-induced forcing. In order to improve the fundamental processes in these models, research is conducted on decade-to-century large-scale dynamics of climate variability and change. Examples of studies in this research program includes: reconstruction and analysis of the climate of the past 2000 years; and dynamics of large-scale multi-decadal phenomena, such as the Atlantic Meridional Overturning Circulation and abrupt climate change. Detection and attribution analyses using model simulations and observations support improved understanding of the causes of past and present changes in climate and provide explanations for evolving climate conditions so society can better anticipate and respond to climate. Model simulations help in developing a comprehensive understanding of the biogeochemical cycle affecting the fate of carbon including uptake from the atmosphere in the land and oceans, as well as the changing biogeochemical cycles and impact on marine ecosystems implicit in an ice-free Arctic and warming permafrost. Statistical and high-resolution dynamic models are developed and used for regional downscaling applications and simulations of extreme events such as hurricanes under

climate change conditions. New and enhanced climate understanding and modeling capabilities will be key to U.S. contributions to the IPCC assessments and other national and international climate change assessments. Comparing the relative forcing by various climate-perturbing agents enables decision makers to evaluate options for mitigation.

The Climate Service will deliver near-term modeling capabilities that address key climate questions (priority societal challenges) identified by the Climate Service, including water, coasts, marine ecosystems, extreme events, and human influences. Future activities will also include coordinated efforts in labs, field campaigns, and computer models to advance understanding of the influence of various components of the climate system on variability, change, and extremes, and to transition advances in research into improved global climate models. Climate Service research will continue to be critical for improved estimates of global and regional climate sensitivity, projections, and impacts, as well as climate mitigation and adaptation strategies for more confident decision-making. Partnerships will be required with the private sector, other public sector agencies, academic organizations, and various international partners in order to deliver authoritative and timely information.

The Climate Service's portfolio of predictions and projection capabilities range from operational (regular and on-going relatively stable products with gradual advances in information format, content and skill delivered), to quasi-operational (episodic with significant advances in modeling components and in the quality of information) to experimental (under development in an exploration mode with rapid improvements in methodology and information content). The climate service will continue to develop, deliver and enhance predictions and projections that span weeks to centuries. Existing capabilities include

- Intraseasonal to interannual climate outlooks produced operationally by the Climate Prediction Center; dynamical and statistical models, tools, guidance and related datasets produced quasi-operationally by PSD, CPC, other research laboratories, River Forecast Centers, and NOAA-supported applied research centers (ARCs)
- Decadal predictions of regional climate information produced experimentally as part of the suite of IPCC simulations by GFDL, as extended CFS runs by NCEP, and trend based projections by PSD, NCDC, and other research laboratories and centers
- Mid to late 21st century climate projections for IPCC assessments produced quasi-operationally every 3-7 years by GFDL
- Mid to late 21st century regional climate projections produced experimentally as collaborative activities such as GFDL's regional climate modeling contribution to the North American Regional Climate Assessment Project and GFDL high resolution hurricane modeling, focused regional climate modeling and statistical modeling by NOAA-supported ARCs and Regional Integrated Sciences and Assessments (RISAs) and NOAA research laboratories.

What the Climate Service Will Do

The Climate Service will provide predictions and projections of global-to-regional climate information to inform climate-sensitive decision making. Climate model predictions and projections, even when provided in extremely high resolution fields and comparable to the best weather models today, will still require additional analysis and translations. The Climate Service

will leverage the long-term and ongoing NWS investments in Model Output Statistics programs to provide seasonal to decadal to multi-decadal predictions and projections of important phenomena such as the frequency of fog, tornadoes, lightning storms, ice storms, and many other extreme weather and climate events. At shorter timescales, the NWS provides forecasts of many phenomena that are not directly derived from its weather models, but rather generated with analysis tools that remove model biases and directly predict societal relevant information. The climate service will make implementation of similar analysis tools a priority to ensure its predictions and projections are just as relevant to its stakeholders. For this reason the Climate Service will not only invest in improved and better integrated climate and earth system models for predictions and projections on time scales from weeks to centuries, but in an analysis system to help translate these results to weather-scale climate information and associated uncertainties of particular interest to businesses and communities.

In the near term, continued improvements in the skill of intraseasonal to interannual predictions of regional US temperature, precipitation, and extreme events will be pursued through advances in the use of multi-model ensembles, in data assimilation, and methods to correct model biases. Implementation of new prediction capabilities will focus on coastal sea level and inundation, on near-shore atmosphere-land-ocean processes impacting marine ecosystems, and on hydrologic processes that affect drought, runoff and water supply. Climate prediction and projections capabilities will be used to explain and interpret significant changes in climate such as recent polar climate variations and change, ocean acidification, behavior and impact of long-lived atmospheric constituents, regional to local coastal erosion and inundation, water challenges (such as floods, sea-level rise, and droughts) and other climate extremes. Efforts to provide mid to late 21st century regional climate information to support the ongoing national climate assessment process, will focus on enhancing the quality of and access to existing regional climate information products while the capability to provide next-generation projections of regional climate information is developed. Mid to late 21st century climate projections for IPCC AR5 will be completed and then evaluated relative to previous CMIP3/AR4 projections.

In the medium term, the Climate Service prediction and projection core capability will build on the suite of near term activities. New efforts will include extending intraseasonal to interannual prediction capabilities for extreme events, coastal sea level and inundation, near-shore atmosphere-land-ocean processes impacting marine ecosystems, and hydrologic processes that affect drought, runoff and water supply to decadal and century regional climate projections. In partnership with USGCRP agencies and academic institutions, the Climate Service stand up a quasi-operation capability to apply very high-resolution coupled climate and atmosphere modeling, regional climate modeling, and statistical modeling to produce next-generation projections of regional climate information.

Specific actions to strengthen the predictions and projections core capabilities include:

- Procurement of a high-performance petaflop scale computing system, which will provide a key platform to characterize and quantify climate variations and change by performing:
    - Long-term simulations using better and improved global climate models that include interactive atmospheric chemistry and aerosols

    - Long-term reanalyses using improved observations to better characterize changes in extreme events
    - Earth system models to determine the fate of the anthropogenic carbon in the land and oceans
    - Research on decadal predictability of the unforced and forced climate system including dependence on initialization and assimilation techniques
    - Progressively higher-resolution atmospheric and oceanic modeling for regional climate change information
- Application of statistical and high-resolution dynamic model development for predictions and projections of regional climate information to support adaptation and other climate-sensitive decisions.
- Predictions, projections, sensitivity tests and analyses that include observations to interpret, attribution and quantification of extreme events such as heatwaves, heavy precipitation, excessive runoff, and hurricanes in the context of climate variability and change.
- Climate predictions and projections of carbon uptake in the oceans resolving linkages between global oceans and the coasts and linkages between physical oceanography and marine ecosystems

How the Climate Service Will Do It

The Climate Service will carry out this work with a broad array of partners. The NWS NCEP will a critical internal partner in both advancing the climate and earth system modeling capability and the integrated climate predictions and projections capability. Academic partners will be integral to this effort through their participation in grant-sponsored work or Cooperative Institutes to fill Climate Service capability and expertise gaps in advancing modeling capabilities, in prototyping analysis tools to transform predictions and projections into regional information, and in the evaluation and analysis of all aspects of climate predictions and projections.

The work of many federal agencies will help NOAA by providing climate modeling, predictions, and projections information to NOAA or, as customers, using this information produced by NOAA. The Climate Service will partner with federal agencies such as NASA, DOE and the NSF/NCAR to augment climate modeling expertise and prediction and projection capabilities. To address the water resources societal challenge, in addition to working with the NWS Office of Hydrologic Development and River Forecast Centers, the Climate Service envisions strong partnerships with existing expertise in land surface processes and ground water modeling at USGS, NASA, the academic community, as well as federal and state water resource management agencies. More general, the Climate Service will partner with resource management and regulatory agencies in the development and deployment of analysis and translation tools to transform model predictions and projections into regional climate information. State agencies that deal with climate and resource management will partner with NOAA in developing such information and in using NOAA's unique predictions and projection capabilities. Partnerships with international agencies such as WMO, WCRP, International Geosphere-Biosphere Programme, and UNEP will provide mechanisms to link with the international communities and to share modeling capabilities and climate predictions and projections.

Core Capability 4: Integrated Service Development and Decision Support

Goals

To support decision makers operating at regional and global scales with timely and authoritative information.

To develop, deliver, and explain information on time and space scales relevant to decision-making through a sustained interactive dialog involving NOAA, and NOAA's partners and stakeholders.

To better understand decision makers and stakeholders needs for climate services and to inform their community planning efforts.

To provide a platform of dependable data, models, and information from which the climate service provider community can depend on to build decision-support tools and products to serve society.

Overall Outcome

The Climate Service will implement a new partnership through which scientists, service providers, and decision makers develop a shared understanding of the nature and consequences of climate variability and change (shared learning) and use those insights to minimize harmful climate impacts, maximize opportunities, and inform climate adaptation decisions.

Requirements

Governments, communities, businesses, and resource managers are increasingly challenged to develop and implement programs, policies, and procedures that reduce vulnerability to changing climate, in the context of other environmental, social, and economic factors, and effectively plan and implement adaptive practices as well as consider mitigation-related actions. These actions should address both today's climate-related challenges (e.g., climate-related extreme events such as droughts, floods and storms) and support planning for the future in the context of climate change. A number of statutes (such as the Climate Program Act, Coastal Zone Management Act, Global Change Research Act, and Weather Service Act) provide NOAA with specific additional climate-related authorities to address issues in the context of state-to-regional needs and/or resource management responsibilities.

Existing Capabilities

Integrated Service Development and Decision Support is currently provided through existing networks at international, national, tribal, regional, and local levels. Internal resources are distributed across NOAA in NWS Weather Forecast Offices, River Forecast Offices, and the Climate Prediction Center, NOS Coastal Service Center, NESDIS National Climatic Data Center, and regional collaboration teams. NOAA supports external resources for experimental integrated services development and delivery in the Regional Integrated Sciences and Assessments (RISA) programs, the International Institute for Climate and Society, Sea Grant, extension agents, communicators, and educators. Over the past two decades, NOAA has also supported Regional Climate Centers to help deliver climate services.

What the Climate Service Will Do

The Climate Service will address the growing requirements for information products and services through a program of enhanced integrated services development and decision support, including regional climate services, assessment services, and engagement and education activities.

The Climate Service will foster the development of an innovative, integrated Regional Climate Services Partnership that brings together and strengthens internal NOAA and extramural partner regional services activities and provides the institutional foundation for the Climate Service regional program with the following objectives:

- Provide climate information that will enable the Climate Services Partnership to develop, routinely update, and improve decision-support tools for climate change adaptation;
- Develop strong ties and ongoing interaction with stakeholders, including non-governmental organizations and the business community, to translate stakeholder needs to the science community and scientific breakthroughs and uncertainties to stakeholder communities. These cross-boundary activities will help ensure that authoritative and relevant climate information is available to decision makers;
- Effectively integrate the three types of Climate Assessments into a cohesive Climate Assessment Services Program;
- Deliver an "Ozone Information Service" based on state-of-the-art science and integrated observations that identifies, explains, and provides solutions for the stratospheric ozone layer depletion.
- Deliver a "Forcings of Climate Change Information Service" through routine updates in the NOAA Annual Greenhouse Gas Index (AGGI), CarbonTracker, Interactive Data Visualization, and GlobalView, through continued development of a national and global greenhouse gas information system to provide regional scale validation of greenhouse gas management strategies, and dissemination of this information in ways that can be easily understood and followed by policy makers, educators, and the general public. Connect the Climate Service regional capabilities with core partners in other parts of NOAA (such as the National Weather Service, the National Ocean Service, the National Marine Fisheries Service), in other agencies, and across the broader climate services enterprise;
- Provide a clear point of entry for other federal agencies, universities, non-governmental organizations and private sector partners interested in working with NOAA on integrated services and support. This includes operating a Climate Research Grant Program that includes integrated service development across the four Climate Service core capabilities; and
- Increase the coordination and effectiveness of NOAA's climate communication, education, and engagement programs, products and partnerships.

The NOAA Regional Climate Services Partnership comprises four coordinated and mutually supportive functional elements:

1. **State, local, and tribal engagement.** Activities focused on enhanced communications related to changing climate and impacts; climate education and literacy; and place-based expertise to support development and evaluation of adaptation programs and policies.

2. **Regional climate science.** Research, modeling and assessment activities to understand changing climate and vulnerability; providing insights into climate-ecosystem connections; and advancing development of new information products and tools.

3. **Assessment services.** A fully integrated and coordinated set of activities to support all three types of assessments and to carry out much of the work related to the Needs Assessments.

4. **Integrated climate products and services for decision support.** Responsibility for ensuring that the data and information are available to support a thriving climate services private sector delivering decision-support tools; and the development, testing, and evaluation of new climate services that can be sustained by the Climate Service or its partners.

Customer Engagement and Education. The Climate Service will build on existing programs designed to improve access to useful and usable NOAA climate data products and services, enhance overall climate literacy among the nation's citizens, provide technical training on Climate Service products and services, and expand the cadre of individuals skilled in understanding the societal consequences of changing climate conditions and the scientific and technical capabilities that they have at their disposal. Fulfilling this goal will require working with a variety of partners in and outside of NOAA. This will require:

- Expanding the number and expertise of trusted experts who understand and can connect both the emerging science within the Climate Service and requirements of users and service provider communities. This includes place-based experts to support development and evaluation of local, state, and tribal adaptation programs and policies
- Ensuring the integration among the core capabilities in order to provide easy access to understandable, relevant, and usable information about the nature and consequences of changing climate
- Delivering problem-focused products, information services, carefully selected decision-support tools, appropriate training, and technical support
- Providing mechanisms for sustained user dialogue to both expand the use of Climate Service products and services and inform future investments
- Delivering climate communication, education and engagement that are aligned with broader national climate literacy efforts, and are consistent with agency priorities.

How the Climate Service Will Do It

These will be accomplished through the following efforts:

- Engage core partners and customers in the evolution of the program
- Manage the Climate Assessment Service framework for the Climate Service
- Establish mechanisms for participation by currently under-represented groups (such as the private sector, non-governmental organizations, and academia)
- Manage transition from individual programs in multiple parts of NOAA to an integrated program managed by the Climate Service, including development of internal governance bodies and an action plan

- Establish roles and responsibilities of NOAA's *Regional Climate Services Partnership* in context with National Assessments and Thematic Problem-focused Assessments
- Implement specific mechanisms for connection across and coordination among other NOAA programs and offices
- Manage the Climate Service research grants program not only to strengthen the science in Climate Service, but to help build the necessary science to decisions connections consistent with the Climate Service goals
- Actively engage internal NOAA customers from all line offices including resource stewardship offices in the National Marine Fisheries Service and the National Ocean Service
- Fully develop and implement interagency coordination and collaboration including definition of complementary roles and responsibilities (such as the National Integrated Drought Information System, West Coast Governors Agreement on Ocean Health, Gulf of Mexico Alliance, and others)

Appendix B: Societal Challenges

Societal Challenge 1: Climate Impacts on Water Resources

Goal

To increase the nation's capacity to manage its water resources in a changing climate, overcoming challenges posed by altered temperature and precipitation patterns and related changes in runoff, timing, and volume of water used for agriculture, human consumption, ecosystems, energy, transportation, and construction.

Overall Outcome

The Climate Service will develop and maintain a coordinated and authoritative information system that provides decision makers with actionable early warning of risks and cost-effective guidance for managing changing water resources, from local water districts to federal water agencies.

Demand for Services

Water managers are asking: Will increased risks for drought and flood require new water supply and flood-control infrastructure or adaptation practices? Current water management systems, designed and operated under the assumptions of unchanging climate, are no longer reliable. Water managers require climate information that can support alternative approaches to managing regional-scale water availability and risks.

Primary Sectors/Users Supported

Local water districts to federal water agencies; agriculture; construction; energy companies/utilities; health services; manufacturing; mining; natural resources; tourism; and transportation.

Capabilities

The Climate Service's core capabilities in observing systems, monitoring, process studies, modeling, impact assessments, and user engagement will produce and deliver projections of regional precipitation, snowpack, runoff, and drought conditions on a range of timescales in the context of vulnerability and risks.

Strategy

Improvements in predicting and communicating integrated climate and water information on a range of timescales will require a coordinated approach that includes:

What is the Climate Service role?

The Secure Water Act directs federal water and science agencies to work together with states and local water managers to plan for climate change and other threats to water supplies, and take action to secure water resources for communities, economies, and ecosystems. NOAA is identified as a source for the credible science required by other agencies, state, and local decisions makers, and the private sector.

"It's a combination of increasing demands for our growing population and the economy, as well as the uncertainty in supply due to drought and climate change … As a region, we have to become more aggressive and a lot smarter in how we manage this resource." – Gov. Brian Schweitzer, Chairman of the Western Governors' Association.

Water management policy, planning, and decision makers are increasingly challenged to balance water supply and demand while minimizing risks to life, property, transportation, and ecosystems. The Climate Service will provide improved monitoring, predictions, and projections of precipitation, evaporation, and runoff on time scales of weeks to decades to support planning, preparedness, and adaptation in the Nation's watersheds.

The 2006 NIDIS Act, 2007 NIDIS Implementation Plan, and 2004 Western Governors' report *Creating a Drought Early Warning System* describe the need for NOAA to provide improved science and information systems to guide decision makers.

- Improved observational networks
- Process studies to quantify the water budget at Earth's surface
- Use of models that integrate ocean, atmosphere, and land surface processes
- Coordination across NOAA line offices and with other agencies
- Coordinate efforts to assess the impacts of changes in climate on water resources in natural, managed and built environments and to produce science-grounded estimates of the associated socioeconomic costs of these impacts
- Coordination with regional climate entities to facilitate collaboration among the climate science community and end users of climate information

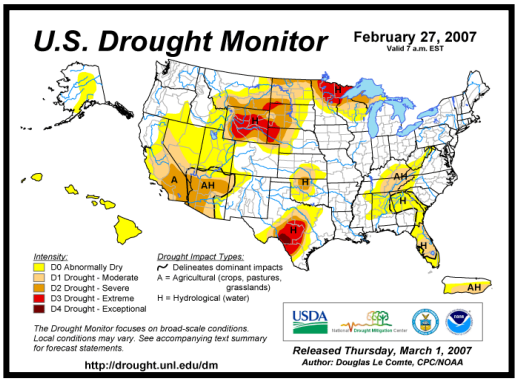
What the Climate Service Will Do

- Work closely with other Federal agencies (e.g., DOI, USACE, USDA, and EPA) and state and municipal water authorities that have direct responsibilities for managing water quality, water supply, and water-related resources to ensure that the best available climate science, information, and practices for its use are developed and applied.
- Use internal capacity and engage external partners to assess the ability of current climate model projections and analyses to accurately represent watershed-scale processes that affect runoff and water supply as well as the severity and duration of drought. This activity involves implementing a Hydroclimate Testbed to identify and quantify parameters that control precipitation, evaporation, transpiration, and runoff in high-resolution climate models.
- Work with the full range of relevant partners to evaluate information needs and advance hydroclimate science to develop and implement accurate and effective early warning systems that will improve public awareness of vulnerability to drought and floods, and to inform adaptation planning and implementation efforts.
- Partner with social scientists in other federal departments, in other DOC agencies and bureaus, and in other NOAA Line Offices to characterize the impacts of changes in

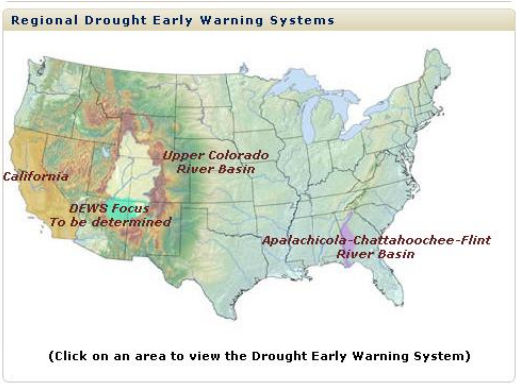
Example Activity: Drought Impacts

Drought results in annual losses of $6-8 billion to all sectors of the economy.

NOAA's US Drought Monitor is an example of an operational product which is produced weekly and used by managers in the water resources, agriculture, and energy sectors.



The National Integrated Drought Information System (NIDIS) and associated web portal drought.gov serve all those who manage and depend upon the nation's water resources. Planned enhancements include improving the usability of drought early warning systems. The Climate Service's initial focus on Water Resources will improve NOAA's ability to participate in this successful interagency collaboration.



climate on water resources in natural, managed and built environments and to compile science-grounded estimates of the costs of climate impacts on water-related resources.

- Support and enhance NIDIS and the drought.gov portal in order to address drought and water supply impacts.

Table B.1 shows examples of new efforts and user groups, and outlines how the Climate Service's four core capabilities will be brought to bear on the *Climate Impacts on Water Resources* societal challenge.

Table B.1. Examples of new Climate Service deliverables and user groups and how the core capabilities contribute.

Societal Challenge: Climate Impacts on Water Resources Contributions from Core Capabilities	
Examples of New Efforts	• Skillful drought and flood outlooks for a range of climate time-scales based on process understanding of watershed-scale hydrologic budgets • Regional drought monitoring tools and impact assessments • Hydroclimate information system enhancements such as inputs into watershed plus state and local drought plans and operations
Example User Groups	• Water resource managers • Civil engineers • Farmers • Emergency management officials • U.S. Bureau of Reclamation • U.S. Department of Agriculture • U.S. Army Corps of Engineers • US Fish and Wildlife • US Forest Service • US Park Service
Observing Systems, Data Stewardship, & Climate Monitoring	• Deploy an array of instruments for long-term hydroclimate observations with a density sufficient to enable comprehensive understanding of water budgets and evaluation of regional model fidelity
Understanding & Modeling	• Conduct research to clarify understanding of water cycle processes at regional scales • Assess the current generation of integrated ocean-atmosphere climate models to identify improvements necessary for predicting and projecting regional climate extremes • Improve ocean modeling of oceanic sea-surface temperatures in integrated climate models to improve regional prediction/projection
Predictions and Projections	• Intraseasonal to interannual predictions of regional precipitation , snowpack, runoff, and drought conditions • Experimental decadal predictions of changes in the probabilities of regional precipitation, snowpack, runoff, and drought conditions • Mid to late 21st century of changes in the probabilities of regional precipitation, snowpack, runoff, and drought conditions
Integrated Service Development and Decision Support	• Provide state-of-the-science climate products for a range of users • Develop tools and processes to effectively communicate uncertainty regarding regional climate predictions for precipitation, snowpack, runoff, and temperature • Provide feedback to climate observation and science activities to address use-inspired research

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Why the Climate Service will be Successful

- There is good scientific evidence linking patterns of sea-surface temperature to drought in North America. Improved predictions for long-term regional-scale precipitation depend on integrated models of the ocean and atmosphere. The ability of these models to generate realistic patterns of sea-surface temperatures is essential for making accurate regional-scale predictions. Current work in this area is expected to produce significant advances and enable more skillful drought and flood outlooks for a range of time scales.
- Existing prototypes of early warning systems for drought provide a strong foundation for new climate information systems.
- Current research on the effects of aerosols is improving the performance of regional climate models and there is growing evidence this plays an important role in the water cycle.
- The current NOAA Hydrometeorological Testbed activity which has addressed extreme events in the weather-climate system including Atmospheric Rivers which tap into tropical climate anomalies is in the planning process for expansion into the Hydroclimate Testbed to improve predictions/projections at large watershed scales.

Examples of engagement activities supporting Climate Impacts on Water Resources include partnerships developed through:

- Intergovernmental Panel on Climate Change Technical Paper on Climate Change and Water
- Interagency Climate Change Adaptation Task Force Workgroup on Water Resources and Adaptation
- Western States Water Council and associated Western States Federal Agency Support Team
- Federal Climate Change and Water Working Group
- California Interagency Watershed Mapping Committee (CalWater)
- Apalachicola-Chattahoochee-Flint Stakeholders (13 stakeholder groups that include water providers, Lake Associations, and the Franklin County seafood association)

NOAA also works closely on water resource issues with:

- Federal agencies including DOI, EPA, USFS, USACE, and NASA
- Tribes, state, and local agencies
- Academic institutions
- Non-governmental organizations and other entities that have expertise, programs, or activities dealing with various aspects of water resources

Examples of projects resulting from these interagency collaborations include NIDIS, the Hydrometeorological Testbed, and the interagency report, *USGS Circular 1331: Climate Change and Water Resources Management—A Federal Perspective*.

NOAA has organized and participated in multi-agency, interdisciplinary workshops that addressed the impacts of climate on water resources. These include:

- Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management
- National Status of Drought Early Warning Systems in the United States

- Western Governors' Association workshops on Water Needs and Strategies for a Sustainable Future: Next Steps

NOAA also works to engage watershed commissions, state and private water utilities, and wildfire and ecosystem managers in contributing to, and learning from, NIDIS.

Societal Challenge 2: Coasts and Climate Resilience

Goals

1. Characterize the physical processes driving local sea-level rise and inundation of coastal regions and communities.
2. Develop and promote understanding of potential impacts to communities and ecosystems from sea-level rise.

Overall Outcome

The nation's decision makers have access to, and sufficient knowledge to apply, the best available information on risk and vulnerability associated with local sea-level rise and inundation. Resource managers and members of coastal communities have a solid understanding of sea-level rise in their locality, including its connections to global sea-level rise, and an awareness of associated risks and vulnerabilities.

Demand for Services

Global sea-level rise is being driven by ocean warming and expansion, and by melting of ice on land. Observed changes in local sea level result from complex interactions among changes in ocean circulation, wave action, storm surges, land movements, tectonic displacement, changes in groundwater, and runoff. Federal, state, tribal, and local decision makers are asking for guidance and information that will help them address sea-level rise and coastal inundation issues. Public awareness of and demand for information on the potential impacts of sea-level rise is at an all-time high. Additionally, demand is driven by NOAA mandates involving Coastal Zone Management, Living Marine Resources and associated habitats, Safe Marine Transportation, and Resilient Coastal Communities.

Improvements in the understanding of the processes that affect sea level and the ability to inform coastal planners and managers requires an understanding of physical and biological responses to rising sea level, vulnerability of coastal regions to inundation, and effective mitigation of impacts and adaptation to these changes.

What is the Climate Service role?

"Coastal communities contain over one half of the U.S. population, generate nearly 60 percent of U.S. economic output, and account for hundreds of millions of dollars in flood loss claims. Coastal decision makers need current science-based information, accurate tools and technology, and the skills to apply them to effectively reduce their communities' vulnerabilities."
– NOAA *Next Generation Strategic Plan*, 2010

Coastal communities need to enhance their resilience to successfully face increasing problems of coastal inundation. The Climate Service will provide easy-to-use information that addresses the combined effects of sea-level rise and changes in storminess including hurricanes and Nor'easters.

"Climate change poses a number of risks to coastal environments. Foremost among these is sea-level rise, which threatens people, ecosystems, and infrastructure directly and also magnifies the impacts of coastal storms."
– NRC 2010

NOAA has an established record of effective partnerships working with federal, state, and local agencies to address coastal issues.

Primary Sectors/Users Supported

Coastal communities; construction; emergency managers; finance industry (including insurance); international trade; maritime industry; marine resources; ports; transportation; utilities.

Capabilities

NOAA-supported activities in the National Ocean Service, Sea Grant, and other parts of the agency provide a wealth of data, capabilities, and expertise related to understanding physical science processes and potential impacts, and providing decision support related to sea-level rise for a range of sectors. In an integrating role, the Climate Service will bring these efforts together to inform local decision makers about the risk of coastal inundation from river flooding and storm surge. In addition to current core capabilities, the Climate Service will:

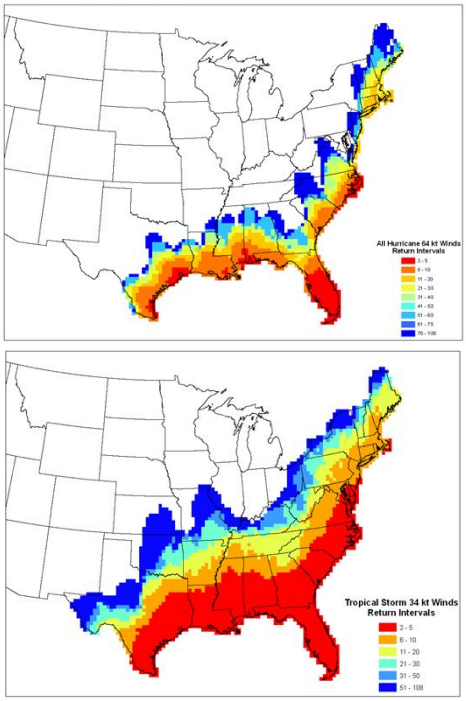
1. Provide information, analysis tools, and descriptions of case studies that support coastal climate adaptation to the public via the Climate Portal (www.climate.gov)
2. Model the potential for local coastal flooding, integrating scenarios of sea-level rise with regional inundation from high-intensity storms
3. Support efforts for global modeling of sea-level rise addressing the effects of temperature on ocean volume
4. Develop an operational seasonal sea-level prediction system for selected coastal regions (those both sensitive to sea-level rise and where there is evidence of skillful seasonal and longer outlooks)
5. Collaborate in efforts to assess the impacts of changes in climate on coastal resources and to produce science-grounded estimates of the associated socioeconomic costs of these impacts

Strategy

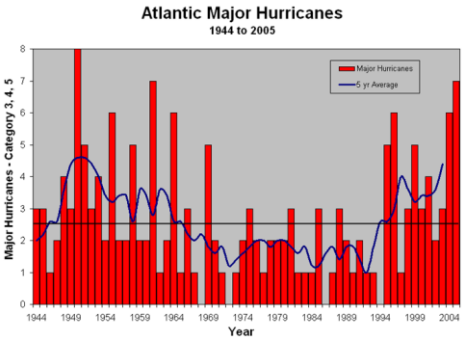
Various agencies currently use dozens of unique near-shore models of inundation and erosion to assess coastal communities' vulnerability. Researchers are making progress in using global-scale models of sea-level rise to produce downscaled output for regional projections. The Climate Service will facilitate integration of information from the full range of local to global climate models to improve predictions for global and regional sea-level

Example Activity: Hurricane Climatology and Decadal Prediction

NOAA maintains a climatology of the frequency of inland hurricanes and tropical storms that informs the coastal climate resilience efforts of state and local coastal and emergency managers.



If both seasonal to decadal hurricane track and frequency prediction capability is demonstrated for Atlantic hurricanes, this may help insurance companies and other hurricane-affected businesses to better assess their near-term (~1-5 yr) risk for hurricane-related damage, relative to long-term baseline risk levels.



rise. Each of the Climate Service core capabilities will be enhanced to address the Coasts and Climate Resilience societal challenge.

What the Climate Service Will Do

The Climate Service will leverage its improved understanding of physical processes with intra-agency and interagency capabilities and its engagement with the private sector to provide regional- and local-scale information and services on sea-level rise. The Climate Service will partner with social scientists in other federal departments, in other DOC agencies and bureaus, and in other NOAA Line Offices to characterize the impacts of changes in climate on coastal resources and to compile science-grounded estimates of the costs of climate impacts on water-related resources.

Table B.2 shows examples of new efforts and provides an outline of how core capabilities will be brought to bear on this societal challenge.

Table B.2. Examples of new Climate Service deliverables and user groups and how the core capabilities contribute.

Societal Challenge: Coasts and Climate Resilience Contributions from Core Capabilities	
Examples of New Efforts	• Prioritize stakeholder needs related to coastal inundation • Conduct stakeholder briefings and generate educational resources about uncertainty in future changes in coastal erosion and inundation • Routinely produce historical projections and predictions for time periods from seasons to decades • Integrate sea-level information into a system that provides improved access to and understanding of local sea-level rise, its relationship to inundation, and associated risks and vulnerabilities
Example User Groups	• State coastal and emergency managers • Federal groups including the National Ocean Service, Federal Emergency Management Agency, U.S. Army Corps of Engineers, U.S. Geological Survey, and Housing and Urban Development • Counties and communities • Academic institutions
Observing Systems, Data Stewardship, & Climate Monitoring	• Observations of trends in local and global sea level, wind intensity, high seas, heavy rains, and storm tracks • Operational analyses of sea surface altimetry • Define ocean temperature-related component of sea-level rise • Augment existing tide gauge network by connecting to state networks and increasing number of gauges
Understanding & Modeling	• Assess usefulness, and focus research, to improve the current generation of climate models to predict and project local and global sea level, including the effects of storm surge, wind intensity, and heavy rains • Develop techniques to run inundation models separately from and/or integrated with global climate projection models • Work with a distributed network of academic and private modelers to develop communities of practice for scaling up of local-scale models • Establish a common set of standards, practices, and operating approaches across all global and local sea-level rise and inundation modeling efforts in NOAA and federal agencies
Predictions and Projections	• Intraseasonal to interannual predictions of regional coastal inundation • Experimental decadal predictions of changes in local and global sea level, including changes in the probablity of storm surge, wind intensity, and heavy rains • Mid to late 21st century projections of changes in local and global sea level rise that include the effects of temperature on ocean volume
Integrated Service Development and Decision Support	• Develop and maintain an integrated sea-level information system, including products and decision-support tools that combine observed and projected changes in climate, local sea level, and global sea level with assessments of risk and socioeconomic vulnerability of coastal communities

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Why the Climate Service will be Successful

NOAA already has many of the assets and capabilities necessary to understand, monitor, model, project, and predict issues related to coastal inundation from all sources. Through direct program efforts at the global scale, and networks of partners among federal agencies, academic institutions, and private sector relationships at state and local levels, NOAA has mission responsibilities for monitoring and addressing water levels as well as inundation and other extreme events. NOAA's unique capabilities in this realm qualify it to establish and implement a national approach for advancing science issues and developing a comprehensive set of forecast, prediction, and decision-support tools for global to local scale inundation management.

Examples of engagement activities supporting the Coasts and Climate Resilience societal challenge include the partnerships established through:

- Interagency Working Group on Ocean and Coastal Mapping (IWGIOCM)
- Ocean Research and Resources Advisory Panel (ORRAP)
- Interagency Climate Change Adaptation Task Force Workgroup on Coasts and Oceans
- Regional Ocean Governance groups such as the West Coast Governors' Agreement on Ocean Health
- Coastal States Organization (CSO) Climate Change Work Group

NOAA also works closely on water resource issues with:

- Federal agencies including DOI, EPA, FEMA, HUD, and USACE
- Tribes, state, and local agencies
- Academic institutions
- Non-governmental organizations and other entities that have expertise, programs, or activities dealing with various aspects of sea-level rise

Two of these collaborations produced four demonstration-level decision-support tools focused on visualizing and mapping coastal impacts of inundation and sea-level rise, and provided support for the Coastal States Organization report on *The Role of Coastal Zone Management Programs in Adaptation to Climate Change*. In Fiscal Year 2010 alone, NOAA participated in multiple interagency workshops on modeling coastal inundation from all sources, climate adaptation, and community resilience from inundation-related hazards. The agency also contributed to efforts such as the *Proceedings from the Local Sea-Level Rise and Inundation Community Workshop*, and conducted public meetings in three regions regarding adaptation efforts and activities of the Council on Environmental Quality. NOAA is already providing experimental seasonal sea-level forecasts for the Hawaiian Island region.

Societal Challenge 3: Sustainability of Marine Ecosystems

Goal

The nation's fisheries resource managers and other decision makers have access to, and sufficient knowledge to apply, the best available information to manage large marine ecosystems in a changing climate.

Overall Outcome

Federal, tribal, state, and local fisheries resource managers prepare for, and respond to, the impacts of climate on large marine ecosystems through improved understanding of how changes in climate can alter ocean circulation and composition, and how such changes in ocean properties impact living marine resources.

Demand for Services

Climate change is clearly impacting ocean ecosystems but how these changes are impacting the ocean food chain is poorly understand. NOAA has statutory responsibility for:

- Conserving 519 fish stocks or stock complexes under the reauthorized Magnuson-Stevens Fishery Conservation and Management Act
- Managing species and populations identified as *threatened*, *endangered*, or *of concern* under the Endangered Species Act
- Protecting marine mammals identified under the Marine Mammal Protection Act
- Designating and managing national marine sanctuaries under the National Marine Sanctuaries Act
- Managing marine national monuments under the Antiquities Act
- Managing in partnership with states national estuarine research reserves and developing coastal management plans under the Coastal Zone Management Act
- Preserving coral reefs under the Coral Reef Conservation Act
- Coordinating research and monitoring of ocean acidification under the Federal Ocean Acidification Research and Monitoring Act

What is the Climate Service role?

In 2008, U.S. commercial seafood industry supported approximately 1.5 million full- and part-time jobs and generated $104 billion in sales impacts and $45 billion in income impacts. An upper bound estimate of the total economic activity of U.S. marine sectors associated with the Northeast Shelf Large Marine Ecosystems alone is $339 billion, including a "value-added" impact of $209 billion. Employment in this sector is estimated to be on the order of 3.6 million people.

NOAA has a stewardship responsibility to conserve and manage marine resources.

> *"The ocean, our coasts, and the Great Lakes provide jobs, food, energy resources, ecological services, recreation, and tourism opportunities, and play critical roles in our Nation's transportation, economy, and trade, as well as the global mobility of our Armed Forces and the maintenance of international peace and security"*
>
> – US President Barack Obama, Executive Order "Stewardship of the Ocean, Our Coasts, and the Great Lakes."

"Marine species were the first to be listed as threatened species due to physical stresses that are clearly related to variability and change in the climate system."
– Federal Register 2006

The Climate Service will provide the information needed to manage the Nation's resources regarding near- and long-term observed and projected changes in marine and freshwater associated with rising water temperatures, as well as related changes in ice cover, salinity, circulation, and other factors important to biological systems.

When making determinations related to the National Environmental Policy Act or the Endangered Species Act, court rulings have required natural resource management agencies to include climate information in their portfolios of "best available science." The Interim Report of the Interagency Ocean Policy Task Force identified "Resiliency and Adaptation to Climate Change and Ocean Acidification" as a priority area.

Primary Sectors/Users Supported

Coastal communities; health services (i.e., marine pharmaceutical industry); marine resources (fishing industry); international trade.

Capabilities

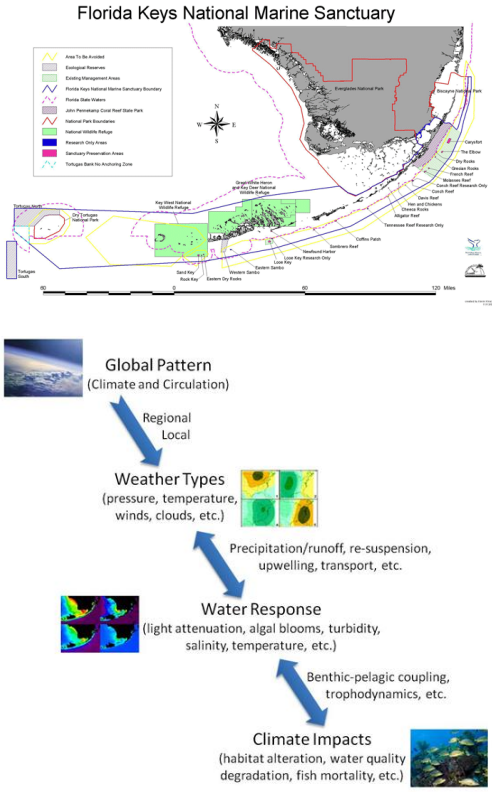
NOAA activities provide a wealth of capabilities, data, and expertise related to understanding climate and marine ecosystems; considerable efforts to advance this understanding are already underway across a range of programs and line offices. Relevant physical, chemical, and biological observation and monitoring capabilities are provided primarily by the National Marine Fisheries Service, National Ocean Service, the Climate Service, Office of Oceanic and Atmospheric Research, and National Weather Service. The Climate Service, Office of Oceanic and Atmospheric Research, and National Weather Service provide leadership in modeling, prediction, and projection of climate states to support climate-marine ecosystem studies. NOAA is involved in cooperative activities of numerous state and federal agencies, governance councils, and Integrated Ocean Observations System Regional Associations. NOAA also works with Sea Grant, Fishery Management Councils, NMFS Regional Offices, state resource agencies, and universities. Examples of climate and sustainability of marine ecosystems efforts already underway include:

- Use of opportunistic monitoring of conditions and outlooks for ocean circulation, nutrient fluxes, and freshwater flows to assess potential impacts on large marine ecosystems
- *Ad hoc* assessments of the role of climate in the collapse and closure of commercial marine fisheries.

Example Activity: Marine Protected Areas

NOAA is uniquely positioned to provide coastal communities and marine resources managers with tools to understand the impact of climate. The Climate Service will improve NOAA's ability to integrate observations of global climate data with its understanding of weather, climate, and ocean fundamentals to provide usable marine ecosystem information products.

An example is the Integrated Marine Protected Area Climate Tools project: a multiagency, multidisciplinary partnership group to compile, assess, and evaluate regional to local climate information, and to integrate this information with ongoing coastal ocean observing, monitoring, and data access networks in the Florida Keys.



Strategy

The *Sustainability of Marine Ecosystems* effort will build upon existing activities in observation, research, and modeling performed by NOAA and its partners to provide a critical capability within the Climate Service. The Climate Service will create a program of coordinated and sustained observing systems staged for individual large marine ecosystems and support development of integrated physical-biological models. Resulting products will inform and support an ecosystem approach to management and decision-making and serve as a critical input for integrated ecosystem assessments.

What the Climate Service Will Do

The Climate Service will focus on developing and prototyping forecasts and compiling assessments of living marine resources to identify climate impacts on large marine ecosystems in support of experimental ecosystem-based management. Specifically, the Climate Service will:

- Provide information for public, private, and government resource management agencies on the role of ocean circulation, nutrient fluxes, and freshwater runoff on large marine ecosystems to inform them of how changes in climate can impact ocean ecosystem food webs
- Collaborate with resource managers to produce and evaluate regional predictions and projections of changes in climate that impact physical and chemical properties of the ocean, including freshwater conditions that impact anadromous species (those that live in the ocean, but swim into fresh water for breeding) and coastal habitats linked to large marine ecosystems
- Provide regular and systematic explanations of climate-related ocean, coastal, and terrestrial impacts on large marine ecosystems and attribution in terms of long-term global human-induced change and natural variability
- Partner with social scientists in other federal departments, in other DOC agencies and bureaus, and in other NOAA Line Offices to characterize the impacts of changes in climate on marine ecosystems and to compile science-grounded estimates of the costs of these impacts.

Table B.3 shows examples of new efforts, identifies example user groups, and provides an outline of how the four core capabilities will be brought to bear on the Sustainability of Marine Ecosystems societal challenge.

Table B.3. Examples of new Climate Service deliverables and user groups and how the core capabilities contribute.

Societal Challenge: Sustainability of Marine Ecosystems Contributions from Core Capabilities	
Examples of New Efforts	• Skillful anomalous ocean circulation, nutrient fluxes, and freshwater flow outlooks based on an understanding of the environmental conditions impacting large marine ecosystems • Ongoing and continuous assessments of the impacts of a changing climate on large marine ecosystems to inform resource managers of the needs for short-term management versus long-term adaptation
Example User Groups	• National Marine Fisheries Service • Coastal states' agencies • National Ocean Service • Fish and Wildlife Service, U.S. Bureau of Reclamation • Fisheries management councils • State and local communities • Commercial and recreational fisheries industries
Observing Systems, Data Stewardship, & Climate Monitoring	• Observations of the atmosphere and of physical and biogeochemical parameters of the ocean on scale relevant to manage marine eccsystems • Maintenance of Climate Data Records • Water mass surveys, Argo floats, cruise Surveys • Coastal survey and open ocean acidification monitoring
Understanding & Modeling	• Develop an Earth system modeling and analysis capability to assess, predict and project physical (temperature, salinity, currents, eddies, fronts, stratification, upwelling) and chemical (carbon, partial pressure of carbon dioxide, pH, and nutrients) properties of the ocean at scales relevant for the management of large marine ecosystems
Predictions and Projections	• Intraseasonal to interannual outlooks of physical and biogeochemical properties of the ocean at relevant scales for managing marine ecosystems • Experimental decadal predictions of changes in physical and biogeochemical properties of the ocean at relevant scales for managing marine ecosystems • Mid to late 21st century regional projections of changes in the physical and biogeochemical properties of the ocean for managing marine ecosystems
Integrated Service Development and Decision Support	• Ongoing assessments of the roles of long-term global change and natural variability in ocean and coastal phenomena impacting large marine ecosystems

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Why the Climate Service will be Successful

NOAA has developed a detailed implementation plan for maintaining and evolving coordinated and sustained observing systems, integrated regional and global climate modeling, and coupled physical-biological ecosystem modeling. The program will use existing and new observation methods and technologies, including moored buoys, gliders, and acoustic ship surveys in coordination with other observing programs and initiatives, especially the West Coast regional ocean observing associations and advanced sampling technologies.

NOAA and its partners have developed methods to downscale global climate model predictions and projections to a scale that they can resolve ocean processes that impact large marine ecosystems and their populations, and to project the economic and societal impacts of such changes in such processes on coastal communities. The Climate Service will develop predictive ecosystem models that incorporate climate impacts to enable resource managers to maintain, conserve, and recover stocks and populations and their ecosystems in a changing climate. Collaborations facilitated by the Climate Service will result in availability of computational resources necessary to run super-ensemble climate model projections at the fine spatial and temporal resolutions needed to resolve changes in coastal and near-shore ocean conditions.

Engagement activities supporting sustainability of marine ecosystems include development of partnerships through active participation in the following groups:

- Interagency Working Group on Ocean and Coastal Mapping (IWGIOCM)
- Interagency Working Group on Ocean Acidification (IWG-OA)
- Ocean Research and Resources Advisory Panel (ORRAP)
- USCCSP Ecosystem Interagency Working Group
- West Coast Governors' Agreement on Ocean Health (and similar groups)
- Governors Mid-Atlantic Council on Oceans
- Coastal States Organization (CSO) Climate Change Work Group
- Non-governmental organizations such as National Fish and Wildlife Foundation
- National Coalition for Marine Conservation
- California Ocean Science Trust
- The Exploratorium

NOAA also supports sustainability of marine ecosystems through work with federal agencies including the Department of Interior, U.S. Army Corps of Engineers, and U.S. Forest Service on National Environmental Policy Act issues and Endangered Species Act determinations, as well as with tribal, state, and local resource management agencies, academic institutions, nongovernmental organizations, and other entities.

A signature example of NOAA's collaborative activities is their 60-year support of California Cooperative Oceanic Fisheries Investigations (CalCOFI) Hydrographic Data and Monitoring program, facilitated through participation in surveys, scientific research, and communication of results.

NOAA has organized and participated in multi-agency, interdisciplinary workshops addressing the impacts of climate on marine ecosystems and resource management. These include:

- Applying IPCC-class Models of Global Warming to Fisheries Prediction
- Biennial Ocean Climate Summit
- Climate Effects on California Current Ecosystems
- NOAA Climate and ESA workshop
- NOAA Workshop on Strengthening Capacity to Address the Impacts of Climate Change on Coastal Communities and Ecosystems
- Planning Coordinated Research on Ecosystems, Climate, and Policy in the Northeast

NOAA has also produced workshop reports such as *Incorporating Climate Change into NOAA's Stewardship Responsibilities for Living Marine Resources and Coastal Ecosystems: A Strategy for Progress*.

Societal Challenge 4: Changes in the Extremes of Weather and Climate

Goal

The public, decision makers, and policymakers apply the best information available to help them anticipate, prepare for, and adapt to ongoing changes in climate extremes and their regional impacts.

Overall Outcome

Society has ongoing access to easy-to-use information that helps them prepare for and adapt to climate extremes (including changes in frequency, intensity, seasonality, and geographical distribution of weather events).

Demand for Services

Climate and weather extremes such as heat and cold waves, heavy rain events, droughts, tornadoes, lightening, storm surge, snowfall, windstorms, hail, freezing rain, tropical and extratropical cyclones profoundly affect society and the environment, resulting in loss of life, property, and natural habitat. Planning for future infrastructure relies on reliable estimates of probabilities of climate extremes. Compelling scientific evidence shows that the nature of extreme events is altered by climate variations and change. Future changes in extremes will present society with some of its most serious challenges. Therefore, decision makers are demanding improved information on how changes in climate may influence future extremes, especially at the scales where preparedness and adaptation decisions will be made.

Primary Sectors/Users Supported

Emergency managers; planners; agriculture; construction; energy/utilities; financial services; health services; local, regional, state and federal government; manufacturing; natural resources and mining; transportation; local, state, regional and tribal economic development agencies; trade.

What is the Climate Service role?

The direct impact of extreme weather and climate events on the U.S. economy is substantial. The U.S. has sustained 96 weather-related disasters over the past 30 years in which overall damages/costs reached or exceeded $1 billion. The total normalized losses for the 96 events exceed $700 billion. (NOAA National Climatic Data Center)

NOAA has a mission responsibility to provide environmental information to protect life and property, and to better manage risks and opportunities associated with a variable and changing climate. Adaptation planning will depend on the service's ability to skillfully predict and project seasonal to multi-decadal regional weather and climate extremes.

A USGCRP summary of activities identified NOAA as the lead agency to address and advance the Nation's capabilities to observe, understand, model, predict, and communicate information on changes in weather and climate extremes.

Some extreme climate events will become more frequent, more widespread, and/or more intense during the 21st century and have the potential to cause large impacts. (IPCC 2007)

The CS will work to provide such information in a framework useful for adaptation decisions in the near- and long-term planning horizons.

The CCSP SAP 3.3 *Weather and Climate Extremes in a Changing Climate* and the forthcoming *IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX) concur that all sectors of the economy and the environment will be impacted and changes in climate will change the nature of extreme events.

Practices and decision rules for building bridges, implementing zoning rules, etc, assume a stationary climate with a similar patterns of variation and the same probabilities of extreme events. The assumption of stationarity is no longer valid. (NRC 2009)

Capabilities

NOAA and its partners' existing capabilities span the range of observing, monitoring, analysis, and modeling activities necessary to develop predictions of climate extremes on time scales from weeks to centuries. Relevant observation, monitoring, and process study capabilities are distributed primarily among the Climate Service, Office of Oceanic and Atmospheric Research, National Environmental Satellite, Data, and Information Service, and National Weather Service; while the Climate Service, Office of Oceanic and Atmospheric Research, and National Weather Service, provide leadership in the modeling, analysis, prediction and projection of climate extremes. Examples of current efforts to understand and predict climate extremes include:

- U.S. Hazards Assessment for temperature, precipitation, wind, soil, and wildfire based on 3–5 day to seasonal forecasts
- Hurricane seasonal outlooks and experimental projections of changes in tropical cyclone intensity and frequency
- The U.S. Climate Extremes Index (CEI), which quantifies observed changes and tendencies in climate extremes within the contiguous United States
- Probable maximum precipitation climatologies used for state and municipality water run-off design standards

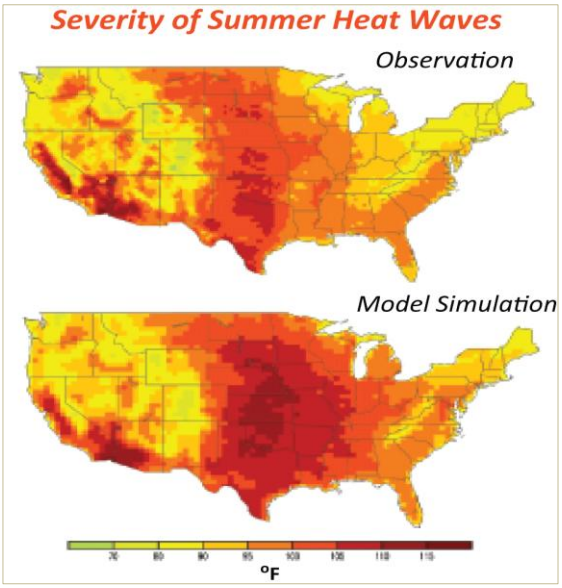
Example Activity: Heat Waves

Heat waves can be responsible for hundreds to thousands of deaths, and severe impacts to urban area peak power loads. Urban planners rely on NOAA's ability to monitor and anticipate heat waves. In particular, NOAA monitors maximum temperatures and their long-term changes, and runs model simulations to better understand and predict heat waves.

A new high-resolution global model (~50 km) developed by NOAA has produced promising results in simulating the severity and duration of summer heat waves.

This model was used to produce the bottom figure, from a 30-year simulation of present-day climate.

The top figure is based on observational data for a 24-year period.



Strategy

To improve the monitoring, modeling, and predicting of extremes in a changing climate, the Climate Service will focus effort on improved understanding and more realistic simulation and prediction of climate system processes that modulate extreme events on local, regional, and national scales. The Climate Service will use an iterative engagement process to optimize development and delivery of climate extremes information products and services. Rigorous documentation of the teleconnections between large-scale features of climate, such as common sea-surface temperature patterns or modes of atmospheric circulation, and the frequency or magnitude of regional to local climate extremes will be used to develop opportunities for early warning information systems through monitoring of observed conditions and development of predictive capabilities that can be incorporated in climate model predictions and projections. Attribution reports for extreme events that explain not

only what happened, but why, along with an estimation of the likelihood of future occurrence will be used to help decisions makers plan for the future.

What the Climate Service Will Do

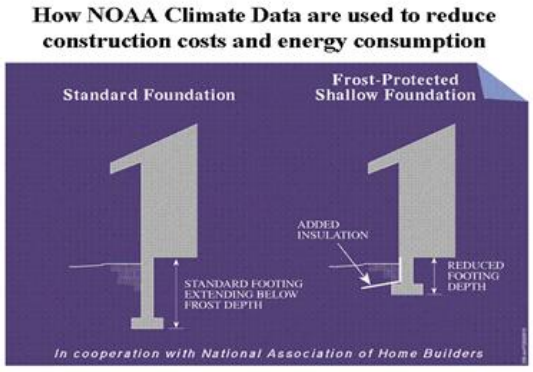
The effort will focus on filling gaps in current NOAA capabilities to observe, understand, model, predict, and communicate about extreme events in a changing climate system. This work will inform development of future early warning information systems that can enhance societal capabilities to prepare, plan, and invest wisely in modernizing infrastructure in risk-prone areas. The Climate Service will work with resource and emergency managers to understand their needs for information on climate extremes. NOAA and its partners will produce regional assessments of trends, provide expert judgments of future patterns, and perform attribution studies for high-profile extreme events, and develop and deliver hazards assessments for the U.S. that extend current two-week outlooks to monthly, seasonal, interannual and decadal timescales.

Table B.4 shows examples of new efforts, identifies example user groups, and provides an outline of how the four core capabilities will be brought to bear on the Changes in the Extremes of Weather and Climate societal challenge.

Example Activity: Construction and Climate

The construction industry needs information on climate variability and change in order to adequately design new construction projects.

An example of how NOAA has served the construction industry is by providing air-freezing index data, which in turn helps builders understand how much insulation is needed to protect a building foundation from frost. In the past, standard foundation depths were several feet, but using NOAA's data, builders used increased insulation to require only 16 inches of foundation. This allowed greener building, less site disturbance, annual building cost savings of $330 million, and energy cost savings of 586,000 megawatt-hours.



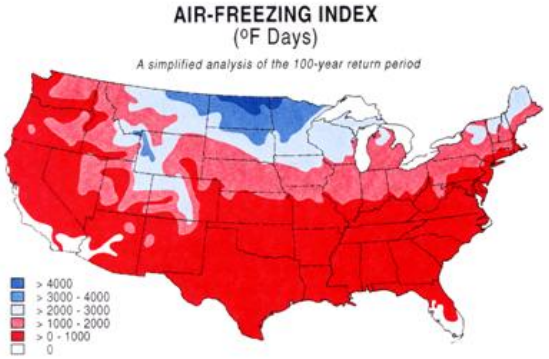


Table B.4. Examples of new Climate Service deliverables and user groups and how the core capabilities contribute.

Societal Challenge: Changes in the Extremes of Weather and Climate Contributions from Core Capabilities	
Examples of New Efforts	• An early warning system for heat events featuring local information on the risk of heat waves from a season to multiple decades for planning and adapting to changes in the frequency and intensity of these events • Probabilistic seasonal to multiyear hurricane outlooks and multi-decadal projections of tropical cyclone intensity and frequency • Probabilistic outlooks of climate extremes on a range of timescales at regional to national scales • Updated suite of extreme event monitoring products (heavy rainfall frequency, air freeze, and other extreme indices) • Predictions of surface ozone levels and particulate matter responsible for air quality in a changed climate and ability to predict the possible influences of additional stressors, such as forest fire, on air quality in the future
Example User Groups	• Public and private sector emergency managers • State and local officials • Energy industry • Built and natural resource managers • City planners • Insurance industry
Observing Systems, Data Stewardship, & Climate Monitoring	• Augment extreme event monitoring products to ensure a climate quality record and that the observations support development of a process understanding and assess predictability
Understanding & Modeling	• Conduct research to understand key physical processes that modulate extreme events on regional and national scales • Assess the current generation of climate models to predict and project regional climate extremes • Develop techniques to transform model predictions of large-scale features of climate such as sea-surface temperature patterns or modes of atmospheric circulation into estimates of changes in the frequency or magnitude of regional to local climate extremes
Predictions and Projections	• Intraseasonal to interannual outlooks of climate extreme • Experimental decadal predictions of changes in the probability of regional climate extremes • Mid to late 21st century regional climate projections of changes in the probability of regional climate extremes
Integrated Service Development and Decision Support	• Develop tools and processes to effectively communicate climate extremes information such as operational extreme event monitoring, prediction, projection, and assessment products to data and services and climate dashboard components

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Why the Climate Service will be Successful

Improved predictions of tropical sea-surface temperatures from coupled ocean-atmosphere models will enable more accurate forecasts of the frequency and intensity of tropical cyclones on seasonal-to-decadal timescales. Improvements in the ability of coupled climate models to simulate and predict intra-seasonal climate phenomena, such as the Madden-Julian Oscillation or Arctic Oscillation and their impacts, will enable new types of probabilistic extreme event outlooks. Current experimental efforts using coupled climate models to provide seasonal outlooks of temperature and precipitation extremes show promise and indicate the potential for improved forecast skill when extending these efforts to longer timescales and to an expanded suite of climate extremes. The Climate Service will have the computational resources to run super-ensemble climate model projections at the fine spatial resolutions needed to resolve changes in the frequency and intensity of climate extreme events.

Examples of engagement activities supporting the development of efforts to address the Changes in the Extremes of Weather and Climate societal challenge build on results from workshops such as the Weather and Climate Extremes in a Changing Climate WCRP-UNESCO Workshop on metrics and methodologies of estimation of extreme climate events as well as practical engagement with other federal agencies and state and local governments. For example, the NOAA-USGS Debris-Flow Warning System—Final Report (Circular 1283) was a joint implementation plan developed by NOAA's Oceanic and Atmospheric Research and the National Weather Service to support the U.S. Geological Survey (USGS) in the advancement of the science of extreme precipitation events, including implementing improved operational weather forecasts and providing better models of the debris flow events. Similarly, NOAA is cooperating in the USGS' Multi Hazards Demonstration Project (MHDP) in preparing a new emergency-preparedness scenario, called ARkStorm, to address massive U.S. West Coast storms analogous to those that devastated California in 1861–62. NOAA has organized and participated in multi-agency, national and international interdisciplinary workshops as part of the WMO Global Climate Observing Systems, the Aspen Global Change Institute workshop on Weather and Climate Extremes in a Changing Climate, and the World Climate Research Programme/United Nations Educational, Scientific and Cultural Organization Workshop on metrics and methodologies of estimation of extreme climate events.

Appendix C: Alignment with National Academy Recommendations

Implementation of the Climate Service will directly address many recommendations presented in four recent U.S. National Academy of Sciences (NAS) reports focused on the role of the federal science and services in informing decisions as climate changes, and will address recommendations from the *America's Climate Choices* reports.

1. NRC. 2009. Restructuring Federal Climate Research to Meet the Challenges of Climate Change. Washington, D.C.: The National Academies Press. (V. Ramanathan, Chair)
2. NRC. 2009. Informing Decisions in a Changing Climate. Washington, D.C.: The National Academies Press. (R. Correll, Chair)
3. NRC. 2010. ACC: Informing an Effective Response to Climate Change. Washington, DC. National Academies Press. (D. Liverman and P. Raven, Co-Chairs)
4. NRC. 2010. ACC: Advancing the Science of Climate Change. Washington, DC. National Academies Press. (P. Matson, Chair)
5. NRC. 2010. ACC: Adapting to the Impacts of Climate Change. Washington, DC. National Academies Press. (K. Jacobs and T. Wilbanks, Chairs)

Examples of how the Climate Service will address some of the recommendations in the NAS reports include:

- The Climate Service Vision and Strategic Framework recognizes the central role of user needs and importance of shared learning in the co-production of knowledge (per recommendations in NRC reports 1, 2, and 3).
- The Climate Service framework is designed to build connections and collaborations across disciplines and organizations (per recommendations in NRC report 2).
- Establishment of the Climate Service, combined with the development and strengthening of critical partnerships with federal, state, tribal, local, and other entities, will be an important first step in coordinating efforts to provide climate services routinely to decision makers (per recommendations in NRC reports 1 and 3).
- The Climate Service strategy recognizes the need to expand and maintain a climate observing and monitoring system that spans the physical, biological, and social systems and to support the interdisciplinary research on adaptation, mitigation and vulnerability required to develop decision-support resources (per recommendations in NRC reports 1, 2, and 4).
- The Climate Service will enhance ongoing international efforts to collect, share and analyze climate observations, model predictions and projections, biophysical and socioeconomic states and trends, international policies, response options, and climate impacts (per recommendations in NRC reports 1, 3, 4, and 5).
- The Climate Service focus on the four Societal Challenges directly address suggestions to focus on integrated scientific-societal issues to facilitate integration and to pursue cross-cutting climate science to inform societal responses to changes in climate (per recommendations in NRC reports 1 and 3).
- The Climate Service efforts to link science to decision making will depend on application research, prototyping and diffusion of decision-support resources accompanied by clear guidance on strengths and limitations (per recommendations in NRC report 4).

- The Climate Service will strengthen the understanding and modeling core capability to support development of next-generation Earth system models and the application of these models to improve climate attribution and the prediction of high-impact regional climate events (per recommendations in NRC reports 1 and 4).
- The Climate Service will expand the role of boundary organizations and adaptation research as part of an overall effort to develop regional decision-support services to inform adaptation and mitigation options (per recommendations in NRC reports 1, 2, 4, and 5).
- The Climate Service will use Climate Science Assessments and Needs Assessments within a larger international and national assessment context as primary mechanisms to help clarify the nature, causes, risks, and costs of current and expected climate impacts (per recommendations in NRC reports 1 and 5).
- The Climate Service will coordinate with its federal partners to provide policy makers with regular communications of new scientific insights assessing the state of, and expected changes in, the climate system, and addressing relevant response options (per recommendations in NRC report 1).
- The Climate Service will use a decision-making framework for prioritizing the portfolio of activities that balances feasibility and fit of activities relative to the Climate Service mission with the potential level of impact (per recommendations in NRC report 4).
- The Climate Service will participate in the development of a national task force to develop a coordinated strategy to improve climate change education and communication (per recommendations in NRC report 4).

Appendix D: Alignment with NOAA Next Generation Strategic Plan

Delivering services to support the four societal challenges will also support NOAA's *Next Generation Strategic Plan* (NGSP). The following tables provide examples of how the core capabilities (represented as icons) and the societal challenges each support the NGSP.

Icon	Core Capability represented
	Understanding and Modeling
	Observing Systems, Data Stewardship, and Monitoring
	Predictions and Projections
	Integrated Service Development and Decision Support

Figure D.1. How the Climate Service will contribute to NGSP Objective 1: Improved scientific understanding of the changing climate system and its impacts

Climate Impacts on Water Resources		Skillful drought and flood sub-seasonal to multi-decadal outlooks based on a process understanding of watershed scale hydrologic budgets
Coasts and Climate Resilience		Characterize the physical processes driving local sea-level rise and inundation of coastal regions and communities
Sustainability of Marine Ecosystem		Skillful anomalous ocean circulation, nutrient fluxes, and freshwater flow outlooks based on an understanding of the environmental conditions impacting large marine ecosystems
Changes in the Extremes of Weather and Climate		Seasonal to multiyear hurricane outlooks, multi-decadal projections of tropical cyclone intensity and frequency, outlooks for climate extremes on a range of time and spatial scales, surface ozone levels and particulate matter predictions

3011 **Figure D.2. How the Climate Service will contribute to NGSP Objective 2:** Integrated
3012 assessments of current and future states of the climate system that identify potential impacts
3013 and inform science, services, and decisions

Climate Impacts on Water Resources		Regional drought monitoring tools and impact assessments
Coasts and Climate Resilience		Assessment and prioritization of stakeholder needs related to coastal inundation
Sustainability of Marine Ecosystem		Assessments of the impacts of a changing climate on large marine ecosystems to inform resource managers of the needs for short-term management versus long-term adaptation
Changes in the Extremes of Weather and Climate		Assess the current state of climate models to predict and project regional climate extremes

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3015 **Figure D.3. How the Climate Service will contribute to NGSP Objective 3:** Mitigation and
3016 adaptation efforts supported by sustained, reliable, and timely climate services

Climate Impacts on Water Resources		Hydroclimate information system enhancements such as inputs into drought plans and operations
Coasts and Climate Resilience		Routine production of historical projections and predictions for time periods from years to decades; an integrated sea level information system providing improved access to and understanding of local sea level rise, its relationship to inundation, and associated risks and vulnerabilities.
Sustainability of Marine Ecosystem		An Earth system modeling capability to predict and project physical (temperature, salinity, currents, eddies, fronts, stratification, upwelling) and chemical (carbon, partial pressure of carbon dioxide, pH, and nutrients) properties of the ocean at scales relevant to large marine ecosystems.
Changes in the Extremes of Weather and Climate		An early warning system for heat events featuring local information on the risk of heat waves from one season to multiple decades for planning and adapting to changes in the frequency and intensity of these events; an updated suite of extreme event monitoring products (heavy rainfall frequency, air freeze, and other extreme indices); forward-looking probable maximum precipitation risks.

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3018 **Figure D.4. How the Climate Service will contribute to NGSP Objective 4:** A climate-literate
3019 public that understands its vulnerabilities to a changing climate and makes informed decisions

Climate Impacts on Water Resources		Develop tools and processes to effectively communicate uncertainty regarding regional climate predictions for precipitation, snowpack, runoff, and temperature
Coasts and Climate Resilience		Develop and promote understanding of potential impacts to communities and ecosystems from sea-level rise; conduct stakeholder briefings and educational resources about uncertainty in future changes in coastal erosion and inundation
Sustainability of Marine Ecosystem		Communication of assessments to the general public and stakeholder community
Changes in the Extremes of Weather and Climate		Develop tools and processes to effectively communicate climate extremes information

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