Weather, Water, and Climate Strategy

FY 2022-2026

SIGNATURE PAGE

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NOAA ADMINISTRATOR'S MESSAGE

In the United States (U.S.) and around the world, risks to life, property, economies, and ecosystems are increasing at an alarming rate, due to extreme weather- and water-related impacts of a changing and warming climate. The August 2021 Intergovernmental Panel on Climate Change (IPCC) Report confirms that human influence is unequivocally causing climate change, and the impacts are widespread and rapidly intensifying.[1] U.S. citizens are in harm's way, infrastructure is increasingly outdated and at risk, and in many places not designed for the new environmental realities and extreme weather events we are experiencing. Addressing the climate crisis is a top priority for the Biden-Harris Administration, and the Department of Commerce's (DOC) National Oceanic and Atmospheric Administration (NOAA). In the context of the climate crisis, the agency, working closely with its partners, is positioned to be the authoritative federal source for climate products and services, leveraging a whole-of-government approach. In doing so, the agency supports lives, livelihoods, and the nation's way of life, as NOAA's products and services continue to stimulate economic growth and new markets.

NOAA's mission, to understand, predict changes, and provide services related to climate, weather, the global ocean, and coasts, is becoming more critical, to inform everyday decisions Americans make. NOAA assists communities in the context of a changing climate, for example, by collaborating with coastal communities to adapt to sea level rise; providing critical early warnings about drought to farmers, rural residents and tribal and indigenous communities; partnering with emergency managers before, during, and after increasingly extreme weather and water events, including hurricanes, tornadoes, floods, and forest fires; working with communities to map heat inequities in urban areas; and collecting and maintaining the authoritative record of greenhouse gas measurements and historical weather, ocean, and climate data. In carrying out this work, the agency is embarking on a comprehensive Weather, Water, and Climate Strategy (Strategy). This Strategy leverages the best-in-class Earth system intelligence and social science to provide products and services in an effective, equitable, and just manner. Through technological innovation and enterprise wide collaboration across the public, private, and academic sectors, we will create a climate-ready nation and a climate-resilient economy that fosters development in areas such as climate products and services, the new blue economy, and sustainable fisheries. The

1 IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

execution of this Strategy will strengthen and galvanize the relationship of NOAA with the private sector, academia, other federal, state, and local agencies helping to ensure the collaboration needed to address the impacts of climate change. Together we will build a climate-ready nation and a climate-resilient economy.

Richard W. Spinrad, Ph.D.
Under Secretary of Commerce for Oceans and Atmosphere & NOAA Administrator

SECTION 1
INTRODUCTION

A changing and warming climate is increasing risks to life, property, economies, and ecosystems in the United States and around the world. Climate change is altering weather patterns and ocean conditions, melting glaciers and sea ice, changing the quantity, quality, and availability of water resources, affecting the range and migration patterns of natural ecosystems, and increasing the frequency and severity of extreme weather, water, and climate events. The impact of these changes vary regionally and include changing sea levels, lake levels, increased frequency of heavy downpours and flooding, longer, more intense periods of drought, modified growing seasons, increased risk of forest fires, amplified coastal hazards, and increased pressure on biodiversity and living marine resources. In addition, the effects of space weather, variations in the space environment between the sun and Earth, pose significant and increasing societal, economic, national security, and health risks. These risks are compounded by related challenges such as population growth, economic development and land use change, deteriorating infrastructure, and changing river and coastal geography.

Actionable Earth system intelligence and decision support are needed across a range of stakeholder audiences and timescales to help society mitigate and adapt to these compounding societal challenges. NOAA has embarked on a comprehensive Weather, Water, and Climate Strategy (Strategy), designed to deliver enhanced and equitable access to the services and information stakeholders need for their unique circumstances. This Strategy includes outcomes and outputs associated with the following six critical challenges that NOAA and its partners are well-positioned to address:

- **Extreme Events and Cascading Hazards;**
- **Coastal Resilience;**
- **The Changing Ocean;**
- **Water Availability, Quality, and Risk;**
- **Effects of Space Weather; and**
- **Monitoring and Modeling for Climate Change Mitigation.**

Outcomes are science and service innovations the agency plans to achieve, in collaboration with its partners, in the next five years to address each societal challenge. The outputs are specific, necessary, and supporting actions NOAA will take to achieve the outcomes. NOAA leadership will work within the agency drawing on the expertise of Line Offices, Staff Offices, and Corporate Service Offices, as well as with its external partners to address these challenges and implement these outcomes and supporting outputs.

This Strategy serves as a foundation for the development of NOAA's outyear investments and future budget requests, building on the significant new investments through the Infrastructure Investment and Jobs Act of 2021 (P.L. 117-58). As such, the agency considers these outcomes and outputs to be achievable within the next five years, with support from the Administration and Congress. The NOAA Climate Council, through the Weather Water Climate Board, will provide oversight to ensure the delivery of associated outcomes and outputs.

NOAA recognizes that the impacts of these societal challenges fall disproportionately on underserved communities[2], which requires a renewed commitment to equity and environmental justice. The agency is committed to delivering services and products in a way that is effective, equitable, and advances environmental justice, supportive of Executive Order 14058: Transforming Federal Customer Experience and Service Delivery to Rebuild Trust in Government. Note that each Societal Challenge section contains associated equity outcomes, which are also summarized in the equitable stakeholder engagement and service delivery section. Additionally, to ensure services are delivered equitably, an enhanced model for more effective, comprehensive, consistent, and continuous stakeholder outreach is being implemented. This service delivery strategy and model promotes service equity and addresses the needs of historically underserved communities across the Nation.

This Strategy is designed to ensure the agency pursues an integrated approach to Earth system science, service, and stewardship. Historically, the scientific communities studying and predicting the atmosphere, ocean, and hydrology have been organized around their disciplines, sometimes resulting in separation from one another, and from the social science necessary to fully address stakeholder requirements. Moving forward, NOAA is strengthening its emphasis on an integrated Earth system science, recognizing the intrinsic connection between weather, water, and climate systems, linked through the hydrologic cycle, driven by ocean, land, and atmospheric processes. This requires a multidisciplinary approach, rooted in open science and open source methods, that integrates atmosphere, cryosphere, biosphere, terrestrial hydrosphere, and ocean science, observations and modeling, and the social sciences, all linked to and driven by stakeholder needs. This linkage between physical and social sciences is critical to closing information and service gaps articulated by diverse stakeholders. NOAA will implement evolved business processes that fully integrate its weather, water, and climate programs providing society with state-of-the-science actionable data, information, and services.

Taking an integrated approach across NOAA's line offices and mission areas, the Strategy leverages the full breadth of capabilities and services across the agency's value chain which include: 1) comprehensive service delivery through continuous engagement, particularly with underserved communities; 2) world-class decision support tools, including forecasts, assessments, and analyses; 3) state-of-the-science

2 The term "underserved communities" refers to populations sharing a particular characteristic, as well as geographic communities, that have been systematically denied a full opportunity to participate in aspects of economic, social, and civic life, as exemplified by the list in the preceding definition of equity.

data assimilation, modeling and prediction capabilities, leveraging high-performance computing and the use of artificial intelligence and machine-learning; 4) cutting-edge applied research and development on pressing science and technology questions; and 5) next-generation systems for observation, data management, data integration, and data dissemination. This value chain is supported by essential enabling capabilities, including a world class workforce, high-performance computing, cloud computing, big-data, and safe and sustainable facilities.

The Strategy supports the DOC and NOAA Strategic Plans, and complements and augments the agency's efforts under Section 211 (d) of the January 27, 2021, Executive Order 14008, Tackling the Climate Crisis At Home and Abroad. This Strategy, while not meant to be a comprehensive statement of NOAA's work in weather, water and climate, is an overarching framework that draws from and links to many existing strategies and mandates (see Appendix A). It also takes account of the recommendations provided by the NOAA Science Advisory Board in the December 2021 Report on Priorities for Weather Research. In addition, this Strategy is designed to promote a continuing culture of scientific excellence and integrity, and strengthen universal confidence - from scientists to decision-makers to the general public - in the quality, validity, and reliability of NOAA science, as required by NOAA Administrative Order NAO 202-735D-2: Scientific Integrity. Moreover, the ideas, concepts, and outcomes in this Strategy represent the culmination of extensive internal collaboration as well as extensive consultation with partners and stakeholders. It also accounts for NOAA's recent listening sessions with businesses across various industries, and Climate and Equity Roundtables which were held to generate ideas, take a fresh approach to the challenges, and identify effective solutions to their information and service gaps. The agency is committed to a whole-of-government approach and continuous interaction with partners and stakeholders.

SECTION 2

VISION, GOAL, AND INTEGRATION APPROACH

NOAA is committed to supporting the people, economy and environment of our nation with equitable and continuously evolving science, service and stewardship. Table 1 provides the Strategy vision, common goal, and impact statement that drive the associated outcomes and outputs achieved in the coming years. The Strategy directly supports NOAA's mission to protect life and property from extreme events, to create and strengthen resilience in ecosystems, communities, and economies, and provide critical support for national climate adaptation, mitigation, equity, and resilience. NOAA, in coordination with its partners, will build on and leverage existing successful programs to foster and employ an integrated approach to weather, water, and climate information systems and services.

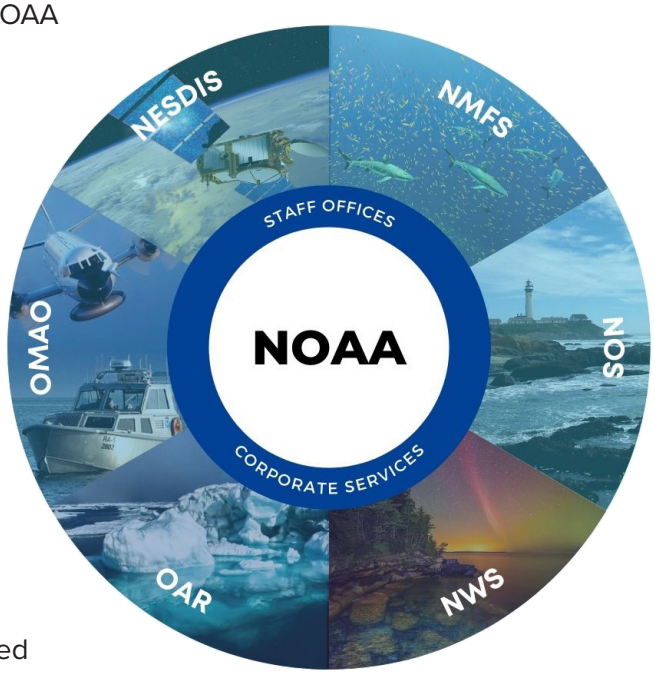
VISION	People, the economy, and ecosystems are thriving, supported by NOAA's equitable and actionable weather, water, and climate services.
COMMON GOAL	To continuously transform weather, water, and climate information service delivery to better meet and support evolving societal needs.
IMPACT	The nation's security, prosperity, environmental sustainability, and well-being will be improved through the provision of science-based, actionable information and services, which address weather, water, and climate vulnerabilities, save lives, protect property, safeguard natural resources, and foster commerce.

Integration Approach and Governance

Weather, water, and climate are common threads that run through NOAA's mission areas and Line Offices, each of which serve stakeholders through a variety of field offices, laboratories and national service outlets. The agency's approach to this Strategy is anchored in its six Line Offices and supported by the critical contributions and inputs of NOAA staff offices and corporate services.[3] In addition, NOAA's regional collaboration teams will be an important source of knowledge and a vehicle for stakeholder engagement in the implementation of this Strategy.

3 See Appendix A for a complete list of NOAA Line Office mission statements and a listing of NOAA staff offices and corporate services.

Enhanced integration across mission areas requires NOAA to embrace agile, transparent, and consistent cross-agency governance by effectively leveraging NOAA's councils, boards, and teams. In July 2021, the agency established the NOAA Climate Council which is composed of senior leaders at the highest levels from across the agency, and provides recommendations to the NOAA Administrator on the agency's climate-related mission, resource, and policy priorities. The Council is strengthening NOAA's climate services and bolstering existing coordination activities. The Weather, Water, and Climate Board, supported by a set of cross-NOAA working teams, plays the critical function of ensuring implementation of this Strategy and associated Council decisions, including coordination with the other NOAA Councils. This cross-Line Office governance structure facilitates increased collaboration and planning across programs and Line Offices through coordinated spend-plans and associated Annual Operating Plans. It also supports NOAA's world-class technical enterprise in integrated decision tools, delivery methods, predictions, observations, and networks of experts and practitioners working collaboratively to contextualize services and products for addressing near and long-term weather, water, and climate challenges.



This Strategy is designed for both internal and external audiences. Internally, it will serve as a foundation for the development of NOAA's outyear investments in weather, water, and climate programs and activities through future budget requests and annual operating plans (AOPs) within Line Office and at the NOAA level. Through the NOAA AOP process, each Line Office will develop actions and activities (milestones) to drive progress toward the outcomes and outputs in this Strategy, and progress against these outcomes and outputs will be reviewed through regular WWC Board meetings and an annual cross-Line Office meeting.

Guiding Principles

This Strategy and its outcomes advance weather, water, and climate services guided by the principles below, which ensure that these services are:

- Equitable and accountable to the public, including underserved communities.
- Driven by user-defined questions and needs, through robust, transparent engagement with stakeholders and partners, including routine feedback to respond to changing priorities.
- Characterized by effective risk communication, including clear communication of uncertainties, both in base knowledge and projected outcomes.

- Relevant to decision making delivered across time and spatial scales, including simulations and scenario planning relevant to a variety of scales.
- Accompanied by education, outreach, training, and capacity building to enable effective use by decision makers.
- Informed by cutting edge science, innovative and proven technology, and excellence in engineering, including social and behavioral considerations and methodologies to enhance understanding and utility.
- Integrated into community decision-making.
- Supportive of a whole of government approach, ensuring NOAA services are complementary to existing Federal agency missions and operations.
- Providing a foundation and reference point for many non-governmental and private sector enterprise activities.

Essential Partners

NOAA cannot accomplish the work of this Strategy alone. In the coming years, the agency will strengthen and expand NOAA partnerships with Federal, State, regional, local, and tribal governments and agencies. In addition, the agency's success will depend on partners in academic, non-governmental, private sector organizations, and international partners. Collaboration with the academic community is strengthened through Cooperative Institutes which serve to advance a broad spectrum of science, technology, and service related activities important to the agency's mission. NOAA engages in international weather-water-climate activities through bilateral and multilateral arrangements, participation in specialized agencies of the United Nations, and various international organization forums.

This Strategy will be executed within NOAA's mission and legislative authorities, in a manner that is complementary to the missions and activities of related Federal agencies and interagency collaborations. At the Federal level, NOAA will continue to partner closely with other agencies in the development and delivery of new information services. Key partner agencies include (in alphabetical order) the Centers for Disease Control and Prevention (CDC), the Environmental Protection Agency (EPA), the Federal Emergency Management Agency (FEMA), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the U.S. Army Corps of Engineers (USACE), the U.S. Bureau of Reclamation (BOR), the U.S. Coast Guard, Engineers, the U.S. Department of Agriculture (USDA), the U.S. Department of Energy (DOE), and the U.S. Department of Transportation (DOT), the U.S. Fish and Wildlife Service, and the U.S. Geological Survey (USGS) among others. This Strategy supports, and is supported by, the work of numerous Federal interagency processes.[4]

4 Key interagency processes include, among others: the U.S. Global Change Research Program (USGCRP), the Interagency Council for Advancing Meteorological Services (ICAMS), the Interagency Water Subcabinet, the National Drought Resilience Partnership (NDRP), the Integrated Water Resources Science and Services (IWRSS) consortium, the Science for Disaster Reduction (SDR) Federal Interagency Coordination Group, and other National Science and Technology Council (NSTC) activities.

Equitable Stakeholder Engagement and Service Delivery

At the heart of NOAA's mission delivery is being responsive and delivering services and information that meet the needs of every American. NOAA's products and services save lives and support economic vitality, affecting more than one-third of America's gross domestic product. The agency's services are delivered through an expansive infrastructure that enables NOAA to deliver integrated services in all communities, informing stakeholder decisions–from national, to regional to neighborhood scales–for emergency management, transportation, power generation, agriculture, coastal planning, natural resource management, and recreation.

To better address these stakeholder needs, NOAA is committed to move towards a common, agency-wide and stakeholder-centric service delivery model. Over the last five years, NOAA has developed and initiated implementation of a Service Delivery Framework which includes best practices for successful service delivery and continuous user engagement strategies to co-develop user-inspired products and services. The framework enables the agency to quickly respond to and align with changing mission needs, innovations, and technological advancements. This responsiveness is even more important in a COVID-impacted world, as more stakeholders rely on gaining remote access to services in new easy to use formats.

Suite of Equity Outcomes

Equity outcomes were identified for each societal challenge area and presented in this summary table and also included below in each societal challenge area section.

Challenge Area	Outcome Number	Description
Extreme Events & Cascading Hazards	1	Underserved communities will have more equitable access to information on the consequences of extreme events. Additionally, these communities will receive more regular and routine information and planning tools regarding the unintended consequences of potential decisions–designed to mitigate the impact of extreme events–that may adversely affect them.
Extreme Events & Cascading Hazards	2	Decision makers will have access to forecast and other services translated into multiple languages and delivered in formats that communicate risk in context-specific ways, emphasizing new media as appropriate.
Coastal Resilience	14	Decision makers in remote areas, including highly vulnerable communities in Alaska and in underserved rural coastal counties, will have access to new coastal resilience services.

Challenge Area	Outcome Number	Description
The Changing Ocean	21	Marine-dependent communities, including underserved communities in the Arctic, islands and other areas, have new tools, information, and training to help them develop and implement adaptation plans to manage risk from the changing ocean and other stressors.
Water Availability, Quality, and Risk	29	Disadvantaged and underserved communities, including urban and rural areas, will have more equitable access to information, delivered in traditional and non-traditional ways, to improve their resilience to water supply and flood risks.
Space Weather	35	NOAA-provided space weather products and services will safeguard communication systems that provide increased government and industry broadband services to underserved communities worldwide.
Space Weather	36	Developing countries will better understand the threat and mitigation of space weather through education provided by the U.S., through NOAA, the world-leading provider of continuous, real-time space-weather information.
Monitoring and Modeling for Climate Change Mitigation	39	Decision makers, including underserved communities, will have climate information and services to better understand the benefits and risks of different climate mitigation choices.

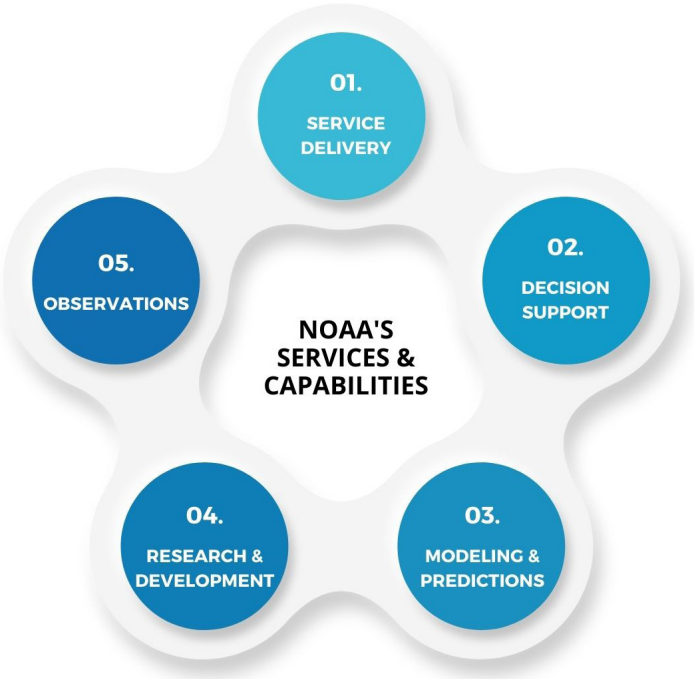
As NOAA addresses growing, increasingly complex, multi-disciplinary societal challenges, and implements the outcomes outlined in this document, it will remain focused on ensuring optimal stakeholder engagement and customer experience focusing on delivering services and products that meet their needs.

Strengthening the NOAA Value Chain

To achieve the Societal Challenge outcomes and outputs detailed in section 3.0, ensure integration, and promote efficiency across NOAA's Line Offices, the agency supports five interdependent areas of work which represent the full breadth of NOAA's services and capabilities value chain. This NOAA value chain includes the following:

- Comprehensive **service delivery** through continuous engagement, particularly with underserved communities;
- World-class **decision support tools**, including forecasts, assessments, and analyses;

- State-of-the-science data assimilation, **modeling and prediction** capabilities, leveraging high-performance computing and the use of artificial intelligence and machine-learning;
- Cutting-edge applied **research, development and engineering** on pressing process science questions; and
- **Next-generation** systems for **observation, data** management, data integration, and data dissemination.



To achieve the outcomes outlined in this WWC Strategy, NOAA will make new and continued investments in each element of its value chain. In addition, the agency will invest in essential enabling capabilities, including workforce, high-performance computing, cloud computing, big-data, and facilities. Note that the elements of the value chain and essential enabling capabilities are outlined in Appendix B.

SECTION 3
CRITICAL SOCIETAL CHALLENGES

This section is organized by the six societal challenges that are connected closely to NOAA's mission, authorities, and legislative mandates. Each section provides an overview of the challenge and the associated benefits that NOAA provides. For each challenge area, outcomes have been identified outlining science and service innovations the agency will achieve to address each societal challenge. Many of the outcomes refer to "decision makers." For the purposes of this document, decision makers include federal, state, local, and Tribal leaders; academia, nonprofit, and private industry leaders; and others who have the capacity to use NOAA data to make informed decisions impacting their constituents, customers, and families. Additionally, associated outputs have been listed in Appendix C, which provide the specific and necessary actions the agency will take to achieve the 5-year outcomes. Importantly, there is no simple one-to-one relationship between each output and outcome, rather they represent a body of work that needs to be completed to achieve the outcomes identified in this Strategy.

EXTREME EVENTS & CASCADING HAZARDS

CHALLENGE AREA 1

SOCIETAL CHALLENGE

Communities across the U.S., particularly underserved communities, face enduring, compounding risks from extreme, high-impact weather, water, and climate events, which have become more severe and more frequent in recent decades.

SOCIETAL BENEFIT

NOAA addresses this challenge by leading whole-of-government approaches, in partnership with private enterprise, academia, and non-governmental organizations, to prepare communities to mitigate and adapt to extreme events such as drought, extreme heat and cold, fire weather, flooding, atmospheric rivers, tornadoes, marine heat waves, and tropical cyclones.

OVERVIEW

Extreme Events

In the context of a warming, changing climate, extreme weather, water, and climate events are becoming more common. Extreme high temperatures in the U.S. are projected to increase, and heat waves will be more intense. Increases in the frequency and intensity of heavy precipitation events in most parts of the U.S. are projected to continue, and future droughts in most regions will likely be stronger and potentially last longer. Conditions conducive to large wildfires have increased in frequency across the western U.S. and Alaska since the 1980s. Atlantic and eastern North Pacific hurricane rainfall and intensity are also projected to increase. Although the number of days per year with tornadoes has decreased, the number of tornadoes on those days has increased.

HURRICANES

Scenario

A hurricane hit the East coast, damaging the beaches/tourist attractions.

Decisionmaker's Question

Are there natural infrastructure mechanisms that could be put into place to help mitigate such damage in the future?

At the coast, ocean circulation changes, sinking land, and Antarctic ice melt will result in greater-than-average sea level rise and coastal inundation for the Northeast and western Gulf of Mexico even under lower emission scenarios. Since the 1960s, sea level rise has already increased the frequency of high tide flooding by a factor of 5 to 10 for several U.S. coastal communities. The frequency, depth, and extent of tidal flooding are expected to continue to increase in the future, as is the more severe flooding associated with coastal storms, such as hurricanes and nor'easters. The Great Lakes, with a coast length exceeding that of the eastern U.S., experienced record high water levels in 2017 to 2020 with coincident flooding, shoreline erosion, disruptions to commercial navigation and tourism. Finally, marine heat waves, which are expected to increase, can have significant impacts on the nation's valuable marine resources (e.g., fisheries, protected species, habitats) and the many people, businesses, and communities that depend on them. With continued ocean warming, marine heat waves will push marine ecosystems into unprecedented states.[5]

For decades, NOAA has served as the primary resource for the emergency management community for understanding and predicting extreme events. Climate change increases the intensity, severity, and

5 https://nca2018.globalchange.gov/chapter/2/

frequency of these events, and NOAA is accelerating its efforts to understand and predict them, and to provide equitable access to services to protect lives and livelihoods from the risk of these extreme events. Enhanced services are also needed to enhance the growing impact of extreme events on key sectors of the economy, including transportation, power generation, agriculture, recreation, and natural resource management and protection.

Cascading Hazards and Tipping Points

As the climate changes, extreme events are becoming more prevalent, and compound extreme events are leading to cascading hazards. Cascading hazards often create a domino effect and although they do not topple along an orderly path, they do have consistent patterns over time. Cascading hazards examples are provided below.

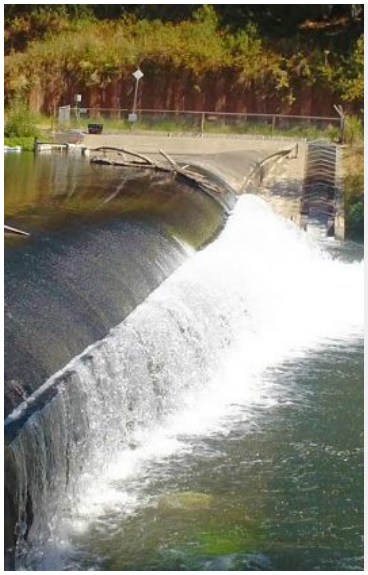
- Extreme heat and drought leads to wildfire, leading to debris flows and impacts on water quality.
- Heatwaves and wildfire-enhancing droughts can interfere with emergency management strategies to deploy wildfire fighting resources, leading to firefighting air tankers being grounded by extreme heat, debris flow, and conflict over water use.
- Increased risk of significant winter and spring precipitation can mobilize nutrients and contaminants and create a corresponding enhanced downstream flood risk that can trigger changes in coastal water quality, impacting marine ecosystem productivity.
- Marine heatwaves can cause harmful algal blooms that contaminate crabs with levels of domoic acid unsafe for human consumption, delaying West coast crab fishing activity from winter into spring, disrupting historically offset seasonal patterns of fishing and whale migration, leading potentially to greater incidents of humpback whale entanglements in fishing gear.

Drought, Extreme Heat, and Wildfires Lead to Cascading Hazards

Can firefighting aircraft take off?	How do wildfires affect the landscape?	What are the ecological impacts of drought?
Extremely high temperatures reduce air density. Aircraft then require higher takeoff speeds, longer runways and less weight to get airborne. Firefighting aircraft become grounded, reducing support for fighting wildfires, which further endangers human lives, property, and infrastructure.	Wildfires create damage impacting air quality, soil fertility and water quality. Charred vegetation, ash, and burnt soil compromise the integrity of the landscape, increasing flood risk for multiple years. Flash floods endanger human lives, property, and water infrastructure, including dams and bridges.	Reservoir levels reach historic lows along with a coincident increase in irrigation demand for agriculture. The lack of water availability for environmental flows adversely affects habitat restoration and species recovery efforts, resulting in biodiversity loss and extinction events.

Tipping points occur when small shifts in human pressures or environmental conditions bring about large, sometimes abrupt changes in a system, whether in a human society, a physical system, an ecosystem, or the planet's climate. For example, the systems being modeled and predicted are not just

physical, but biological, ecological, and socio-economic, including the dynamics of human communities and actions driving phenomena. Tipping points are often difficult to anticipate and can be impossible to reverse and, as such, are an area of particular concern. NOAA's science and services are critical to enhance the understanding and predicting extreme events and their impacts, and determining the paths and impacts of cascading hazards resulting from extreme events, as well as identifying tipping points and their associated environmental thresholds. The agency is addressing cascading hazards and tipping points through an integrated management approach by participating in activities such as the National Integrated Drought Information System (NIDIS), Forecast Informed Reservoir Operations (FIRO), the National Interagency Fire Center (NIFC), and NOAA Fisheries' Bycatch Reduction Engineering Program (BREP).



FORECAST INFORMED RESERVOIR OPERATIONS

Scenario

Reservoir operators in the Russian River of California face competing requirements for flood control and water supply operations of Lake Mendocino. In order to have sufficient space for flood control, operators evacuated water from the reservoir that potentially could be used for ecological flows or water supply after the winter flood season.

Decisionmaker's Question

What is the relative likelihood of excessive rainfall leading to flooding in the watershed over the next 14 to 30 days? NOAA, through the provision of Hydrologic Ensemble Forecast Services, can provide a probabilistic forecast that characterizes the uncertainty of the potential volumetric info into Lake Mendocino thus aiding the operator in making decisions to evaluate or retain water in the reservoir. This forecast informed reservoir operations, or FIRO, saves over 8,000 acre-ft of water per-year.

FIVE-YEAR OUTCOMES: EXTREME EVENTS

Societal Outcome	Key Word(s)	Description
1	Equity (Extreme Events)	Underserved communities will have more equitable access to information on the consequences of extreme events. Additionally, these communities will receive more regular and routine information and planning tools regarding the unintended consequences of potential decisions–designed to mitigate the impact of extreme events–that may adversely affect them.
2	Equity (Extreme Events)	Decision makers will have access to forecast and other services translated into multiple languages and delivered in formats that communicate risk in context-specific ways, emphasizing new media appropriate.

Societal Outcome	Key Word(s)	Description
3	Temperature	Public health officials and emergency managers will have to access skillful, reliable forecasts of extreme temperatures, particularly dangerously high night-time low temperatures, to reduce associated hospitalization and deaths from extreme heat.
4	Fire	Fire managers will have access to more accurate forecasts for the spread of fire, including improved short-range and hourly fire forecasts, as well as extended range forecasts of smoke and air quality. Fire managers will also have access to more accurate wildfire risk forecasts out to three months, as well as retrospective summaries, to evaluate past decisions about assets and seasonal positioning. Finally, the wildland fire community will have access to timely detection and notification of newly ignited wildfires within critical fire environments that support extreme fire behavior.
5	Coastal Storms	Decision makers will have access to improved forecasts of the magnitude, frequency and duration of storm surge and coastal rainfall, which account for sea level rise, relying on robust probabilities from NOAA observations and models. These forecasts will be provided in context--assessing annual storm patterns, tracking for trends--based on the social science of the personal, institutional, and societal experience(s) of NOAA stakeholders.
6	Precipitation	Every business and community will have access to accurate, reliable, and timely precipitation information, to include analysis, forecasts, assessments, understanding of seasonal and regional trends and projections to better manage the risks and impacts of too little and too much water.
7	Marine Heat Waves	Fishery managers, national marine sanctuaries, tribal leaders, and other stakeholders will have access to a comprehensive marine heatwave forecast capability to support decision making to manage and protect commercial fisheries and other living marine resources.
8	Tornados	Emergency managers and local communities will have access to tornado warnings with more advanced lead-times, taking account of new social science with regard to tornado warning response.
9	Winter Storms	Local communities will have access to better snow, ice, wind, and temperature forecasts and estimates of their combined impacts to achieve earlier warnings and inform critical decisions to protect life and property.

FIVE-YEAR OUTCOMES:
CASCADING HAZARDS AND TIPPING POINTS

Societal Outcome	Key Word(s)	Description
10	Cascading Flood Impacts	Decision makers will have access to the actionable information, informed by social science, to optimally manage, mitigate, and build resilience to the cascading impacts of floods on water quality and quantity. These include red tides and water borne pollutants and their effects on human health, living marine resources, and recreation and tourism.
11	Forecast Informed Reservoir Operations	Reservoir managers will have access to the actionable forecast informed reservoir (FIRO) services, informed by social science, to more effectively balance flood and drought risk while maximizing water availability for environmental flows and consumptive uses.
12	Drought	Decision makers, including those in resource-managing partner agencies, and those in underserved areas, will have access to regional drought early warnings and forecasts, covering weather-to-climate timescales, as well as new methods for accurately capturing the full economic cost of drought beyond the agricultural sector.
13	Cascading -Wildfire-Debris Flow	Decision makers will have access to actionable information on the Impacts of wildfire on snowpack properties/evolution and soil hydraulic behavior, and their associated effects on infiltration, runoff, streamflow prediction, and debris flow formation.

COASTAL RESILIENCE

CHALLENGE AREA 2

SOCIETAL CHALLENGE

U.S. coastal communities, economies, and ecosystems, as well as the natural and built infrastructure on which they depend, are increasingly impacted by accelerating changes at the coast — the continued impacts of severe storms coupled with the impacts of rising seas, variable Great Lakes water levels, the warming ocean, loss of sea ice, changing ecology, reduced water quality, and coastal erosion and shoreline change, among others. Creating resilience to these changes requires risk-informed decision making and adaptation via enhanced emergency response, coastal data collection, and predictive capabilities, as well as equitable service delivery and decision support. A resilient coastal zone is required to reduce the risk of adverse impacts on our coastal and ocean infrastructure, ecosystems, marine transportation, tourism, recreation and other key economic sectors at the coast.

SOCIETAL BENEFIT

NOAA addresses this challenge by providing equitable access to actionable, authoritative information on coastal change that helps communities (state, local, tribal, and territorial) plan for and take actions that increase their resilience and mitigate risks, and by advancing stewardship and planning for the long-term resilience and adaptation of the nation's diverse blue economy in a changing climate.

OVERVIEW

Sea level rise, dramatic shifts in Great Lakes water levels, the warming ocean, loss of sea ice, changing ecology, reduced water quality, and coastal erosion and shoreline change are severely impacting coastal states and territories, communities, economies, and ecosystems. Nearly 40% of the U.S. population live in coastal counties, and the nation's marine economy produced $665.7 billion in direct sales—a 5.1 percent increase over the previous year—and supported 2.4 million jobs in 2019 through activities such as tourism and recreation, shipping and transportation, commercial and recreational fishing, power generation, research, and related goods and services. Increasing impacts from coastal change represent a threat to lives and livelihoods as well as national and economic security. More extreme storms and changing water levels have heightened risks to lives and property and challenged navigation and sustainable supply chains in dynamic coastal environments.

Demands on our coastal and ocean environment, which raise important economic and social equity concerns, have been heightened by the growth of industries leaving imprints on coastal and ocean waters (e.g., energy production, mineral extraction, bioproducts) as well as greater appreciation of other ecosystem services provided by coastal and ocean environments (e.g., blue carbon, erosion control, storm surge protection, water quality).

SEA LEVEL RISE

Scenario

Areas of San Francisco, especially those with vulnerable populations, are especially prone to nuisance flooding, which will continue to worsen as sea levels rise.

Decisionmaker's Question

Are down-scaled sea level rise predictions available that will allow for the development of a regional resilience plan?

Our societal response to these threats requires comprehensive and sound decision making. Accurate and authoritative data, modeling, mapping, and services are required to quantify and communicate coastal hazards and change. This will improve our understanding of present and future coastal impacts and to identify sustainable recovery approaches, thereby enabling sound public policy and risk informed decision making.

NOAA provides information, expertise, partnerships and on-the-ground support to promote resilient coastal and Great Lakes communities and ecosystems that in turn support a vibrant national and global blue economy. The agency's observation and monitoring capabilities in our ocean, atmosphere, and from space enables us to track both imminent risks and long-term coastal changes. These observations feed NOAA weather, climate, ocean, and Earth system models which provide predictions from days to

decades to meet coastal resilience needs and contribute to the blue economy. The agency's scientists are building the expertise and partnerships to translate these observations and predictions into the "actionable analytics" required for climate-smart decisions to help protect, sustain and restore valuable coastal resources that are the life-blood of the nation's blue economy.

NOAA and its Federal partners have clear authorizations and extensive expertise in measuring, forecasting, visualizing, and communicating coastal change information, and for the underlying geospatial information that supports those services. The agency's authorizations also convey the responsibility to convene Federal, state, local, tribal and private sector interests that both produce and consume science at the coast. Strengthening, sustaining, and coordinating these programs, networks, and services to address the impacts of coastal change is an urgent national priority, which will require a one NOAA response, and close coordination with interagency partners.

COASTAL FLOOD RISK

Scenario

A coastal community of 15,000 people is faced with meeting the challenges of economic recovery, aging infrastructure, and increased impacts from high tide flooding, coastal storms, and heavy precipitation.

Decisionmaker's Question

What is the community's exposure to flood risk, from all sources (i.e., rainfall, riverine, and coastal), today and how will the risk and exposure be different in 30 years? How do I build partnerships with local, regional, and state leaders to tackle these challenges together? How do we approach financing possible adaptation/resilience investments (e.g., elevation or relocation of infrastructure, green infrastructure, stormwater retrofits, pump stations, sea walls)?

There is an urgent need for NOAA – in partnership with other Federal agencies and the broader private and non-governmental enterprise – to expand and enhance observations, mapping, modeling, future-conditions projections, and services that inform the public about environmental and physical coastal risks. Continued investment in infrastructure, research capabilities, new technologies, sustainable resource management and on-the-ground conservation action is also needed to address current gaps and keep pace with a rapidly changing environment, and a rapidly changing blue economy. In response to this need, NOAA will leverage and expand upon existing capacities and capabilities to assess and predict coastal change and its impacts; support a national effort to deliver enhanced authoritative and science-based products, services; and provide technical assistance and capacity building that empowers coastal stakeholders to become more resilient and gain a better understanding of regional and local impacts to a changing climate.

COASTAL STORMS

Scenario

A coastal storm will impact the East Coast in five days.

Decisionmaker's Question

Whether, when, and where do we need to evacuate people and mobilize emergency responders? What mitigative actions need to be taken, and how long will each one take? What is the expected extent and duration of coastal flooding throughout the impacted areas? How will we clearly communicate the threats to residents? How much coastal erosion will occur and where will it be most severe? How will the salinity and temperature of estuarine and coastal waters vary before and after the storm?

FIVE-YEAR OUTCOMES: COASTAL RESILIENCE

Societal Outcome	Key Word(s)	Description
14	Equity (Coastal Resilience)	Decision makers in remote areas, including highly vulnerable communities in Alaska and in underserved rural coastal counties, will have access to new coastal resilience services.
15	Inundation Forecasts	Through a comprehensive, operational near-shore coastal forecast system, decision makers will have access to new total water level and inundation risk forecasts and mapping tied to the built environment and vital infrastructure in all coastal communities on both weather and climate timescales, including recurrent flooding/high-tide flooding forecasts.
16	Inundation Planning Tools	Through newly developed coastal services, decision makers will have access to new analysis, scenario planning and other tools for managing inundation and protecting coastal infrastructure on 20, 50, and 100 year time horizons.
17	Coastal Water Quality Risk	Through newly developed prediction services, decision makers will have access to forecasts of temperature, salinity and other water quality risks in bays, estuaries, and sounds.
18	Resilience to Human Health Risks at the Coast	Decision makers in coastal communities will have access to new products and services for effective preparation and response to ocean-related threats to health, including harmful coastal algal blooms; shellfish poisoning; and marine pollution.

Societal Outcome	Key Word(s)	Description
19	Nature-Based Protection at the Coast	Decision makers will have access to new services for coastal habitat conservation and restoration to increase the resilience in coastal communities and ecosystems to inundation and water quality threats.
20	Hazardous Spill Response & Restoration	Decision makers in coastal communities will have access to new products and services for hazardous spill response and nearshore search and rescue operations.

THE CHANGING OCEAN

CHALLENGE AREA 3

SOCIETAL CHALLENGE

The ocean is a dynamic and connected component of the earth system. Ocean warming, decreasing sea-ice, changing currents, rising seas, ocean acidification and deoxygenation are affecting the nation's valuable living marine resources and the many ocean-dependent businesses and communities. These changes impact the nation's security through many sectors from marine navigation, transportation and energy to fisheries, aquaculture and protected resources.

SOCIETAL BENEFIT

NOAA addresses this societal challenge by providing products and services essential to understanding, preparing for and responding to changing ocean and climate conditions. These products and services are part of an end-to-end value chain that spans observations, research, modeling, forecast, tools, training and applications to help society and decision-makers make ocean-informed and climate-informed decisions that increase resilience, adaptation, and sustainability in a changing world.

OVERVIEW

The ocean plays a pivotal role in the global weather and climate system by absorbing and redistributing both heat and carbon dioxide, and provide the largest source of water vapor for global precipitation. Human-caused carbon emissions have led to ocean warming, acidification, deoxygenation, and decreasing sea-ice. More than 90% of the extra heat linked to carbon emissions is contained in the ocean, and ocean surface waters have warmed on average 1.3° ± 0.1°F (0.7° ± 0.08°C) per century globally between 1900 and 2016. This warming impacts ocean physical conditions including sea levels, sea ice covers, ocean circulation and stratification (density contrast between the surface and deeper waters), which in turn affect the seasonality, productivity, and biological diversity of ocean food-webs.[6] As a result, ocean ecosystems are being disrupted in a variety of ways, including the loss of highly valued habitats, and changes in the distribution and abundance of species that support the nation's valuable fisheries, tourism, and recreation.[7]

The impacts of a changing ocean are expected to increase and there is much at risk. Marine ecosystems annually contribute over $210 billion and 1.7 million jobs from fisheries and provide a range of other vital services including transportation, energy and carbon mitigation. Many marine-dependent communities are on the front lines of changing ocean conditions, including the many underserved fishing communities, Arctic and island communities. For Pacific Islands, the ocean is much more than a daily resource for transportation and sustenance, the ocean is linked to identity and culture. For example, rising sea levels are displacing villages from ancestral lands, disrupting traditional aquaculture and farming cycles, and inundating family burial grounds. To safeguard fisheries and marine-dependent communities in the face of a rapidly changing ocean, resource managers and other decision-makers urgently need better information on what is changing, who is at risk, what to plan for and how to respond.

Understanding the nature of the changing ocean and the dynamics of large-scale, ocean-related atmospheric circulation patterns is also vital to improving climate, weather, and ecosystem models, projections and responses. The climate of the U.S. is strongly affected by the ocean and large-scale atmospheric circulation variability influenced by ocean conditions.

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6 Pershing, A.J., R.B. Griffis, E.B. Jewett, C.T. Armstrong, J.F. Bruno, D.S. Busch, A.C. Haynie, S.A. Siedlecki, and D. Tommasi, 2018: Oceans and Marine Resources. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 353–390. doi: 10.7930/NCA4.2018.CH9

7 Pershing, A.J., R.B. Griffis, E.B. Jewett, C.T. Armstrong, J.F. Bruno, D.S. Busch, A.C. Haynie, S.A. Siedlecki, and D. Tommasi, 2018: Oceans and Marine Resources. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 353–390. doi: 10.7930/NCA4.2018.CH9

Coupled atmosphere–ocean phenomena cause year-to-year variations in U.S. temperatures and precipitation as well as other extreme weather phenomenon over land, coastal and high seas regimes. On longer time scales, U.S. climate anomalies are linked to slow variations of sea surface temperature.[8] For example, the potential slowing of the Atlantic meridional overturning circulation (AMOC; of which the Gulf Stream is one component)—as a result of increasing ocean heat content and freshwater driven buoyancy changes—could have dramatic climate feedbacks that would also affect the climates of North America and Europe.9 In addition, temperature changes in the equatorial Pacific, leading to changes in El Nino/La Nina Southern Oscillation, have significant and well-known impacts on U.S. weather patterns. Also, loss of sea-ice coverage due to increased atmospheric and oceanic heat, particularly in the Arctic, directly impacts heat and moisture exchanges between the ocean, atmosphere, and cryosphere, leading to significant variability both locally for native communities and their ecosystem and globally with alterations in large scale weather patterns.

Improving long-term consistent in situ and satellite monitoring, understanding and modeling of these ocean dynamics and atmospheric interactions will help improve near term forecasts and longer term projections of weather and climate changes affecting every segment of society.

ARCTIC

Scenario

The Northwest Passage is becoming a major shortcut for commercial shipping.

Decisionmaker's Question

When will the Arctic be free of ice for six weeks (increasing lead times for this information improves planning for shipping routes)?

8 Perlwitz, J., T. Knutson, J.P. Kossin, and A.N. LeGrande, 2017: Large-scale circulation and climate variability. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 161-184, doi: 10.7930/J0RV0KVQ.

9 Jewett, L. and A. Romanou, 2017: Ocean acidification and other ocean changes. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 364-392, doi: 10.7930/J0QV3JQB.

FIVE-YEAR OUTCOMES:
THE CHANGING OCEAN

Societal Outcome	Key Word(s)	Description
21	Equity (The Changing Ocean)	Marine-dependent communities, including underserved communities in the Arctic, tropical islands, and other areas, have new tools, information, and training to help them develop and implement adaptation plans to manage risk from changing oceans and other stressors.
22	Fisheries and Resilience	Living marine resource managers and resource-dependent sectors have access to robust forecasts, projections, risk assessments and management strategies to optimize fisheries management and increase the resilience of marine resources and the communities that depend on them.
23	Marine Protected Areas and Species	Decision makers supporting protected areas, such as National Marine Sanctuaries, Monuments, National Estuarine Research Reserves and others, as well as those supporting endangered and threatened marine and anadromous species under the Endangered Species Act, will have increased capacity to support resilient, thriving marine and coastal ecosystems, support responsible recreation and tourism, and educate and inspire people around the world.
24	Blue Carbon	Decision-makers will have increased understanding and access to reliable assessments of ocean-based solutions to mitigating climate change including coastal and ocean carbon sequestration.
25	Aquaculture	Aquaculture-based industries and economies will be supported by a comprehensive national framework for sustainable and productive aquaculture.
26	Marine Transportation	Decision makers, including mariners, business owners, and indigenous communities will have access to new services for safe and efficient marine transportation. These will include new and more accurate forecasts of coastal and ocean wave and sea state, sea ice conditions, marine weather, tides, and electronic chart displays of oceanographic and meteorological hazards. NOAA will also provide services that support the exploration of new opportunities for energy development and shipping (renewable energy exploration, NW passage).
27	Polar Regions	Decision makers, including polar mariners, will have improved services in the Arctic and Antarctic, with significant benefits to the U.S. Blue Economy for marine transportation in polar waters, ocean exploration, resource exploration and extraction, hazard response, and seafood competitiveness.

Societal Outcome	Key Word(s)	Description
28	Ocean Exploration and Discovery	Decision makers will gain new insights from expanded exploration and discovery of ocean resources, including its biodiversity, rare earth minerals, to close the prominent gap in our basic understanding of U.S. deep waters and seafloor and deliver the ocean information needed to strengthen the economy, health, and security of our nation.

WATER AVAILABILITY, QUALITY, AND RISK

CHALLENGE AREA 4

SOCIETAL CHALLENGE

The U.S. is facing emerging threats to our economic and national security, and ecosystem and habitat health, from competing demands for our increasingly limited and stressed water supply and other water risks nationwide, in the context of aging water infrastructure, degrading water quality, population growth, and climate change.

SOCIETAL BENEFIT

NOAA, in collaboration with partners, addresses this challenge by helping ensure water security, to protect human and ecosystem health and inform water resources decisions, including availability, quality, and risk, while promoting equity and resilience. Water availability, quality, and risk lie at the nexus for food (via irrigated agriculture), energy (via hydropower), ecosystems (especially protected resources) and municipal and industrial water services. NOAA's water predictions and services are and will continue to inform decisions to support the protection of life and property, human and ecosystem health, recreational water use, and the optimal allocation of water supply in the context of competing demand.

OVERVIEW

Water is essential for life and is inexorably linked to environmental protection, sustainable development, and international peace and security. Too much water, too little water, or poor water quality endangers life, property, communities, economies, and ecosystems. As a nation we are faced with many water challenges especially in the context of a changing climate, including flooding, drought, water availability, and water quality. Water challenges affect all economic sectors, from agriculture to utilities, and the impacts are escalating. Population growth and economic development, particularly in flood and drought-prone regions, are stressing water supplies and increasing the vulnerabilities facing communities and businesses. An aging water infrastructure is forcing critical, expensive decisions, and the socio-economic risks of floods and droughts are escalating. In recent years, flooding disasters in the U.S. represented one of the costliest natural hazard events in terms of life and property loss.[10]

Additionally, the changing climate is intensifying the impacts to water availability and quality, further increasing the uncertainty and risk facing the nation. This is necessitating new observations and tools, as well as the use of more physically-based water modeling and fully coupled Earth system modeling approaches which leverage the rapid expansion of available data and technology. Moreover, the increasing water-related challenges require a multidisciplinary approach, to employ the best science and technology while ensuring the enhanced information and services created are actionable by the diverse water resources community. For the third consecutive year, The World Economic Forum Global Risk Report placed water crises in the top five highest impact, highest likelihood global risks, along with climate action failure, biodiversity loss, extreme weather events, and natural disasters.[11]

In response to growing stakeholder demands for enhanced and integrated water resources forecasts and services in the face of these challenges, NOAA is actively engaged with partners to develop new modeling tools and capabilities leveraging complementary capabilities, resources, and missions.

Recent engagements with water resources stakeholders across the U.S. revealed the need for consistent, high space and time resolution, observations, integrated water analyses, predictions and data to address critical unmet information and service gaps related to floods, drought, water quality, water availability, and a changing climate. Converting this information into actionable water intelligence and its effective communication to decision makers, requires the integration of social science and the development of visualization and decision support tools that link hydrologic, infrastructural, economic, demographic, environmental, and political data.

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10 National Academies of Sciences, Engineering, and Medicine. 2019. Framing the Challenge of Urban Flooding in the United States. Washington, DC: The National Academies Press. https://www.nap.edu/catalog/25381/framing-the-challenge-of-urban-flooding-in-the-united-states

11 World Economic Forum. The Global Risks Report 2020. http://www3.weforum.org/docs/WEF_Global_Risk_Report_2020.pdf

NOAA must enhance its analysis and prediction of our nation's water resources that range from forecasts of floods to year long water supply volumes, to the potential quality of water along our coasts in the context of an emerging earth system modeling framework. This new approach, as it is researched, developed, and transitioned into operations, will leverage increased skill in precipitation from coupled systems. This will translate into improvements for water forecasts from actionable flood inundation to enhanced long range water supply forecasts that inform reservoir operations. Moreover, to support the design, development, and operation of our nation's built infrastructure, from new power plants to transportation systems, NOAA will update and revise Precipitation Frequency Atlases for the United States and develop 21st century Probable Maximum Precipitation studies that account for climate change.

FLOOD INUNDATION MAPPING

Scenario

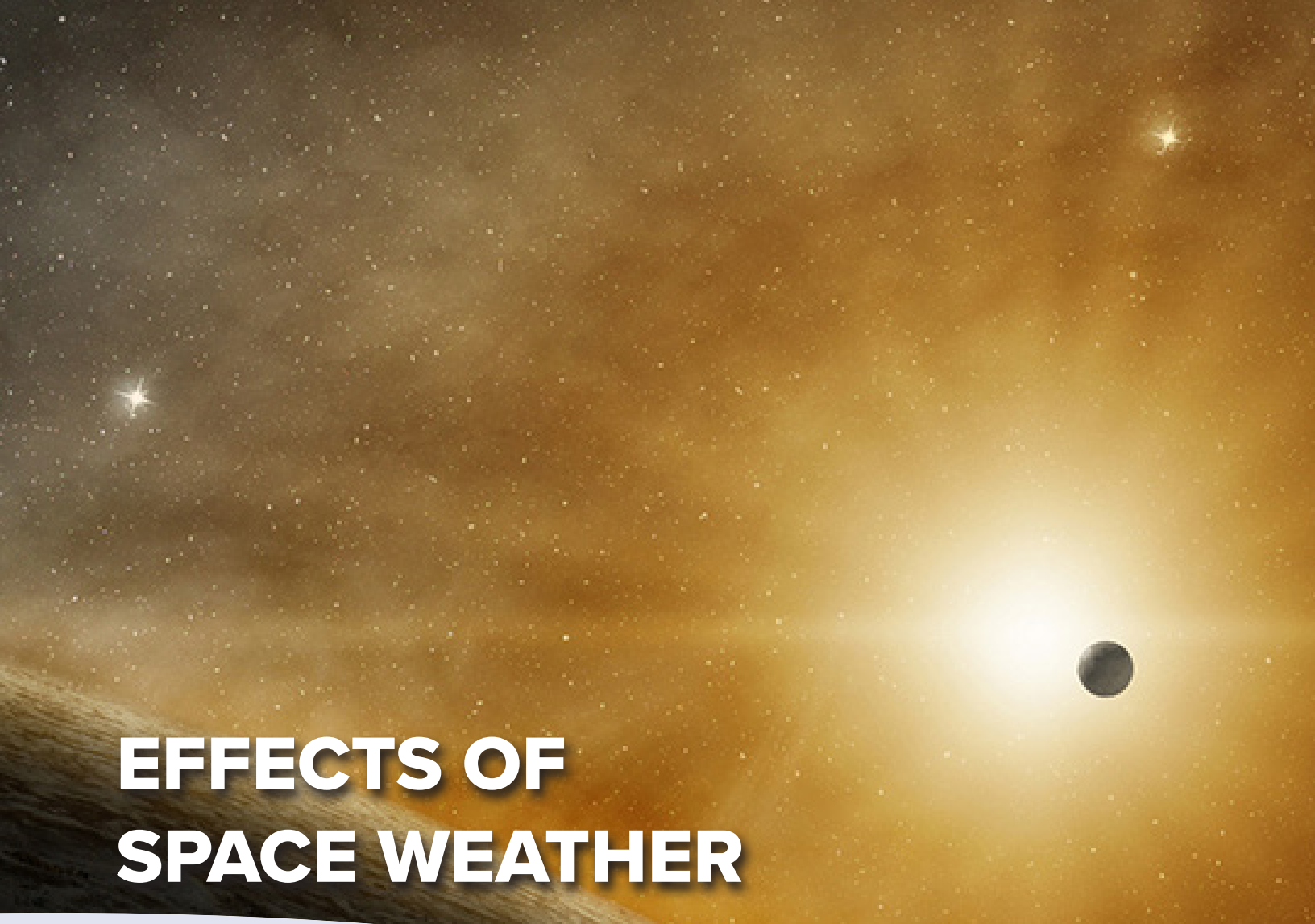
Local Emergency Managers and State Department of Transportation Officials are concerned about the impact of tropical storm induced flooding inhibiting travel on Interstate 10 in Florida.

Decisionmaker's Question

Will Interstate 10 become impassable due to flood waters on the Yellow River? If so, when and for how long? How deep will the flood water be and what infrastructure will be impacted? NOAA, through the delivery of real-time and forecast flood inundation maps, translates forecasts from the River Forecasts Centers and guidance from the National Water Model into actionable intelligence on the flood water from heavy rains that occur with landfalling hurricanes.

FIVE-YEAR OUTCOMES:
WATER AVAILABILITY, QUALITY, AND RISK

Societal Outcome	Key Word(s)	Description
29	Equity (Water Availability Quality, and Risk)	Disadvantaged and underserved communities, including urban and rural areas, will have more equitable access to information, delivered in traditional and non-traditional ways, to improve their resilience to water supply and flood risks.
30	Water Stress	Decision makers will have access to the actionable information, informed by social science, to optimally manage water resources, water supply, and risk in the face of water stress exacerbated by climate change.
31	Floods	Decision makers will have access to the actionable information, informed by social science, to optimally manage, mitigate, and build resilience to inland and coastal flood threats.
32	Navigation, Recreation, and Economic Development	Decision makers will have access to the actionable information to optimize the operation of commercial port infrastructure, and ensure safe and efficient navigation and recreation services on inland waterways, as well as other management and planning purposes.
33	Critical Infrastructure	Decision makers will have access to updated and revised Precipitation Frequency Atlases for the United States that account for climate change, as well as 21st century modernized Probable Maximum Precipitation (PMP) studies, to support the design, development, and operation of our nation's built infrastructure, from single family dwellings to new power plants to transportation systems.
34	Water Quality	Decision makers will have access to the actionable information, informed by social science, to understand and manage water quality risks in rivers, lakes, estuaries and other coastal environments impacted by flooding and long-term inundation.



EFFECTS OF SPACE WEATHER

CHALLENGE AREA 5

SOCIETAL CHALLENGE

The effects of space weather pose significant and increasing societal, economic, national security, and health risks to the United States and nations worldwide. These include risks to the electric power grid; aviation operations; positioning, navigation, and timing (PNT) services; satellites and communications; human space exploration; and other space-based assets.

SOCIETAL BENEFIT

To safeguard national security assets, critical infrastructure and technology, and crewed and uncrewed space assets, NOAA addresses this challenge by providing actionable space weather observations, forecasts, alerts, warnings, and decision support services.

OVERVIEW

Space weather refers to variations in the space environment between the Sun and Earth, and throughout the solar system, that have the potential to adversely affect critical functions, assets, and operations in space and on Earth. Events driven by space weather can disrupt the technology that forms the backbone of this country's economic vitality and national security, including satellite and airline operations, communications networks, navigation systems such as GPS, and the electric power grid. NOAA provides critical services to safeguard society with actionable space weather information.

ELECTRIC GRID

Scenario

A severe space weather event causes a major disruption to the electric grid.

Decisionmaker's Question

When and where will grid operators experience impacts, and what will be the severity?

NOAA is the Nation's official source for space weather forecasts, warnings, alerts, and real-time space weather monitoring, exclusive of the responsibilities of the Secretary of Defense. The agency's products are distributed to end-users worldwide to enhance mitigation, response, and recovery actions that safeguard assets and maintain continuity of operations during space-weather events.

In support of this mission, NOAA provides continuous and timely access to space weather data and products from its unique, global, operational space weather instruments and platforms. The agency's products also draw upon data from NASA and international and commercial partner satellites. These satellite data sets are complemented by a suite of ground-based measurements from USGS, NSF, and DOD to create NOAA's suite of space weather warnings and alerts. In addition, NOAA operates in partnership with various universities and cooperative institutes to deliver space weather science and services.

SPACE WEATHER EVENT

Scenario

An extreme geomagnetic storm is inevitable in the future.

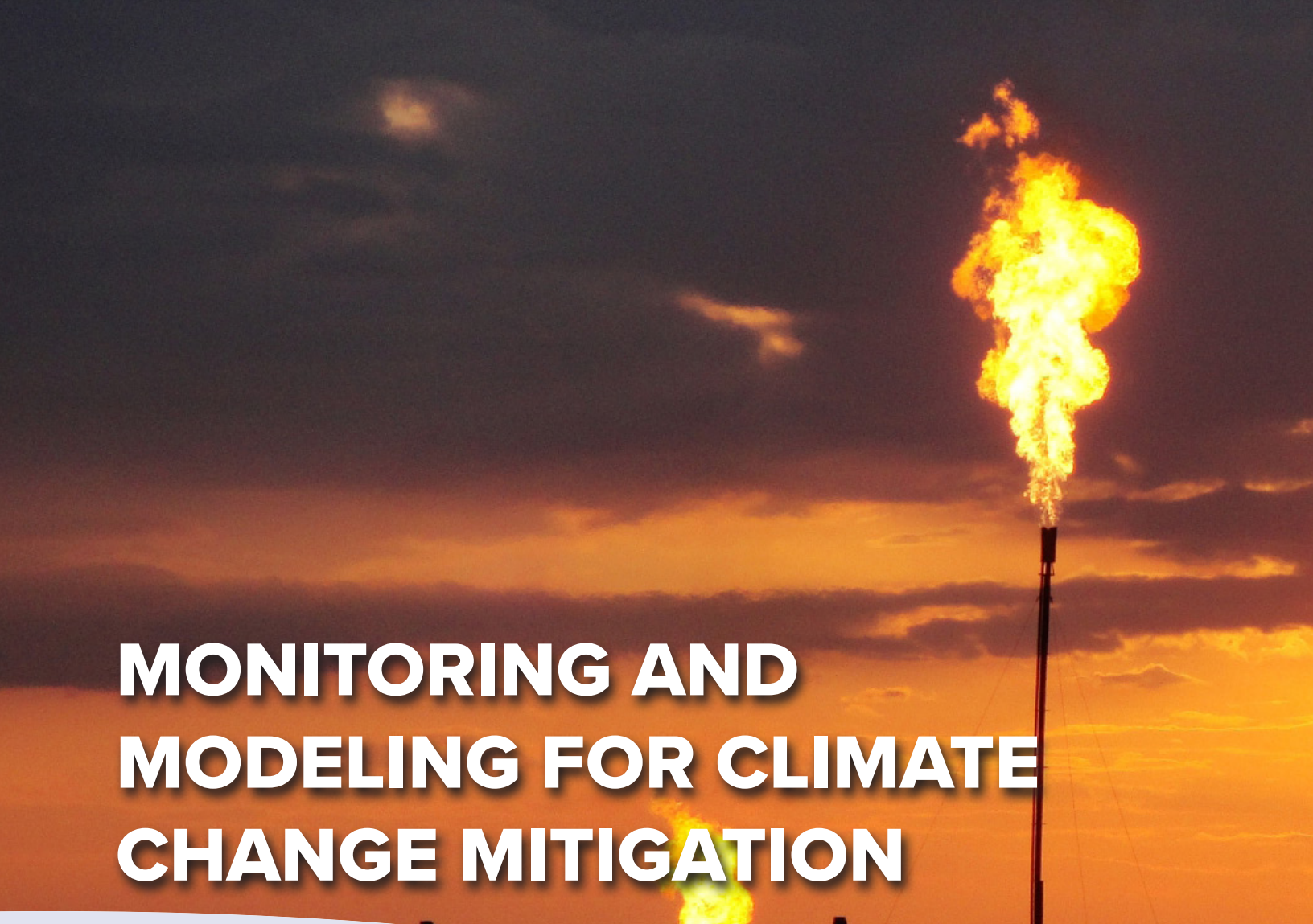
Decisionmaker's Question

What are the theoretical intensity limits of space weather events and thus the risk to the electric grid, the economy, and national security?

NOAA and its partners are developing the next generation of space-based observations and models to improve space weather predictive capability and the next generation of analysis-ready archive services to fuel the Research to Operations to Research (R2O2R) pipeline. This empowers the agency to capture emergent technologies, such as machine learning and artificial intelligence, to enhance its space weather capabilities. The agency will improve its space weather products and services to help protect infrastructure and activities vital to national security and the economy.

FIVE-YEAR OUTCOMES: EFFECTS OF SPACE WEATHER

Societal Outcome	Key Word(s)	Description
35	Equity (Space Weather)	NOAA-provided space weather products and services will safeguard communication systems that provide increased government and industry broadband services to underserved communities worldwide.
36	Equity (Space Weather)	Developing countries will better understand the threat and mitigation of space weather through education provided by the U.S., through NOAA, the world-leading provider of continuous, real-time space-weather information.
37	Critical Infrastructure	New region-specific space weather products and services, including scenario planning, will provide decision-makers with improved characterization and prediction of the timing, intensity, and impact of space weather events on critical infrastructure.
38	Space Traffic Coordination	Actionable information from an operational space-weather observation system for the inner solar system will enable decision-makers to take more robust space-weather event mitigation actions for space traffic coordination and development of the nascent space economy.



MONITORING AND MODELING FOR CLIMATE CHANGE MITIGATION

CHALLENGE AREA 6

SOCIETAL CHALLENGE

Worldwide, there is now widespread recognition of the impact of greenhouse gas emissions on the climate system, leading to dangerous, accelerated warming. Within the U.S. and internationally, there is a growing demand for information about current and future greenhouse gas emissions, their impact on the state of the global climate system, and options and effectiveness of climate change mitigation measures at different scales.

SOCIETAL BENEFIT

NOAA addresses this challenge by informing mitigation choices through greenhouse gas and climate system monitoring and modeling. Additionally the agency has modeling capabilities to assess the climate, atmospheric, and oceanic implications of both current and proposed mitigation options, including renewable energy, coastal and oceanic carbon removal, and climate intervention strategies.

OVERVIEW

In 2021, the U.S. helped to strengthen the global response to the threat of climate change by rejoining the Paris Agreement, which established the objective of keeping the global temperature rise this century to well below 2 degrees Celsius (2^{o}C) above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius (1.5^{o}C). Given the trajectory of anthropogenic greenhouse gas (GHG) emissions and Earth-system feedbacks, the Nation requires accurate, reliable, and timely information about the feasibility of meeting the 1.5^{o}C, 2^{o}C and other climate targets. Further, the Nation and decision makers at sub-national scales require information about a number of difficult-to-quantify GHG emission sources and sinks, the effectiveness of GHG mitigation actions over time, and the benefits and potential risks of some mitigation and removal measures, some of which have been proposed but remain untested at scale.

GREENHOUSE GAS MITIGATION

Scenario

Climate-carbon cycle feedbacks are stronger than anticipated and lead to even more carbon dioxide in our atmosphere.

Decisionmaker's Question

How will this affect our ability to meet Paris Agreement targets?

NOAA has core, unique capabilities for measuring GHG emissions and aerosols, and changes in emissions over time at local, regional, and global scales. Additionally the agency co-develops these systems with federal and international partners. The U.S. and other nations are required under international guidelines to produce national inventories of anthropogenic greenhouse gas emissions, based on activity data (e.g., tons of coal burned) in combination with emission factors (i.e., emission per unit activity). These current inventories continue to lack accuracy, temporal and spatial coverage for certain emission sources and sinks. NOAA augments national emission inventories with actual atmospheric and oceanic measurements, rather than derived estimates, of GHG sources and sinks. These measurements are enabled through NOAA's global observing system assets, which are the world's most comprehensive, including real-time data from multiple space-based, airborne, terrestrial, and marine platforms, as well as from the agency's unique Earth system modeling capabilities and comprehensive earth and environmental data archives. As the density of the agency's observation systems increases and the sophistication of its modeling improves, these systems enable ongoing, systematic, assessment of the dynamic change in the climate system resulting from these emissions.

With these baseline data and modeling results, the agency provides authoritative products and services that discern which emissions are based on anthropogenic sources, and which come from natural

background sources. NOAA's models also provide information on the implications and effectiveness of different mitigation scenarios and activities at multiple spatial and temporal scales. For example: (1) the identification of GHG emission hotspots and opportunities for mitigation; (2) renewable energy choices (including how climate change itself can impact renewable energy); (3) major changes in carbon-climate feedback affecting uptake of CO2 by land and ocean processes; (4) the effectiveness and risks associated with carbon dioxide removal in the ocean, on land, and through coastal ecosystems, and of other climate intervention strategies such as solar radiation management in the stratosphere.

FIVE-YEAR OUTCOMES:
MONITORING AND MODELING FOR CLIMATE CHANGE MITIGATION

Societal Outcome	Key Word(s)	Description
39	(Monitoring and Modeling for Climate Change)	Decision makers, including underserved communities, will have climate information and services to better understand the benefits and risks of different climate mitigation choices.
40	Identifying Mitigation Opportunities	Decision-makers will have access to an empirical assessment of the magnitude, trend, and future projection of GHG emissions–from both anthropogenic and natural sources from local to global scales–to identify mitigation opportunities and to assist the evaluation of mitigation efforts over time.
41	Evaluating Mitigation Strategies	Decision-makers will have improved scientific information to evaluate the performance, effectiveness, benefits, and risks of certain mitigation strategies at multiple scales, including climate interventions.
42	Climate Targets	National and international policy makers will have the tools to determine the feasibility and implications of meeting or not meeting future climate targets, including those under the Paris Agreement. This includes access to critical information about GHG feedbacks from Arctic, tropical, and oceanic sources and sinks, and their implications for mitigating anthropogenic emissions in order to keep climate targets within reach.

SECTION 4
THE WAY AHEAD

This Strategy envisions a boundary-spanning partnership across multiple sectors to create and deliver actionable weather, water, and climate information and services to meet the growing needs of the 21st century. NOAA will support this vision by achieving the outcomes documented in this Strategy. To do this, the agency will leverage its resources to provide equitable, next-generation, science-based weather, water, and climate information and decision support services nationwide. The agency looks forward to collaborating with a full array of partners, decision makers, and users to achieve this vision, strategy, and the associated supporting outcomes and outputs, for the benefit of our communities, economy, national security, and planet.

SECTION 5
APPENDICES

Appendix A — NOAA's Mandates, Strategies, and Line Office Missions

RECENT RELATED MANDATES

- Weather and Research Forecasting Innovation Act of 2017
- National Integrated Drought Information System Reauthorization Act of 2018
- Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act or the PROSWIFT Act (2019-2020)
- The Coordinated Ocean Observations and Research Act of 2020
- Executive Order 14008: Tackling the Climate Crisis at Home and Abroad
- Infrastructure Investment and Jobs Act of 2021
- Executive Order 14058: Transforming Federal Customer Experience and Service Delivery to Rebuild Trust in Government

STRATEGIES

- Building a Weather Ready Nation: NWS Strategic Plan 2019-2022
- DOC Strategic Plan (2018-2022)
- Earth Prediction Innovation Center: Strategic Plan (2021)
- FY2022 OSTP R&D Priorities Memo
- National AI Initiative Act (in National Defense Authorization Act; DIVISION E, SEC. 5001)
- NOAA 'Omics Strategy
- NOAA Artificial Intelligence Strategy
- NOAA Climate and Fisheries Initiative Strategy
- NOAA Cloud Strategy
- NOAA Coastal Inundation at Climate Timescales
- NOAA Data Strategy
- NOAA Fisheries Climate Science Strategy
- NOAA Hurricane Forecast Improvement Program Five-Year Plan (2019-2024)
- NOAA Next Generation Strategic Plan (2010)
- NOAA Ocean Acidification Research Plan
- NOAA Precipitation Prediction Grand Challenge
- NOAA Research and Development Vision Areas (2020-2026)
- NOAA Unmanned Systems Strategy
- NOAA's Policy on Partnerships in the Provision of Environmental Information
- NWS Partnership Strategy
- OSTP Earth System Predictability Strategic Framework and Roadmap
- OSTP National Space Weather Strategy and Action Plan
- Service Delivery Framework

NOAA AND LINE OFFICE MISSIONS

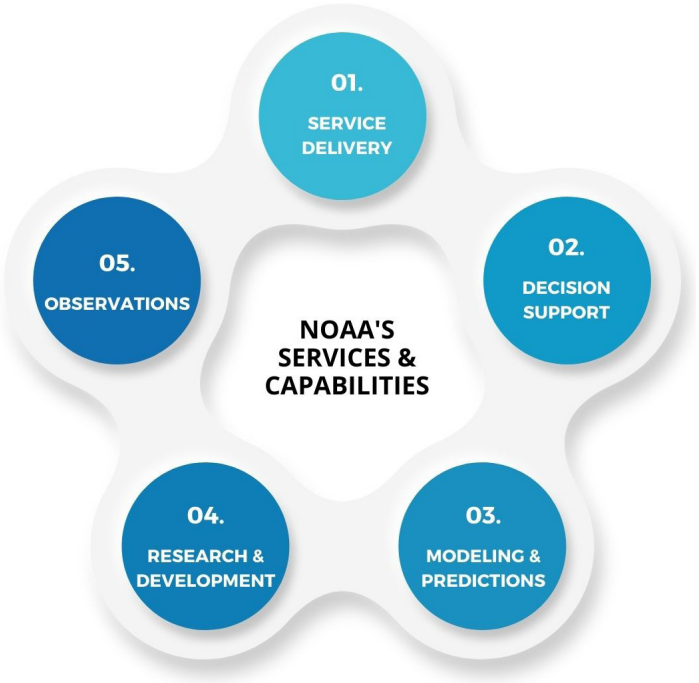
National Oceanic and Atmospheric Administration	To understand and predict changes in climate, weather, ocean, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources.
National Environmental Satellite, Data, and Information Service	NESDIS provides secure and timely access to global environmental data and information from satellites and other sources to promote and protect the Nation's security, environment, economy, and quality of life.
National Marine Fisheries Service	NMFS provides stewardship of the nation's ocean resources and their habitat. Providing vital services for the nation, all backed by sound science and an ecosystem-based approach to management, ensuring productive and sustainable fisheries, safe sources of seafood, recovery and conservation of protected resources, and healthy ecosystems.
National Ocean Service	NOS provides science-based solutions through collaborative partnerships to address evolving economic, environmental, and social pressures on our ocean, Great Lakes and coasts.
National Weather Service	NWS provides weather, water and climate data, forecasts, warnings, and impact-based decision support services for the protection of life and property and enhancement of the national economy.
Office of Oceanic and Atmospheric Research	OAR conducts research to understand and predict the Earth system; develop technology to improve NOAA science, service, and stewardship; and transition the results so they are useful to society.
Office of Marine and Aviation Operations	OMAO optimizes NOAA's observational platforms and unique workforce capabilities to meet NOAA's Science, Service, and Stewardship missions.

NOAA STAFF OFFICES AND CORPORATE SERVICES

• Office of Communications	• Acquisition and Grants Office
• Office of Education	• Office of the Chief Administrative Officer
• Office of the Federal Coordinator for Meteorology	• Office of the Chief Financial Officer
• Office of General Counsel	• Office of the Chief Information Officer
• Office of International Affairs	• Office of Human Capital Services
• Office of Legislative & Intergovernmental Affairs	• Office of Inclusion and Civil Rights

Appendix B — NOAA's Value Chain Elements and Enabling Capabilities

Ensuring integration, and promoting efficiency across NOAA's Line Offices, the agency supports six interdependent areas of work which represent the full breadth of NOAA's services and capabilities value chain. The five components of NOAA's value chain are outlined in detail below.



SERVICE DELIVERY

NOAA is dedicated to effective and equitable service delivery, which is central to accomplishing the agency's mission. The agency is present in communities nationwide and strives to establish and enhance relationships with stakeholders at the national, regional, state, local and tribal levels. Through sustained engagement with stakeholders, which spans jurisdictions, geographic boundaries, agency mission areas, and sectors, the agency addresses the evolving requirements of regional and local stakeholders. The Service Delivery Framework, adopted by all NOAA Line Offices, outlines a process for continuous stakeholder and user engagement for the development, delivery, and evolution of products and services. The agency is committed to delivering services and products in a way that is effective, equitable, and advances environmental justice, supportive of Executive Order 14058: Transforming Federal Customer Experience and Service Delivery to Rebuild Trust in Government.

The Framework's elements are outlined below.

- **Build.** Building trusted relationships with NOAA's internal and external users and partners.
- **Gather.** Understanding the decisions of those users, the environment within which our users operate, their use of NOAA information, and gathering the users' information, understanding their problems and needs, and assessing user capacity.
- **Translate.** Considering user needs through a lens of current and future capabilities from NOAA as well as its partners, including directing users to current and future capacity building resources available through NOAA and other agencies.
- **Assess.** Reviewing and prioritizing NOAA's current and future products and services to determine which needs may be met and how quickly.

- **Address.** Responding to user needs by developing new, or refining existing, products and services across NOAA and partners.
- **Deliver.** Delivering these products and services to users.
- **Evaluate.** Evaluating impact of NOAA's engagement, products, and services through iteration and feedback.

NOAA will take the following actions and required investments to implement the Service Delivery Framework.

- **Collaborate with Stakeholders to Gain Experience, Understand their Challenges, and Garner Feedback:** Invest in evaluating stakeholder experience and feedback. This includes the alignment of budgets that support the collection and analysis of social, behavioral, and interdisciplinary data, including social science, economics, and risk communication science, to enhance service delivery. Support both traditional and non-traditional users of NOAA products, by providing them with the integrated solutions they require, through collaboration and co-development.
- **Advance Understanding of Social and Economic Impacts:** Advance understanding and application of complex social and economic impacts of weather, water, and climate events in communities throughout the U.S., especially historically underserved and socially vulnerable communities, to inform response strategies and resilience and adaptation planning.
- **Advance Social Science Research Capacity:** Advance fundamental social science research capacity and infrastructure in terms of new and archival data collection, storage, and management, analysis, and archival visualizations, decision-models, and best practices compilations.
- **Gather and Prioritize Requirements:** Support a formal NOAA process and cadence for gathering operational requirements and prioritizing how NOAA labs, cooperative institutes, regions, and private enterprise can best be used to meet those requirements.

DECISION SUPPORT TOOLS

NOAA works with decision makers to supply information at appropriate time and geographic scales through analytical and geospatial support tools that directly address stakeholder questions. Through sustained partner engagement, these user-defined, question-specific tools are designed to provide "actionable analytics"— data mined from diverse sources and placed in context so that it can be acted upon or factored into decisions. In keeping with the design principles of the new model of service development and delivery, NOAA will collaborate with its partners to foster the development of new decision support tools, leveraging existing networks and tools where possible, to create accessible solutions that work across multiple platforms. Wherever possible and appropriate, these tools focus on place-based questions and will focus on consultation, interpretation, and impact-based decision support services (IDSS).

NOAA will take the following actions and required investments will be made to strengthen its decision support tools.

- **Consider Tailored Products:** In conjunction with private sector partners, consider that in an increasingly complex environment, users demand more tailored products and expect consistency and continuity when using NOAA products.
- **Apply State-of-the Science Analytics:** Apply state-of-the science analytics to best integrate and extract the full utility of NOAA data sets.
- **Use Consistent Research-to-Science Delivery Process:** Leverage NOAA Administrative Order NAO 216-115A: Research and Development in NOAA, and funding structures such as the Joint Technology Transfer Initiative (JTTI) to implement a more consistent framework for the "research-to-service delivery" process, to increase the effective incorporation of NOAA research findings into decision support products and services.
- **Expand Training and Education:** Expand the development and delivery of internal and external training and education, to increase the connection between the research question and the stakeholder data, information, tool, and/or service requirements.
- **Place Social, Behavioral, and Economic Science at the Core:** Place social, behavioral, and economic science at the core of decision-support tool design and delivery, to ensure maximum impact and effectiveness. For example, NOAA will incorporate the concept of "context-on-forecast" for multi-day extreme events (such as heat, cold, drought, tropical cyclone remnant rainfall). Providing historical context for extreme events helps convey the relative magnitude of such an event to our constituents' personal, institutional, and societal experience.

MODELING AND PREDICTION

Advances in NOAA's broad spectrum of environmental services necessitate advances in the agency's science and technology to provide integrated weather-water-climate modeling, predictions, and forecasts across a range of time and geographic scales, leveraging opportunities for community development. To accelerate scientific research and modeling contributions, including continuous and sustained community engagement, NOAA established a Modeling Board to engage on all matters of Earth system modeling across the agency's portfolio, including major initiatives such as NOAA's Earth Prediction Innovation Center (EPIC) and Unified Forecast System (UFS).

The Modeling Board guides the agency's modeling systems and processes, including community engagement and agile model improvement ensuring the appropriate connection between NOAA research and operational modeling activities. Further, the Board operates with a collaborative cross-agency approach to achieve the agency's modeling system and research objectives in coordination with the broader community.

NOAA will take the following actions and required investments will be made to strengthen its modeling and prediction capabilities.

- **Coordinate, Leverage, and Economize Investments:** Coordinate, optimize, and leverage resources within NOAA to implement operational requirements, share priorities, reduce redundancies, promote joint programs, and create efficiencies. This includes economizing investments in research and development, and utilizing observations, data assimilation, post-processing, emerging technologies, and high-performance computing.
- **Ensure a Coordinated NOAA Approach:** Provide advice, guidance, and coordination for cross-Line Office modeling strategies and objectives ensuring a coordinated NOAA approach. Develop near- and long-term modeling strategies for the agency that inform the comprehensive modeling systems' annual operating plan and the map for integrated implementation for NOAA operational and research objectives across programs, laboratories, centers, and grant programs. Articulate values and priorities for NOAA modeling that are informed by agency mission responsibilities, the NOAA Science Advisory Board, NOAA Science Council, community partners, and operational systems.
- **Facilitate Community Modeling and Link to Enterprise Modeling Capabilities External to NOAA:** Collaborate with community partners to facilitate a Community Modeling Environment and community-wide strategies and objectives. Improve NOAA's modeling ability by improving the representation of physical, chemical, and biological processes by linking to other enterprise modeling capabilities outside of NOAA.
- **Align Research with Operational Needs:** Address operational and applications requirements through the application of research, technology, and engineering innovations in coordination with community partners.
- **Utilize Artificial Intelligence:** Use artificial intelligence (AI) to detect and identify patterns from big data and to develop efficient modeling solutions. AI refers to those techniques in machine learning and deep learning that will help NOAA automate analysis and extract the full utility of the information contained in large datasets.

RESEARCH AND DEVELOPMENT

NOAA research operates as an integrated, connected, and aligned organization with a shared vision to deliver world-class products. Focusing research on improved process understanding, the innovative development and operationalization of weather-water-climate models, and innovations in derived information products and services, is necessary to meet user needs. NOAA will continue to prioritize mission-driven research agendas to drive the delivery of future agency products and services. We recognize that research and development partnerships are paramount to achieving the outcomes in this Strategy.

NOAA will take the following actions and required investments will be made to strengthen its research and development.[12]

- **Prioritize Mission-relevant Research and Strengthen internal NOAA Collaboration:** Prioritize mission-relevant research and continue fulfilling NOAA's vision of resilient and sustainable ecosystems, communities, and economies. Anticipate future scientific and operational needs, while delivering on current expectations. Consistently apply sound systems engineering approaches to speed the transition to operational systems to realize the value of this applied research and development.
- **Strengthen External Collaboration:** Strengthen external collaboration by leveraging the breadth of expertise across the Department, and external domestic and international communities to improve mission effectiveness. Improve processes and structures that facilitate stronger and more consistent external collaboration expanding the use of existing tools and forums.

NEXT GENERATION OBSERVATIONS AND DATA

To remain on the cutting edge and lead the world in Earth system observations and data dissemination, NOAA must sustain and improve its observing and data dissemination system infrastructure with new technologies while leveraging more observations through innovative public and private partnerships. Through 2030 and beyond, the agency will deploy next generation satellite programs and data processing systems, and other remote sensing and in-situ observation platforms, to include advanced aircraft, ships, and uncrewed systems, which are both affordable and offer leading-edge capabilities in environmental monitoring.

In addition, NOAA leverages the integration of private sector, academic, Federal, and non-profit data to understand and respond to our changing weather, water, climate and coastal conditions. NOAA is committed to expanding and enhancing observations, data assimilation, and data management to improve weather-water-climate modeling and prediction services. The agency will sustain and grow investments in critical observational time series required to establish baselines and track changes, next-generation systems for observation, data management, data integration, and data dissemination, and leverage the latest cloud smart and big data strategies.

NOAA will take the following actions and required investments will be made to strengthen its next generation observations and data.

- **Commercial Partnerships and New Technology:** Leverage increased commercial partnerships and new small modular satellite technology to optimize the operations and procurement of our fleet of environmental satellites that provide critical observations of the Earth and space.

12 Oceanic & Atmospheric Research (OAR) 2020-2026 Strategy

- **Comprehensive Data Management Strategy:** Utilize a comprehensive data management strategy and cyberinfrastructure system that enables the ingest, integration and assimilation of the data, and the dissemination of diverse and distributed data sets, products and services.
- **Data-source Agnostic Common Services:** Implement Data-source Agnostic Common Services using the cloud to grow operational stewardship and science services as well as enhance consumer services.
- **Operations of Remote and In-situ Observing Assets:** Ensure continuous operations with foundational remote and in-situ observing assets, including radar, aircraft, ship, UxS and satellite systems, and adoption of emerging technologies, especially through UxS activities, to reduce costs and improve information.
- **Utilize All Observational Capabilities:** Utilize the broad observational capabilities of the NOAA Enterprise to establish the best possible analysis of the atmosphere, land surface, ocean, and cryosphere to ensure situational awareness, enable enhanced data assimilation, and meet growing user demands.

ESSENTIAL ENABLING CAPABILITIES

NOAA's value chain is supported and sustained by the agency's continued investments in its workforce, research capabilities, new observing and data analytics technologies, advanced data collection platforms, new communications methodologies, and its facilities all of which are needed to address current gaps and keep pace with a rapidly changing environment. Outlined below are agency investments and priorities in the coming years.

- **World Class Workforce:** NOAA will attract, hire, train and retain a world class workforce that is committed to using the best science and technology to ensure mission delivery. The agency's workforce requires advanced skills in scientific and engineering disciplines, as well as the best skills in management, social science, and interdisciplinary work. Steps have been taken and will continue to enhance the NOAA employee experience by creating a culture of belonging, inclusion and diversity. With a substantial percentage of the workforce approaching retirement eligibility, intentional steps are being taken to attract, hire, train, and retain a new generation of diverse professionals to accomplish its mission. Over the coming years the agency will implement comprehensive workforce training and professional development, enable leaders to manage and lead through our ever changing post COVID work environment, and support strong labor-management relations.
- **High Performance Computing (HPC)**: NOAA is and will continue to make critical investments in key capabilities, including HPC, and associated research, operations and maintenance programs. These include significant investments in the Weather and Climate Operational Supercomputing System (WCOSS) by transitioning to WCOSS-2 (increasing operational computing capacity by nearly a factor of 3 by 2022) and investing in the HPC systems of NOAA's research activities and laboratories.

Additionally, NOAA will leverage high performance computing external resources. The NOAA HPC Board provides holistic management promoting balance and efficiency between the HPC needed to develop the next generation of numerical prediction systems and the agency's imperative to deliver numerical guidance operationally.

- **Cloud Computing:** NOAA has and will continue to use the "Cloud Smart'' approach to harness the capabilities of the commercial cloud and internal cloud systems. The agency collects, integrates and uses a formidable amount of data daily to monitor and model complex Earth systems. The cloud provides safe, reliable, redundant, and scalable storage and computing resources for developing applications to continue improved performance and skill. New investments in cloud computing will support improvements in satellite data products and services, numerical weather, water, and climate prediction, coastal and ocean models, big data analysis, storage, and dissemination.
- **Big Data:** NOAA will continue to leverage commercial partnerships, big data projects, and contractual arrangements with commercial cloud providers that set NOAA apart from other agencies in making more of its data publicly accessible. Limits on NOAA's ability to store and process the more than 20 terabytes of daily observational data it collects means innovative partnerships with cloud service providers are well suited to provide free public access to 70+ NOAA datasets and counting.
- **Safe and Sustainable Facilities:** NOAA will ensure its facilities provide modern, sustainable, and safe environments to fulfill its mission successfully and to attract and retain a world class workforce. The agency is currently in the analysis and design phase of developing its 2030 Federal Facilities Footprint. This will ensure optimal alignment of NOAA's facilities with its mission, while consolidating and reducing its footprint into more modern, 21st-century workplaces for its employees. An added benefit will be reduced overhead costs, which will allow for savings to be invested back into the core mission.

Appendix C — NOAA's Weather, Water, and Climate Outputs

This Appendix includes the outputs organized by the six societal challenges. These outputs are the specific actions that the agency will take to achieve the 5-year outcomes. Note that there is no simple one-to-one relationship between each output and outcome, rather they represent a body of work that needs to be completed to achieve the outcomes identified in this Strategy.[13]

FIVE-YEAR OUTPUTS: EXTREME EVENTS & CASCADING HAZARDS

Area	Output
Extreme Heat and Cold	1. Improve extreme heat and cold forecasts, particularly for improving decision support, and deep engagement with vulnerable and underserved communities.
	2. Develop methods and services that place weather forecasts for heat waves and cold waves in context. These services, developed with demographic and socio-economic data from the Census Bureau, other agencies and end users, will convey the relative magnitude of these events in historical context, based on the social science of the personal, institutional, and societal experience(s) of NOAA stakeholders.
	3. Improve modeling and forecasting of urban heat island effects and its impact on air quality, particularly in underserved communities.
	4. Incorporate climate-change science in operational forecasts of extreme heat and cold, in order to improve understanding of extreme event variability and uncertainty in the prediction of high impact events.
Floods	5. Deliver a comprehensive real-time and forecast flood inundation mapping (FIM) capability at the street level for all communities nationwide, to better depict when, where, and how deep flood waters will be for improved Emergency Management decision support before, during, and after an event.
	6. Better inform decisions in support of interagency forecast informed reservoir operations (FIRO), e.g., DOI/USGS, DOI/BoR, FEMA, USACE, to more effectively balance flood and drought risk while maximizing water availability for environmental flows and consumptive uses.
Droughts	7. Deliver regional drought early warnings and forecasts, covering weather-to-climate timescales, for communities and economies across the country by expanding and enhancing the interagency National Integrated Drought Information System (NIDIS), and the many NOAA activities that support improvements in drought information.

13 All NOAA actions will be taken within the context of NOAA Administrative Order 216-112: Policy on Partnerships in the Provision of Environmental Information, providing opportunity for feedback and engagement on potential impacts to external entities or opportunities for collaboration.

Area	Output
Droughts	8. Leverage the Unified Forecast System to provide skillful and reliable prediction of drought onset, intensity and duration through improved modeling of land surface and ecosystems, land-atmosphere interactions, coupled data assimilation of ocean, atmosphere and land conditions, and drought impact information. (with partners)
	9. Develop a holistic methodology for accurately capturing the full economic cost of drought beyond the agricultural sector.
	10. Within 10 years, leverage the UFS-based, integrated earth prediction system to deliver experimental multiyear to decadal predictions of the influence of climate change on drought conditions resulting in increased wildfires, post-fire flood risk, debris flows, and water quality for environmental flows to support recovery of listed and endangered fish.
Wildfire	11. Understand the sources of predictability of fire weather, including associated climate phenomena (e.g., ENSO, MJO, droughts), on seasonal, interannual, and decadal timescales, and provide skillful S2S Probabilistic Fire-Risk forecasts and retrospective summaries so that decision makers can evaluate past decisions about assets and seasonal posture.
	12. Incorporate the impacts of wildfire on snowpack properties/evolution and soil hydraulic behavior, and their associated effects on infiltration, runoff, streamflow prediction, and debris flow formation into the NextGen National Water Model.
	13. Integrate fire behavior observations, modeling, and meteorology to better forecast the spread of fire, providing improved short-range, hourly fire forecasts, and explore extending the range of fire and smoke forecasting through the inclusion of forest and ecosystem features with agency partnerships. Test new concepts and forecast techniques leveraging test bed environments and evaluations.
	14. Utilize artificial intelligence and machine learning algorithms to vastly improve early detection of wildfires from satellite data, meeting a long-standing need by the wildland fire community for timely detection and notification of newly ignited wildfires within critical fire environments that support extreme fire behavior.
	15. Accelerate the research, development, and transition to operations of NWS forecasting capability for impacts of wildfires on air quality to support improved community decisions for resulting hazards, which disproportionately impact underserved and vulnerable communities. The project will accelerate development and transition of a new high-resolution forecast capability enabled by the coupled high-resolution Rapid Refresh Forecast System (RRFS) and Community Multiscale Air Quality Modeling System (CMAQ).
	16. Establish infrastructure to prepare for a fire weather testbed: implement Cloud computing framework for shared development, investigate infrastructure needs including data sets, products, tools, hardware that are need to enable cross-agency development and testing, and perform user-assessment to collect requirements that would provide an initial set of products for testing

Area	Output
Precipitation Extremes	17. Advance the physical process understanding of extreme precipitation, improve extreme precipitation prediction, and expand operational prediction information for decision makers to improve the nation's resilience to extreme precipitation events.
	18. Improve the skill of 7-day precipitation forecasts by 15%, through the development and implementation of NOAA's full Earth system-prediction capabilities, to provide improved precipitation products for critical applications.
	19. Produce probabilistic precipitation forecasts that are sufficiently calibrated to better represent extreme events, including reasonable worst case scenarios, to better communicate the likelihood of high-impact events and support critical risk management decisions.
Coastal Storms	20. Define, expand, operate, and sustain targeted ocean observation systems for hurricane forecasting. These systems will be continuously coordinated and deployed using an evidence-based approach that supports the highest priority R&D and operational needs.
	21. Leverage subseasonal to seasonal (S2S) hurricane risk forecasts to inform NOAA's seasonal-annual sea level rise and coastal flood risk predictions.
	22. Develop improved forecasts of the magnitude, frequency and duration of storm surge and coastal rainfall, which account for sea level rise, relying on robust probabilities from NOAA observations and models. These forecasts will be provided in context – assessing annual storm patterns, tracking for trends – based on the social science of the personal, institutional, and societal experience(s) of NOAA stakeholders.
	23. Develop joint probabilities between heavy-rain and storm-surge events along U.S. coastlines, using observations and models (e.g., in hindcast or synthetic simulations under current or future climates).
Tornadoes	24. Expand the use of in-situ observations to advance the physical process understanding of tornadoes for improved modeling and prediction.
	25. Demonstrate threat grids and deliver warn-on-forecast capability from minutes to hours by leveraging the Forecasting a Continuum of Environmental Threats (FACETS) framework.
	26. Incorporate next-generation technology into the national radar network.
Marine Heat Waves	27. Develop a Marine Heatwave Forecast System, to provide operational forecasts, based on improved understanding of the sources of predictability for marine heatwaves on subseasonal to decadal timescales, and exploit these sources of predictability in marine models.
Cascading Hazards	28. Ocean Heat-Precip-Water - Enhance monitoring and modeling of 4-dimensional marine conditions (space and time) in key tropical and extratropical regions of the ocean for the prediction of drought and extreme precipitation.

Area	Output
Cascading Hazards	29. Heat-Drought-Debris Flow-Water - Provide skillful and reliable seasonal to interannual predictions of a) drought onset, duration, intensity, and termination, b) frequency of extreme heat events, c) frequency of extreme precipitation events, d) snowpack evolution, and e) fire weather potential to guide enhanced debris-flow early warning hazard risk assessments, and water management activities such as FIRO.
	30. Heat-Drought-Wildfire - Provide skillful and reliable predictions at all time scales, for enhanced planning and early warning of a) flash drought, b) extreme heat, c) extreme precipitation, d) snowpack runoff, and e) fire weather potential for emergency managers to strategically preposition and manage resources during wildfire emergencies.
	31. Precip-Flood-Water Management - Provide enhanced weather timescale forecasts (minutes to days) of extreme precipitation duration and intensity to inform debris flow and flood forecast, watch and warnings, and water management activities such as FIRO.
	32. Provide enhanced forecasts from the National Water Model of soil saturation, infiltration, runoff, and streamflow as hydrologic forcings[14] for flash floods, debris-flow early warning, and FIRO.
	33. Precip-Water Quality- Marine Ecosystem - Advance total water prediction to inform living marine resource management practices in rivers, lakes, bays, estuaries, and other coastal environments. Provide enhanced decision-support services to maximize availability of water for environmental flows, while balancing flood and drought risks, in support of habitat restoration and species recovery. Provide enhanced decision support for effectively minimizing the impact of freshwater releases from riverine flood events on coastal marine resources, including commercial fisheries, habitat restoration efforts, and protection of endangered and threatened species recovery. Advance process understanding of the multiple factors affecting commercial fisheries, estuarine ecosystems and coastal marine productivity to guide resource management decisions that can alleviate overall impacts. Produce assessments that provide probabilistic estimates of the risk for freshwater events impacting the coastal environment to inform policy and planning strategies.
Tipping Points	34. Provide integrated regional assessments of risk and ecosystem resilience to anticipate and mitigate the impacts of cascading events and of exceeding critical thresholds due to environmental and human stressors.
	35. Provide remote sensing products to monitor and identify rapid transitions in environmental conditions in communities nationwide.

14 Hydrologic forcings are defined as observed and forecast environmental conditions and variables used to initialize hydrologic models.

FIVE-YEAR OUTPUTS: COASTAL RESILIENCE

Area	Output
Coastal Oceanic Modeling	1. Deliver a complementary suite of operational coastal oceanographic modeling, as appropriate, for coastal open ocean and coastal wave and sea state, marine weather (e.g., wind, tides, coastal flood hazards to support port operation, etc.). These include storm surge, sea and freshwater ice extent, nearshore currents, erosion hazards, water temperature and salinity, concentrations of dissolved oxygen and macronutrients (i.e, nitrate and phosphate), and harmful algal blooms.
Observational Infrastructure	2. Define, expand, operate, and maintain the necessary suite of observational infrastructure which are required to support the modeling envisioned above, leveraging regional, state, federal and private sector partnerships as appropriate. This will include high resolution nearshore bathymetry, water level, waves, shoreline change, wetland delineation, modernization and maintenance of the National Spatial Reference System, and observations of meteorology and nearshore ocean circulation (temperature, salinity, currents, turbidity, macronutrients, dissolved oxygen, etc.) using various data collection platforms.
High resolution Topographic and Bathymetric	3. Collect, integrate and disseminate comprehensive, high-resolution topographic and bathymetric information to significantly expand the National Bathymetric Source, the definitive bathymetric digital elevation model for the United States.
Consistent Coastal Water Level Variability Predictions	4. Create nationally consistent, 2-dimensional gridded estimations of the probabilities of coastal water level variability, including integrated monthly-to-annual outlooks of the probabilities of coastal inundation, and national gridded projections of mean and extreme sea level probabilities, and lake level variability, out to 2100. Projections will consider changes in relative and global mean sea level or lake level including satellite measurements of land subsidence. Provide scenarios of coastal hazards compounded by rising sea levels and associated changes in tidal flooding impacts.
Develop Research, Observations, and Modeling Capabilities	5. Develop the research, observations, and modeling needed to skillfully project physical, ecological, and biogeochemical change due to sea level rise, a warming ocean, and other environmental change at the coast, inclusive of possible human made interventions. This will include natural and nature based interventions applicable to specific coastal environments under local conditions (e.g., tropical islands, Great Lakes shorelines, etc.)
Community Based Adaptation Specialist Training	6. Implement a national program, building on existing NOAA programs, to train community-based adaptation specialists and extension agent networks on availability and delivery of NOAA tools, products, training, and services at the coast. When faced with requests for information services, NOAA will explain existing NOAA services, including their uses and limitations, and inform the requester that others in the environmental information enterprise may be able to meet the requester's needs.
Integrated Web-based Dissemination Interface	7. Create an integrated web-based framework and a prototype dissemination interface with necessary backend infrastructure in existing coastal applications. This will leverage existing NOAA equities, including NCEI and the Big Data Program, and represent a uniform and consistent data services framework that meets the needs of both internal and external data users and modelers.

Area	Output
Expand Marine Blue Economy Statistics	8. Continue to support and expand statistics that quantify the value of the major sectors of the marine blue economy through NOAA's Economics: National Ocean Watch program and the joint NOAA-BEA Marine Economy Satellite Account, to measure progress and inform investments in the blue economy.
Develop Coastal and Ocean Normals	9. Develop a comprehensive set of coastal and ocean normals and other key indicators of environmental change, similar to those used for terrestrial climate and weather, leveraging its historical records and data as well as its operational tracking, monitoring, and assessments of coastal conditions.
Five-year Natural Infrastructure Initiative	10. Complete a specific new five-year natural infrastructure initiative for protecting and restoring the natural infrastructure provided by coastal habitats.

FIVE-YEAR OUTPUTS: THE CHANGING OCEAN

Area	Output
Nowcasts and Forecasts to Generate Economic Benefit and Improve Safety	1. Supply skillful, comprehensive ocean, sea ice, atmosphere and wave nowcasts and forecasts, to generate economic benefit, improve the safety and cost-effectiveness of the Nation's marine transportation sector, sustainably manage living marine resources, and facilitate decisions in challenging coastal environments, particularly in the Arctic. Nowcast and forecast skill will be maximized through the integration of transformative observational technologies, including uncrewed observational platforms (UxS), non-traditional, low-cost in-situ moored or drifting sensors and advanced satellite-based approaches.
Improved Ocean Physics Models	2. Provide improved ocean physics models that better represent the mass and energy of the global ocean and its integral role in driving Earth, ocean, atmosphere, cryosphere coupled models, resulting in improved weather, ocean, sea ice, and climate forecasting and applications.
Expand Ocean Observations and Improved Data Assimilation	3. Expand observations of the ocean and improved data assimilation into ocean models, specifically for observations of the air-sea interface, including remotely sensed and in-situ observations, particularly for adaptive sampling to optimize the geographic deployment of observing resources over the ocean.
Integrated Satellite Marine and Ice Information	4. Provide integrated satellite marine and ice information in polar regions to enable safer marine transportation and operation in polar waters and to allow for efficient emergency response.
Expand Ocean Remote Sensing and In-situ Monitoring	5. Expanded remote sensing and in-situ monitoring for regionally-optimized ocean ecosystem and biogeochemical observations.

Area	Output
Create Robust Indicators	6. Create a robust set of indicators that track and provide early warnings for changes in the ecological, social and economic sector conditions and value.
Create Robust Statistics	7. Create a robust set of statistics at appropriate scales that depict and value the major sectors of the marine (blue) economy to measure progress and inform investments in the blue economy.
Provide Ocean Normals and Key Change Indicators	8. Provide ocean normals and other key indicators of environmental change, similar to those used for terrestrial climate and weather, leveraging its historical records and data, including consistent long-term time series for satellite data, as well as operational tracking, monitoring, and assessments of ocean conditions. Extend the entire satellite data record over the period 1982 through the present.
Build end-to-end Ocean Modeling and Decision Support System	9. Build an end-to-end ocean modeling and decision-support system to provide living marine resource managers with climate-informed risk assessments and management strategies for effective management of living marine resources in a changing climate (NOAA Climate and Fisheries Initiative).
Tools for Adaptation Planning	10. Provide fishing-dependent sectors and communities with new information, tools and services to develop and implement adaptation plans for changing ocean and marine resources.
Strengthen Monitoring	11. Strengthen monitoring of National Marine Sanctuaries, Monuments, and other protected areas to support resilient, thriving marine and coastal ecosystems, support responsible recreation and tourism, and educate and inspire people around the world.
Ocean Technologies and Exploration	12. Expand NOAA's commitment to innovative ocean observation technologies and ocean exploration, including the deep ocean, to improve ocean understanding, promote more effective management, and reveal new social and economic opportunities and maximize the potential of the U.S. blue economy.
Oceanographic and Socio-economic Information	13. Develop oceanographic and socio-economic information necessary to expand carbon mitigation activities in coastal and offshore waters, to support quantitative economic approaches to carbon emissions control, such as carbon credits or markets.
Aquaculture Framework	14. Create a comprehensive national aquaculture framework, to foster sustainable, productive aquaculture-based industries and economies.

FIVE-YEAR OUTPUTS: WATER AVAILABILITY, QUALITY, AND RISK

Area	Output
Equitable Water Service Delivery	1. Define audiences, terminology, and approach for equitable service delivery. Build and sustain relationships in disadvantaged and underserved communities to gather and understand user needs in the context of their decisions; review and translate into the capacities needed to respond; assess and prioritize product and service development; evaluate impacts; and enhance products services.
Comprehensive and Real-Time Flood Inundation Mapping	2. Deliver a comprehensive, real-time and forecast flood inundation mapping (FIM) capability for a wide range of applications, expanding NOAA's FIM services from 300 miles of rivers and streams to over 3.4 million miles, specifically reaching previously underserved communities. These applications will better depict when, where, and how deep flood waters will be for improved Emergency Management decision support before, during, and after an event; and for natural resources management, will address the intersection of aquatic resources (wetlands) and events that connect streams and rivers to these wetlands.
Common Digital Elevation Models to Improve Hydrologic Prediction	3. Collect, and process, integrate, and disseminate comprehensive, high-resolution, topographic and bathymetric, impervious surface, and hydraulically-relevant feature data such as flood walls, structures and embankments, into common digital elevation models to profoundly improve the accuracy of hydrologic prediction, enable hydraulic modeling capabilities, and improve the accuracy of FIM capabilities.
Coastal Modeling Capabilities, Particularly for Underserved Coastal Communities	4. Deliver coastal modeling capabilities, particularly in previously underserved coastal communities, that provide: (1) Total Water Prediction along the coastal boundaries for FIM applications; (2) Coupled riverine and coastal modeling systems (wind, coastal, and ice) that better account for fresh and saltwater contributions to surface and subsurface applications supporting enhanced predictions of coastal and estuarine processes.
Temperature, Salinity, and Turbidity Initial Water Quality Prediction Capabilities	5. Deliver initial water quality prediction capabilities for water temperature, salinity, and turbidity in rivers, lakes, bays, estuaries, and sounds to (1) better inform decisions related to ecosystem, habitat, and species management and water supply; (2) better represent surficial aquifers that impact streamflow generation; and (3) provide an extended-range ensemble capability to address water temperature prediction.
Hydrological Ensemble Forecast Services	6. Deliver Hydrologic Ensemble Forecast Services (HEFS), leveraging improved seasonal to subseasonal, weather and climate forecasts, at all applicable stream gage locations nationwide. These services will include improved quantification of risk and uncertainty in streamflow forecasts from the NWS River Forecast Centers on scales of hours to seasons and longer, including improved seasonal volumetric water supply forecasts in the West and for previously underserved communities in the Southeast. This will expand the application of HEFS to water supply questions across the nation, and improve skill for critical forecast points necessary to accurately characterize the relationship between streamflow, flood, and drought.

Area	Output
Evolve NextGen National Water Model	7. Evolve the Next Generation of NOAA's National Water Model (NextGen NWM) to improve overall forecast skill. NextGen NWM will include model components that better account for process dominance and land surface variability, as well as the development of a community standards-based software framework that facilitates collaboration, accelerates development, and promotes interoperability of hydrologic, hydraulic, water quality, and coastal hydrodynamic models using an open source software development paradigm.
National Water Center Full Operating Capability	8. Achieve the Full Operating Capability for the National Water Center to deliver 24 hours a day, 7 days a week providing an integrated common operating picture and decision support services for water resources, across NOAA and partner Federal agencies.
Revise Precipitation Frequency Atlases	9. Update and Revise Precipitation Frequency Atlases for the United States including Probable Maximum Precipitation, which account for climate change, and make these data publicly available. These updated atlases will benefit from a study on the state of practice and research needs for precipitation estimation, including probable maximum precipitation estimation, conducted by National Academies of Science, Engineering, and Medicine and consultation with relevant partners.
Subseasonal and Annual Integrated Water Capabilities	10. Build out Subseasonal to Annual Integrated Water Capabilities by developing new techniques and analysis which will enable NOAA to produce coastal water level information, both means and extremes, at subseasonal to annual temporal scales. This new information and related services will enable the nation to quantify and communicate the impacts of longer-term inundation due to sea level rise, high tide flooding and Great Lakes water level fluctuations.
Subseasonal to Decadal Integrated Water Capabilities	11. Build out Subseasonal to Decadal Integrated Water Capabilities by developing new techniques and analysis which will enable NOAA to produce coastal water level information, both means and extremes, at subseasonal to decadal temporal scales. This new information and related services will enable the nation to better assess the impacts of longer-term inundation due to Great Lakes water level fluctuations, sea level rise and high tide flooding.

FIVE-YEAR OUTPUTS: EFFECTS OF SPACE WEATHER

Area	Output
Space-base Observational Infrastructure	1. Build, operate, and augment the necessary space-based observational infrastructure required for short-term and long-term predictions of space weather including continuity of solar wind measurements, and new imagery of the solar corona.
Sun-Earth System Coupled Modeling Continuum	2. Build a coupled modeling continuum of the sun-Earth system, that addresses solar wind, impact on Earth's magnetic field, and impacts on the upper atmosphere.
Space Traffic Management Capabilities	3. Develop new, operational observation capabilities for space traffic management, including specifically, measurements of thermospheric density, and the capacity to assimilate those measurements into operational models.

Area	Output
Ground-based Geomagnetic Measurements and Neutron Monitoring	4. Build and sustain partnerships with the public and private sector for ground-based geomagnetic measurements and neutron monitoring.
Integration of Commercial Space Weather Data	5. Obtain, validate, and demonstrate the integration of commercial space weather data from commercial sector providers into NOAA's operational space weather models.
Space Weather Prediction Testbed	6. Establish a Space Weather Prediction Testbed and associated community R2O2R Framework to increase coordination of space weather research-to-operations (R2O) and operations-to-research (O2R), and also operations to service delivery –producing applied products that meet societal needs.
Space Weather Products and Services	7. Continue to build and sustain partnerships with end-users to evolve space weather products and services to help in the development of plans and procedures for responding to and recovering from space weather events.
Satellite-based Broadband Internet and GPS Access	8. Increase satellite-based broadband internet and GPS access by strengthening NOAA's investment in new space weather platforms in collaboration with commercial providers.

FIVE-YEAR OUTPUTS: MONITORING AND MODELING FOR CLIMATE CHANGE MITIGATION

Area	Output
Greenhouse Gas observation and Modeling Capabilities	1. Develop GHG observation and modeling capabilities with NOAA domestic and international partners to reliably track changes in natural and human-made GHG emissions and sinks over time and at local, regional, continental, and global scales. Ensure the quality and necessary scientific stewardship of in situ and remotely sensed data sets from NOAA and partner observing systems.
Models, Tools, and Products for Climate Mitigation	2. Be a reliable provider of models, tools and products for decision makers to determine the feasibility of achieving climate mitigation targets, taking into account anthropogenic emissions, ocean fluxes, and feedbacks in the earth system, and to evaluate the broader climate implications of various mitigation measures.
Quantification of Key Emission Sources Products and Services	3. Deliver products and services that improve quantification of key emission sources to help decision makers at various scales identify important mitigation opportunities. Such sources include GHG emissions from urban sources, from the land-use and agricultural sectors, methane leaks from industry, and small quantities of potent GHG emissions from niche applications.

PHOTO CREDITS

FRONT COVER

Single cell thunderstorm cloud to ground strike with impressive illuminated structure. Photo credit: NOAA Photo Library, (Joseph Brown, NOAA Weather in Focus Photo Contest 2015).

Bird Island, Saipan. Commonwealth of Northern Mariana Islands, Saipan. June, 2006. Photo credit: NOAA Photo Library, (David Burdick).

Independent meteorologist provides support to the fire community. Photo credit: National Weather Service Twitter, (January 11, 2016).

An iceberg captured on camera during a 30-day mission in 2012 to map areas of the Arctic aboard the NOAA Ship Fairweather. Photo credit: NOAA Photo Library, NOAA's National Ocean Service.

A school of anthias (Pseudanthias bartlettorum) and a school of white tip sharks at Jarvis Island. Photo credit: NOAA Photo Library, (NOAA/NMFS/ Pacific Islands Fisheries Science Center Blog, Kelvin Gorospe).

Artist's rendering of the GOES-R spacecraft in orbit with Earth in the background. Photo credit: NOAA Photo Library, NOAA/Lockheed Martin.

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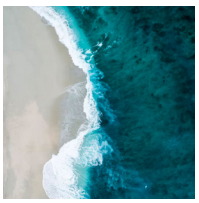
PAGE 10. A collage of typical climate and weather-related events: floods, heatwaves, drought, hurricanes, wildfires and loss of glacial ice. Photo credit: NOAA.

PAGE 10. A tornado churns up dust in the sunset light near Traer, Iowa by Brad Goddard, Orion, IL. Photo credit: NOAA



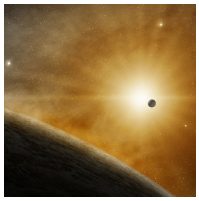
PAGE 16. National Coastal Zone Management Program. Photo credit: NOAA Office for Coastal Management.

PAGE 20. Gulf Salt Marsh. Photo credit: NOAA Fisheries.

PAGE 21. A buoy collecting data on the carbon cycle and the role of the ocean in climate. Photo credit: NOAA Global Ocean Monitoring and Observing Program.

PAGE 25. Unmanned Ocean Gliders Head to Sea to Improve Hurricane Prediction: Partners are Helping Boost Ocean Data Photo credit: NOAA/ CIMAS/ S

PAGE 26. A wide view of Idaho's Hells Canyon reservoir in drought, showing a dry shoreline and receding waterline.
Photo credit: NOAA.



PAGE 30. Sun glowing in deep space. Photo credit: NOAA.

PAGE 33. Methane is flared from a Bakken Field well site in North Dakota (2014). Photo Credit: NOAA/ CIRES, (Jeff Peischl).

PAGE 36. As Arctic tundra warms and thaws, incursions of shrubs and small trees have created new habitat for beaver, which create ponds and wetlands that further transform the once-frozen landscape. Photo credit: NOAA, (Courtesy of Kenneth Tape/University of Alaska Fairbanks Geophysical Institute).

BACK COVER

A Colorado rainbow and rainshaft observed while on College of Dupage's Storm Chasing Trip 3. Photo credit: NOAA Photo Library, Jared Rackley, NOAA Weather in Focus Photo Contest 2015.

NOAA Ship FAIRWEATHER in Glacier Bay. Photo credit: NOAA Photo, Crew and Officers of NOAA Ship FAIRWEATHER.

NOAA's Satellite Operations Facility in Suitland, Maryland.
Photo credit: NOAA Photo Library, NOAA Satellites.

NOAA Corps.
Photo credit: NOAA, (Tim Smith).

A magnificent photo of sea, swell, sky, and a monk seal swimming over a coral reef bottom. Photo credit: NOAA Photo Library, NOAA/PIFSC/ HMSRP.

NOAA'S WEATHER, WATER, AND CLIMATE STRATEGY