National Oceanic and Atmospheric Administration
Strategic Research Guidance Memorandum
FY2024

The National Oceanic and Atmospheric Administration (NOAA) maintains a robust research and development (R&D) portfolio that enables the Agency to:

- Understand and predict changes in climate, weather, oceans, coasts, and space;
- Conserve and manage coastal and marine ecosystems and resources; and,
- Share and disseminate knowledge and information with the public.

To accomplish these goals, NOAA brings together the best R&D from internal and external organizations and transforms that R&D into operations, applications, policies, and commercial products that create value for the public. NOAA's R&D activities also form the basis for the agency's commitment to build a scientifically literate public, ready to adapt to a changing environment through the best available science, as well as enabling the preparation, recruitment and training of the future NOAA workforce. NOAA's mission is a marvelous attraction and inspiration for STEM students, as well as the many additional areas of talent needed to support the science mission. Strategic engagement and partnerships with educational organizations such as our Cooperative Science Centers, Cooperative Institutes, and Sea Grant Institutions, as well as commercial and private entities contribute to and use NOAA R&D for the advancement of NOAA-relevant science, technology, engineering and modeling. These are tools and opportunities to advance the equitable preparation, recruitment, and development of the future NOAA workforce.

NOAA's Administrative Order on Research and Development (NAO 216-115A)[1] defines the process and principles that guide the planning, execution, and evaluation of NOAA's research and development (R&D) portfolio. Section 5.03 of that NAO requires the Chief Scientist, through consultation with the NOAA Science Council, to issue a Strategic Research Guidance Memorandum highlighting areas of R&D that merit special consideration in budget formulation.

The research portfolio of NOAA can be defined by the long term missions which are documented in NOAA's organic origin and subsequent laws. These missions define the purpose of the agency, but do not limit our methods of pursuing them. The vision and innovation of our scientists and extramural colleagues, the state of technology, plus new and emerging opportunities and priorities are open doors to enrich the R&D portfolio. Pursuing and implementing an Earth Systems approach in all of our work is a clear priority throughout and needs to be a foundation of our R&D portfolio, ensuring a fully integrated and comprehensive approach to our mission. Among the emerging priorities are those of the Administration, which are to address the Climate Crisis, providing services to all members of the public in every

[1] NAO 216 115A
http://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-115.pdf

community on an equitable basis, and contributing to the economy to build back better and sustainably. The Under Secretary for Oceans and Atmosphere, Dr. Spinrad, has further refined these priorities addressing NOAA's expertise to:

> • Establish NOAA as the U.S. federal government **authoritative source for climate** products and services;
> • Advance **economic development** without sacrificing **environmental stewardship**, with a particular focus on advancing the **New Blue Economy**; and,
> • Integrate **equity** into everything we do, including our science, and how we build and provide services.

Within NOAA, we will promote diversity, equity, inclusion and accessibility in the workforce. Externally, we will provide equitable access to our products and services. The R&D portfolio should reflect these values and objectives as the agency prepares our submission for consideration in the FY24 President's Budget Request.

The innovation of our scientists and extramural colleagues has generated opportunities and paths for us to pursue, defined in the products of our Councils and Boards, including the Climate Council, Science Council, Weather Water and Climate Board, Fleet Council, and Oceans and Coasts Council. The NOAA Science Advisory Board and other Federal Advisory Committees have given focused recommendations to NOAA, and should be heeded and considered in budget planning. Attend to the current science and technology (S&T) focus areas[2], the harmonization of modeling infrastructure as used in the Unified Forecast System, the Precipitation Grand Challenge, Climate and Fisheries Initiative, and other internally driven advancements. Consider the interdependencies of these initiatives and do not take them up in isolation. Link the observation needs with process studies and analysis, and with the modelers. Link and coordinate the land, ocean, and air observation missions. No profound advancement will succeed in isolation, and NOAA's most successful innovations involve multiple Line Organizations. Plan accordingly for success.

This is an active Appropriation season. We stand with a Continuing Resolution for FY22, ready to further develop FY23 for the President's Budget Request, and begin the earnest consideration of what needs we have for FY24. We have seen the passage of the Disaster Supplemental and the Bipartisan Infrastructure Law which provide much funding to the NOAA mission. We have defined spend plans for these and must take into account what has been gained in those Appropriations as we contemplate FY24 formulation. Similarly, we should consider what may come further in the supplemental process commonly described as the Build Back Better initiative. Any FY24 request should consider how the stated needs stand in relation to these existing or expected Appropriations.

This Strategic Research Guidance Memorandum does not intend to mention every element of the NOAA R&D portfolio, nor to discourage sustained investment in the existing portfolio. The Memorandum provides guidance in areas that warrant additional focus, advancement, and/or

[2] NOAA Science and Technology Focus Areas. Available here: https://sciencecouncil.noaa.gov/NOAA-Science-Technology-Focus-Areas

investment in the view of the acting Chief Scientist, after consideration of the constructive input from the NOAA Science Council, with senior representatives from every Line Organization. This is intended to be guidance, and not replace the many tools NOAA has to define and support budget justifications.

Research Priorities

To determine R&D priorities, researchers, technology developers, and managers at all levels of the Agency should review their current portfolios in light of the principles articulated in NAO 216-115A[3] and the NOAA R&D Vision Areas: 2020-2026[4].

1. Authoritative Source of Climate Products and Services.

Climate Crisis
Climate change is stressing the traditional balance of the Earth system. Warming has caused the Arctic to warm faster than any other place on the planet. Increased water vapor in the atmosphere from a warmer ocean brings more rainfall in tropical cyclones and storms impacting coastal and inland areas. Marine heat waves cause meteorological and biological disruption. The oceans' ecosystems and associated food web dynamics are deconstructing in ways far beyond latitudinal migration. Drought, wildfire, tornados, hurricanes all are changing in distribution, intensity, and frequency. Research investments in these areas have brought marked improvement in forecasting and further investment will advance forecast skill. As climate change disrupts our traditional understanding, we need to discover anew the likes of a future marine ecosystem, or the future high latitudes - Arctic and Antarctic. These require investment internally and in the extramural community. Science to support climate services and information is necessary.

Extreme Events
The toll in lives and property from wildfires rivals that of hurricanes. Improving wildfire forecasts from the daily incident scale, to the seasonal and inter-annual scale is necessary for community planning and preparation. Fire behavior models and tools for the Incident Meteorologists save the lives of local citizens and firefighters. Air quality impacts from fire degrades public health and is not completely understood. Properly funding the Fire Weather Testbed research activities and planning for the transition to operations of the resulting products will better prepare the nation for the increase in fire weather extremes. Blend these needs with global and regional scale weather and climate models to incorporate and advance fire prediction, behavior, and determine climate impacts.

Hurricane forecast improvements have not reached the potential envisioned by the Hurricane Forecast Improvement Project owing to a loss in steady funding. Funding to continue the original Hurricane Forecast Improvement Project path of success is necessary. Now that an uncrewed vessel has been proven to make surface observations in the eye of a hurricane, pursue the expansion of the hurricane picket line concept. Supplemental funding is an unreliable basis for

[3] Ibid.
[4] NOAA R&D Vision Areas: 2020-2026. Available here: https://repository.library.noaa.gov/view/noaa/24933.

extreme weather impacts, including tornado research, atmospheric rivers, droughts, and other extremes, on land and in the ocean and Great Lakes. Investments in severe weather forecast improvement, including defining and eliminating the cause of the "drop-outs" of the 500 mb Correlation Coefficient, are overdue.

Advance the use of Satellite Data
The satellite derived information that NOAA collects in the present and forthcoming satellite systems (GEO-XO) is necessary for weather, climate, atmospheric and ocean integrated forecasts. The wealth of data from these systems needs to be further exploited and applied to improve the assimilation of satellite observations in NWP and ecosystem models – including Earth System models, to blend the satellite and *in situ* observations for process studies and assessments, and to learn new methods of application for the data collected (e.g. AI techniques) for early detection of extreme events and hazards.

Climate Relevant Modeling
NOAA's expertise in modeling of the atmosphere, ocean, cryosphere, land, hydrologic cycles, and the chemistry of the atmosphere will continue to lead in providing the best climate outlooks and information to the American people. Further investment in each of these areas is the path to defining the extent of the Climate Crisis by understanding the future state, including the development and interpretation of sector specific climate futures to support economic growth.

Proper coordination of investments and programmatic direction should be aligned between the Seasonal Forecast System objective and the current seasonal-to-centennial fully coupled research model, SPEAR, and the continued work to produce translating wrappers from the Flexible Modeling System to the Unified Forecast System. Determining how to translate the advances of an energy conserving model that covers both weather and climate timescales into operations is upon us, timely, and necessary. Further coordinated work on Data Assimilation improvements and historical reanalysis and reforecast for multi-decades are needed for model calibration. Proving seasonal forecast products by post-processing methods can be accelerated with Machine Learning. Relying on the proven paths of peer-vetted models, quality data assimilation and initialization, quality control of model simulations and forecasts, and dissemination of forecasts through the social sciences will continue to build this enterprise.

Sub-seasonal to seasonal prediction
Across the NOAA mission portfolio the subseasonal to seasonal timescale has emerged as a compelling period of forecast need for multiple users and constituencies from water managers, to emergency managers, to the fishing industry, transportation, agriculture, financial futures, and many other markets. While captured in the authorizations for the National Integrated Drought Information System and in the Weather Research and Forecasting Innovation Act, the timescale is important to many additional mission applications including the ocean future in subseasonal to seasonal to decadal ocean predictions, captured in the Climate and Fisheries Initiative. The dynamics of fishery and ecosystem management are increasingly influenced by climate change, beyond traditional recruitment and harvest rates. Understanding the dynamics and forecasting the future marine ecosystem can realize solutions for ocean sustainability, but also inform coastal communities of their economic future. These are all timely and beneficial investments.

Precipitation
Precipitation prediction improvements largely stalled compelling investments in improving hydrologic models including by not limited to the National Water Model. The NRDD has over 200 hydrology research projects in the database and the relationship to advances in the National Water Model from these activities needs to be defined and best utilized. From sub-hourly to seasonal time scales, the Precipitation Prediction Grand Challenge (PPGC) Initiative defines the goal of increasing the improvement rate of precipitation forecasts skill from 15% to 30% per decade. This ambitious but appropriate undertaking will involve working across multiple organizational levels and is well planned. It needs to be resourced with a sustained budget.

Total water and flood inundation mapping
NOAA will deliver version 3.0 of the National Water Model in FY23 including an Integrated Water Prediction capability to provide total water level forecasts along the coastal and inland waterways where storm surge, tides, wave run-up, and riverine flooding cause inundation. This will link STOFS (Surge and Tide Operational Forecast System) model output with P-SURGE (Probabilistic Tropical Storm Surge) forecast products when and where available. But the development of this linked probabilistic total water level forecast requires significant additional research including post-processing to quantify and mitigate the uncertainties that arise from meteorological inputs and from coupled coastal and inland process models.

Near-real-time national flood maps derived from integrating various satellite and aerial observations are valuable to river forecasters and decision makers for disaster monitoring and relief efforts. Research, development and demonstration are needed to deliver a flood inundation mapping (FIM) and forecast capability at the street level for all communities nationwide to depict location, time, duration and depth of flood waters.

Insurers and infrastructure related industries and governments need the future state of flood and water levels in order to prepare and inform proper infrastructure investments. Knowing the current state of flooding during or just before and immediate event is equally important as knowing the flood potential and likelihood, decades in advance and science is necessary to product both at a scale useful to the wide community of users. Make these investments.

(Some of this work is funded in the Bipartisan Infrastructure Law passed in 2022; any additional need should be clarified against amounts already appropriated.)

Polar Considerations:
Arctic
The Arctic is rapidly warming and warrants further focused study from new observing systems, global GHG effects and feedbacks, decreased snow cover and surface albedo, and the many changes noted in the 2021 Arctic Report Card. Today, NOAA can only cover half of the Arctic for study, from the Pacific approach. For years, the Arctic has eluded appropriate agency prioritization. NOAA's Arctic research priorities align with the 2022-2026 Interagency Arctic Research Plan and the goals of the US Arctic Research Commission. NOAA has an important role to respond to Arctic challenges through innovative research and monitoring including establishing an Arctic GOOS. NOAA should expand Arctic science in collaboration with other

participating agencies and nations, and determine the necessary funding, tools and methods.

Antarctic

The Southern Ocean and the Antarctic play an outsized role in the global climate system and despite ongoing efforts, remain under-observed. Carbon flux of the region remains unquantified. Understanding the land and sea ice cover, ocean, and atmospheric variations and their impact on the Earth's climate system require strategic research in multiple areas from rehabilitating and raising the NOAA Laboratory at the South Pole, to better measuring and understanding the variations in Antarctic krill populations that support large components of its the marine ecosystem, consistent with the demands of Earth System science and international treaty obligations.

Ocean Research and the UN Decade of Ocean Science for Sustainable Development

The UN Decade of Ocean Science for Sustainable Development is a once in a career, or lifetime, opportunity for ocean science to make accelerated advances to achieve sustainable pathways for society. The Ocean Decade is cast on the mold of the US ocean science and technology agenda. Multiple NOAA programs and scientists are engaged in formulating and implementing activities for the Decade. These will only be successful if funded appropriately. Currently there are over 200 Ocean Decade activities that have been endorsed by the Intergovernmental Oceanographic Commission and more coming. NOAA should engage to sponsor those activities involving our people and our interests. Principal among the Decade activities are the National Ocean Mapping Exploration and Characterization strategy that defines mapping the US EEZ by the end of the Decade, and Seabed 2030, which defines the global community working to finally map the world ocean by 2030. Physical and chemical oceanography bring compelling research needs including the carbon cycle and Marine Carbon Dioxide Removal. These and other ocean science and exploration activities in the Decade inventory of proposed and endorsed projects deserve attention. This is a unique time for leveraged investments.

The ongoing S&T initiatives: Artificial Intelligence, UxS, AI, 'Omics

The benefits of Artificial Intelligence and Machine Learning (AI/ML), UxS (uncrewed systems), and 'Omics are emerging across NOAA's mission areas. Advancements in each of these technologies can reduce costs and accelerate delivery of new discoveries and methods, and provide higher quality and more timely scientific products and services for societal benefits. There is a need and opportunity to leverage NOAA's current organizational structure to more effectively implement these technologies through improvements in computational and analytical capacities, targeted research, technology transition, workforce proficiency, and partnerships across NOAA's lines, federal agencies, and extramural research and commercial communities.

The benefits of Artificial Intelligence (AI), including Machine Learning (ML), are emerging across NOAA's mission areas. Once perfected, this technology can reduce cost and accelerate delivery of new discoveries and methods. Further investment in this technology area, ideally leveraged with other contributors, is warranted. This includes activities under the virtual NOAA Center for Artificial Intelligence (NCAI) (see noaa.gov/ai) and the Artificial Intelligence Strategic Plan 2021-2025.

Investments in research and development to prepare for operational execution of UxS is necessary. The NOAA operational inventory of UxS is outpaced by what is currently available in commercial use and by other operators. To close this gap and reach the leading edge will require research and development investments. While we have penetrated a hurricane with an unscrewed surface vessel, consider whether there is a mission profile for an uncrewed heavy aerial vehicle, or autonomous ocean exploration surface platform that can deploy an ROV for undersea characterization. Follow the work described in the Uncrewed Systems Strategic Plan 2021-2025

The promise of 'Omics is materializing as the cost of sequencing is declining. Following the ‘Omics Strategic Plan 2021-2025 will advance the state of science across the agency. Bioinformatics expertise and analytical equipment may be beneficial investments, as well as other elements in the Plan. Those are choices but the overall investment in this ripening technology is a need.

2. Economic Development, Environmental Stewardship, New Blue Economy

Sustainable wind energy development

Support for sustainable wind energy development invites research questions ranging from impacts to trust resources. NOAA science can inform planners and regulators about impacts, siting benefits, and hub height wind productivity and wind forecasts. The regulatory consultation process will require the best available science within the areas of NOAA’s jurisdiction. Every Line has a role in contributing to the success of the national offshore wind strategy objectives. NOAA can provide information for the most economic installations of renewable energy and boost the New Blue Economy with reliable data.

Authoritative Source in Government for Industry

The Climate Crisis is generating business interest in providing climate outlooks and tailored products similar to the commercial weather industry. NOAA, as the authoritative mission agnostic provider of state of the science climate information should produce the work necessary to support a commercial climate outlook industry that can serve as a force multiplier to accelerate the provision of information to decision makers in multiple sectors. As in supporting the Weather Enterprise, NOAA can provide the guideposts and root information about the climate system and define what is indeed predictable. Consider research investments to prepare America to become a Climate Ready Nation.

Accelerating Science through Scientific Data Stewardship and Open Science

Modern information technologies have revolutionized the speed and scale of scientific research and discoveries. These technologies similarly provide opportunities for greater availability, access, visibility and democratization of scientific data, information, and research methods and results -- commonly referred to as Open Science. Scientific Data Stewardship creates opportunities for vastly wider participation in and advancement of Open Science.

Scientific data stewardship targets making data and information more Findable, Accessible, Interoperable, and Reusable (the FAIR principles). To enable and facilitate Open Science and

FAIR principles, NOAA must revolutionize its scientific data stewardship tools and services. This requires adoption of cutting edge data collection, preserving and sharing technologies and policies to best utilize them, especially those afforded by networked systems and services, including the cloud and related technologies. NOAA will have to automate many data stewardship tasks using artificial intelligence and machine learning, among other technologies in order to maximize the utility of data under our stewardship and to make our data holdings more beneficial to the New Blue Economy.

3. Enabling Equity and Environmental Justice, connecting NOAA's missions

NOAA shall deliver mission products and services on an equitable basis across all communities and economies. The concept of equity and Environmental Justice (EJ) will be included in the science NOAA pursues, in the assessment of users in need of the information, and in recruiting diverse talent into the agency. Listening sessions and community engagements allow Lines to determine service needs and gaps and define new research directions in social and physical science. Examples are creating social vulnerability indices, targeted studies of urban heat mapping, community based climate risk, and addressing the disparities in services provided to underserved populations. Research necessary to perfect our approach to true Equity and EJ will likely center on applied social sciences. Prepare for success with proper investments.

NOAA's science and technical work force does not represent the cultural diversity of America. We are among the worst in minority recruitment among technical federal agencies yet we sponsor academic preparation in multiple Cooperative Science Centers (CSCs) matched to our scientific disciplines. Increasing the CSC participation in the S&T portfolio and within the Cooperative Institutes will reveal a diverse breadth of talent for hiring.

How to Achieve our Research Priorities; Methods and Tools:

NOAA shall continue to follow an Earth System approach in our R&D portfolio and continue to improve integration across Lines. Partnerships have proven beneficial though they take both time and relationship management. The benefits of aligning with other federal agencies bilaterally as with NSF, USGS, Navy, and through the National Ocean Partnership Program, ICAMS implementation, and USGCRP can be even more fruitful if NOAA programs lead with initiatives. Philanthropic and NGO partnerships are increasing and beneficial. Engaging private sector or non-governmental entities through CRADA, MOU's, and other agreements should be established at a high level to allow for later unanticipated participation across NOAA. Use the SBIR as an innovation tool. Consider new entrants and collaborators into the research fields of NOAA, including the climate forecast industry, but also the materials science, medical, environmental engineering, non-traditional sensor designs, citizen science, and use of prize incentives. Be expansive and innovative in structuring and securing partnerships.

High Performance Computing

High Performance Computing (HPC) has been an invaluable but limiting enabler in providing success in the NOAA mission. OCIO has established a measure of NOAA HPC needs today.

Even with the additional Appropriations for research HPC in 2021, NOAA will still hold less than half of the HPC necessary to fulfill our mission. While NOAA holds the best climate model in the country (arguably the world), that model is built based on the limits of the HPC available, not on our performance capability. Continue the informed acquisition of next-generation systems and services that span the traditional and cloud markets, securing the proper architectures for the various research missions. Include laboratory-integrated software engineering efforts focusing on new and emerging computing architectures and modern software development methodologies. Expand HPC capability will reach the required level and ensure partnerships between the research laboratories and operational components.

Environmental observations design, evolution, integration, and exploitation
Accurate and efficient observations and measurements of the complex Earth System, of space, atmosphere, land, and ocean are essential for the NOAA mission. Much of the world relies on the observing systems that NOAA has invented, developed, organized, and deployed. They represent the inputs to the different models used in NOAA to provide products and services that serve the public. Upgrade and complete modernization of NOAA's observing system should be led by research proven tools and methods. Rapid commercial development of sensors and methods that formerly had been NOAA's responsibility to develop are increasingly market available. Finding or developing a more modern and efficient set of observing systems will enhance mission economy and performance. From satellites, to ground based instruments, use of unscrewed systems, ships, UxS, submersible and surface platforms – whatever the mechanism - reliable sensors and measurements need to be proven at research grade accuracy. From the sun to the deepest part of the ocean, NOAA's mission and observing systems need to be fit for purpose, and today they are not complete. Solve that problem. Invest to leap beyond the current state of operational methodology and fill the gaps. Look to merge the measurements of multiple systems which will allow for a more effective monitoring of the different environmental domains (land/hydrology, ocean, weather, cryosphere, biosphere, space weather) spanning time scales from nowcasting to climate scales. Connect observing communities to modelers, to user communities of those models, through research proven systems.

Consider, for example, the challenge of sustaining the measurements of marine ecosystems for one of NOAA's primary mission challenges of fisheries management when portions of the traditional grounds surveyed may be inaccessible by traditional means of ship based trawl surveys owing to the necessary installation of offshore wind farms for renewable energy. Couple the advancements in autonomous technology and unscrewed systems with the rapid growth and availability of Omics and eDNA and find solutions through new and better methods. Find better integrations between satellite and *in situ*, for weather, oceans, and climate similar to the harmony between the growing hurricane glider picket line and hurricane flights. Such synergy should extend from observation methodology to support the NOAA Climate-Fisheries Initiative and provide climate-ready information for the management of the marine ecosystem and resources.

From space to atmospheric chemistry, Boundary Layer to Stratosphere, from precipitation forecasts to a fully coupled model for weather and climate time scales, and from marine ecosystem to Essential Ocean Variables, observation systems alone will not be complete without funds to analyze the resulting data streams. The NOAA programs and activities that are the

stewards of the observing system need to be resourced to do more than develop and maintain an observing system, but to resource the scientific analysis of these data sets and to provide internal and extramural support for renewed understanding.

Integration of social, behavioral, and economic research across NOAA mission areas. The NOAA Science Advisory Board has admonished the agency to demonstrate more progress in the use of social science to more effectively achieve our mission, information dissemination, and to most effectively inform the public. The protection of life and property from the insult of environmental hazards, extreme events, and emergencies invites the most urgent need of social science working and included within the physical science community to most effectively transmit an informed understanding to the public, well in advance of the detection of the event. For too long we have ignored, then added, social science. Now we need to incorporate social science within the fabric of our work and demonstrate the resolve to produce outcomes and products that are readily useable, understandable, and beneficial to the public.

Weather is not the only subject warranting social science investment. Understanding how people receive information, particularly in understanding a climate future, and in understanding changes in the marine and coastal communities is a proven but underfunded benefit.

Addressing the needs of traditionally underserved communities in urban areas and in communities of Indigenous Peoples warrant the application of social, behavioral, and economic science to determine the gaps in service need, provision, and to help engage with a community in understanding needs and equitably serving those needs.