National Oceanic and Atmospheric Administration (NOAA)
Response to the Science Advisory Board (SAB) Environmental Information Services Working Group (EISWG) report on the Priorities for Weather Research (PWR)
November 30, 2022

Priorities in Weather Research Report

In December 2020, Congress charged the National Oceanic and Atmospheric Administration (NOAA) Science Advisory Board (SAB) to publish a report that provides the information necessary to prioritize federal investments in weather research and forecasting over the next decade. In response, the NOAA SAB launched the Priorities for Weather Research (PWR) study, which through a broad consultative process, engaged over 150 subject matter experts from across the Weather Enterprise to develop this report. The report was approved by the SAB at its December 8, 2021 meeting and transmitted to NOAA on December 9, 2021. NOAA's response to that report follows.

This document provides NOAA's response to the PWR Report. NOAA is grateful to the SAB for providing these detailed recommendations. For each recommendation, current actions being undertaken by NOAA to address the critical actions are described, as well as planned activities. As can be seen in the individual responses, NOAA largely concurs with the recommendations. In some instances, additional resources need to be made available to adequately address the recommendations. A listing of acronym definitions is available at the end of this document.

Response to High-Level Recommendations

OBSERVATIONS AND DATA ASSIMILATION (OD)
Priority Area 1: Use and Assimilation of Existing Observations

Recommendation OD-1; Critical Actions OD-1.1, 1.2, 1.3, 1.4
Recommendation: Maximize the use and assimilation of underutilized ground-based, airborne, and marine-based in situ, remote sensing, and crowd-sourced observations. Observations are the foundation that supports the NOAA mission. Effective utilization of the existing observations is critical for accurate forecasts.

Response:
NOAA concurs with this recommendation. The NOAA Observing System Council (NOSC) coordinates observational and data management activities across NOAA, proposes priorities and investment strategies for observational related initiatives, and identifies programs that benefit most from integration. NOAA will continue to assess end-user utilization of existing observations and will codify processes to prioritize emerging ground-based, airborne, coastal, and marine-based in situ observations from other federal entities, the private sector, and academia. Improving data assimilation is a key part of the NOAA Precipitation Prediction Grand Challenge (PPGC) initiative, which, which aspires to substantially advance seamless weather-to-seasonal coupled prediction using global high resolution, cloud-resolving, regionally-refined systems targeting extreme precipitation, severe heat, and drought within the Unified Forecast

System (UFS). Key ocean, coastal, land, and atmospheric observations will be identified and assimilated into the UFS models.

Recommendation OD-2; Critical Actions OD-2.1, 2.2, 2.3, 2.4

Recommendation: Maximize the use and assimilation of underutilized satellite observations. United States leadership in delivering accurate weather forecasts for weather of all types requires assimilation of best available satellite observations to inform numerical models.

Response:

NOAA concurs with this recommendation. The ability to utilize all available satellite data is impacted due to limited funds and available expertise. The NOAA Modeling Board recently created the Enabling Observations in Models (EOM) working group to identify and address underutilized satellite and in situ observation from current and near future observations by defining forecast objectives and mapping them to data assimilation projects. NOAA is partnering with the multi-agency collective JCSDA and Cooperative Institutes (CIs) to co-develop coupled Earth system data assimilation to maximize utility of satellite observations. Specifically, JCSDA is leading the development of JEDI to evaluate and assimilate under-utilized and new satellite data through research, collaboration, and impact assessments. Within JEDI, the Community Radiative Transfer Model (CRTM) is being developed to improve data use for all-sky, all surfaces, including cases impacted by aerosol and hydrometeors, in the ultraviolet, visible, Infrared, far-Infrared, and microwave spectral regions. CRTM will be expanded to support planned future satellite instruments, small satellites, research missions such as Plankton, Aerosol, Cloud, ocean Ecosystem (PACE), and data from commercial satellites. The NOAA Satellite Proving Ground provides a collaborative environment between Science Teams and operational staff to co-develop new satellite products and applications. NOAA's QOSAP provides an agile infrastructure to assimilate and quantify the impact of current and proposed observing capabilities, as indicated in OD-1.

Priority Area 2: Advanced Data Assimilation Methods, Capabilities and Workforce

Recommendation OD-3; Critical Actions OD-3.1, 3.2

Recommendation: Significant new support for novel methodology research and workforce development for data assimilation is necessary to establish and maintain state-of-the-science capabilities. Data assimilation plays a critical role in addressing nearly all NOAA mission areas across all scales. Advancement of data assimilation research and development at early readiness levels will help the United States advance world leadership in weather prediction and allow sustained workforce development to fill the severe workforce gap in data assimilation.

Response:
NOAA concurs with this recommendation. NOAA is committed to supporting research ideas and activities throughout the research to operations (R2O) funnel, including novel, agile, innovative, and high-risk approaches to weather forecasting challenges using a Development Operations (DEVOPS) environment. For example, a NOAA FY22 competition supported several projects making advances in data assimilation for UFS; as well, the most recent funding opportunity will provide support for cross-cutting research with its “Innovations for Community Modeling" competition - a collaborative funding opportunity between the Earth Prediction Innovation Center (EPIC), Joint Technology Transfer Initiative (JTTI), Subseasonal to Seasonal (S2S), and Fire Weather (FW) programs to drive innovative research, which includes data assimilation. The goal of this competition is to introduce new approaches into the UFS to advance forecast skill and efficiency, as well as enhance community engagement and workforce development. Additionally, NOAA is one of the primary funding agents for JCSDA, which supports innovative work for JEDI. JCSDA is working with OAR and the NWS to implement JEDI as the new data assimilation system for UFS operational models.

NOAA dedicates a portion of its work portfolio to the development of novel technologies and methodologies, and regularly invests in supporting internships and other student programs as part of its future workforce development responsibilities according to the NOAA Education Strategic Plan for a diverse and highly skilled future workforce that pursues careers in disciplines that support NOAA’s mission. Furthermore, in alignment with this recommendation, NOAA is exploring opportunities dedicated to addressing critical research challenges for data assimilation (DA) and stimulating a growing DA workforce.

Through the NOAA PPGC, the agency would provide more accurate, reliable and timely precipitation forecasts through developing and applying a fully-coupled Earth system prediction model. This is, in large part, dependent on strengthening and developing strategies in effective DA applications.

Recommendation OD-4; Critical Actions OD-4.1, 4.2, 4.3, 4.4, 4.5
Recommendation: Advance coupled Earth system data assimilation for weather, water, and sub-seasonal to seasonal forecasting. Earth system components are truly coupled in nature. Hence, NOAA’s Earth system models should accurately emulate this coupling. The data assimilation system should also fully integrate all components of the Earth system (e.g., atmosphere, hydrosphere, ocean, cryosphere, land, aerosol). In other words, the observations in one Earth system component should influence the correction of other Earth components during the data assimilation for both short-term weather (e.g., hurricane, convection at continental United States) and S2S scale forecasts.

Response:
NOAA concurs with this recommendation. NOAA is working closely through its partnership with the JCSDA to develop a coupled Earth system data assimilation, including all Earth system components, for weather, water, and sub-seasonal to seasonal forecasting capability through

JEDI. JCSDA receives a majority of its funding from NOAA and has received additional funding through supplemental appropriations. As noted in OD-1, NOAA's QOSAP improves quantitative and objective assessment capabilities by evaluating operational and future observation system impacts and trade-offs to assess and to prioritize NOAA's observing system architecture. For example, OSSEs and OSEs assess the impact and value of a potential observing system through a structured experimental process. NOAA is working on a weakly coupled and strongly coupled data assimilation system for the land-atmosphere and for the ocean-atmosphere. NOAA's PPGC would further identify the observations required to improve prediction and also optimize the use of existing observing systems. To achieve improved predictions for weather, water, and S2S forecasting, NOAA's coupled DA system must undergo major evaluations through process studies, field campaigns, and data collection efforts to model the Earth's boundary layer and land-ocean-ice-atmosphere transition zones. NOAA will explore how best to reduce data latency to improve operational coupled DA by working directly with data providers. NOAA is also seeking to augment efforts in establishing a skilled workforce in coupled DA through internship programs such as the William M. Lapenta NOAA Student Internship Program, and JCSDA training programs to address critical research challenges associated with DA.

Recommendation OD-5; Critical Actions OD-5.1, 5.2, 5.3, 5.4

Recommendation: Advance the production of regional and global reanalyses. Reanalyses serve a large number of purposes, including long-term monitoring, detection and attribution of extreme events, forecast performance evaluation, improved use of observations, calibrating sub-seasonal to seasonal prediction, and development of numerical models and data assimilation methods. They are invaluable to both research and operations.

Response:

NOAA concurs with this recommendation. The agency is currently conducting global and regional reanalysis with traditional and novel variables, for example, aerosol reanalysis to support monitoring and data assimilation. NOAA will continue to support the advancement of data assimilation capabilities to improve earth system reanalysis through the exploitation of new demonstration, research, and commercial missions of opportunity data for use in reanalysis. Data from NOAA, interagency partners, and the private sector are used to validate and improve the performance of regional and global model reanalyses. NOAA is building a Common Cloud Framework to facilitate coordinated research and reanalysis of weather and climate data as well as support open science and open data. It will provide secure, scalable, and interoperable services, including data ingest, stewardship, and dissemination connected to research and development, ensuring data integrity, provenance, and computing resources for analysis and reanalysis. Interagency and international collaborations are critical to make best use of re-processed observations from the past.

NOAA is supportive of the recommended action to develop a multi-decade reanalysis using AI and ML, should HPC resources become available for this activity. These tools could also improve data processing/analysis such as data monitoring and interpretation, real-time quality control for observational data, guided quality assignment and decision making, data fusion from different sources, correction of observation errors, and bias correction.

Priority Area 3: Observation Gaps and Use and Assimilation of New Observations

Recommendation OD-6; Critical Actions OD-6.1, 6.2, 6.3, 6.4
Recommendation: Develop and deploy a national boundary layer, soil moisture, and smoke observing and data assimilation system for weather and sub-seasonal to seasonal prediction. People live and work in the atmospheric boundary layer, and its characteristics exert a major influence on many weather phenomena ranging from thunderstorms to atmospheric rivers and overall seasonal weather patterns, and yet it is poorly observed. The requirement is to establish a national ground-based boundary layer, soil moisture, and smoke and aerosol observing system, with a vertical profiling network at its core. It supports research and prediction of processes within the lowest levels of the atmosphere, at the interfaces of the atmosphere with the underlying surfaces and in smoke and aerosol plumes.

Response:
NWS conducted a series of workshops in 2020-21 to identify top needs for NOAA's forecast systems from forecaster perspectives, and improving boundary layer characterization was among the top recommendations. NOAA currently has various platforms to obtain this critical boundary layer data, including the Upper-air Observing Program that oversees the operation of 92 radiosonde stations providing vertical data profiles essential for weather forecasts and research. NOAA also operates three wind profilers in Alaska as part of the NOAA Profiler Network to observe and detect volcanic ash, wind speed, and wind direction. The NEXRADs produce a vertical profile near/above the radar site of wind speed and direction every volume scan, and technology implemented during the past decade enables faster and more frequent radar scanning of the boundary layer. NOAA laboratories, programs, and offices are leading numerous initiatives focused on enhancing and expanding capabilities to monitor and measure the boundary layer using a variety of observing systems, while also assimilating this data into numerical models and conducting impact assessments. Planetary Boundary Layer (PBL) profiling capabilities are available via the National Mesonet Program, and upgrades are planned to the Automated Surface Observing System (ASOS) network to monitor the PBL. Innovative platforms such as Uncrewed Aircraft Systems (UAS) are being expanded by NOAA labs to collect data from vertical profiles over its network sites with existing ground-based instrumentation. The EPIC program and JCSDA tools and technologies may also be leveraged to incorporate PBL observations into models. NOAA will continue collaborative engagements and data exchanges with other national and international centers to advance this effort.

The Automated Surface Observing System Service Life Extension Program has captured the Planetary Boundary Layer Height (PBLH) requirement in addition to the requirement for smoke and aerosol layer sensing and reporting. The baseline software being fielded with ASOS 2.0 will have organic capability to produce attenuated backscatter profiles through the use of its currently fielded Lidar Ceilometers. Upon deployment of the SLEP updated ASOS, NETCDF2 binary files will be disseminated for public consumption, scientific evaluation and assimilation into numerical modeling. The ASOS network covers the CONUS, Alaska and other less densely populated areas in the Pacific and at Naval Aviation facilities. This appears to be the beginning of what was requested in the development of a national boundary layer and smoke observing and data assimilation system, sans the soil moisture component.

The U.S. Climate Reference Network (USCRN), developed by NOAA in the early 2000s, provides the Nation with long-term, high quality observations of air temperature, precipitation, and soil moisture and temperature collected in relatively stable and pristine environments. Supplemental boundary layer profiles may be taken at USCRN stations. The USCRN's measurements also provide critical anchor points for evaluating other observing networks, both public and private. Society and the economy benefit from the USCRN as its data are used in the decision support activities for a number of applications including weather warnings, water resource management, and reinsurance. Data are also used to improve both short- and long-term forecasts to protect lives and property.

Recommendation OD-7; Critical Actions OD-7.1, 7.2, 7.3, 7.4

Recommendation: Observe the ocean, its surface boundary layer, and ocean-atmosphere feedbacks, on weather space and time scales for seamless Earth system data assimilation and forecasting from minutes to years. The ocean has been underutilized as a source of predictability, particularly for the coastal regions where a large fraction of the population is concentrated. Combined oceanic and atmospheric boundary layer observations will increase understanding of the fundamental physics of the air-sea interactions required for an Earth systems approach. NOAA is an international leader in integrated ocean observations for science and operations. Combining that leadership with advanced Earth system models (FO-1) that include ocean forecasting capabilities, coupled data assimilation (OD-4), and development of a skilled workforce at multiple degree levels (FE-9), will enable U.S. leadership as a pathway for delivering accurate weather forecasts for high-impact weather (FO-6), water cycle extremes (OD-8, FO-4), and comprehensive coastal applications (FO-7).

Response:

NOAA concurs with this recommendation. In general, NOAA recognizes the need to more effectively assimilate ocean observations into NOAA forecast models. The NOAA Modeling Board's new Expanding Operational Ocean Forecasting and Prediction Working Group includes this in their scope of activities.

NOAA supports the National Water Level Observation Network (NWLON) and the National Currents Observation Program (NCOP), which both collect in situ data. The NWLON is a network of 210 long-term, continuously operating water level stations throughout the U.S. and its territories. NCOP collects, analyzes, and distributes at least 30 days of tidal current data at upwards of 30 U.S. locations from within two estuaries each year. Working through local, state, and regional partners, NOAA also maintains the U.S. Integrated Ocean Observing System

(IOOS) Program to produce, integrate, and communicate high quality ocean, coastal and Great Lakes information that meets the safety, economic, and stewardship needs of the Nation.

NOAA continues to maintain and augment the world's largest ocean observing network (e.g. deep-ocean and coastal weather/ocean buoys and coastal marine stations, deep-ocean assessment and reporting of tsunamis (DART) and tropical atmosphere ocean (TAO)) including adding biogeochemical (BGC) and current monitoring sensors. Based on the final report (2021) of the Tropical Pacific Observing System 2020 (TPOS 2020), NOAA received funding to enhance the Tropical Atmosphere Ocean (TAO) array with additional boundary-layer sensors and planning for expanding ARGO, which is presently underway. The NOAA Global Ocean Monitoring and Observing (GOMO) Program further supports BL measurements from several moorings and cross-mooring calibration, as well as measurements over Arctic ice and in the marginal ice zone. Plans for expanding BGC information in the boundary layer are under development internationally. NOAA is also collaborating on the practice of using uncrewed systems to make colocated and simultaneous measurements of the air-sea transition zone (upper ocean, air-sea interface, and marine atmospheric boundary layer).

NOAA will continue collaborative opportunities and scientific exchanges with national and international centers. For example, the UN Ocean Decade project proposal includes development of the Open Access Global Telecommunications System (Open GTS), which would greatly facilitate the reformatting and expansion of private sector observing systems for use by NOAA in an operational capacity.

Recommendation OD-8; Critical Actions OD-8.1, 8.2, 8.3

Recommendation: Leverage and expand atmospheric river (AR) observations to improve flood and drought prediction and to enable forecast-informed reservoir operations. Water resource and emergency managers often cope with too much or too little water and require better information on storms that produce extreme precipitation. However, precipitation prediction skill has not improved substantially in the last 20 years. The multi-agency, OSTP-led Earth System Prediction Roadmap (2020) identified expanded research, observations and communication needed to better anticipate and mitigate water cycle extremes and their cascading impacts, including atmospheric river type storms.

Response:

NOAA concurs with this recommendation. The NOAA PPGC initiative aims to provide and sustain improvements to the forecasts of extreme precipitation, such as from ARs, from days to seasons. A key part of this initiative is the use of an advanced DA system and integration of ocean surface and mixed layer observations, as well as satellite imagery, derived products, radiance data, land-based radar systems, and surface observations. The NOAA Hydrometeorological Testbed also hosts annual experiments focused on Atmospheric Rivers, bringing diverse academic, model developer and forecaster perspectives and tools to advance prediction. Building on rapidly improving hydrologic advances, the PPGC would ensure clear and effective delivery and communication of weather information designed to meet the needs of impacted communities and ultimately protect lives and property. NOAA Laboratories develop tools that aid in the assessment of AR forecasts and detection of ARs, conduct studies that evaluate and improve those forecasts, and develop products to deliver those forecasts. NOAA is partnering to develop an interagency Western Hydrology program that, if supported, includes improved prediction of ARs/drought, their impacts on hydrologic prediction, and support for management and decision tools. Additionally, major research and development efforts are underway in NOAA and other national/international weather forecasting centers to accelerate the needed advancements in data assimilation techniques to ensure faster, more accurate forecasts of parameters associated with atmospheric rivers.

In addition to weather satellites, NOAA maintains operational deep-ocean and coastal weather buoys, coastal marine stations, and NEXRADs that assist in AR monitoring and forecasting. Climate observations from the Tropical Atmosphere Ocean (TAO) network in the equatorial Pacific also contribute to improved understanding of ENSO and ARs. NOAA is mitigating observational gaps through targeted aircraft observation sampling such as AR Reconnaissance for winter storms. The expansion of observations to more fully support AR forecasting will require additional resources. Forecast-informed reservoir operations (FIRO) should continue to be examined and applied where practical and economical as a strategy for optimizing reservoir releases through use of enhanced monitoring and improved weather and water resources forecasts for enhancing flood-risk and ecosystem management.

Recommendation OD-9; Critical Actions OD-9.1, 9.2

Recommendation: Fill radar gaps using diverse weather radars and data assimilation. Deploy and integrate smaller, cheaper scanning radars into NOAA's current network of very large radars, roughly doubling the number of radars, to better detect significant precipitation and severe weather over more of the Nation and more equitably across the population, starting immediately.

Response:

The NOAA Strategic Plan underscores advancing critical research on weather radar technologies and operations to meet the unprecedented challenges of weather observing and forecasting in the coming decades. The NWS continually updates its policy for the use of non-NOAA radar data; NOAA currently has ongoing research efforts to analyze the potential benefits that data from supplemental radars could add to numerical models. Presently, non-radar observational platforms and advanced data integration applications are being used to supplement radar coverage. For example, there are collaborative efforts between NOAA and its partners to create Quantitative Precipitation Estimates (QPE) from satellite observations over rough terrain, which is typically not observable with traditional radar systems. The Multi-Radar Multi-Sensor (MRMS) is a system that integrates data from a variety of sources including radar, surface and upper air observations, lightning detection systems, satellite observations, and forecast models to produce QPE and other products for use in meteorological and hydrological forecasting. The MRMS ingests WSR-88D and Canadian radar networks, along with one state-owned, commercial radar. MRMS advancements also include surface precipitation estimates with evaporation corrections and radar data overlapping techniques. NOAA will consider radar coverage as part of post-NEXRAD follow-on radar, considering the benefits and potential impacts on existing capabilities.

Recommendation OD-10; Critical Actions OD-10.1, 10.2

Recommendation: Prioritize smallsat/cubesat observation and data assimilation. NOAA observations have been based on large satellites that are reliable, capable, impactful, yet expensive with a long development cycle. Recently, substantial and rapid progress has been made in smallsat/cubesat technology. This provides a great opportunity for NOAA to define the role of smallsats/cubesats in its observing system; i.e., for gap mitigation, faster technology refreshment, more frequent revisit opportunities; complementing large satellites in temporal and spatial coverages; opening up new ventures with the private sector.

Response:

NOAA strives to evaluate the operational value and associated costs when considering the prioritization of investing in observational data. Assimilation of cubesat data is supported by NOAA QOSAP which provides an agile infrastructure to assimilate and quantify the impact of current and proposed observing capabilities, as noted in OD-1 and OD-2. NOAA's future satellite architecture plans include use of smallsats and cubesats, where appropriate, to meet its operational needs. Smallsats provide relatively inexpensive access to space allowing smallsat technology advancements to be rapidly incorporated into NOAA's satellite architecture. NOAA is already leveraging smallsat technology through commercial data buy of radio occultation observations. Planning for a smallsat pilot project, called QuickSounder, is underway with an expected launch in 2025. The QuickSounder pilot will use an Advanced Technology Microwave Sounder (ATMS) engineering development unit to enhance the availability of microwave soundings for weather prediction.

FORECASTING (FO)

Priority Area 1: Foundational Earth System Modeling

Recommendation FO-1; Critical Actions FO-1.1, 1.2, 1.3, 1.4, 1.5

Recommendation: Accelerate Earth system model development and seamless prediction. NOAA's mission - to understand and predict changes in climate, weather, oceans, and coastal environment - covers the entire Earth system, requiring predictive capabilities for the key processes within, and interactions among, the components of the Earth system. To provide societally relevant forecasts, spanning weather to climate time scales from global to local spatial scales, a seamless and fully coupled modeling framework that provides a holistic treatment of the Earth system is essential.

Response:

NOAA concurs with this recommendation. NOAA is embracing the community-based Earth system model development in the UFS framework for research and operations. These efforts are coordinated among the UFS Steering Committee, UFS R2O Project, and EPIC, with support from the NOAA Modeling Board and Community Modeling Board. Forecaster and stakeholder priorities are collected along with verification metrics through various workshops (i.e., DTC UFS Evaluation Metrics Workshop), which guides the development and evaluation/verification of coupled earth system models for various applications using common UFS infrastructure.

The goal of EPIC is to accelerate scientific research and modeling contributions through continuous and sustained community engagement to produce the most accurate and reliable operational modeling system in the world. For seamless weather-to-seasonal coupled prediction, NOAA is using global high resolution, cloud-resolving, regionally-refined systems targeting extreme precipitation, severe heat, and drought within the UFS. The coupling includes the following component models: atmosphere, ocean, land, sea ice, wave, aerosol, and cryosphere. NOAA is scheduled to implement multiple NWP applications in the next few years including a six-way coupled earth system modeling (air-land-ocean-sea ice-wave-aerosol) system that is being developed within the UFS infrastructure for various operational applications along with JEDI-based coupled DA. The GFSv17 and GEFSv13 are scheduled for operational implementation in 2024. Operational products will consist of coupled ensembles with reanalysis and reforecasts for calibration and validation. As resources become available, the GEFS system can be extended to seasonal timescales. Global Earth system models at convection permitting/resolving scales are becoming increasingly possible with emerging HPC resources, but the feasibility of mesoscale resolving ESMs in operations requires significant investment in R&D and operational computing, smarter and efficient input/output (I/O) handling, and product dissemination.

ESM4.1 marks the culmination of a 4th generation model development effort that included comprehensive revisions of atmospheric dynamics, physics and chemistry, ocean physics, biogeochemistry and ecosystems, sea ice, and land physics, biogeochemistry and ecosystems. These efforts were merged into NOAA's first coupled carbon-chemistry-climate model with state-of-the-art representation of each, along with comprehensive interactions between components. Over 50 simulations from ESM4.1 have been made publicly available. Analyses of these simulations will serve as the basis for research in years to come, helping to improve our understanding of coupled carbon-chemistry-climate interactions, and reducing uncertainty in projections of future climate change and its impacts and feedbacks. ESM4.1 is also a key contributor to the 6th Coupled Model Intercomparison Project.

The OAR/GFDL Flexible Modeling System-generated coupled climate model, SPEAR, forms the basis of NOAA Research's state-of-the-art seamless seasonal-to-decadal (S2D) prediction system. SPEAR shares many components with the ESM4.1 (minus the Biogeochemistry component) model but with configuration and physical parameterization choices in SPEAR geared toward physical climate prediction and projection on S2D time scales. SPEAR also shares many common components with the GEFS, including the dynamical core and ocean model. SPEAR advances NOAA's capacity to improve society's ability to plan for and respond to changing environmental risks.

Recommendation FO-2; Critical Actions FO-2.1, 2.2, 2.3
Recommendation: Achieve the best possible operational numerical weather prediction at all time scales. Accurate and actionable weather forecasts are the foundation of society's ability to be resilient to weather and to leverage weather for the improvement of life and economy. This includes using forecasts for everything from planning daily activities to preparing for major weather disasters. However, weather forecasts are not perfect, nor optimally used, and hence the Nation continues to be vulnerable to the adverse effects of weather. Further, the Nation faces increasing vulnerabilities associated with a changing climate, which extends its exposure to impactful weather. Numerical weather prediction (NWP) is foundational for weather forecasting and NOAA's NWP and forecast products are foundational to the Weather Enterprise. NWP models encapsulate our understanding of weather; effective use of their products is critical to further improving the Nation's resilience to weather.

Response:
NOAA agrees that striving to continuously improve numerical weather prediction is one of many actions that will improve society's response and resiliency to weather and climate impacts. According to the NOAA Strategic Plan, published in June 2022, NOAA will continue to make critical investments in high performance computing and associated research, operations and maintenance programs. These include significant investments in the Weather and Climate Operational Supercomputing System (WCOSS) by transitioning to the WCOSS-2 and investing in the high performance computing systems supporting NOAA's research activities and laboratories. The NOAA High Performance Computing Board will provide holistic management promoting balance and efficiency between the powerful computing needed to develop the next generation of numerical prediction systems and the agency's imperative to deliver numerical guidance operationally.

NOAA is making progress toward unification and simplification of the operational production suite through the transition of distinct legacy modeling systems into UFS-based applications. NWS/EMC is developing a 5-year implementation plan for future model upgrades, which includes an integrated master plan, work breakdown structure, decision trees, and testing and evaluation strategies for all operational applications. This plan is consistent and aligned with the DOC, NOAA, NWS, and NCEP strategic plans, US Congress Weather Research and Forecasting Innovation Act of 2017 (Weather Act) and the UFS Strategic Plan. Governance of UFS applications is done through the UFS Steering Committee, Working Groups, and cross-cutting development teams. Milestones and deliverables are tracked through the use of advanced project management tools.

Improvement of NOAA forecast systems will be achieved through collaboration with the broader NWP community. To achieve this, all UFS- based applications are developed as open-source community modeling systems available through GitHub, with dedicated code management and support from EPIC, EMC, GFDL, DTC, NCAR, and JCSDA. EPIC applies an open-innovation and open-development framework that embraces open-source code repositories integrated with automated Continuous Integration/Continuous Deployment (CI/CD) pipelines on cloud and on-prem HPCs. EPIC also supports UFS public releases, tutorials and training opportunities (e.g., student workshops, hackathons, and codesprints), and advanced user support via a virtual community portal (epic.noaa.gov). This framework allows community developers to track the status of their contributions, and facilitate rapid incorporation of innovation by implementing consistent and transparent, standardized and community-driven validation and verification tests.

Recommendation FO-3; Critical Actions FO-3.1, 3.2, 3.3

Recommendation: Establish a regular, sustained Earth system reforecasting activity to enable a more effective cadence of operational model improvements. Regularly produced global reanalyses and reforecasts are critically important components of operational prediction systems and provide the basis for long-term monitoring, detection and attribution of extreme events, model bias correction, and weather modeling and forecasting research.

Response:

NOAA concurs with this recommendation. Progress on this has been resource-limited, particularly HPC resources. NOAA plans to contribute to a regular, sustained Earth system reforecasting activity through external partnerships. This effort is essential for model calibration, validation, and it will serve as a dataset for research. Interagency and international collaborations are critical to make the best use of re-processed observations from the past. Additional research areas include optimal length of reanalysis and reforecasts, ensemble size and resolution for various applications. A NOAA-wide strategy and dedicated resources are needed for the production of periodic or on-the-fly reanalysis and reforecasts. Additional research is necessary to advance reanalysis and reforecasts for monitoring weather/climate variability, diagnosing and understanding weather/climate events, initializing ensemble forecasts, identifying model deficiencies, calibrating model forecasts, and providing forcings for downscaled applications.

NOAA is scheduled to implement multiple NWP applications in the next few years, including a six-way coupled earth system modeling (air-land-ocean-sea ice-wave-aerosol) system that is being developed within the UFS infrastructure for various operational applications along with JEDI-based coupled data assimilation. Operational products will consist of coupled ensembles with reanalysis and reforecasts for calibration and validation. The Climate Program Office supports climate attribution efforts to understand the contribution of natural variability and forced change to extreme events.

Priority Area 2: Advancing Critical Forecasting Applications

Recommendation FO-4; Critical Actions FO-4.1, 4.2, 4.3, 4.4, 4.5

Recommendation: Enhance prediction of Earth's water cycle extremes to achieve integrated water cycle modeling. NOAA plays a unique and vital role in predicting water cycle extremes, including floods and droughts, that supports hazard mitigation, water supply, transportation, agriculture, fisheries and innumerable users of water cycle information. Droughts and floods are both deadly and costly weather and climate disasters, with costs of $6.4 billion and $3.8 billion per year, respectively. A key Weather-Ready Nation (WRN) objective is to "Deliver actionable water resources information from national to street-level and across all time scales; provide minutes-to-months river forecasts that quantify both atmospheric and hydrologic uncertainty; improve forecasts of total water in the coastal zone by linking terrestrial and coastal models in partnership with the National Ocean Service; and deliver forecasts of flood inundation linked with other geospatial information to inform life-saving decisions."

Response:
NOAA concurs with this recommendation, as shown in numerous efforts to enhance water-cycle prediction through prioritization and collaboration. NOAA funds multiple projects improving land modeling, surface physics and land interactions, and snowpack modeling, for integration into UFS.

Advances in next generation water resources modeling, flood mapping and coastal inundation, as well as investment in making associated products more effective, are augmented by recent FY22 Bipartisan Infrastructure Law (BIL) supplemental funds. A key part of the NOAA PPGC initiative is careful evaluation of water-cycle variables in atmospheric models and associated precipitation forecasts. Advances in the National Water Model and NWS River Forecast Center (RFC) Forecast Models will be used to drive near real-time flood inundation map services, and will be deployed operationally to 100% of the U.S. population during FY 23-26. The National Water Model has been coupled with 2D hydrodynamic models to produce Total Water Level forecasts or Integrated Water Prediction as directed by Congress, and future iterations will couple with three dimensional hydrodynamic models to facilitate navigation and ecological predictive services in the coastal periphery highlighting the partnership between NOS and NWS. Implementation and continued enhancement of the Hydrologic Ensemble Prediction Service (HEFS) operated at RFCs, will provide improved short through extended range hydrologic forecasts, which account for meteorological and hydrological uncertainty, for water resource applications from floods to water supply. Development and implementation of the NextGen Water Resources Modeling Framework, which is open source, standards based, and modular, will enhance and accelerate community collaboration and development, advance predictive skill, and be employed operationally by future versions of the National Water Model. Moreover, routine evaluation of both model and forecast performance drive investments in research and research to operations across the water resources enterprise.

The NOAA/NWS Community Advisory Committee for Water Prediction (CAC-WP) collaborates with other federal agencies, academia, and the private sector to prioritize research associated with the collaborative development, testing, and implementation of the NextGen Water Resources Modeling Framework to specifically advance community water quantity and quality process understanding, modeling, and forecasting capabilities. NWS is also collaborating with contributors of the National Integrated Drought Information System to identify ready-to-implement research advances for improving drought and water resources service delivery across NOAA.

Development and evolution of the NextGen Water Resources Modeling Framework and Data assimilation are research themes for the recently established Cooperative Institute for Research to Operation in Hydrology (CIROH). CIROH research themes will address scientific gaps in the predictive tools associated with all manner of water resources challenges from floods (including compound and pluvial processes) to droughts, and issues related to water quality such as temperature, salinity and turbidity. Additionally, NOAA Research has funded research projects to advance National Water Model capabilities and improve snowpack, atmospheric boundary layer, or vegetation modeling within UFS.

Recommendation FO-5; Critical Actions FO-5.1, 5.2, 5.3, 5.4

Recommendation: Substantially increase the level of effort to advance predictive capabilities for fire weather and air quality. Air quality (AQ) and fire weather forecasts have high societal and economic value in preventing or mitigating disease and mortality. Climate change and rising frequency of compound hazards, such as heat waves in conjunction with drought or poor AQ, are driving increased importance of and reliance on these forecasts that are critical for decision support for evacuations, power shutoffs, public health advisories, and other incident responses.

Response:

NOAA concurs with this recommendation. NOAA remains committed to serve as the leading authority in increasing efforts to advance predictive capabilities for fire weather, fire spread, and atmospheric composition to better inform the public ahead of and during wildfire events and hazardous air pollution episodes. NOAA will continue to systematically improve the development and delivery of coupled Earth system models capable of predicting atmospheric composition and air quality, optimizing satellite-derived fire radiative power for use in coupled fire-weather model workflows to improve fire spread forecasts, providing continuous scientific updates and input emissions datasets to operational products that produce multi-day forecasts of ground-level ozone and aerosols, providing substantial contributions to the development of new aerosol and atmospheric composition models, and extending fire, fire emissions, and air quality algorithms to future sensors. NOAA leverages a variety of partnerships in its efforts, including the multi-agency collective JCSDA, which is critical for developing innovative approaches to satellite data assimilation. NOAA is also investing in additional HPC resources which are crucial for continued substantive AQ and fire weather forecasting improvements and machine learning models that predict extreme fire behavior to improve fire incident awareness and assessment. In addition, NOAA’s Geostationary Extended Observations (GeoXO) satellite system, expected to begin operating in the 2030s, will include a hyperspectral spectrometer (ACX) that would provide hourly observations of air pollutants emitted by transportation, power generation, industry, oil and gas extraction, volcanoes, and wildfires, as well as secondary pollutants generated from these emissions once they’re in the atmosphere. For management of planned and unplanned fires, NOAA collaborates with civil agency partners to provide high resolution models supporting fuel condition, fire behavior, initial fire ignition and burn area characterization. NOAA is also investing in research, working with EPIC, to develop a coupled fire behavior model in the UFS.

Through the FY22 Disaster Relief Supplemental Appropriations (DRSA) Act and FY22 Bipartisan Infrastructure Law (BIL), NOAA is substantially increasing the level of effort to advance the predictive capabilities for fire weather and air quality. An interagency Fire Weather Testbed has been established to leverage partnerships for model, technology, and service improvements. NOAA is advancing aerosol and atmospheric composition predictions for all time scales through the UFS-based Community Multiscale Air Quality (CMAQ) model, global aerosol assimilation, fully coupled UFS smoke and fire weather prediction capabilities built into the Rapid Refresh Forecast System (RRFS), and very high resolution on-demand fire weather prediction capabilities. An AI emulator is being developed to provide computational efficiencies at high resolutions for RRFS-CMAQ. Both UFS-based CMAQ and GEFS-Aerosol are primed to use satellite derived fire detections and emissions to forecast air quality.

Recommendation FO-6; Critical Actions FO-6.1, 6.2, 6.3, 6.4, 6.5
Recommendation: Commit to improving forecasts of high-impact weather through multi-sector partnerships, in concert with the EPIC program. High-impact weather (HIW) includes severe thunderstorms (tornadoes, hail, lightning, downbursts), hurricanes (high winds, storm surge and inundation), flooding, blizzards, cold and heat waves, ice storms, fire weather and severe pollution events. In addition to the 800 storm-related deaths per year from HIW, there are roughly 700-1,300 heat-related fatalities per year, while premature deaths from poor air quality may total as many as 200,000. More accurate and timely forecasts of HIW are key to mitigating risk from these events, thus saving lives and property. Achieving this goal requires that NOAA, through the UFS and EPIC, effectively coordinate model improvement efforts, both internally and with external partners. It should be noted that the NWS has other Mission Service Areas that address phenomena not covered in this report, such as space weather and tsunamis. They are characterized as extreme events that are infrequent but have high impact. For example, a large coronal mass ejection could disable global power grids, GPS-based systems and other satellite communications. The December 2004 tsunami caused over 200,000 deaths along Indian Ocean coasts. The NWS has engaged in multiple partnerships with other agencies to monitor, predict and warn for these events.

Commit to improving forecasts of high-impact weather through multi-sector partnerships, in concert with the Earth Prediction Innovation Center program.

Response:
NOAA concurs with this recommendation. The EPIC program facilitates innovation and accelerates the R2O2R of NOAA weather forecasting systems by providing a cloud development environment, software engineering, and fostering community engagement through workshops and tutorials. Building multi-sector community partnerships are a critical component of EPIC. The program provides opportunities to improve NOAA's operational modeling systems; fund research, modeling, and compute initiatives; and collaborate with external stakeholders in developing innovative tools and applications to advance the UFS. NOAA laboratories partnered with EPIC to issue the UFS Short-Range Weather (SRW) v2 public release, which serves as the basis for NOAA's regional severe forecast system (RRFS). The SRW will be an initial focus for EPIC, with plans to establish the end-to-end release, training, testing and evaluation, and implementation with this system to prepare for other forecast applications. To support the development of the UFS-based Warn on Forecast (WoF), NOAA laboratories collaborated to

add a new microphysical parameterization to the Common Community Physics Package (CCPP).

Through EPIC, NOAA works with partners within the UFS framework to develop sophisticated regional and nested models with enhanced model physics to increase their predictive skill. NOAA is developing advanced static and moving nest capabilities in the UFS global and regional configurations for hurricanes and severe weather applications. Examples include the WoF sub-km scale ensemble system and Hurricane Analysis and Forecast System (HAFS). HAFSv1 will be transitioned to operations ahead of the 2023 hurricane season.

NOAA is taking a comprehensive approach to improving the understanding and conceptual models of HIW phenomena by working with community collaborators through EPIC, JTTI, Testbeds, and other funding opportunities for driving R2O transitions. An example of this effort includes collaborating with the external community to use the Hierarchical System Development approach for all UFS applications. This includes testing innovations using conceptual models, single column models, limited area models, and fully coupled earth system models including data assimilation, with emphasis on high-impact weather events. NOAA will leverage weather Testbeds (Space Weather Testbed, Hazardous Weather Testbed, Hydrometeorology Testbed, and the Hurricane and Ocean Testbeds) to put new model innovations and tools to the test to advance predictions of high-impact weather.

NOAA is working with forecasters and social, behavioral, and economic scientists on innovative diagnostic and guidance products and effective communication of risks and impacts through NWS' Model Evaluation Group (MEG). The MEG interacts and collaborates with field forecasters and stakeholders in evaluating and validating the performance of operational models.

Recommendation FO-7; Critical Actions FO-7.1, 7.2
Recommendation: Advance research on coastal processes in Earth system models to achieve comprehensive coastal modeling. The coastal zone supports diverse uses, stakeholders and concerns, including approximately forty percent of the U.S. population; navigation and commercial shipping; alternative energy; pollutant tracking and cleanup; water quality; fisheries; recreation; and search and rescue. It is a critical component of the Blue Economy. At the same time it affects and is subject to some of the most energetic weather on the planet. Forecast modeling provides critical decision support information that protects lives and property and promotes the safe and efficient use of this environmentally treasured and economically vital area. The need for enhanced decision support is increasing as economic growth, migration patterns and climate change bring more people into this increasingly multi-use and hazardous portion of the Earth. An Earth system modeling approach is vital, as this is where atmosphere, ocean, land and watersheds converge and interact.

Response:
NOAA concurs with this recommendation and seeks to advance research on coastal processes in Earth system models through cooperative research programs. The NOAA Coastal and Ocean

Modeling Testbed (COMT) serves as a conduit between the federal operational and research communities and allows the sharing of numerical models, observations, and software tools. The COMT supports integration, comparison, scientific analyses, and archiving of data and model output needed to elucidate, prioritize, and resolve federal and regional operational coastal ocean issues associated with a range of existing and emerging coastal oceanic, hydrologic, and ecological models. Programs within NOAA contribute greatly to the coastal storm surge modeling capabilities, including emerging efforts to couple waves and hydrology.

The UFS is actively engaged with a community-driven UFS-Coastal Application Team that uses the ESMF/NUOPC coupling infrastructure, data assimilation in the JEDI framework, and features wave, sea ice, coastal ocean, and hydrology components for predicting Total Water Levels (TWL) and nearshore processes. The UFS community has been collaborating with NOAA/NOS, NOAA/OWP and USGS on AI and ML methods to improve the fidelity and computational efficiency of coupled coastal river, ocean, wave, storm surge, and morphologic modeling; QA/QC and extract information from both coastal observations and coastal model outputs; post-process system output for feature detection and extreme event prediction; and produce new value-added coastal water intelligence products. The National Water Model v3.0, scheduled for implementation in FY23, couples freshwater prediction from the NWM with output of the Surge and Tide Operational Forecast System (STOFS), to provide routine total water forecasts in the coastal zone. Through the FY22 BIL, NOAA will enhance efforts to transform water prediction capabilities by working toward coupled, continental-scale, operational coastal and inland flood forecasting and inundation mapping services.

INFORMATION DELIVERY (ID)
Priority Area 1: Highly Reliable, High-resolution Weather Information Dissemination

Recommendation ID-1; Critical Actions ID-1.1, 1.2
Recommendation: Embrace open science. To support this recommendation, develop and maintain highly available, disaster-proof, operationally (24/7/365) supported, scalable data access portals, within two years; and fund an open science consortium to coordinate activities in response to the 2021 draft United Nations Educational, Scientific, and Cultural Organization (UNESCO) Recommendations on Open Science.

Response:
NOAA strives to provide data access across the agency and to the broader community in usable formats and in a timely manner. Baseline and regional observatories collect observations in geographically and economically-diverse environments, including those located near underserved communities and indigenous populations. The NOAA Chief Data Office report on NOAA Data Dissemination provides requirements for open, equitable dissemination of NOAA data that meet the IQA and Evidence acts using commonly agreed on community and data management practices.

The Open Geospatial Consortium (OGC) continues to work on transforming web services to Restful API standards, making use of OpenAPI. The API will be designed as “building blocks”, meaning one or more APIs will be interoperable and may be used together to produce an outcome. NOAA is involved in developing API standards through participation in multiple Standards and Domain Working Groups. The OCG API standards are designed to be F-A-I-R (Findable, Accessible, Interoperable, and Re-usable). NWS is further investigating Cloud Native alternatives to NetCDF and GeoJSON, given the challenges of portability and interoperability across platforms, to promote data equity. NWS is reviewing, categorizing, and analyzing all existing data formats to determine those requiring conversion to formats that are recognized by industry.

NOAA/OAR is creating more equitable research outcomes by improving access to funding opportunities across a variety of diverse stakeholders, institutions, and recipients. NOAA is building support for a robust community infrastructure and mechanisms to embrace open science, collaboration, and innovation across the Weather Enterprise through the EPIC Program.

Recommendation ID-2; Critical Actions ID-2.1, 2.2

Recommendation: Within two years, implement the existing plan to address NWS operational data dissemination challenges by leveraging content delivery networks and accelerating the migration to commercial cloud networks, as described in the Environmental Information Services Working Group (EISWG) report, Recommendations 3 and 4. Prioritize retention of expertise in software, data, and networking within NOAA and NOAA contractors to address limitations and ensure future innovation.

Response:

NOAA concurs with this recommendation. As stated in the NOAA Strategic Plan, leveraging cloud infrastructure is a major priority toward the key activity of Data & Information Stewardship. Progress toward this objective will be evident as datasets become openly available via partners' cloud platforms through the next several years. With the increase of NWS Office of Dissemination FY22 appropriations, NWS expanded its use of a Content Delivery Network Provider to include access to operational model data from NOAA's High Performance Computing. Furthermore, NWS operationally deployed the NWS National GIS Viewer and NWS Cloud GIS Services in Q4 FY22 in an AWS cloud environment.

The NWS has begun an analysis of applications and web services remaining on legacy end-of-life hardware to determine which will be migrated to either the on-premise private cloud (Integrated Dissemination Program Infrastructure in College Park, MD, and Boulder, CO) or a secure public cloud environment. The pending FY23 appropriations will determine the transition rate of these applications as well as possible expansion of model data delivery via NOAA's Open Data Dissemination (NODD) public cloud environment.

NOAA is investing in technology to process data locally and parse that data to deliver only the relevant information to users, minimizing the need to constantly move data, while providing tools for end users to process data in a central location. The NWS has been prioritizing ongoing work to investigate the implementation of the Advanced Weather interactive Processing System (AWIPS) within a cloud environment that includes initiating the refactor of the AWIPS back-end processes to work efficiently within a cloud environment.

For example, NOAA is working to set up on AWS a new open source, high-reliable, scalable version of NOAA's nowCOAST. The new version is being built on the cloud to ensure the ability during extreme weather events (e.g., landfalling hurricanes) to provide present and future weather, oceanographic and hydrologic data and information for the coastal U.S. and territories via web mapping services and interactive map viewer for NOAA's users and partners. In addition, the new version is being designed to have the capability to incorporate forecast guidance from NOAA's new and planned weather, oceanographic, storm-surge, hydrologic, and wave forecast modeling systems of the UFS framework. Once transitioned to AWS, the nowCOAST application on the IDP infrastructure will be decommissioned allowing for those on-site private cloud resources to be used for more-focused data and alert services.

NOAA concurs that onboarding and retaining IT expertise is essential to achieving Data & Information Stewardship activities. Providing flexible work schedules for IT specialists is being pursued to retain talented employees.

Recommendation ID-3; Critical Actions ID-3.1, 3.2, 3.3, 3.4

Recommendation: Create a NOAA-wide function to provide Weather Enterprise data integration and dissemination strategy and operational oversight to ensure preparedness and response, within five years. This function should plan, monitor, and respond to issues to ensure consistent, reliable, secure data access and dissemination across NOAA and with enterprise stakeholders for ingress and egress of data in the national interest.

Response:
NOAA concurs with this recommendation. NOAA has not yet fully addressed this recommendation from a NOAA-wide perspective, but is making progress through collaborative efforts among the Line Offices, as stated within this response. According to the NOSC, the Environmental Data Management Committee coordinates the development of NOAA's environmental data management strategy and policy, and provides guidance to promote consistent implementation across NOAA, on behalf of the NOSC and NOAA CIO Council. Environmental data management is an end-to-end process that includes acquisition, quality control, validation, reprocessing, storage, retrieval, dissemination, and long-term preservation activities. The goal of the EDMC is to enable NOAA to maximize the value of its environmental data assets through sound and coordinated data management practices. NOAA’s IT investments are managed by the CIO Council and the Office of the Chief Information Officer (OCIO). Goal 4 in the NOAA Information Resources Management Strategic Plan is to Deliver Customer-Centric Service Excellence by developing strategic relationships with customers and partners' and continuously improving the delivery of technology, data, and information services.

NWS is using the OGC Environmental Data Retrieval (EDR) API for multiple platforms and instances. Additional prototypes are being developed for the National Water Model, NOMADs, and NESDIS satellite data (GOES and Himawari). The World Area Forecast (WAFS) Internet File System (WIFS) will use the EDR API operationally by 2024. NWS was funded by Earth Science information Partnership (ESIP) NOAA Cloud Pathfinder Program (NCPP) to explore and assess an operational implementation of the OGC EDR API in the cloud and to prototype a Cloud Native environment that connects geospatial APIs with NOAA Open Data Dissemination (NODD) data. This study will facilitate the assessment of the most cost effective and performant EDR API environment for the dissemination and visualization of NODD datasets.

NWS is analyzing current applications that reside on legacy end-of-life hardware to determine if they should be transitioned to on-premise cloud (IDP) or move to the public cloud. Once these applications are analyzed and prioritized, NWS will refactor and shift the applications and eliminate outdated dissemination methods. NWS is also leveraging Google Analytics (GA) to understand usage of NOAA data disseminated via websites.

NOAA pursues both intra- and interagency coordination activities to build efficiencies in data integration and dissemination. Examples include the NOAA cross-line office Fire Observations, Research and Services Team (FOReST) chartered under the Weather Water Climate Board (WWCB), a NOAA-NASA collaboration to share data needed to initialize coupled subseasonal to seasonal forecast systems, as well as numerous collaborative efforts between the FAA and the NWS on respective agency programs to modernize the FAA/NWS data exchange and utilization. NOAA and core partners collaborate and share information via the NOAA Virtual Laboratory.

The Aviation Weather Testbed (AWT) serves as the facilitating focal point of NOAA's aviation weather R2O by leveraging relationships with partner agencies, the private sector and universities. AWT activities are prioritized based on International Treaties, FAA requests, NTSB recommendations, and NOAA strategic goals. The Aviation Weather Center is updating its presentation and data delivery capabilities on their website and the World Area Forecast System (WAFS) Internet File Service (WIFS). The FAA is consolidating multiple NWS/FAA communications circuits into one cloud-based communications pathway between the agencies.

The Space Weather Prediction Testbed (SWPT) provides an environment where stakeholders participate in collaborative exercises and experiments using new capabilities. Evaluations of the capabilities are conducted in either an on-going, real-time, manner and/or an event-based, retrospective manner. The impact on users will be evaluated during live exercises or experiments with participation by forecasters, end-users, and researchers.

HYSPLIT models simulate the dispersion and trajectory of substances transported and dispersed through our atmosphere, over local to global scales. HYSPLIT continues to be one of the most extensively used atmospheric transport and dispersion models in the atmospheric sciences community. The model can be run interactively on the Web through the ARL READY system, or the code executable and meteorological data can be downloaded to a Windows or Mac PC.

Priority Area 2: Virtuous Cycle of Collecting and Analyzing Social, Behavioral and Interdisciplinary Observations

Recommendation ID-4; Critical Actions ID-4.1, 4.2, 4.3, 4.4, 4.5
Recommendation: Prioritize and integrate inter- and trans-disciplinary research on equitable and effective use of hazardous weather information—including both deterministic and probabilistic information—for risk assessment and protective decision-making, including at individual, group, and community levels. Utilize multiple research methods whose results can be compared, contrasted, and cross-referenced.

Response:
NOAA concurs with this recommendation. The NOAA PPGC initiative aspires to provide and sustain improvements to the forecasts of extreme precipitation, such as from Atmospheric Rivers, from days to seasons. A key part of this initiative is stakeholder feedback and co-development of innovative guidance products to effectively communicate risk. This includes developing and delivering key products incorporating the needs of underserved communities using social science.

Ongoing work within the NOAA Testbeds and Proving Grounds includes the use of AI first-guess fields to assist the forecaster. Projects range from extreme rainfall to severe weather to temperatures and surface analysis. The NWS and NOAA Testbeds and Proving Grounds are exploring the use of scenarios for Impact-based Decision Support. The NWS is currently leveraging two geospatial platforms to deliver interactive geospatial information: the NWS developed "GIS Viewer" and an NWS designed ArcGIS Online Dashboard. Both systems are capable of providing hazard and uncertainty information along with other geospatial information (e.g., infrastructure, landmarks, shelters). Additionally, the NWS is developing new methods for coupling weather and vulnerability information into easy to understand indices such as the Winter Storm Severity Index and the Heat Risk concept. Public online tools, such as the experimental Graphical Hazardous Weather Outlook (GHWO), issued by each CONUS Weather Forecast Office, display the 7-day forecast, by weather element, in such a way that these risk-based forecasts are quickly and easily accessible and understood by broad audiences.

NOAA Research prioritizes interdisciplinary and transdisciplinary research on equitable and effective use of hazardous weather information for risk assessment and protective action decision-making, including at the individual, group, and community levels. Communicating uncertainty is a major focus area and remains a key science priority in funding calls. Resourced projects identify, develop, test, and validate methodologies that systematically collect data to understand information ecosystems in support of weather-related decision making in a variety of contexts including vulnerable and/or under-represented populations. NOAA is leading a collaborative Societal Data Insights Initiative that will build a Social, Behavioral and Economic

Science data infrastructure that will significantly enhance NOAA's capabilities to evaluate societal response to products and services.

Recommendation ID-5; Critical Actions ID-5.1, 5.2

Recommendation: In collaboration with researchers working on Recommendation ID-4, NOAA should partner with other agencies and the private sector to develop, test, and evaluate probabilistic and deterministic hazard information delivery capabilities for a broad spectrum of end-users.

Response:

NOAA concurs with this recommendation. NOAA is developing reliable probabilistic guidance products for predicting the development and evolution of extreme weather hazard events. The improving skill of numerical weather prediction models, combined with emerging post-processing techniques and model diagnostic tools, will be the dominant source of premier weather information for the NWS during the next decade. Moreover, the assimilation of higher resolution satellite-derived data sets in the GOES-R era will enhance the accuracy, reliability, and value of model output information for a broad spectrum of forecasting services. NOAA is creating and evaluating probabilistic and deterministic hazard information delivery and visualization capabilities, using NOAA Testbeds and Proving Grounds, for a diverse range of users. This will improve the rapid dissemination of useful products and strengthen quantitative and qualitative impact-based decision support services, and allow multiple sectors to participate in the R&D process.

NOAA continues to work with researchers across other federal agencies, academia, and the private sector to simplify hazard information, increase capacity to provide dynamic geospatial information for improved interaction on web and mobile devices, and improve risk communication efforts. NOAA is also investigating technologies to translate information into multiple languages to improve service delivery to non-English speaking users. NOAA Testbeds and Proving Grounds are actively testing these new efforts across a broad spectrum of hazard scenarios and timelines. NOAA Testbeds and Proving Grounds and NOAA Laboratories and programs are working with the NWS to develop new probabilistic information covering multiple hazard scenarios at multiple time scales. NOAA also supports, through grants (e.g. JTTI), several Research-to-Operations projects across academia and private sectors to improve communication of risk and forecast uncertainty and communication of probabilistic information. NWS also brings sub-regional communities together through the IDSS Communities of Practice (CoP) with the goal of identifying local and regional best practices and challenges to facilitate common national IDSS solutions. The IDSS CoP focuses on identifying and sharing best practices, discussing IDSS challenges and developing inter-office support plans and procedures for shared NWS Core Partners.

Recommendation ID-6; Critical Actions ID-6.1, 6.2, 6.3

Recommendation: Build capacity to develop multi-dimensional metrics, data repositories, and new data collection methods and standards for "baseline" data (i.e., not event-specific) and for event-specific "perishable" social and behavioral data, particularly perishable data in the predictive phase of a threat as well as in the aftermath. These data should be quantitative and qualitative, and should include collection and analysis of data from conventional research instruments (e.g., surveys, interviews, participant observations) and less conventional data types and data sources (e.g., social media, citizen science and crowdsourced databases, mobile apps and smartphones). They should include, for example, geospatial metadata (on temporal and spatial scalar characteristics) from Did-You-Feel-It type immediate post-event cross-sectional data collection, to data from experiments, to longitudinal data on weather information usage patterns within and across events and event-type.

Response:
NOAA concurs with this recommendation. Through the FY22 BIL, NOAA is building capacity to collect and analyze quantitative and qualitative baselines, longitudinal, and event-specific social, behavioral, and economic data to learn what weather information is needed when, by whom, and how it can and will be used. NOAA is investing in longitudinal data to establish metrics, build baselines, and thereby measure the impacts of IDSS investments on end-user comprehension, utility and response. Funding priorities encourage the development of construct measurements for the effectiveness of the IDSS program to stakeholders. Given OMB standards, care is always given, and limitations noted, with regard to the limits of the generalizability of a project's findings. The OAR Weather Program Office's (WPO) Social Science Program is working with their award recipients to ensure more robust compliance with NOAA's data sharing policies for both qualitative and quantitative data.

To advance this recommendation, NOAA supported efforts in both longitudinal and event-based data collection. In partnership with the Natural Hazards Center at the University of Colorado, Boulder and in collaboration with the National Science Foundation, the Weather-Ready Research Quick Response Program was established to collect event-specific perishable data and require data and research instrument publication (e.g., surveys). In addition to event-based data, the Social Science Program also supported the collection of baseline and longitudinal data through the Extreme Weather and Society Survey. In partnership with the Institute for Public Policy Research and Analysis at the University of Oklahoma, this longitudinal survey effort provides data on developing trends in the public's forecast and warning reception, comprehension, and protective action decision-making for a variety of weather hazards.

The NWS IDSS Program has established a formal process for gathering and evaluating NWS Core Partner needs. Core Partner requirements and needs will be captured and documented through engagement and Core Partner surveys. This survey will be conducted in FY23 and will provide a baseline of qualitative data for NWS to initiate a longitudinal dataset of Core Partner feedback.

FOUNDATIONAL ELEMENTS (FE)
Priority Area: Science

Recommendation FE-1; Critical Actions FE-1.1
Recommendation: Develop a weather-knowledge ecosystem, with social mechanisms to effectively leverage academic, governmental, and industrial partners to create, educate, apply, and advance weather information synthesis and modeling, and to integrate automated and human forecasting skills and weather communications and decision support.

Response:
NOAA concurs with this recommendation. NOAA understands the critical value of engaging with outside partners and stakeholders in deepening weather-knowledge to deliver the best available products and services. The agency will continue to make important investments to advance a collaborative weather research and development network with academic, governmental, and industry partners to continuously improve weather information, products, and services. NOAA is an active member of the Interagency Council for Advancing Meteorological Services (ICAMS) through the Committees on (a) Observational Systems, (b) Cyber, Facilities, and Infrastructure, (c) Services, and (d) Research and Innovation. For example, through the Committee for Research and Innovation (CoRI), NOAA is coordinating an earth system approach for research and innovation to advance meteorological services in maximizing technological innovations, creating new modalities/processes/efficiencies, building collaborations, and pursuing frontier capabilities. Ongoing efforts include numerous longstanding partnerships with universities to collaboratively collect, analyze, and disseminate weather related information. These synergistic relationships allow NOAA to not only remain a leader in advancing weather science through information synthesis, advance forecasting capabilities, and modeling but also a leader in educating the public and providing products to the private sector. NOAA actively engages with social scientists to understand how the agency's data and visualizations are used to make important weather-related decisions, collect further metrics on data usage and how improvements can be made, and also how to most efficiently develop structures that capture, process, and disseminate data to a wide spectrum of users.

Recommendation FE-2; Critical Actions FE-2.1
Recommendation: Continue to invest in understanding the basic physics, chemistry, and dynamics of the Earth system, and new data assimilation science, particularly in two-way coupled assimilation techniques that allow the new (and in some cases existing) Earth system observations to be incorporated into the UFS.

Response:
NOAA concurs with this recommendation. The NOAA Strategic Plan (FY22-FY26) states that NOAA will advance its weather, water and climate predictions which will be achieved through improved modeling of land, ocean and ice ecosystems, atmosphere-land-ocean-ice interactions as well as coupled data assimilation of atmosphere, land, ocean, ice, biogeochemistry and ecosystems. NOAA will develop and operate next-generation Earth system models using state-

of-the-science and community approaches in concert with advances in high-performance computing. NOAA is fundamentally involved with the development of physical parametrizations that directly benefit UFS research and operational capabilities and has increased its collaborations in the development of UFS applications.

NOAA is investing in the development of new data assimilation, particularly two-way coupled techniques beginning from weak coupling and exploring strong coupling methods. NOAA's investment in critical partnerships with EPIC, NCAR/DTC, and JCSDA further ensure the testing of new capabilities and advancements are performed in relevant systems for accelerated pathways to operations. NOAA will continue to engage with users/stakeholders (forecasters), modelers, and researchers to inform research investments that address critical model deficiencies and needs.

Recommendation FE-3; Critical Actions FE-3.1, 3.2, 3.3, 3.4

Recommendation: Accelerate the NOAA AI strategy and expand efforts in data aggregation, scientific research and social science for AI.

Response:

NOAA concurs with this recommendation. NOAA is partnering with civil agencies, academia and industry to establish the Earth Science Information Partners (ESIP) Data Readiness cluster with the objective of developing a standard for the AI readiness of open environmental data, along with use case driven metrics and working to train an AI-ready Workforce. NOAA provides leadership in AI implementation by co-leading the ICAMS AI/ML and Cyber Facilities & Infrastructure Subcommittees to help coordinate development of AI Ready Data and computing resources.

Following NOAA's AI Strategic Plan, NOAA established the NOAA Center for Artificial Intelligence (NCAI) to efficiently coordinate AI across NOAA, harvest AI capacity from partner agency investments and industry capabilities, and ensure NOAA deploys inclusive trustworthy AI applications for social environmental justice. NOAA is targeting AI training needs by coordinating a pilot gap assessment and is building an AI-ready workforce by developing interactive training material using NOAA data. NOAA is formatting data in machine readable formats with complete metadata, and providing access through the NOAA developed Environmental Research Division's Data Access Program (ERDDAP) server. NOAA is enhancing data assimilation to improve numerical weather prediction by developing physics-based AI for radiative transfer parameterization and uncertainty quantification for various AI models.

Several NWS observational (e.g., NEXRAD) and numerical weather prediction (e.g., GFS, CFS, NWM, NBM) datasets contain neural network emulations and are made available on cloud platforms through the NOAA Open Data Dissemination (NODD) program, but additional resources are needed to prioritize and convert further datasets for AI applications.

Recommendation FE-4; Critical Actions FE-4.1, 4.2
Recommendation: Increase university involvement in NOAA research to gain assistance in advancing the NOAA mission and in training the next generation of NOAA scientists. This should include, as appropriate, leveraging partnerships with other funding agencies (e.g., NSF).

Response:
NOAA concurs with this recommendation. NOAA program offices, laboratories, and weather forecast centers have hosted numerous university students, interns, and postdocs over the years. For example, NOAA Research has actively engaged with awardees of the Developmental Testbed Center (DTC) Visitor Program, and coordinated activities with university communities through the DTC Science Advisory Board. NOAA hosts both undergraduate and graduate scholars through various NOAA Office of Education programs, such as the NOAA Experiential Research and Training Opportunities Program; William M. Lapenta Internship Program; Ernest F. Hollings Undergraduate Scholarship Program; and Educational Partnerships Program with Minority Serving Institutions (EPP/MSI) undergraduate Scholarship Program.

NOAA also partners with the NSF, engaging and mentoring students through the NSF Artificial Intelligence for Environmental Science (AI2ES) program, focusing on preparing the next generation of scientists and engineers to embrace and use AI/ML to improve forecast capabilities. These opportunities provide nurturing experiences for professional development; mentoring and collaboration with NOAA scientists, researchers and forecasters; allows students to assist with developing cutting-edge projects for model and forecast improvements; and gaining first-hand knowledge of management and administrative activities at a leading environmental agency. A recent roundtable meeting between NOAA and the National Science Foundation highlighted opportunities for collaboration across several areas: weather and climate; earth system modeling and prediction; and social science, education and equity, and ocean innovation for the New Blue Economy. As a follow-up to this roundtable, NOAA and NSF are exploring a Memorandum of Understanding (MOU) to develop an NSF-led university and industry institute on catastrophe risk modeling. In the next few months there will be additional follow-up discussions with NOAA and NSF leadership to support specific ideas for collaboration.

The recent well-supported public releases of the UFS, with enhanced user-support through EPIC, are enabling increased academic engagement with NOAA scientists to improve the model, conduct research with it, and contribute to NOAA's forecast system. The UFS Research to Operations (R2O) Project is an exemplary case where a broad collaboration among NOAA and non-NOAA scientists was launched to accelerate innovation into NOAA operational modeling for weather and climate prediction.

The NOAA Weather Program Office (WPO) Innovation for Next Generation Scientists (WINGS) Dissertation Fellowship will launch in FY23, and is specifically designed to target innovative research in areas of scientific importance relevant to NOAA's mission. Potential focus areas include DA, atmospheric physics, model component development (land, ocean, air quality, ice, etc.), systems architecture, AI/ML, software engineering, coastal resilience, fire weather modeling, social science, observations, and computational science. The overall goal is to establish a pipeline enabling the next generation of STEM majors to enter the NOAA workforce and Weather Enterprise. This program is in addition to the community engagement performed by the EPIC to grow the user base of university students and researchers that can contribute to the advancement of NOAA's operational models.

Recommendation FE-5; Critical Actions FE-5.1, 5.2, 5.3

Recommendation: Create multi-university research consortiums to address critical research issues for NOAA. These could be patterned on the highly successful NSF Science and Technology Center programs.

Response:

NOAA concurs with this recommendation. NOAA continues to strengthen and expand relationships with academic institutions and explore multi-university research consortia, through programs such as Cooperative Institutes (CIs) and Cooperative Science Centers, to understand future research directions and address critical NOAA science priorities. One potential option under careful consideration by NOAA includes the creation of a multi-university consortia for data assimilation (DA) to leverage the academic community, develop the DA workforce, and address requirements depending on operational needs for basic vs. applied research.

NOAA hosts multiple grant programs, including the Collaborative Science, Technology, and Applied Research (CSTAR) Program, its COMET Partners Projects, the Next Generation Global Prediction System (NGGPS) Program, and Hurricane Forecast Improvement Program (HFIP) to address critical research issues. NWS has greatly increased university involvement in NOAA research through hosting the William M. Lapenta Internship Program, where students are directly engaged in NOAA research and are eligible for direct hire following their successful participation in the program. Through the internship program, NOAA recruits fresh talent and seeks to diversify the future workforce of the Weather Enterprise.

The NOAA José E. Serrano Educational Partnership Program with Minority Serving Institutions (EPP/MSI) program targets students from traditionally underrepresented minority communities. This program leverages academic partnerships through the Cooperative Science Centers (CSC) - a consortium of academic institutions led by an MSI - which has been integral in increasing the number of students from these communities graduating with degrees that are aligned with the NOAA mission. CSC centers train students in core NOAA mission fields (i.e., atmospheric sciences and meteorology, earth system sciences, remote sensing technology, coastal and marine ecosystems, and living marine resources), resulting in a diverse pool of top-rated graduates with degrees in NOAA-mission sciences, engineering, natural resource management, and policy. Since the inception of the program in 2001, over half of U.S. doctoral degrees earned by African Americans in atmospheric sciences, and almost 40 percent of all U.S. doctoral degrees earned by Hispanics in marine sciences were granted through CSC institutions. NOAA's partnership with the CSCs exemplifies the agency's efforts to successfully support and prepare for its future workforce. The CSCs work collaboratively with NOAA in applying social science solutions to real world problems in local communities. The EPP/MSI funds the NOAA Cooperative Science Center in Atmospheric Sciences and Meteorology

(NCAS-M), which is comprised of 13 partner institutions, representing a unique niche within an academic community that combines research-intensive institutions, advanced education, collaborative research training, and capacity-building in NOAA mission-relevant disciplines across all campuses. The mission of NCAS-M is to increase the number of workforce-ready graduates from underrepresented communities in NOAA-related sciences, to support NOAA, other Federal agencies, academic institutions, and the private sector.

Priority Area: Computing

Recommendation FE-6; Critical Actions FE-6.1, 6.2, 6.3, 6.4, 6.5
Recommendation: The federal government should immediately invest in substantially more computing resources dedicated to weather forecasting research, development, testing and operations, and demonstrate a long-term intent to sustain the United States as the leader in computing technology and resources for weather. Based on the preliminary estimate above for future NOAA HPC requirements, we recommend a goal of at least a 100X increase by 2031.

Response:
NOAA concurs with this recommendation. NOAA must increase its foundational operational and R&D HPC infrastructure to effectively implement world class research innovations in addressing the Grand Challenges of modeling the Earth system. The unified and integrated strategy requires unprecedented levels of HPC capability with a strong and resilient workforce that effectively coordinates across Federal, academic, and scientific communities.

The FY22 DRSA and FY22 BIL will allow NOAA to increase its HPC by a factor of 2. NOAA will use this increase to demonstrate the need for a factor of 100 increase. A portion of the supplemental resources will also be used to increase investment in the software engineering skills needed to improve code efficiency and use of next-generation computational architectures.

Pending additional FY23 appropriations, NOAA will transition the demonstration of NOAA's Big Data Project public cloud environment for model data to full operating capability, either via Public Cloud or Content Delivery Network Provider.

NOAA prepares an annual congressional report on NOAA's Cloud Computing Strategy and NOAA's Supercomputer Plan. This report requires information on existing supercomputing capacity and needs, as well as a long-term cloud computing strategy for future research needs. It discusses the goals and plans of the NOAA HPC program to provide computing resources to the scientific community and how to broaden engagement.

Recommendation FE-7; Critical Actions FE-7.1, 7.2
Recommendation: NOAA must immediately invest in long-term programs to convert, prepare for, and leverage new and emerging high performance computing architectures such as cloud, GPUs, exascale and quantum.

Response:
NOAA concurs with this recommendation. Adding computing capacity will no longer provide performance increases once realized through hardware acquisition alone. NOAA is undertaking a concentrated and deliberate approach for software development and modernization to adapt and harness the performance potential of new architectures. This approach provides a guiding framework to set a path for development while placing engineering resources in collaboration with scientists through interdisciplinary teams. The result will yield usable code by both the engineering and scientific community, which is essential to ensure corresponding progress in the scientific area keeps pace with technological enhancements. The engineering talent needed to mature these development processes will be fostered within NOAA through the training of staff and the development of a new generation of the workforce with a balance of engineering and scientific expertise. NOAA makes investments through the Software Engineering for Novel Architectures (SENA) project which is an effort to ensure NOAA's modeling suite is ready for future landscape changes in HPC. In the short term, SENA efforts include support of standards activities, porting codes to fine-grain architectures and the examination of programming methods. In the long term, SENA plans to address alternative algorithms and general approaches to solving environmental modeling problems. NOAA's investments in next-generation science, exascale technologies, and cloud computing will allow the agency to establish the future continuum of computing that simulates the entire Earth System for Weather, Water, and Climate Prediction.

As noted above, supplemental resources provide an opportunity to make advances in using next-generation HPCs, however sustained resources are also needed. In that regard, EPIC does provide sustained support, particularly for using cloud and for improving code efficiency for operational forecast systems.

NOAA funded a grant at Mississippi State University (MSU) to support research activities in environmental modeling, including weather modeling and simulation. The R&D HPC system provides additional high performance computing capacity to run large, more complex and more detailed environmental models, while advancing the historical and on-going relationships between MSU and NOAA scientists. The partnership with MSU provides greater research opportunities with our collaborators and provides millions of compute hours to enhance NOAA's scientific research.

Priority Area: Workforce Development

Recommendation FE-8; Critical Actions FE-8.1, 8.2
Recommendation: Develop a pipeline of diverse talent from K-12 students to undergraduate and graduate students to NOAA employees to lifelong learning and professional development.

Response:
NOAA concurs with this recommendation. NOAA's internship and fellowship programs provide unique and valuable opportunities to undergraduate and graduate students to gain hands-on research experience, professional development, and training to study various scientific topics.

For example, the John A. Knauss Marine Policy Fellowship places graduate and postdoctoral students, including international students, in NOAA offices like the National Weather Service to collaborate and lead projects that advance the agency's mission. The Pathways Program is an opportunity for students and recent graduates to join Federal Service. It includes three programs – (1) current students, (2) recent graduates, and (3) Presidential Management Fellows. Participants who complete the requirements for their program may be eligible to be non-competitively converted to a permanent position. In addition, the José E. Serrano Educational Partnership Program with Minority Serving Institutions (EPP/MSI) and the Ernest F. Hollings Undergraduate Scholarship programs support the training and graduation of students and develop their skills to increase their eligibility to join the workforce in climate-related fields, including weather. The EPP/MSI program in particular targets students from traditionally underrepresented minority communities. The program leverages academic partnerships through the Cooperative Science Centers (CSC), which are a consortium of academic institutions led by an MSI. The centers train students in core NOAA mission fields: atmospheric sciences and meteorology, earth system sciences and remote sensing technology, coastal and marine ecosystems, and living marine resources. One of the primary goals of the CSCs is to work collaboratively with NOAA in areas of science, resource management and social science solutions to real world problems in local communities. NOAA's internship and fellowship program alumni are eligible to be directly hired into the NOAA federal workforce through the Conservation Corps Act and are also well positioned to apply for NOAA fellowships (e.g. Knauss) and contractor positions at NOAA or its partners.

As noted in FE-4, the NOAA WPO WINGS Dissertation Fellowship will enable the next generation of STEM majors to enter the NOAA workforce and Weather Enterprise. NOAA also provides professional leadership development opportunities to enrich and empower their workforce, such as the Foundational Leadership Development Program (FLDP) for GS 1-8 (or equivalent), the Mid-Career Leadership Development Program (MCLDP) for GS 9-12 (or equivalent), and the Leadership Competencies Development Program (LCDP) for GS 13-15 (or equivalent).

Recommendation FE-9; Critical Actions FE-9.1, 9.2
Recommendation: Develop an enterprise vision for workforce education and training at multiple degree levels that is flexible enough to accommodate different line office needs and leverage existing resources available to the community.

Response:
NOAA concurs with this recommendation. Goal 4 of The NOAA Office of Education Strategic Plan highlights the importance of a diverse and highly skilled future workforce pursuing careers in disciplines that support NOAA's mission. NOAA provides opportunities for undergraduate and graduate students that help them develop the skills and networks to transition into NOAA-related careers. Students work with NOAA experts to conduct research that is applied in the real world, and NOAA collaborates with academic institutions and faculty to reach postsecondary students. Opportunities are provided to recent graduates to help them transition from their education and training activities into the workforce.

NOAA also offers opportunities for employee professional training in needed areas of expertise. For example, NOAA is targeting AI training needs by coordinating a pilot gap assessment and is building an AI-ready workforce by developing interactive training material using NOAA data. Numerous online courses focused on technology and computer science have been developed by third party vendors (e.g. Skillsoft, COMET) and are available to NOAA employees on the Commerce Learning Center. Examples include AI/ML, the use of Azure in HPC environments, using Git/GitHub for open source code development, and basics on data assimilation in NWP models. Line offices offer targeted training and educational forums related to innovative technology when opportunities arise. For example, NWS hosted a series of webinars by a distinguished professor on topics including AI/ML, advanced forecasting techniques, and statistical post-processing. In addition, NWS offers online distance learning and residence training courses through Professional Development Series to develop competencies for weather, water, and climate service delivery and decision support. More formal training is provided to NOAA employees when requested and involves opportunities via third party vendors such as Redhat, Learning Tree, and AWS.

Priority Area: Weather Enterprise Integration

Recommendation FE-10; Critical Actions FE-10.1, 10.2
Recommendation: Create a NOAA-wide function to provide Weather Enterprise data integration and dissemination strategy and sustained operational oversight to ensure preparedness and response.

Response:
NOAA concurs with this recommendation. NOAA has not yet fully addressed this recommendation from a NOAA-wide perspective, but is making progress through collaborative efforts among the Line Offices, as stated within this response. Comprehensive numerical modeling of the global system is the cornerstone of weather forecasting, weather and climate research, and understanding ecosystems and coastal issues. NOAA will continue to move to end-to-end integrated computing platforms for mission critical modeling, speeding the research-to-operations (R2O) process and operations-to-research (O2R) feedback through dependable HPC. Capacity and architecture requirements will be met through a mix of NOAA-owned and leased HPC capabilities, leadership-class computing facilities available through partner federal agencies, and publicly available commercial cloud platforms. NOAA will continue to foster a culture that values data as a strategic asset to understand the environment, creating scientific insights and economic value, improving government efficiency and providing quality services for the public. This is reflected in NOAA's data, cloud, and HPC strategic planning.

As more NWS applications migrate to the public cloud, NWS is exploring opportunities to minimize the expense of data egress to ensure it can put as much data in the public cloud to be shared with weather enterprise partners as possible and to make it more easily accessible. NWS is analyzing the applications remaining on legacy end-of-life hardware to determine which will be recommended to migrate to the on-premise private cloud (IDP) versus the public cloud, and efforts to begin those migrations will begin in FY23. NWS has procured a content delivery management service for IDP. As referenced in FE-6, NWS will transition the demonstration of NOAA's Big Data Project public cloud environment for model data to full operating capability either via Public Cloud or Content Delivery Network Provider.

NOAA's Meteorological Assimilation Data Ingest System (MADIS) collects data from NOAA and non-NOAA sources through partnerships with outside agencies, universities, the private sector, and public, and integrates these data sets with NOAA data sets, with quality controls, and a standardized interface for disseminating the data to the greater meteorological community.

Appendix A: List of Acronyms

AI	Artificial Intelligence
AI2ES	Artificial Intelligence for Environmental Science
AON	Arctic Observing Network
AQ	Air Quality
AR	Atmospheric River
ASOS	Automated Surface Observing System
ATMS	Advanced Technology Microwave Sounder
AWIPS	Advanced Weather interactive Processing System
AWS	Amazon Web Services
AWT	Aviation Weather Testbed
BGC	Biogeochemical
BIL	Bipartisan Infrastructure Law
CAC-WP	Community Advisory Committee for the Office of Water Prediction
CCPP	Common Community Physics Package
CI	Cooperative Institute
CIO	Chief Information Officer
CIROH	Cooperative Institute for Research to Operation in Hydrology
CMAQ	Community Multiscale Air Quality
COMT	Coastal and Ocean Modeling Testbed
COMET	Cooperative Program for Operational Meteorology, Education, and Training
CoP	Community of Practice
CoRI	Committee for Research and Innovation
CRTM	Community Radiative Transfer Model
CSC	Cooperative Science Centers
CSTAR	Collaborative Science, Technology, and Applied Research Program
DA	Data Assimilation
DIS	Office of Dissemination
DRSA	Disaster Relief Supplemental Appropriations Act of 2022
DTC	Developmental Testbed Center
EDMC	Environmental Data Management Committee
EISWG	Environmental Information Services Working Group
EMC	Environmental Modeling Center
EPIC	Earth Prediction Innovation Center
EPP/MSI	José E. Serrano Educational Partnership Program with Minority Serving Institutions
ERDDAP	Environmental Research Division's Data Access Program
ESIP	Earth Science Information Partners
ESM	Earth System Model
ESMF	Earth System Modeling Framework
FAA	Federal Aviation Administration
FAIR	Findable, Accessible, Interoperable, Reusable

FE	Foundational Elements
FIRO	Forecast-Informed Reservoir Operations
FO	Forecasting
FOReST	Fire Observations, Research and Services Team
FV3	Finite-Volume Cubed Sphere
FW	Fire Weather
GFS	Global Forecast System
GIS	Geographic Information System
GOES-R	Geostationary Operational Environmental Satellite - R series
GOMO	Global Ocean Monitoring and Observing
GSL	Global Systems Laboratory
HAFS	Hurricane Analysis and Forecast System
HFIP	Hurricane Forecast Improvement Program
HIW	High-Impact Weather
HPC	High Performance Computing
ICAMS	Interagency Council for the Advancement of Meteorological Services
ID	Information Delivery
IDP	Integrated Dissemination Program
IDSS	Impact-Based Decision Support Services
I/O	Input/Output
IOS	Impact of Observing Systems
IOOS	Integrated Ocean Observing System
IQA	Information Quality Act
IT	Information Technology
JCSDA	Joint Center for Satellite Data Assimilation
JEDI	Joint Effort for Data Assimilation Integration
JTTI	Joint Technology Transfer Initiative
MADIS	Meteorological Assimilation Data Ingest System
MEG	Model Evaluation Group
ML	Machine Learning
MRMS	Multi-Radar Multi-Sensor
NCAI	NOAA Center for Artificial Intelligence
NCAR	National Center for Atmospheric Research
NCAS-M	NOAA Cooperative Science Center in Atmospheric Sciences and
Meteorology	
NCEP	National Centers for Environmental Prediction
NCOP	National Currents Observation Program
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	Next Generation Weather Radar
NGGPS	Next Generation Global Prediction System
NIO	New and Improved Observations
NOAA	National Oceanic and Atmospheric Administration
NOSC	NOAA Observing System Council
NOS	National Ocean Service

NSF	National Science Foundation
NTSB	National Transportation Safety Board
NUOPC	National Unified Operational Prediction Capability
NWLON	National Water Level Observation Network
NWP	Numerical Weather Prediction
NWS	National Weather Service
OAR	Oceanic and Atmospheric Research
OCIO	Office of the Chief Information Officer
OD	Observations and Data Assimilation
OMB	Office of Management and Budget
OSE	Observing System Experiments
OSSE	Observing System Simulation Experiments
OSTP	Office of Science and Technology Policy
OWP	Office of Water Prediction
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PBL	Planetary Boundary Layer
PI	Principal Investigator
PPGC	Precipitation Prediction Grand Challenge
PWR	Priorities for Weather Research
QA/QC	Quality Assurance/Quality Control
QOSAP	Quantitative Observing System Assessment Program
R2O[2R]	Research to Operations [to Research]
R&D	Research and Development
RRFS	Rapid Refresh Forecast System
S2D	Seasonal to Decadal
S2S	Subseasonal to Seasonal
SAB	Science Advisory Board
SRW	Short-Range Weather
TAO	Tropical Atmosphere Ocean
TDWR	Terminal Doppler Weather Radars
TPOS	Tropical Pacific Observing System
TWL	Total Water Level
UAS	Uncrewed Aircraft Systems
UFS	Unified Forecast System
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USGS	United States Geological Survey
UxSRTO	Uncrewed Systems Research Transition Office
WCOSS	Weather and Climate Operational Supercomputing System
WINGS	[WPO] Innovation for Next Generation Scientists
WoF	Warn-on-Forecast
WPO	Weather Program Office
WRN	Weather-Ready Nation
WSR-88D	Weather Surveillance Radar 88 Doppler
WWCB	Weather Water Climate Board