SCIENCE ADVISORY BOARD
National Oceanic and Atmospheric Administration

A Report on Priorities for Weather Research (PWR): Report in Brief

Full Report: https://sab.noaa.gov/wp-content/uploads/2021/12/PWR-Report_Final_12-9-21.pdf

In December 2020, Congress charged the National Oceanic and Atmospheric Administration (NOAA) Science Advisory Board (SAB) to publish a report that provides the information (including benefits) necessary to prioritize federal investments in weather[1] research and forecasting over the next decade.

> ***Report on Weather Research Priorities*** *- In lieu of House language on a Weather Decadal, the agreement directs NOAA's Science Advisory Board to publish a report, not later than one year after enactment of this Act, that provides policymakers with the relevant information necessary to prioritize investments in weather forecasting, modeling, data assimilation, and supercomputing over the next ten years; and that evaluates future potential Federal investments in science, satellites, radars, and other observation technologies, to include surface and boundary layer observations so that all domestic users of weather information can receive data in the most efficient and effective manner possible.*
>
> *- FY21 Omnibus Consolidated Appropriations Act, Book 1, page 232*

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 recommends accelerated and increased investments in priority areas that build upon, and are balanced across, the entire weather information value chain. When taken as a whole, the investments will be transformational, enabling NOAA and the Nation's weather services to meet accelerating weather, water and climate challenges, better protect life and property, and promote greater economic prosperity and environmental justice for all.

Urgency for the PWR Study

The United States (U.S.) has long benefited from a productive and collaborative relationship across the public, private, and academic sectors (known collectively as the Weather Enterprise) in its promotion of a vibrant, weather-informed economy, and its defense against severe weather. More accurate and actionable weather information has grown in its value to the Nation, including forecasts for: solar and wind for renewable energy; water management for urban, agriculture and environmental needs; road, marine and aviation weather forecasts for safe and efficient transportation; and routine forecasts for recreation. With transformational investments, this value will grow even more rapidly in the coming decade, at a time when the United States and the world will depend increasingly on renewable energy sources and are increasingly challenged by weather extremes - including record-breaking heat waves, drought, wildfires, tornadoes, hurricanes, winter storms, heavy

[1] Per the Weather Research and Forecasting Innovation Act, weather is defined as ranging from nowcasting (minutes) to seasonal (up to 2 years).

rains and floods, and storm surges layered on the top of rising sea levels.

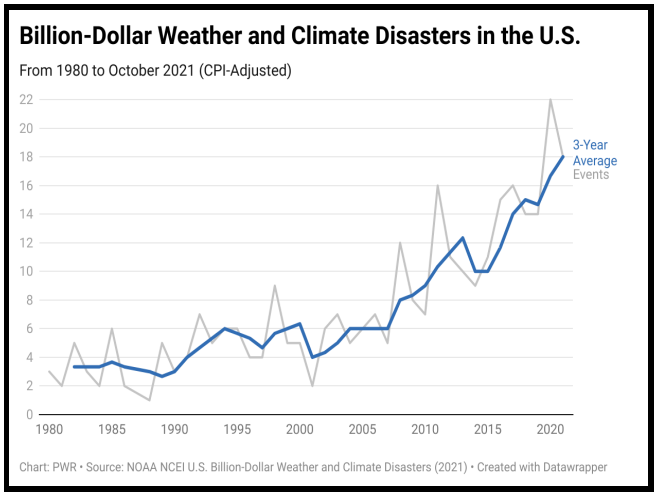

Figure 1: *Annual (gray) and 3-year running average (blue) number of U.S. Billion Dollar Weather and Climate Disaster Events 1980-2021*

Extreme weather now causes hundreds of deaths and hundreds of billions of dollars in damage annually. The United States is currently experiencing approximately six times as many billion-dollar weather and climate disasters per year than it did in the 1980s (Figure 1). We see ample evidence that this alarming trend will continue to increase over time; these increasing weather extremes threaten our sources of food, water, energy, and economic well-being, which are all weather dependent and interconnected. The risks fall disproportionately on historically underserved and socially vulnerable communities. Engaging these communities is necessary to identify and address their needs and will strengthen the Weather Enterprise and the resilience of all communities.

All of these factors confirm an urgency for making Federal investments in weather research and forecasting; and a need for this study.

Strategic Framework of the PWR Study

Despite excellent progress toward a Weather-Ready Nation[2] and an enhanced weather information value chain, there remain significant gaps and untapped opportunities that this report identifies and responds to with its core set of recommendations. The PWR study identifies an urgent need to accelerate and increase investments across three pillars: Observations and Data Assimilation, Forecasting, and Information Delivery. The pillars support improved forecasts and warnings that save lives and property, promote a weather-informed economy, and achieve environmental justice (Figure 2).

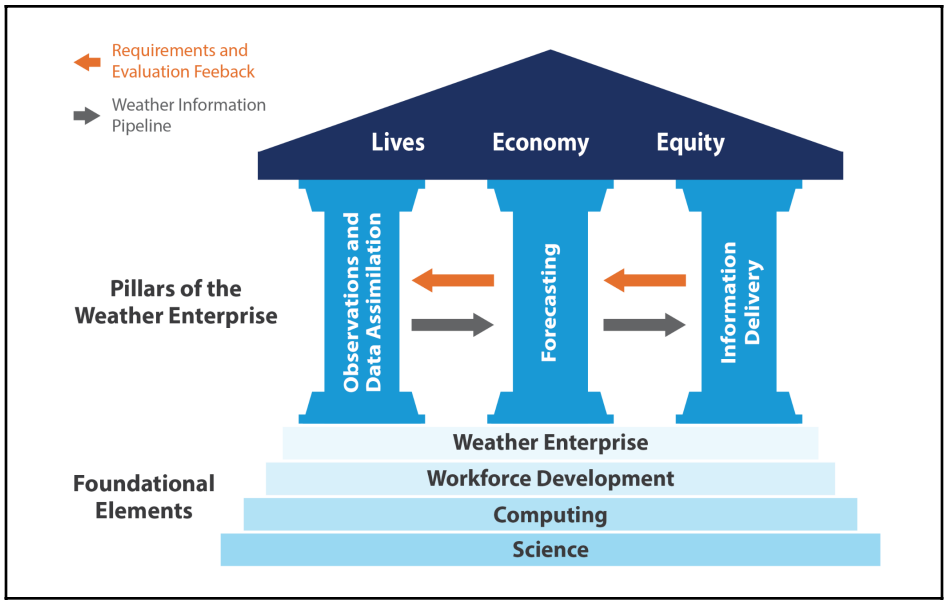

Figure 2: *Priorities for Weather Research Strategic Framework*

[2] Weather-Ready Nation (WRN) is a strategic outcome where society's response should be equal to the risk from all extreme weather, water, and climate hazards.

The *Observations and Data Assimilation Pillar* recommends maximizing the use of existing data sets for additional value; filling critical observation gaps by completing existing networks or establishing new networks that utilize new technologies; and supporting research and training in advanced data assimilation methodologies that are not being supported by other research agencies. The *Forecasting Pillar* identifies the need for foundational Earth system modeling to improve the accuracy and extend the lead time of forecasts (across all relevant time scales); and describes what is needed to improve forecast applications in key critical areas such as water cycle extremes, fire weather and air quality, high impact weather, and coastal processes. The *Information Delivery Pillar* identifies the need to support broader and more reliable dissemination strategies; and recommends the collection and analysis of data on weather product use and impact to inform a continuous cycle of product improvement through a user-oriented paradigm. The PWR Report also identifies investment priorities in science, computing, workforce development and the Weather Enterprise that are cross-cutting *foundational elements* supporting the three pillars. In total, the report highlights eleven priority areas and thirty-three recommendations across the pillars and foundational elements that are summarized in Table 1 below.

Narrative Themes

The five narrative themes presented in the PWR report (Figure 3) highlight the broad scientific and societal benefits delivered by a focused and well-supported National Weather Service.

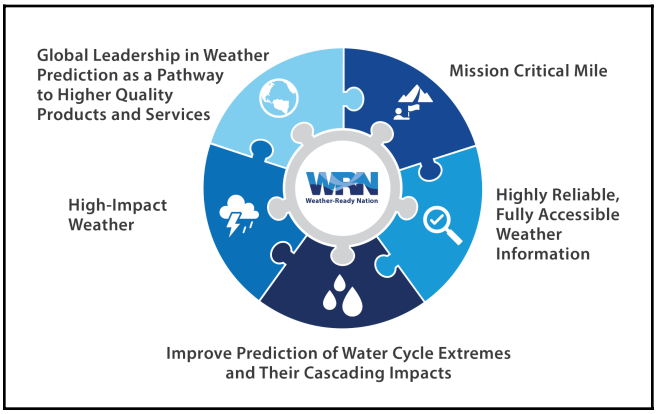

Figure 3: *Narrative Themes highlighting the benefits of a Weather-Ready Nation*

Each of these narrative themes exemplifies the motivation and value of key recommendations. Their storylines directly relate recommendations to impacts and benefits, communicating the "Why?" and motivating the recommendations that are detailed in the more technical pillars that follow.

Immediate First Steps

The overarching consensus of the PWR Study Team is the urgent need to immediately expand U.S. investments in weather research and forecasting across the entire value chain, and to dramatically increase that upward trend over the next decade. In response, the PWR Study Team has highlighted the following immediate first steps, across four core areas; each one reflects an extreme immediate need, or the long lead time required to spin up a critical component. The immediate first steps are a subset of all recommendations (see Table 1) and critical actions identified by the PWR Study Team. There are a total of 10 (not listed in priority order):

Research & Development:

(1) Accelerate development of an **Earth system modeling (ESM) framework** to improve forecast accuracy and lead time (Forecasting, Priority Area 1). This framework would be transformational and highly beneficial across many fronts. The framework is needed to bring all of the parts of this report together efficiently and effectively, as essentially every priority area within this report will benefit from its successful development.

(2) Increase investments in **social and human behavioral data collection and sciences** to better understand how weather products are used and to support co-development of improved products (Information Delivery: Priority Area 2; Foundational Elements: Science). Immediate investments are needed to address service gaps and systematically engage historically underserved and socially vulnerable populations. Expanded capacity is needed to coordinate and support weather information delivery in a holistic approach that cuts across hazards and the full diversity of decision makers and weather information users. New metrics, inclusive design principles, and systematic research and evaluation strategies will also enhance the development and delivery of user-oriented,

timely, meaningful, skillful (accurate), usable, and actionable weather information.

(3) Prioritize immediate investments in fundamental **research on data assimilation** to deliver sustained improvements in forecast skill and to train the next generation of experts in this area to fill an existing critical workforce gap (Observations and Data Assimilation, Priority Area 2). Early support of innovative data assimilation research and development, especially at early Readiness Levels (RL), will prove to be the catalyst for many related and downstream benefits. The effective utilization of existing and future observations all depend on the rapid and significant advancement of data assimilation capabilities.

Infrastructure:

(4) Fully implement and rapidly expand the existing plans for improved **weather data dissemination**, increasing understanding through open science approaches, and expanding applications through weather industry partnerships (Information Delivery, Priority Area 1). Today's operational data dissemination challenges are real and significant. While an existing plan is commendable, its solutions are still insufficient and slow. The United States stands alone in its highly successful Weather Enterprise partnership, which depends upon a reliable infrastructure with unfettered access to core data assets. Restrictions and outages in this area cut into the very fiber of this success and must be mitigated with utmost urgency.

(5) Expand **high performance computing (HPC)** capacity by two orders of magnitude (over ten years) to support operational forecasts and data dissemination and provide critically lacking capacity in U.S. weather research (Foundational Elements, Computing). HPC must be an immediate and ongoing investment. HPC shortfalls and requirements have been highlighted in many of the report's recommendations where it is called out as critical for success, not only for operations, but especially so for research. Without sufficient HPC investments, the loss of potential advancements is tremendous and cannot be overstated.

(6) Fill gaps in existing **Earth system observing networks** with existing, proven or augmenting technologies to expand coverage, especially in underserved regions; existing observing system technologies, including private sector, academic, and unattended observing systems, must be immediately prioritized for deployment to fill current gaps (Observations and Data Assimilation, Priority Area 3). There is a backlog of well-known observational gaps with established potential to fill them. These sensors exist and can be deployed; it is a matter of capacity alone. Such investments quickly support improved weather forecasts from minutes to two-year lead times, enable scientific advances, and engage academia and the private sector.

Actions & Impacts:

(7) Support **reanalysis and reforecasting** vital to Earth system model evaluation and improvement, to characterize extremes, and provide training datasets for artificial intelligence (AI) product applications (Observations and Data Assimilation: OD-5; Forecasting: FO-3). A plan to complete the reanalysis/reforecasts (RA/RF) for NOAA's forecast systems is absent and critical. A successful ESM effort is not possible unless a full plan for RA/RF with immediate execution is defined and completed. One of the known inhibitors of completing this plan is the absence of a dedicated HPC allotment for the task (Foundational Elements: Computing). The success of completing this recommendation is critically important to all other modeling system efforts as well.

(8) Target the **understanding and prediction of high-impact weather (HIW)** to match the urgent need imposed by climate trends, population and infrastructure increases, and disproportionate impacts on vulnerable communities; including exploring new innovations with AI and machine learning (ML) applications (Forecasting: FO-6). A few examples of HIW are fire weather (and associated air quality), water extremes (floods and drought), heat, hurricanes, and severe thunderstorms. These challenges are only going to grow, and early focused research and attention on providing relevant targeted observations, modeling, and forecasts, will best serve the national interest and the WRN strategy.

(9) Target **water cycle extremes and their cascading impacts** to improve flood and drought prediction and to enable forecast-informed reservoir

operations (Observations and Data Assimilation: OD-8; Forecasting: FO-4). Water cycle extremes, i.e., drought and flood are leading causes of economic and human disruption, and yet the prediction of precipitation extremes has been exceedingly slow to improve, with serious adverse impacts on people and the economy. Numerous opportunities exist that would increase resilience to extremes if precipitation, streamflow and flooding could be better predicted. Immediate and substantial action to implement these recommendations are poised to yield high-value benefits in hazard mitigation and cost avoidance and economic efficiency and opportunity, and environmental justice.

NOAA Prioritization & Investment:

(10) Develop **improved, increasingly objective, methods to balance investments** across the weather information value chain and expand efforts to more precisely target future investments. It is critical that NOAA immediately develop more systematic methods to prioritize investments, including improved metrics to measure success, set goals, and focus resources. Ideally this effort will integrate the recommendations from this report with its current priorities. It is also recommended that NOAA develop and or revise its own implementation plans with timelines that respond to the recommendations. In addition, a gap analysis may be needed to identify unfunded requirements to support near- and long-term funding decisions. Not only will these methods better inform NOAA leadership, they will also provide Congress additional tools to prioritize investments for the greatest impact. Ideally these methods will be structured, cross line offices, and promote an integrated approach to budget decisions.

These ten first steps provide fertile ground for immediate action and will set the course over the next decade for delivering an even stronger Weather-Ready Nation and a more productive economy.

External Context and Future Engagement

The combined recommendations (see Table 1) provided in the PWR Report are based on a snapshot of where the Weather Enterprise is today, and the anticipated trends that will influence it into the future. The expected rapid evolution of external world influences over the next decade will result in changes that NOAA, and the Weather Enterprise, should continue to anticipate, and ultimately take advantage of, to best fulfill their missions. As a result, priority areas for investment may evolve, and new priority areas may arise. Critical actions may need to be adjusted based on advances in science, technology, capabilities, or public need. Long-term recommendations may need revisiting at regular intervals (for example, at the midpoint of the decade) if they are to remain relevant for a decade in this rapidly changing environment.

Keeping pace with rapid change is not a new challenge for NOAA. To help meet this challenge, the SAB and the PWR Study Team encourage multiple levels of engagement between NOAA and the broader community at the Weather Enterprise level through open science approaches, at the government leadership level through interagency coordination (e.g., Interagency Council for Advancing Meteorological Services), and at the advisory level through continued engagement with the SAB and others.

The PWR Report is an urgent call to action - for Congress, NOAA and the greater Weather Enterprise to act in a timely way on the recommendations for weather research now and into the future. The study fosters an interactive, collaborative approach to setting priorities for at least the next decade, and offers an adaptable framework for continuous improvements. The recommendations provide a structured approach for the government to address critical gaps and elaborate near and long term funding decisions. The lasting impact of science investments will result in a more vibrant weather-informed economy and a Nation that is much more prepared, is better able to respond, and is more resilient to extreme weather. It will be a nation that provides environmental justice and equity for all.

Table 1: *Summary of the eleven priority areas, thirty-three recommendations and outcomes found in the Report on Priorities for Weather Research*

PRIORITIES FOR WEATHER RESEARCH - RECOMMENDATION SUMMARY TABLE	
OBSERVATIONS AND DATA ASSIMILATION (OD)	
Priority Area 1	**Use and Assimilation of Existing Observations**
OD-1	Maximize the use and assimilation of underutilized ground based, airborne and marine observations - *to ensure maximum value is derived from the full suite of observations in the Earth system model*
OD-2	Maximize the use and assimilation of underutilized satellite observations - *to ensure maximum value is derived from the full satellite constellation in support of an Earth system model approach*
Priority Area 2	**Advanced Data Assimilation Methods, Capabilities and Workforce**
OD-3	Establish new support of novel methodology research and workforce development for data assimilation - *to advance weather prediction and develop the future workforce*
OD-4	Advance coupled Earth system data assimilation for weather, water and sub-seasonal to seasonal forecasting - *to enable observations in one Earth system component to influence corrections in multiple components*
OD-5	Advance the production of regional and global reanalyses - *to improve detection of extreme events, forecast performance evaluation, improve use of observations*
Priority Area 3	**Observation Gaps and Use and Assimilation of New Observations**
OD-6	Develop and deploy a national boundary layer, soil moisture and aerosol observing system - *to improve research and prediction at the interfaces with other Earth system model components*
OD-7	Observe the ocean, its surface boundary layer, and ocean-atmosphere feedbacks - *to fully utilize knowledge of the ocean as a source of predictability in an Earth system model*
OD-8	Implement a multi-phase program to improve the forecasting of atmospheric rivers - *to better anticipate and mitigate water cycle extremes and their cascading impacts*
OD-9	Fill radar gaps using diverse weather radars and data assimilation - *to better detect significant precipitation and severe weather over a greater area and more equitably across the population*
OD-10	Prioritize smallsat/cubesat observation and data assimilation trade studies and demonstrations - *to define the role of smallsat/cubesat technologies for complementing large satellite systems*
FORECASTING (FO)	
Priority Area 1	**Foundational Earth System Modeling**
FO-1	Accelerate Earth system model development and seamless prediction - *to improve forecasts of all components of the Earth system - atmosphere, oceans, cryosphere, land - on all time and space scales*
FO-2	Achieve the best possible operational numerical weather prediction system - *to provide more accurate weather information to the American public, thus decreasing our vulnerability to weather extremes*
FO-3	Establish a regular, sustained Earth system reforecasting activity - *to enable a more effective cadence and accelerated process for operational model improvements*
Priority Area 2	**Advancing Critical Forecasting Applications**

FO-4	Enhance prediction of Earth's water cycle extremes - *to improve forecasting of floods, droughts and hydrologic processes*
FO-5	Increase efforts to advance predictive capabilities for fire weather and air quality - *to better inform the public during wildfire events and hazardous air pollution episodes*
FO-6	Improve forecasts of high-impact weather through multisector partnerships - *to provide more accurate and timely watches and warnings for extreme weather events*
FO-7	Advance research on coastal processes in Earth system models for comprehensive coastal analyses - *to improve coastal forecasts of waves, currents, storm surges, total water levels and water quality*
INFORMATION DELIVERY (ID)	
Priority Area 1	**Highly Reliable, High-resolution Weather Information Dissemination**
ID-1	Embrace open science - *to provide uniform access to all communities, support a geographically distributed, diverse workforce, broaden access to talent, and increase agility and innovation*
ID-2	Complete the existing plan to address National Weather Service operational data dissemination challenges - *to solve critical data access and visualization software issues facing weather forecasters*
ID-3	Develop NOAA-wide strategic and operational support for Weather Enterprise data integration and dissemination - *to ensure effective NOAA data sharing and use across all sectors and hazards*
Priority Area 2	**Virtuous Cycle of Collecting and Analyzing Social, Behavioral and Interdisciplinary Observations**
ID-4	Prioritize research on equitable and effective use of hazardous weather information - *to better understand and inform diverse hazard and risk assessment needs, protective decisions and action*
ID--5	Develop and evaluate probabilistic and deterministic hazard information delivery capabilities for diverse end-users - *for rapid dissemination of useful products and to strengthen decision support*
ID-6	Build capacity to collect and analyze baseline and event-specific social and behavioral data - *to learn what weather information is needed when, by whom, and how it can and will be used*
FOUNDATIONAL ELEMENTS (FE)	
Priority Area	**Science**
FE-1	Develop a weather-knowledge ecosystem - *to create, educate, apply and advance weather information synthesis, modeling, automated/human forecasting, communication & decision support*
FE-2	Continue to invest in understanding the basic physics and chemistry of the Earth system - *to ensure that all important processes that affect weather are accurately included in the forecast models*
FE-3	Accelerate the NOAA Artificial Intelligence (AI) Strategy and expand artificial intelligence research - *to provide higher quality and more timely products and services for societal benefits*
FE-4	Greatly increase university involvement in NOAA research - *to gain their assistance in advancing the NOAA mission and in training the next generation of NOAA scientists*
FE-5	Create multi-university research consortia - *to address critical research issues for NOAA*
Priority Area	**Computing**
FE-6	Immediately invest and develop plans for substantially more computing resources - *in order to achieve the goals recommended in this report that are vital to enhance the U.S. Weather Enterprise*
FE-7	Convert, prepare for, and leverage emerging high performance computing architectures - *to keep pace with technological advances and develop the software tools and IT workforce for the future*

Priority Area	Workforce Development
FE-8	Develop a pipeline of diverse talent from K-12 students to lifelong learning - *to train and keep current generations of researchers and practitioners in weather science and technologies*
FE-9	Develop an enterprise vision for workforce education and training - *to accommodate different line office needs and leverage existing resources available to the broader community*
Priority Area	**Weather Enterprise Integration**
FE-10	Support a Weather Enterprise data integration and dissemination strategy and sustained operational oversight - *to improve weather data, modeling, computing, forecasting, and decision support*

Suggested Citation

NOAA Science Advisory Board, 2021: A Report on Priorities for Weather Research. NOAA Science Advisory Board Report, 119 pp. https://sab.noaa.gov/wp-content/uploads/2021/12/PWR-Report_Final_12-9-21.pdf

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