13 April 2022

TO: John Kreider, Chair, NOAA Science Advisory Board (SAB)

CC: SAB members Jason Hickey and Zhaoxia Pu, Liaisons to the Environmental Information Services Working Group (EISWG), and Cynthia Decker, NOAA SAB Executive Director

SUBJECT: 2022 EISWG Report to the United States Congress
[The Fifth NOAA SAB EISWG report to the US Congress, as required by the Weather Research and Forecasting Innovation Act of 2017 (P.L. 115-25, 18 April 2017), as amended (P.L. 115-423, 7 January 2019)]

Dear Mr. Kreider:

We submit to you this fifth report to the United States Congress from the National Oceanic and Atmospheric Administration (NOAA) Science Advisory Board (SAB) Environmental Information Services Working Group (EISWG). It is made in accordance with Title IV, Sec. 401(c) of the Weather Research and Forecasting Innovation Act of 2017 (P.L. 115-25, signed 18 April 2017), and as amended (most recently by P.L. 115-423, 7 January 2019) (hereafter, the "Weather Act"), which assigns EISWG the responsibility to prepare and transmit an annual report, along with specific follow-on actions, to be completed as follows:

> *"ANNUAL REPORT.—Not less frequently than once each year, the Working Group shall transmit to the Science Advisory Board for submission to the Under Secretary a report on progress made by National Oceanic and Atmospheric Administration in adopting the Working Group's recommendations. The Science Advisory Board shall transmit this report to the Under Secretary. Within 30 days of receipt of such report, the Under Secretary shall submit to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives a copy of such report."*

Overview: This year's report includes three sections. The first section covers the EISWG's assessment of NOAA's overall progress and response to two past submitted EISWG reports. The second section is an update on internal EISWG planning activities related to the Weather Act and ongoing sub-panel review efforts. The final third section of the report links the recent SAB Report on *Priorities of Weather Research (PWR)* to both the EISWG in general, and the Weather Act, specifically.

Section 1. Summary and assessment of NOAA responses and reported activities related to past EISWG reports

NOAA prepared written responses to each of two recent EISWG reports; namely, EISWG's *Statement Concerning the Ongoing NWS Data Dissemination Challenges* (June, 2021) and EISWG's *Report and Recommendations to the NOAA Science Advisory Board concerning the Hurricane Forecast Improvement Program* (Oct, 2020). In addition to the written reports, NOAA briefed the SAB and EISWG on each report in December 2021. Each of these efforts represents a multi-year dialogue between the EISWG and NOAA, and engagement across the broader enterprise. Here we present summary assessments, including highlights and remaining challenges. The original full reports and written responses are included as attachments for reference.

A. NWS Data Dissemination Challenges Statement (submitted in June 2021)

The EISWG *Statement Concerning the Ongoing NWS Data Dissemination Challenges* was approved by the SAB on 11 June 2021. The report called attention to the urgency of operational data dissemination challenges that the National Weather Service was experiencing and contained four primary recommendations. NOAA submitted to the SAB a written response to this report dated 30 August 2021. EISWG reviewed the NOAA response and provides a high-level summary here.

The EISWG commends NOAA for providing a thorough response that clearly links report recommendations to several positive steps taken to address the identified challenges. For example, the response documents NOAA's increasing use of mitigating technologies (e.g., Content Delivery Networks [CDN]), which is aligned with the initial EISWG statement, and identifies plans consistent with the EISWG report (including the use of the Cloud) to further address identified issues.

It is also clear from the NWS written response, the NWS presentation to the SAB, and the actual work the NWS has done, that they are considering user feedback in a more complete manner. They are: using this feedback to inform strategy and operations toward the NWS' important mission of providing critical foundational weather data across the entire Weather Enterprise; and continuing to be open to such feedback and using it to inform strategy & operations. This is highly beneficial for the entire Weather Enterprise.

The EISWG also recognizes as a positive development the NWS' reduction in the severity of the initially-proposed bandwidth constraints, and their effort to make them more focused on a specific set of services. Another positive step includes a commitment to accelerate the usage of commercial cloud platforms for the "last mile" delivery of NWS foundational data. These actions are positive and consistent with the longstanding NOAA principle of equal access to all data at no cost and establishes a mechanism to ensure that no entity receives preferential treatment in terms of access speed or data availability.

NOAA also provided updates about their plans to use publish/subscribe systems, such as the testing of Simple Notification Service (SNS) to announce data availability, which is extremely positive and should be accelerated. Many data calls to NOAA's system today are in fact unnecessary because they result from users who are "polling" for new data – a publish/subscribe system addresses that concern and is a great best practice widely used by Industry.

Unfortunately, even with the substantial gains being made, not all concerns expressed in the report have been addressed. Of greatest concern is that NOAA does not feel it has sufficient resources to fully address the challenges and recommendations. NOAA indicates at several places within the report "based on requested funding" or "based on additional resources proposed"; yet, these are associated with critical items that must be done and it remains uncertain as to whether they will be quickly accomplished based upon budget. While NOAA has a plan in place, which is to be commended, it needs to be funded sufficiently or the issues will continue to be as problematic as they currently are today.

The EISWG statement characterized the immediate situation as an emergency with increasing impacts typically occurring during severe weather events. While the EISWG is encouraged at the progress, it identifies two additional related aspects that remain a concern. First, the NWS emergency response seems to be singularly focused on expanding bandwidth. While that is understandable, the issue is broader – e.g, optimized usage of CDN and other items can play an important role in reducing origin data requests and should be prioritized as part of the emergency response. Second, while it is great to see some legacy applications being transitioned to function in the cloud successfully, which reduces the volume of requests coming to the Integrated Dissemination Program (IDP) origin – the systems mentioned such as the GIS Viewer, Damage Assessment Toolkit and HydroVIS, etc., don't seem like the largest items driving requests (vs. model data, etc). Moving foundational data to the cloud environment could drive greater reduction in data request volume to IDP origin and also enhance value for users of foundational data and should be appropriately prioritized.

In summary, the EISWG commends NOAA for their heightened focus on designing and implementing a plan that ultimately eliminates vulnerabilities, re-builds robust backups, and successfully anticipates accelerating demands for their data. We urge NOAA to remain focused and aggressive toward this plan as outages with significant impact are continuing to occur and must be eliminated. As such, the urgency remains.

B. EISWG's Report and Recommendations to the NOAA Science Advisory Board concerning the Hurricane Forecast Improvement Program (Oct, 2020)

The *EISWG's Report and Recommendations to the SAB concerning the Hurricane Forecast Improvement Program (HFIP)* was approved by the SAB on 28 October 2020. The report contained five summary recommendations and 21 sub-recommendations. NOAA submitted to the SAB a written *Response to the SAB EISWG Report on HFIP* dated 22 November 2021. EISWG reviewed the NOAA response and assembled detailed comments that are included in the Appendix of this Report to Congress. A high level summary is provided here.

EISWG appreciates the effort and care NOAA put into formulating their written response to EISWG's HFIP recommendations. The NOAA response highlights where significant progress has been achieved, where alternative paths forward have been found, and where resource needs continue to challenge the achievement of HFIP goals. EISWG sincerely thanks the NOAA personnel and their external partners who continue to dedicate their energy and experience to HFIP's success.

HFIP is self-described as a rapid transition vehicle between high readiness level research and hurricane forecast operations and warning delivery. Numerous HFIP activities that are improving hurricane track, intensity and storm surge forecasts, as well as the communication of risk to the public, are documented in the NOAA responses (see Appendix for details). It is critical to continue HFIP support for the proven value of the program as the urgent need for improved hurricane forecasts and warnings is accelerating.

Still, the EISWG Report and the NOAA Response agree that significant challenges remain. Both note that the scope of the current Five-Year Strategic Plan has expanded, yet the annual core funding for HFIP has been contracting since 2015. Temporary Disaster Supplementals have contributed significantly to HFIP successes (e.g., ongoing Hurricane Forecast and Analysis System [HAFS] development), but have only partially filled the HFIP budget gap.

Some of HFIP's expanded scope is addressed by leveraging an increasingly broad range of internal NOAA (e.g., National Ocean Service [NOS] storm surge expertise) and external capabilities (e.g, Navy hurricane forecasts for multi-model ensembles) to make progress. Further expansion of community involvement across the Weather Enterprise could be accelerated through open science and open data approaches (e.g., HAFS in Earth Prediction Innovation Center [EPIC], broadly accessible data repositories for operational data and forecast products) that are envisioned, but the capacity to embrace them is uncertain. While NOAA agrees with the many EISWG recommendations on Social, Behavioral and Economic Science (SBES), NOAA states that HFIP is not able to support SBES at the levels planned or desired.

Even if HFIP were fully resourced, longer-term basic and applied research is still needed to fill knowledge and capability gaps (e.g., Earth system science, data assimilation, and social sciences) that are beyond the current HFIP scope. Similarly, new capabilities transitioned to NWS operations may require broader NOAA support that may not be available (e.g., High Performance Computing [HPC] for Earth System models, data assimilation, and ensemble forecasts; completion of existing Earth System observation networks that support the new coupled Earth System model forecasts). The SAB PWR Report (discussed later in this report) provides a framework for future NOAA-wide investments that a fully-resourced HFIP can leverage to even more effectively achieve the Weather Act goals.

Section 2: Status of new report reviews and an overview of an internal focus area selection process

A. Report Reviews in progress

The EISWG continues to survey Weather Act-required NOAA reports as they are released and selects reports for review when a significant need for additional attention or some other motivating factor is identified. The EISWG currently has two sub-panels in place to review:

- Subseasonal And Seasonal Forecasting Innovation: Plans for the Twenty-First Century
- Gaps in NEXRAD Radar Coverage

Both report reviews are entering the writing phase and the EISWG expects the reports to be submitted to the SAB for review in July of 2022.

B. EISWG Focus Area Selection and Planning Process

The EISWG has found success in its focus on the Weather Act reports as a way to gain awareness of relatedNOAA's efforts, as the reports provide a view into NOAA's perspective and priorities related to specific Weather Act topics. As demonstrated in this report, the process is also resulting in real change and overall benefit to NOAA and its stakeholders. However, due to unavoidably complicated processes, the material can be out-of-date and may require additional effort to ensure newer efforts are included. As such, the EISWG developed an internal process to identify focus areas for potential white papers or written statements where the working group's expertise can contribute important perspectives to the SAB and NOAA.

After publication of the PWR report, EISWG recently reviewed the focus areas to identify overlap with PWR and new SAB activities to determine which focus areas it will move forward with in 2022. Foremost is the focus area on Space Weather - a NWS Mission Service Area not covered in the PWR report or the Weather Act. EISWG is moving forward on the Space Weather focus area and received its first briefing from NOAA on the topic in March 2022. Other topics are also being considered.

Section 3: Priorities of Weather Research (PWR) report[1] and its contributions to the Weather Act process:

We want to draw attention in this report to a closely related decadal study report, Priorities for Weather Research (PWR), that was just completed and submitted to the NOAA Leadership (December, 2021) by the NOAA Science Advisory Board. This effort originated from within the December 2020 Appropriations Act as a task to the SAB.

The PWR report was developed to provide Congress the information necessary to prioritize federal investments in weather research and forecasting over the next decade.The PWR report is focused on weather time scales ranging from current conditions to two years into the future, consistent with the Weather Act. The year-long effort benefited from the participation of over 150 subject matter experts. Additionally, in setting up the PWR study team, the SAB leveraged the strong connection between the PWR effort and the responsibilities of the EISWG in general, and the Weather Act

[1] 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

specifically. As such, the PWR study team benefited from strong EISWG involvement with over half of the membership having participated in the process.

Most importantly, and why we include a direct reference to the report here, is that the Weather Act includes specific high-value examples of critical needs that would benefit from NOAA implementations of the broader PWR recommendations.

Summary:

As presented in this report, the EISWG Weather Act activities in calendar year 2021 were significant and characterized by an exchange of ideas and recommendations with NOAA, along with ongoing productive dialogue on several critical topics. Through this process NOAA has demonstrated a willingness to listen and openly consider community input, which has contributed to better services for the public and partners.

The EISWG also acknowledges and appreciates the budgetary increases for NOAA enacted in the FY2022 appropriations from Congress in response to the President's budget request. These increases will help address some of the needs and priorities identified in EISWG's work and summarized in this report. Additionally, and as discussed above, these investments are likely consistent with and further substantiated by the recommendations and findings outlined in the PWR report. Yet, in a number of cases, resource constraints are preventing fully achieving the gains made possible by new technological and scientific advances. Nevertheless, the EISWG looks forward to observing the progress, the EISWG looks forward to observing and commenting on the progress enabled by these resource additions in the coming months and years.

Appendix 1. NOAA progress on EISWG recommendations concerning the Hurricane Forecast Improvement Program (HFIP)

Urgency

Hurricane-impacted states and territories are home to over half of the U.S. population[2]. Hurricane and tropical storm damage since 1980 now exceeds $1 Trillion, more than all other billion dollar weather and climate disasters combined[3]. Physics-based projections indicate future hurricanes will have stronger winds resulting in higher storm surges, as well as slower translation speeds resulting in more rain and flooding[4]. Without doubt, the urgent need for improved hurricane forecasts and warnings to save lives and property is critical and increasing.

Process Overview

Title 1, Sec. 104 of The Weather Act states that the Hurricane Forecast Improvement Program goal "*shall be to develop and extend hurricane forecasts and warnings in order to reduce loss of life, injury and damage to the economy, with a focus on –*

> *(1) Improving the prediction of rapid intensification and track of hurricanes;*
> *(2) Improving the forecast and communication of storm surges from hurricanes; and*
> *(3) Incorporating risk communication research to create more effective watch and warning products."*

NOAA published a *HFIP Five-Year Plan: 2019-2024* on 22 June 2018 that was updated on 25 June 2019, and from the Five-Year Plan produced a more compact version that was submitted as a *Report to Congress HFIP* in late 2019. EISWG reviewed both the *Report to Congress* and the updated *Five-Year Plan*, consulted with six external subject matter experts with significant experience in the three Congressional focus areas, and developed the *EISWG Report with Recommendations to the SAB concerning HFIP*. The EISWG report and recommendations were approved by the SAB on 28 October 2020 and transmitted to NOAA on 5 November 2020. NOAA submitted a written *Response to the SAB EISWG report on HFIP* on 22 November 2021.

The *EISWG Report and Recommendations to the SAB concerning HFIP* contained five summary recommendations, one on each of the three focus areas defined by Congress

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[2] Estimated July 1, 2021 population totals from https://www.census.gov/quickfacts/fact/map/US/PST045219. Hurricane impacted states and territories here include: VI, PR, TX, LA, MS, AL, FL, GA, SC, NC, VA, MD, DE, PA, NJ, NY, CT, RI, MA, VT, NH, ME, HI.

[3] https://www.ncdc.noaa.gov/billions/

[4] Gori, A., N. Lin, D. Xi and K. Emanuel, Tropical cyclone climatology change greatly exacerbates US extreme rainfall-surge hazard, *Nat. Clim. Chang.,* **12**, 171-178, (2022). https://doi.org/10.1038/s41558-021-01272-7

above, and two on cross-cutting topics noted by EISWG during the review process. One cross-cutting topic concerned the Congressionally-requested mapping between the expanded scope, resources and timelines, and the other highlights the value partnerships and collaborations bring to achieving the Weather Act goals. Each of the summary recommendations was accompanied by multiple specific sub-recommendations (21 in total). EISWG reviewed NOAA's progress on the summary and sub-recommendations based on NOAA's written response, and assembled its findings here in this Appendix to the annual *2022 EISWG Report to Congress.*

Findings on NOAA Responses to EISWG Recommendations

Overall support for HFIP

NOAA, and the dedicated efforts of NOAA scientists and their external partners, can be commended for 14 years of coordinated, sustained and impactful HFIP activities. HFIP has fostered and transitioned numerous research products and results into measurable improvements in operational hurricane forecasts and warnings. The positive impacts have been demonstrated both in the U.S. and globally.

Summary Recommendation 1: Mapping expanded scope to necessary resources and timelines.

As noted in the NOAA HFIP Five-Year Strategic Plan (p. 53), the EISWG Report and Recommendations (p. 9), and in the NOAA Response (p. 2), the initial 5-year goals of HFIP were successfully met when the annual core baseline funding was above $22M, but the 10-year goals were <u>not</u> met after a FY15 HFIP baseline budget reduction to ~$14 M slowed the rate of progress. Since then, HFIP's core baseline budget continued to decrease to an FY21 level of ~$12 M. While the Congressionally requested mapping of future scope to resources and timelines is not provided, the NOAA Response (p. 2) does indicate that the required budget for HFIP to address the expanded scope within the current Five-Year Strategic Plan timeframe is $22 M annually. This leaves HFIP with an annual budget gap of ~$10M.

In some responses to the recommendations that follow, NOAA indicates how HFIP has closed some of the budgetary gaps through temporary short-term Disaster Supplementals. In other cases, NOAA has indicated that while they agree with a recommendation, their ability to respond is resource limited, especially in the social sciences. In addition, current HFIP funding for external collaborators, occasionally enhanced through Disaster Supplementals, is focused on transitioning high Readiness Level (RL) research to operations. EISWG recommendations note that to meet the

goals of The Weather Act, there also is a growing need for long-term basic and applied research at the lower RLs. Long-term low-RL research in both the physical and social sciences cannot be efficiently and effectively supported by research funding from short-term Disaster Supplementals or high-RL HFIP transitions, leaving HFIP with an expanding knowledge gap to fill.

Summary Recommendation 2: Improvements to rapid intensification and track

Collaborative approaches to improved understanding of rapid intensity change (both rapid intensification and weakening) are proceeding with (a) Office of Naval Research (ONR) Tropical Cyclone Rapid Intensification (TCRI) Initiative using research aircraft and multi-scale modeling, and (b) OAR/Global Ocean Monitoring and Observing (GOMO) and NOS/ Integrated Ocean Observing System (IOOS) use of coordinated uncrewed and aircraft-deployed systems for improved sampling in the atmosphere, across the air-sea interface, and into the ocean. The development of the Hurricane Analysis and Forecast System (HAFS) as the next generation operational hurricane forecast system was enhanced by Disaster Supplementals and is leveraging broader NOAA-wide programs (e.g. Unified Forecast System [UFS], Joint Effort for Data Assimilation [JEDI]). A Difficult Tropical Cyclone Cases Working Group was established, and research areas have been targeted with international forecast centers. HFIP is developing multi-model ensembles to improve probabilistic forecasts, including the recommended NOAA-Navy ensemble, but co-development of a communication plan for probabilistic forecasts requires additional funding. Ocean data assimilation (3DVar) is being implemented within the future Modular Ocean Model - 6 (MOM6) model, but the current operational data-assimilative ocean model used for the hurricane forecast initial conditions is Real-time Ocean Forecast System (RTOFS). As noted in the EISWG recommendations, 3DVar improvements implemented in RTOFS-Data Assimilation (DA) will impact today's hurricane forecasts and can inform pre-operational implementations in MOM6-DA.

HFIP participated in the UFS metrics workshop and is now reporting an expanded set of hurricane metrics that includes genesis, track, intensity change, structure, precipitation and landfall impacts to evaluate progress. The OAR/GOMO/Extreme Events-Ocean Observations Task Team (EEOOTT)/Integrated Modeling Prediction Assimilation Coordination Team (IMPACT) has developed and shared a set of hurricane-relevant metrics for the ocean component of the coupled models. Research campaigns are being planned through Intensity Forecasting EXperiment (IFEX) partnerships with ONR and NASA that started in 2021 and with OAR/GOMO/EEOOTT for 2022, with a growing interest in Tropical Cyclone (TC) hazards at landfall through NOAA's Advancing the Prediction of Hurricanes Experiment (APHEX).

It is anticipated by NOAA that EPIC should enable public access to the first operational release of HAFS as a coupled atmosphere-ocean-wave model. Current access to operational hurricane model results that are behind the NOAA firewall remain severely limited. The recommended broader access to hurricane datasets remains a future goal. Implementation of open data policies can be the first enabling step of an open science approach that broadens participation across the Weather Enterprise.

Summary Recommendation 3: Forecast and communication of storm surges.

HFIP budget reductions have shifted storm surge research and development to the Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act and UFS. While this shift increases the dependency of hurricane storm surge forecasting improvements on continued support for the COASTAL Act, and on the continued coordination through the UFS Working Groups, it has the benefit of broadening participation in storm surge R&D, including increased leveraging of the NOS/IOOS Coastal and Ocean Modeling Testbed (COMT). Storm surge forecast stakeholders have been identified, and a specific storm surge forecast metric of 90% accuracy level across the full time series has been prioritized. Continued stakeholder engagement and broadening of the stakeholder pool is encouraged, as useful metrics may vary by stakeholder, by the physical environment, socio-economic status, and local infrastructure, and over the course of the storm. COMT has provided recommendations to study the source of hurricane storm surge forecast errors (e.g. different components of new coupled atmosphere - wave - ocean - hydrology storm surge models versus the hurricane model forcing), but this requires additional support. The future strategy for improved total water level forecasts is now being developed within the collaborative UFS network, but with additional support could be expanded to also include stakeholder information needs.

The NOAA response indicates there is agreement with the EISWG recommendation on the need for social science research on the use of hurricane forecasts and warnings. It provided four examples of how Disaster Supplemental funds have been used to look across multiple hurricane hazards, at map perceptions, enhancing product design, and how risk perceptions evolve over the course of a hurricane. The existing effort by the Weather Program Office (WPO) social science program is encouraging, however, the current funded projects are limited in scope and lack resources to address fundamental issues in social and behavioral sciences for weather hazards, and hence the findings may be less generalizable. While there are defined performance metrics for weather forecasts, there are no established metrics (or milestones) for WPO social science research. The listed examples demonstrate significant progress in NWS/WPO support

for social science research. A strategic HFIP social research plan with milestones will provide a synergistic framework to connect seemingly ad-hoc projects for integrated knowledge. It is also important to reach out to a broader social science community.

Summary Recommendation 4: Risk communication research for watch/warning products.

The NOAA response indicates that HFIP's social, behavioral and economic sciences (SBES) research, including its goals and metrics, as outlined in the Five-Year Strategic Plan, will not be supported at the levels planned or desired due to budget constraints. As a partial bridge, Disaster Supplementals supported 6 projects over FY19-22, and OAR/WPO plus NWS/Office of Science and Technology Integration (OSTI) supported 5 projects for FY20-21. While the NOAA response states agreement with the EISWG recommendation on the need for this research, the existing SBES projects are nevertheless limited in scope by funding. Additional leveraging and funding opportunities will be needed, including seeking collaborations with FEMA, DHS, USGS and NSF.

NOAA similarly agrees with the need to develop the next set of meaningful SBES metrics. The WPO Social Science Research to Operations workshop was an important start with a rich set of presentations and discussions that could inspire follow-up activities on metrics. Leveraging the underway SBES activities across NOAA is being pursued, as is the search for additional resources for data gathering to support the research.

Summary Recommendation 5: Expanding partnerships and collaboration.

Collaborations across NOAA line offices continue to grow, with some internal collaborations enabled through Disaster Supplementals. Expanded collaborations with NOS is a shared vision and is occurring through (a) the cross-line office reach of the OAR/GOMO/EEOOTT program, (b) the growing collaborations with NOS/IOOS and its academic/industry partners, and (c) the NOS/ COMT for storm surge improvements. However, the NOAA response notes that the Disaster Supplemental funding that expands collaborative GOMO and IOOS hurricane observation programs is not sustained. The immediate result will be a relatively sparse 2022 season for leveraging GOMO and IOOS hurricane observations for both operational forecasting and research.

Intergovernmental collaborations are topic dependent. Collaborations with NSF in social science existed early on, but budget reductions have led to the current decline in effort exactly when it is needed - as new physical models (e.g. HAFS) are coming online

and new probabilistic products (e.g. multi-model ensembles) are being developed. Much of the social science research is supported by occasional short-term funds from Disaster Supplementals rather than the necessary long-term funding mechanisms for early RL research. Beyond TCRI, collaborations with the Navy, further encouraged through the Commercial Engagement Through Ocean Technology (CENOTE) Act, are growing through overlapping needs in observing systems, modeling, data assimilation and forecasting.

Summary

HFIP is self-described as a rapid transition vehicle between high readiness level research and hurricane forecast operations and warning delivery. HFIP met its initial 5 year goals when it was fully funded, but budget reductions slowed progress and 10 year goals were not achieved within the projected timeline. The scope of the current Five-Year Strategic Plan has expanded, but the annual budgets have contracted even further. The NOAA response to EISWG recommendations indicates the goals of the current Five-Year Strategic Plan will not be met within the current funding levels without a significant extension in time. Temporary Disaster Supplementals have only partially filled the HFIP budget gap. This is occurring at a time when the urgent need for improved hurricane forecasts and warnings is accelerating.

Moreover, the NOAA responses to EISWG recommendations illustrate that achieving The Weather Act goals for HFIP - improving forecasts, warnings, and the communication of risk, for hurricane track, intensity and surge, to reduce loss of life, injury and damage to the economy - are increasingly dependent on HFIP leveraging of NOAA-wide efforts. Transitions of high Readiness Level research to operations (R2O) rely on a vibrant basic and applied research environment (both physical and social) to feed HFIP candidates for transition. The low Readiness Level basic and applied research, often involving external researchers, benefits from access to operational modeling tools (e.g. HAFS in EPIC) and operational forecasts and datasets (e.g. Hurricane Weather and Research Forecasting [HWRF]/Hurricanes in a Multi-scale Ocean-coupled Non-hydrostatic model [HMON], aircraft flight data) in an open data/open science research environment (O2R) that is envisioned but currently not available. Operations must have (a) both the human and high performance computing capacities to accept and implement new operational products, and (b) support the delivery of new products with the operational datasets (e.g. GOMO and IOOS sustained observations) required to add value. Social science research must be expanded from the current occasional short-term Disaster Supplemental approach to a broader sustained community where hurricane risk communication is viewed as a significant use case opportunity for wide-ranging research of interest to multiple agencies.

One approach to meeting the NOAA-wide challenges of supporting the goals of the Weather Act for specific applications such as HFIP was developed through the NOAA SAB Priorities for Weather Research (PWR) study conducted in 2021. Supporting the NOAA-wide activities leveraged by HFIP is an impactful use case for implementing the PWR recommendations. All ten of PWR's Immediate First Steps include NOAA programs HFIP is leveraging, or can leverage in the future, to achieve its goals (see Table 1 for specific examples).

PWR Immediate First Steps	**Examples of HFIP Leveraged Use**
1. Accelerated development of coupled Earth system modeling	HAFS in EPIC
2. Increased investments in social and human behavioral data collection	Data collection supporting hurricane watch and warning risk communication, especially for probabilistic forecasts
3. Immediate investments in fundamental research on data assimilation	JEDI, MOM6-DA, RTOFS-DA
4. Full implementation of existing plans for weather data dissemination (also noted in EISWG data dissemination statement)	Distribution of existing operational hurricane forecast (HWRF/HMON) 4-D fields and operational flight data
5. Expanding high performance computing for operations and research	Multi-model ensembles for probabilistic forecasts; community use of HAFS
6. Filling gaps in existing Earth system observation networks	Need for expanded and sustained observations by GOMO and IOOS
7. Supporting reanalysis and reforecasting for model evaluation	Difficult TC Cases Working Group studies
8. Targeting understanding and prediction of high-impact weather	Hurricane track, intensity and storm surge research to improve forecasts
9. Targeting water cycle extremes and their cascading impacts	Research on extreme rainfall and flooding in slow moving hurricanes
10. Developing improved methods to balance investments	Hurricane OSEs/OSSEs to inform co-design of Earth system observing networks

Table 1. Immediate First Steps extracted from the NOAA SAB Priorities for Weather Research (PWR) and examples of leveraged activities that could support the Weather Act goals for HFIP.

Fully supporting HFIP as the transition vehicle for high Readiness Level research to operations, and investing in the PWR recommendations for prioritized weather research

and forecasting needs that HFIP and other high-impact weather use cases can leverage, is a potential success path for achieving the Weather Act's specific goals of supporting improved hurricane forecasts and warnings that save lives and property, and promoting a vibrant and resilient economy.