24 July 2020

To: John Kreider, Chair, NOAA Science Advisory Board

CC: Robert Winokur, SAB Liaison to the Environmental Information Services Working Group (EISWG)

Cynthia Decker, NOAA SAB Executive Director

SUBJECT: Third 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:

This is the third 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 following responsibility:

> *"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. …"*

Background and overview of process: The EISWG is committed to delivering valuable insights to NOAA and the Congress, and works closely with the NOAA Line Office liaisons to carry out its assigned role in assessing NOAA's progress toward meeting the objectives of the Weather Act. An important part of this close collaboration is a prioritization process that both ensures attention to the critical topics and also recognizes the limits on what the working group can do based on resourcing. The EISWG also continues to explore ways to optimize both the review process and the value of its feedback, including: leveraging additional information gathering opportunities; engaging NOAA experts more frequently and informally; and designing a more efficient internal report-writing and review process. As a result, the EISWG is becoming increasingly effective at addressing topics within the Weather Act identified and systematically prioritized through this collaborative process.

In the past two years, EISWG efforts have generally followed a reactive review process guided by the release of individual NOAA reports mandated by the Weather Act. Upon receipt of a publicly released report, a small task group of EISWG members and outside experts is formed. A brief report is then prepared by this task group. The report contains prioritized findings and recommendations, is reviewed by the EISWG membership, and is forwarded to the NOAA SAB for its consideration and transmittal to NOAA leadership. Unfortunately, through this period we have found this process to be slow given many of the reports are complex and subject to extended periods of internal review. Currently, EISWG members are not allowed to preview any report prior to it being made public (after this lengthy internal review and formal submission to the Congress). However, if EISWG members were to become Special Government Employees (SGE), previews would be allowed. This designation has been discussed, but no action has been taken.

In addition to reviewing the Weather Act mandated reports as they become publicly available, the EISWG will continue to shift to a more proactive approach to fulfill its responsibilities. While gathering information through informal avenues is more challenging and resource intensive, the EISWG recognizes that often this kind of information is significantly more timely and aligned with current activities~~,~~ than the more formal reports that can be long out-of-date by the time they are publicly released. Example sources that will be explored include program wikis and web pages, and other informal discussions or opportunities that can be identified, especially in collaboration with our NOAA liaisons.

Going forward, in each of its face-to-face meetings, the EISWG will review how NOAA is progressing within a key Weather Act topic. Such reviews will involve presentations by NOAA staff and outside experts. A similar task group approach as described above will be used to compile and report on this review as with each of the formal NOAA reports. This proactive process was used in the EISWG's review of the use of Observing Systems Simulation Experiments (OSSE) within NOAA. It is worth noting that the EISWG's OSSE report has been accepted for formal publication in the scientific literature; specifically, in the American Meteorological Society's Bulletin (BAMS).

New reports received: As of this writing, EISWG has received one new report required to be delivered by NOAA to the Congress. This report is on the Hurricane Forecast Improvement Program (HFIP). The EISWG has formed the task group and it is in the process of reviewing the report. We anticipate submitting the report to the SAB in the fall of this year.

Additional opportunities: A new program, the Earth Prediction Innovation Center (EPIC), appears prominently within the 2019 National Integrated Drought Information System (NIDIS) reauthorization of the Weather Act (PL-115-423). Given this visibility, the EISWG committed considerable attention to the rapidly emerging community conversations around this new program. Over this past year, we committed significant time during one of our face-to-face meetings on the topic with presentations from NOAA and other stakeholders. The EISWG also sent representatives to a community workshop on EPIC (August 2019, Boulder, CO), and, finally, prepared a report with recommendations to the NOAA Science Advisory Board concerning the Earth Prediction Innovation Center (EPIC). In its report the EISWG strongly endorsed the EPIC initiative but also called out several significant concerns that must be overcome if EPIC is going to be successful. These concerns include, but are not limited to, topics around governance, infrastructure, resources, and community commitment. In addition, while it may be more a matter of timing, the current program efforts prioritize infrastructure and lack an emphasis on enabling critical scientific advancement in support of EPIC. Finally, as presented, to become a successful and highly impactful program, it will need to be funded at considerably higher levels than currently prescribed. The EISWG EPIC report is included here as Attachment A.

NOAA prepared a written response to the EISWG regarding the EPIC report early this year and the EISWG met with NOAA Leadership in February of 2020 to discuss their feedback. NOAA's written response to the EISWG's findings and recommendations regarding EPIC is included as Attachment B.

The EISWG will continue to prioritize EPIC and monitor its progress. Future reports will include updates and assessments on NOAA's progress with this highly visible and potentially valuable effort.

NOAA response to EISWG findings and recommendations: Our 2019 annual report contained two reports with findings and recommendations for NOAA regarding:

(1) the use of Observing Systems Simulation Experiments (OSSE) in NOAA; a focus area identified by the Science Advisory Board (SAB) and one that appears in several key areas within the Weather Act.

and, (2) the NOAA report to Congress, *Tornado Warning Improvement and Extension Program Plan* produced by the NOAA Office of Oceanic and Atmospheric Research. This is a required report from the Weather Act legislation.

Dated: 9 July 2020
TO: John Kreider, Chair, NOAA SAB
SUBJECT: NOAA SAB EISWG third report to the US Congress as required by the Weather Act.

In December 2019, the EISWG received a summary report from NOAA with a response to each of our recommendations in these two reports, of which there were five (5) in the OSSE report; and eight (8) in the Tornado Warning Improvement and Extension Program Plan report. NOAA's report is included as Attachment C. While the responses to each recommendation were brief, and generally without significant detail, they were highly valuable in that they provided the EISWG important visibility into the thoughts and priorities of the NOAA Leadership Team - as well as future plans and directions. This summary report, which was also submitted to the Senate Committee on Commerce, Science, and Transportation in December 2019, is attached here for reference. The EISWG feels strongly that similar written feedback following future EISWG submissions of findings and recommendations will prove to be an important part of this overall Weather Act review process.

In summary, the EISWG is generally satisfied with NOAA's attention to, and progress toward, achieving the objectives of the Weather Act (and the NIDIS reauthorization).

We have found our access to NOAA experts and Leadership productive and collaborative.

Nonetheless, some frustration remains around the pace of development of required reports within the NOAA line offices and even more so with the slow delivery of the completed reports to the Congress due to the slow onerous internal review process mandated by the Executive Branch. Not only does this make it more difficult for EISWG, and the Congress, to monitor NOAA's progress regarding the Weather Act, but the pace and delay are such that the content when finally released is often outdated and less relevant. We will continue to leverage other approaches to help mitigate this challenge. We note that granting SGE status to EISWG members has the potential to improve this situation.

On behalf of the members of the EISWG, Co-Chairs:

John T. Snow

Brad Colman

Attachments:

Dated: 9 July 2020
TO: John Kreider, Chair, NOAA SAB
SUBJECT: NOAA SAB EISWG third report to the US Congress as required by the Weather Act.

A. Environmental Information Services Working Group (EISWG) Report and Recommendations to the NOAA Science Advisory Board concerning the Earth Prediction Innovation Center (EPIC)

B. NOAA response to the EISWG's report on EPIC

C. NOAA response to the EISWG's 2019 Report to Congress

Attachment A

Environmental Information Services Working Group (EISWG) Report and Recommendations to the NOAA Science Advisory Board concerning the Earth Prediction Innovation Center (EPIC)

To: Lynn Scarlett, Chair, NOAA Science Advisory Board

CC: Robert Winokur, SAB Liaison to the EISWG
Everette Joseph, SAB Liaison to the EISWG
Cynthia Decker, NOAA SAB Executive Director

Date: 3 September 2019

SUBJECT: Environmental Information Services Working Group report and recommendations to the NOAA Science Advisory Board concerning the Earth Prediction Innovation Center

Dear Ms. Scarlett:

Given the prominence of the Earth Prediction Innovation Center (EPIC) in the amendment of the Weather Research and Forecasting Innovation Act of 2017 (P.L. 115–25) by the National Integrated Drought Information System Reauthorization Act of 2018 (P.L. 115-423), the Environmental Information Services Working Group (EISWG) is compelled to inform the NOAA Science Advisory Board (SAB) of recent developments and make recommendations concerning this important emerging effort.

This past 28 June, the EISWG dedicated a portion of its meeting to an update on the EPIC program provided by senior NOAA professionals; see Attachment A for a short summary of that update. Following the June meeting, EISWG members were provided with documents relevant to EPIC from NOAA web pages and the Community Modeling Advisory Committee. Further, NOAA hosted the EPIC Community Workshop in Boulder, CO, 6-8 August 2019. Three EISWG members (Colman, Petty, and Ramamurthy) participated in this workshop. The purpose of this workshop was to gain insight from a diverse group of potential partners, high-performance and Cloud computing experts, and the broader weather R&D community (i.e., academia and private industry) in the planning, development, and strategic vision for the EPIC. Subsequent to the workshop, the EISWG worked virtually between 26 August and 3 September 2019 to hear from these three members and to develop observations and recommendations to pass on to the SAB. This letter is the result of those deliberations.

Based on the information obtained from the various sources described in the preceding paragraph, **the EISWG strongly endorses the EPIC initiative** [as described in the summary report presented by Carr and Kinter on 8 August at the end of the Community

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Workshop (Attachment B)]. EPIC is a very timely and important endeavor for both the research and operational numerical weather prediction (NWP) communities; one that has the potential to direct the priorities of US NWP R&D and R2O/O2R for years to come.

To help ensure the success of this important initiative, the EISWG recommends NOAA take quick and aggressive action in the following areas:

- **It is recommended that NOAA implement EPIC's governance structure and processes as soon as possible, with a focus on the managing institution, leadership team, and advisory boards, and providing the community clear statements of the EPIC vision, mission, and values.** Governance is one of the fundamental components of standing up an effective, efficient Center. Governance will be instrumental in enabling several aspects of the Center deemed critical for its success, including but not limited to: community engagement and culture, talent acquisition and retention, and scientific direction and scope. During the EPIC Workshop there was considerable discussion and general alignment that the EPIC management structure should exist outside of NOAA. While the EISWG does not have a unique perspective here, this structure would require special attention be paid to ensure operational forecasting priorities are successfully communicated and incorporated into EPIC. Further, the Working Group emphasizes that regardless of where EPIC is located, it is critical that a leadership team be quickly put in place that has the necessary intellectual grasp of the big picture and the required technical expertise to garner broad community support and respect. This leadership team must be fully committed to the initiative and able to devote 100% of its time and energy toward EPIC's success. Without a proper and agile governance structure in place, EPIC will struggle to reach its envisioned state.

  The success of EPIC will be closely linked to its ability to be a community-focused organization, one that encourages and values input from all stakeholders and positions; therefore, there is a need to institute a governance framework that is capable of successfully representing broad community interests while remaining true to the goals and objectives of the Center. Moreover, EPIC's governance structure, processes, and values must be such

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that they help in creating a culture of collaborative and inclusive cross-sector involvement, recognizing and respecting the diverse contributions of individuals, institutions, and organizations, particularly on the topics of computing, software engineering, and numerical modeling. It is important to explicitly call out that this collaboration must extend to the ocean and full Earth system communities and include institutions like NOAA/NOS and existing government/academic/industry partnership groups like IOOS, and the Navy.

- **It is recommended that NOAA work with the broader community to develop inclusive community engagement processes, and to anticipate and articulate the appropriate roles NOAA and other entities will play in EPIC.** The roles of potentially important players in the EPIC program have not been clearly defined. These players include UCAR/NCAR, in general, and JCSDA and the DTC, in particular; the various NOAA OAR laboratories and programs; NWS Centers; the Cooperative Institutes (CIs); and researchers/developers in the academic and private sectors. The current lack of specificity has produced confusion in the academic and private sector communities as to how they are to be involved. This recommendation should not be construed as encouraging detailed assignments or restricted roles, but rather as an encouragement for engagement and discussion on how a diverse set of players can work together to best leverage existing programs and efforts to achieve EPIC's vision.

- **It is recommended that early and direct efforts be made to welcome into the Unified Forecast System (UFS) research and development sandbox contributions from other dynamic cores, physical parameterization schemes, Earth-system observation strategies and data assimilation techniques (atmosphere and ocean) and models (e.g., MPAS, UKMO Unified Model).** EISWG feels it is essential that the FV3 dynamic core be the focal point of the UFS and hence the focus of most R&D in EPIC. Yet, there is great value to be had in learning from the operational characteristics and experiences of other operational NWP systems. This will likely result in advancing more quickly along the R2O pathway. In addition, to reclaim leadership in Earth system coupled-model prediction, it is critical even in these early steps of formation that groundwork be laid to aggressively pursue

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contributions in the area of observations (ocean and atmosphere), data assimilation schemes, and boundary conditions between the different components of the Earth System. This also requires a significant amount of leveraging for the observations necessary for those who do the model-output comparisons, model validation, the data assimilation studies, and broad availability to the scientists and students who advance our understanding and improve the operational models.

- **It is recommended that NOAA initiate a multi-agency R&D partnership program into which NOAA and other agencies contribute significant multi-year resources.** The EPIC budget and related fiscal challenges are areas of general concern. The EPIC program had an initial $5M for FY2019, $15M in FY2020, and the same amount projected for FY2021. Given the scale of the problems to be addressed, and the cost of working in the Cloud, this is marginally enough money to open a small program office and establish a modest grants program. The $15M/FY budget for the next two fiscal years is insufficient to grow the required vigorous program, so NOAA must recognize that to accomplish any real, sustainable gains quickly, it must not only request more funds through the federal budgeting process, but also entrain other entities across the federal meteorological R&D community. This will require EPIC leadership to consider carefully how EPIC benefits these other partnering agencies and ensure that each is considered an invested stakeholder into the effort.

- **It is recommended that NOAA organize its Cooperative Institutes that have existing capabilities in NWP and related areas into a nascent, distributed EPIC co-laboratory charged with quickly carrying out one or two narrowly focused R&D thrusts that have potential for near-term success.** EPIC must organize and move quickly to demonstrate that a distributed national collaboration can make significant contributions to improving model performance over the next 12 to 18 months (the time frame being driven by the federal budget cycle). Looking across NOAA, the types of (non-federal) personnel needed -- including some of the best and brightest recent graduates with MS and PhD degrees -- and the highly desirable linkages to the relevant NOAA laboratories are found in the NOAA Cooperative Institutes (CI). The CI's should inventory

existing programs and staff for alignment to EPIC priorities. In addition, if provided the necessary funds, the NOAA CIs have the ability to hire new staff quickly and to spin up new programs to expand and diversify the EPIC community, as they have existing administrative structures backed-up by the management of the host universities.

- **it is recommended that NOAA immediately invest in and execute a Cloud implementation plan to promote community engagement and in support of research-to-operations.** Attracting and maintaining broad community participation in the cloud environment where the UFS is hosted is another challenge that needs to be addressed early on. There will be a tendency for many members of the community to sit back and observe before committing to what has the potential to be an expensive and impactful transition from local modeling R&D to the cloud-hosted R&D that is a key part of EPIC. As such, EPIC needs core players and stakeholders to work together to remove obstacles, create incentives, and to be change agents or champions for the broader community.

  For example, NOAA might appeal to the large commercial cloud providers for initial seed resources to reduce or eliminate the overhead required for researchers and developers to transition to the Cloud. This will be essential in the early stages of EPIC as well as a potentially smart investment by the commercial cloud providers. In addition, an effort to develop simple entry points for diverse graduate students, faculty and researchers, as well as thorough supporting documentation will be urgently needed. Further, within the Cloud environment, the more opportunities that can be provided to draw the community to participate the better. This could include investing in refactoring the existing code into Linux, or AIX of IBM, and ensuring it all remains open source. This would then become a fertile area of study for an inclusive and more diverse community of graduate students, faculty, and researchers. In order to facilitate community and collaborative development of the UFS, an extremely beneficial capability will be the availability of a GTS-like (Global Telecommunications System) capability in the cloud environment that delivers all needed observations and model output for real-time data assimilation and model initialization, testing, and evaluation.

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Date: 3 September 2019
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In closing, the EISWG again strongly endorses the EPIC initiative. NOAA, and the broader Earth system modeling community, as well as its extensive stakeholder community, have the opportunity to make profound and valuable contributions to society by successfully implementing EPIC. The members of EISWG are both excited about and committed to supporting this effort and look forward to future conversations with NOAA leadership toward this end.

On behalf of the members of the EISWG,

John T. Snow
EISWG Co-Chair, and Dean Emeritus and Regents' Professor Emeritus of Meteorology, The University of Oklahoma, Norman, OK

Brad Colman
EISWG Co-Chair, and Director of Weather Strategy, Bayer Crop Sciences - The Climate Corporation, Seattle, WA

Attachments:

A. Summary of EPIC update brief. June 2018 meeting of the EISWG
B. Fred Carr and Jim Kinter, Summary and Recommendations from the EPIC Community Workshop in Boulder, CO, 6-8 August 2019

Attachment B

NOAA Response to the EISWG's Report on EPIC

National Oceanic and Atmospheric Administration (NOAA)
Responses to the Annual Environmental Information Services Working Group Report
January 28, 2020

The Environmental Information Services Working Group (EISWG) report provides six recommendations to the NOAA Science Advisory Board (SAB) concerning the Earth Prediction Innovation Center (EPIC). The EISWG report was generated in response to the inclusion of EPIC in the National Integrated Drought Information System Reauthorization Act of 2018 (P.L. 115- 423), which amends the Weather Research and Forecasting Innovation Act of 2017 (P.L. 115-25). These recommendations are also a result of the assessment of EISWG members of the EPIC Community Workshop that was held in Boulder, CO, on August 6-8, 2019. The EISWG transmitted this report to the SAB on September 3, 2019, and the SAB approved the report during its Fall meeting on September 9, 2019.

In general, the report offers a strong endorsement of the EPIC initiative by the EISWG, noting it is both timely and critical to the U.S. Earth-system modeling efforts and has the potential to bring value to public and private stakeholders. The report offers six recommendations to NOAA.

Recommendations on potential NOAA actions related to EPIC

Recommendation 1: *NOAA should implement EPIC's governance structure and processes as soon as possible, with a focus on the managing institution, leadership team, and advisory boards, and providing the community clear statements of the EPIC vision, mission, and values.*

NOAA Response: We agree, and we are developing and tuning our path of governance to achieve the vision of EPIC and to ensure the smooth transition of useful contributions to the operational weather forecast. NOAA decision and control will increase as products intended for the operational weather model move forward, whereas the ideas of how to make improvements on the areas NOAA identifies will largely left to the imagination of the community participants. NOAA should focus on the lessons learned over the past 5-7 years in our own internal improvements of Research to Operations, and Operations to Research, in which the presumed recipient of the new technology is closely aligned and well informed early to the research advances as they proceed. This process cannot exist in complete independence, or transition will be frustrated and put EPIC at risk.

Recommendation 2: *NOAA should work with the broader community to develop inclusive community engagement processes, and to anticipate and articulate the appropriate roles NOAA and other entities will play in EPIC.*

NOAA Response: Yes, we have been active in promoting community engagement by hosting workshops, industry day, requests for information and open sessions at professional conferences. The community cannot develop the EPIC program; NOAA must. We have taken much input to our benefit and all of our plans are well informed by the community.

Recommendation 3: *Early and direct efforts should be made to welcome into the Unified Forecast System (UFS) research and development sandbox contributions from other dynamic cores, physical parameterization schemes, Earth-system observation strategies and data assimilation techniques (atmosphere and ocean) and models (e.g., MPAS, UKMO Unified Model).*

NOAA Response: NOAA agrees with this recommendation. The UFS is a community modeling framework that will allow contributions that may not result in direct operational benefits. As long as operational standards are met with respect to unit tests and regression tests, and success metrics are evaluated; the UFS framework will allow contributions to earth system model development.

NOAA's Next Generation Global Prediction System (NGGPS) program selected the FV3 model as the dynamic core of the future through an evidence-based evaluation. The UFS will need to undergo a similar process for additional modeling components in the future. NOAA understands the possibility of the UFS accommodating other dynamic cores, but as NOAA has selected the FV3, we are not investing in or funding work on other cores. NOAA signed a Memorandum of Agreement (MoA) with the National Center for Atmospheric Research (NCAR) in 2017 that will allow for development of different model components within a common infrastructure to advance research and development efforts across organizations.

EPIC will provide a consistent code base and framework for multiple dynamic cores and physics options, but providing a common code base for additional options and supporting those options are distinct differences that NOAA is keenly aware of in establishing EPIC. It is important that EPIC remain aligned to operational outcomes for effective management and acceleration of the R2O process.

Recommendation 4*: NOAA should initiate a multi-agency R&D partnership program into which NOAA and other agencies contribute significant multi-year resources.*

NOAA Response: NOAA concurs with this recommendation. To address this, NOAA is engaging all partners to explain the role of EPIC and the importance of the UFS as a capability that integrates labs/centers/academia/private sectors/agencies as they conduct Earth-system model development to improve forecast skill. NOAA will continue to seek multi-agency R&D partnerships that will leverage resources and advance our collective missions.

Recommendation 5: *NOAA should organize its Cooperative Institutes that have existing capabilities in NWP and related areas into a nascent, distributed EPIC co-laboratory charged with quickly carrying out one or two narrowly focused R & D thrusts that have potential for near-term success.*

NOAA Response: NOAA will take the recommendation under consideration. NOAA is seeking quick wins by releasing a version of the UFS v1.0 in early 2020, which will leverage existing resources as mandated by the Weather Research and Forecasting Innovation Act of 2017. We are gradually transitioning all of our operational modeling codes to Github in an effort to fully realize the concept of open source development. The CIs maintain a vital role in NWP development at NOAA, and we will determine through proper planning the distribution of EPIC resources to gain near-term success.

Recommendation 6: *NOAA should immediately invest in and execute a Cloud implementation plan to promote community engagement and in support of research-to- operations.*

NOAA Response: NOAA concurs with this recommendation. To address this, EPIC plans to transition research and development of the UFS to a Cloud environment to dramatically improve Research to Operations (R2O) contributions from the community.

SAB Conclusion: *In conclusion, EISWG notes that EPIC is a program which will offer do great potential, but the delivery is dependent upon leadership, community engagement, successfully meeting early milestones, and long-term funding. Although*

the SAB approved the report, members acknowledged that a follow-up discussion would be needed to address several outstanding questions raised at the meeting. Such topics include the absence of cybersecurity and the role of the private sector, to what extent EPIC should remain an internal effort by NOAA, and the ability of NOAA to get funding for EPIC as outlined in Recommendation 6.

NOAA Response: NOAA concurs with the overall conclusion drawn by the SAB. Cybersecurity will be part of the contract to provide a robust and secure environment to transition codes back to NOAA's operational environment. NOAA envisions strong private sector involvement in model development, but we need to establish the requirements for attribution and licensing regulations.

Attachment C

NOAA Response to the EISWG's 2019 Report to Congress

National Oceanic and Atmospheric Administration
Responses to the 2019 Annual Report of the
Environmental Information Services Working Group

General Comments

The National Oceanic and Atmospheric Administration Science Advisory Board's Environmental Information Services Working Group (EISWG) 2019 annual report contained two sets of recommendations for the National Oceanic and Atmospheric Administration (NOAA), based on reviews provided by EISWG of: 1) the use of Observing Systems Simulation Experiments (OSSE) in NOAA; and 2) the NOAA report to Congress, *Tornado Warning Improvement and Extension Program Plan* produced by the NOAA Office of Oceanic and Atmospheric Research.

(c) 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.

Recommendations on Potential NOAA Actions Related to OSSEs

Recommendation 1: "OSSE, OSE, FSO, EFSO research efforts should be coordinated nationally (e.g., sharing of software tools) to avoid duplication of effort (e.g., via the QOSAP program). These methods each have their pros and cons, and should all be used to assess the relative benefit of different observing systems. Besides full-scale OSSE experiments, simple experiments could also be very powerful (e.g., for sampling strategies and data value evaluation)."

NOAA Response: NOAA concurs with this recommendation and will work through appropriate mechanisms to avoid duplication.

Recommendation 2: "The OSSE development for earth system models (e.g., for sea ice prediction) needs to be accelerated. Furthermore, global 5 km (and preferably 3 km) Nature Run based on earth system models should be developed as the basis for a variety of OSSEs. This may require the purchase of new high-performance computers or the partnership with other agencies."

NOAA Response: NOAA concurs with the recommendation to accelerate OSSE development and increasing the Nature Run resolution to 5 km. However, the agency notes that this activity will be well suited for cloud computing and may not require adding additional high performance computing capacity to existing NOAA assets.

Recommendation 3: "NCEP data assimilation and prediction system will continue to improve. OSSEs are used to evaluate the observational network likely decades ahead. Therefore, the choice of observations and investment decisions based on OSSEs need to explicitly consider the potential impact of deficiencies in the current data assimilation and prediction system."

NOAA Response: NOAA concurs with this recommendation.

Recommendation 4: "Besides existing OSSE activities at NOAA, OSSEs should also be used to:

- assess the value of NOAA partnership in satellite remote sensing with foreign agencies (e.g., India) and the private sector (e.g., purchasing data from privately-launched satellites),
- assist the exploration of strategies for the most effective and efficient way to do sea ice prediction (observations, models, data assimilation). Should NOAA request ice-breakers? How many?
- compare the value of (polar, geostationary, small/cube) satellite network strategy (e.g., small number of large satellites versus large number of small and cube satellites) for weather and climate prediction, and
- do a gap analysis in NOAA; i.e., what are the greatest new observational needs? What combination of old and new systems will work best?"

NOAA Response: NOAA agrees with this recommendation.

Recommendation 5: "OSSEs have been primarily used to evaluate the impacts of observing systems and/or observation denial on forecast performance per se, that is, on the physical parameters, and treating all forecast locations, times, and circumstances as equal. But this idea should be extended to societal impacts, whether monetizable, or in terms of lives at stake, etc. In other words, there are national priorities (e.g., saving human race) where money does not matter, and there are priorities depending upon the constraint of financial resources. This could be a possible additional avenue of research. In an Earth system model where social systems and the built environment are included, one can imagine collecting human data or propagating just the physical earth system information through the social systems as well.

Indeed, while OSSEs provide quantitative analyses of future observing system impacts for a specific model, the effects on products that rely on that model can only be estimated qualitatively. The NOAA/NESDIS Technology, Planning and Integration for Observation (TPIO) division has developed a qualitative tool for assessing supporting investment decisions, called the NOAA Observing System Integrated Analysis (NOSIA-II), also known as NOAA's Value Tree. This Value Tree is based on a survey of subject matter experts across all NOAA Line Offices to gauge the impacts of Earth observation investments on NOAA's key products and services. Therefore the aforementioned OSSE, OSE, FSO, EFSO and PQC tools should be used in concert with the current NOSIA-II system to determine NOAA's future observing needs."

NOAA Response: As the EISWG reports states, an OSSE modeling experiment is used to evaluate the impact of new observing systems on operational forecasts when actual observational data are not available. While NOAA acknowledges the value of OSSEs as a quantitative analysis tool, there are certain assumptions made when using a simulated dataset, and the agency is concerned that extending this tool to also evaluate societal impacts could potentially compound any assumptions or errors in the simulated dataset.

However, observing system investments can be assessed by combining Observing System Experiments (OSE)/OSSE results with NOSIA model data to assess mission service impacts such as hurricane warnings and fisheries stock assessments. Using OSE/OSSE and NOSIA data in concert facilitates decision making before acquiring substantial observing systems to minimize risk, manage costs, and maximize impact. Additionally, economists have used NOSIA mission service impacts to estimate the return-on-investment from NOAA observing systems.

Recommendations on Potential NOAA Actions Related to the Tornado Warning Improvement and Extension Program Plan

***With respect to technological objectives**, the EISWG notes that some of the challenges could be accomplished with currently deployed technologies through software or hardware upgrades, or the deployment of readily adaptable commercial-off-the-shelf technologies. In particular, NOAA should recognize the following:*

(1) While convection-allowing models have made great progress, they still do not capture every important mesoscale feature. Timing and position of thunderstorms can be off in time by an hour or two and in space by a county or more. Model forecasts seem less accurate when storms are already present when the model is initialized.

Recommendation 1: "In its development of Warn on Forecast (WoF) procedures, NOAA should include pattern recognition and artificial intelligence algorithms that take into account and adapt for the various known shortcomings in explicit computer model forecasts."

NOAA Response: NOAA agrees with this recommendation and notes that the agency is already doing this in a research and development environment. The WoF research program uses statistical techniques to pull probabilistic information out of model ensembles (rather than using explicit/deterministic model forecasts). The ensemble forecast output provides a range of possible outcomes based on variations in model physics and initial conditions that represent the variability of the atmosphere. The resultant probabilistic information can provide forecasters with a better understanding of the potential for severe weather, given that storms develop within the area. Output from the WoF research program have been tested and evaluated in the NOAA Hazardous Weather Testbed and have shown promising capability to assist forecasters with advance notifications to the public. In addition, NOAA is actively researching the use of machine learning methods as a way of post-processing the ensemble output from the WoF system and hopes to test these forecaster tools from the new methods in the Hazardous Weather Testbed with forecasters within the next several years.

(2) The greatest successes with tornado warnings come in supercell situations; skillful warnings for non-supercell tornadoes remain a serious challenge.

Recommendation 2: "NOAA should focus more strongly on reducing the false alarm rate (FAR) and other metrics of skill in current generation tornado warnings. Polygon-based warnings challenge the way FAR is determined and so demand new methods to quantify true positive, false positive, true negative, and false negative for precision, recall, and accuracy. As warning polygons are now updated as severe storms evolve, FAR measures will need to be assessed over space and time. The ways these metrics are computed should be transparent. National metrics are nearly meaningless by themselves; NOAA should compute and release metrics by Forecast Office. Importantly, while the focus should be on reducing the FAR, such reductions cannot come at the expense of affecting negatively other tornado warning-based metrics, such as the probability of detection (POD). In other words, reducing the FAR while decreasing the POD would not be a positive outcome. These are related metrics, both very important and clearly improving the quality of tornado warnings will require a balance between these two important metrics to provide people with more accurate warnings to support decision making."

NOAA Response: NOAA agrees with this recommendation, and we are already working to revise how FARs are calculated. We disagree, however, that "... national metrics are nearly meaningless by themselves." They provide the national perspective on warning performance. Also, the NOAA National Weather Service (NWS) Performance Management website already provides warning statistics for each Workforce Management Office (WFO), multiple WFOs, NWS Regions, and nationally. NOAA concurs that FAR needs to be improved without negatively impacting POD. NOAA is continuing its research and development activities to better understand the tendencies that lead to FAR and how to address them.

Recommendation 3: "As a means for obtaining greater low-level radar coverage of non-supercell tornadic circulations and so significantly aiding in the warning of tornadoes, NOAA should consider ...

a) ... reducing the lowest allowable elevation angle on all NEXRAD/WSR88D radars to the minimum possible value, consistent with ground clutter and local environmental considerations, and
b) ... adding one or two tower sections to selected existing NEXRAD to reduce ground clutter, increase the radar horizon, and allow better overall coverage."

NOAA Response:

a) NOAA notes that we have done this already in several locations; however, it is not practical in all locations due to terrain blockage and other environmental impacts. NOAA has lowered the angle for the Next Generation Weather Radar (NEXRAD) at 10 sites so far – Langley Hill, Washington; Monterey, California; Cedar City, Utah; Medford, Oregon; Buffalo, New York; Minot, North Dakota; Greenville-Spartanburg, South Carolina; Raleigh, North Carolina; Jackson, Mississippi; and Shreveport, Louisiana. The NWS Regions are prioritizing NEXRAD sites where lowering the angle

will provide maximum benefits. Lowering the angle costs about $100,000 per site to conduct the environmental assessment and make the software changes in the NEXRAD unit and also to the WFO's Advanced Weather Interactive Processing System (AWIPS) to be able to use the data from the lower angles.

b) NOAA disagrees with the recommendation. While increasing radar height could reduce blockage from nearby terrain, trees, and buildings, it will further extend the range of ground clutter. Furthermore, it is very expensive to raise the tower, and benefits are limited except in very few locations. NOAA considers raising the tower as a last resort when beam blockage has increased since the radars were installed, and lowest angles of data are no longer available. To date, we have raised the tower at only one site. Furthermore, the maximum height of the radar is 30 meters. It is not feasible to raise the tower greater than 30 meters due to the resultant degraded data quality related to distance between the feedhorn and signal processor, as well as the increased potential for high wind damage.

Recommendation 4: "To aid in the warning of short-lived tornadoes, NOAA should build on the experiences in south-central Oklahoma and across the multicounty Dallas-Fort Worth metropolitan area and include networked X- or C-band as gap-filling radars to obtain greater low-level coverage of non-supercell circulations and strong winds."

NOAA Response: NOAA notes that this is technically feasible, but not cost effective at this time. The proven benefits of such systems have not been categorically demonstrated to have a significant impact on NWS warnings. In the Dallas-Fort Worth area, the NEXRAD coverage is excellent. Via the National Mesonet program, NWS provides support to Collaborative Adaptive Sensing of the Atmosphere (CASA), a network of commercial X-band radars supplementing NEXRAD coverage in the DFW region. Given the NEXRAD coverage, the CASA data are supplemental and most useful in determining where to conduct post-storm surveys, rather than to warn for tornadoes. Forecasters appreciate having the CASA data, but still rely predominantly on the NEXRAD for issuing warnings in the Dallas-Fort Worth area. The real challenge remains to better understand these short-lived tornadoes and be able to warn before they form.

Recommendation 5: "The NEXRAD processing software used to detect mesocyclone and tornado vortex signatures should be modernized/upgraded to reflect the best science now available. An example is provided by the Mesocyclone Detection Algorithm (MDA), which currently uses only a portion of the available shear information. A modernization of this key algorithm might allow circulations of (weak) intensity levels 1 and 2 to be detected sooner and utilized with some confidence. This could make possible earlier (by several minutes, or equivalently two or three volume scans) detection of the earliest stages of formation of long-lived tornadoes, and allow tracking of at least a portion of the life cycle of short-lived tornadoes."

NOAA Response: In regards to NEXRAD software, NOAA is currently working to update both the Mesocyclone Detection Algorithm (MDA) and the Tornado Detection Algorithm (TDA), the latter of which identifies the Tornado Vortex Signature. NOAA is researching advanced algorithm technologies to track storm-scale circulation features of all intensities. These Rotation Track products are implemented on the Multi-Radar Multi-Sensor system which is available to

forecasters. Additionally, new MDA and TDA are being developed that also includes dual polarization variables as well as shear estimates. The new TDA will be evaluated in the Hazardous Weather Testbed in spring 2020.

With respect to the sociological objectives, *NOAA should recognize that the protection of life and property from the impact of tornadoes is not only a meteorological challenge, but also a sociological one. For example, to justify the costs and effort involved in developing and deploying WoF systems that may provide people advance skillful warnings of an hour or more, NOAA needs to understand better if people will take appropriate actions upon receipt of such lengthy advance warnings.*

Recommendation 6: "Given the limited number of federal social science positions within the agency, NOAA should utilize its set of joint and cooperative institutes to access social science expertise in the national university community."

NOAA Response: NOAA concurs with this recommendation and is beginning discussions to implement this action with the cooperative institutes. For example, NWS is working with the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) and the Center for Risk and Crisis Management (CRCS) on the conveyance of uncertainty and probabilistic forecasts.

Recommendation 7: "NOAA should have social science programs charged with investigating questions such as the following: Will people take action more than a few minutes in advance, even if given warnings an hour in advance? Where is the balance between lead-time and good decision-making? If actions are taken based upon lead times an hour or longer than at present, will this include fleeing and, if so, will road infrastructure and traffic management suffice? Will the public take action based upon probabilistic tornado warnings? How should the public best receive such warnings? Will the public be responsive to repeatedly updated warnings (N.B., The Report (see Attachment 1), p. 7 suggests that such warnings could be updated every 2 minutes), or simply confused by such frequent updates, and so waiting until the last minute to attempt to take action?"

NOAA Response: NOAA agrees with this recommendation and notes that we are doing this now, however, expanding these efforts merits additional consideration. As an example, the National Weather Service is working with CIMMS and CRCS on the conveyance of uncertainty and probabilistic forecasts. Both WoF and the Forecasting a Continuum of Environmental Threats (FACET) programs have social science based research initiatives focused on the public response to these new warning techniques.

Recommendation 8: "To reduce impacts in terms of minimizing property losses (as well as improve life safety measures), it will be necessary to implement stronger building codes. NOAA should develop and implement - in partnership with NIST, universities such as Texas Tech, and entities such as the Institute for Business and Home Safety - a weather-ready home certification program as an extension of its StormReady community and Weather-Ready Nation program,. This could encourage in-home shelters, hurricane clips to hold on roofs, etc."

NOAA Response: While this may be beyond the scope of the agency's mission, it is a good idea and NOAA will continue to build partnerships with other Federal agencies, non-governmental organizations, and industry to marry weather, water, and climate information from NOAA with structural information to help save lives and protect property. For example, NOAA works with NIST as they are the lead agency for the National Windstorm Impact Reduction Act. The NIST National Windstorm Impact Reduction Program was created to improve the understanding of windstorms and their impacts and to develop measures to reduce the damage they cause. In various storm areas (i.e., Great Plains, Southeast U.S.), or within regions associated with land-falling hurricanes, NOAA has deployed mobile observation platforms to better understand the winds embedded within the tornadoes.

In closing, *the EISWG notes the resources portion of the plan seems generic. This leads to questions such as, "Has a detailed action plan been produced?" "If so, what are the detailed timelines?" "Has a detailed cost/benefit analysis been performed?" Such information is needed by the EISWG to know if NOAA is tracking favorably against the intended deliverables when reviewing subsequent reports.*

NOAA Response: Resource requirements are still being considered within the agency and will be reflected in NOAA's future year budget requests, as well as in the annual budget plan required by Section 103 of the Weather Act.