



**NOAA
SCIENCE
ADVISORY
BOARD**

**REPORT CONCERNING THE NOAA REPORT TO
CONGRESS: SUBSEASONAL AND SEASONAL (S2S)
FORECASTING INNOVATION: PLANS FOR THE
TWENTY-FIRST CENTURY**

PRESENTED TO THE NOAA SCIENCE ADVISORY BOARD
BY THE SAB ENVIRONMENTAL INFORMATION SERVICES WORKING GROUP

AUGUST 30, 2022

OUTLINE

- I. Executive Summary
 - A. Background
 - B. Overall Assessment
 - C. Summary Findings and Recommendations
- II. Specific Review Results – Findings and Recommendations
 - A. NOAA Report Section II. *Current S2S Products and Services*
 - B. NOAA Report Section III. *Current Plans for Improving S2S Products and Services*
 - C. NOAA Report Section IV. *Requirements for Improving S2S Products and Services*
- III. Review Methodology
 - A. Members of the S2S Review Team
 - B. Subject Matter Experts Consulted for this Report
 - C. References Used for this Report

Appendix I: Weather Act Title II, Sect. 201. Improving Subseasonal and Seasonal Forecasts

Appendix II: Table of Recommendations

I. EXECUTIVE SUMMARY

A. Background

This report presents a review of NOAA's October 2020 *Report to Congress, Subseasonal and Seasonal Forecasting Innovation: Plans for the Twenty-First Century* (hereafter *NOAA S2S Report*) by the Environmental Information Services Working Group (EISWG), an advisory working group reporting to the NOAA Science Advisory Board (SAB). The *NOAA S2S Report* notes the importance of an Earth systems approach (Section I), describes current subseasonal and seasonal (S2S) products and services (Section II), and then presents current plans (Section III) and longer term requirements (Section IV) for improving S2S products and services.

Working Group Charge and Approach: In order to fulfill its charge in the Weather Research and Forecasting Innovation Act of 2017 (hereafter Weather Act), Title IV, Section 401, EISWG reviews select NOAA Weather Act reports submitted to Congress. To ensure that the review provides the most value to NOAA, the EISWG formed a review team that included EISWG members as well as supporting members from the SAB Climate Working Group (CWG) given the influence of climate conditions and knowledge in Subseasonal and Seasonal timeframes as defined in the Weather Act, Title II, Section 201 (between two weeks and two years). In addition to extensive reviews of the report and associated references, the review team received briefings from NOAA on the NOAA S2S Report and related, ongoing programs, and consulted with external Subject Matter Experts (see Section III of this report). Members of the Review Team and references used in this review are also provided in Section III.

B. Overall Assessment: Is the NOAA S2S Report responsive to the Congressional request?

In this section, we provide an overall assessment of the NOAA S2S Report based specifically on Congressional language and successful continuation of S2S plans, programs, and research activities described in the report. The following subsection (C) includes summary findings and associated recommendations regarding the overall report and information gained during the review process. Specific results of the review related to the chapters of the NOAA S2S Report aligned with specific request language from Congress are provided in the next section of this report (Section II).

Assessment Background: The Congressional request for the NOAA S2S Report was included in the Weather Research and Forecasting Innovation Act of 2017, commonly referred to as the "Weather Act of 2017." It specifically directed three things be included in the report:

- a. How NOAA S2S information "is utilized in public planning and preparedness"

- b. Specific plans and goals for the continued development of S2S forecasts and related products
- c. Identification of research, monitoring, observing, and forecasting requirements to meet the specific goals

The major sections of the NOAA S2S Report are titled and structured to address these three specific topics, which also provided a natural structure to conduct our review as described in Section II of this report.

The NOAA S2S Report (including the 156-page Supplement that was provided to the review team and is mentioned in the official report to Congress) provides an extraordinary amount of detailed analysis into NOAA's S2S products, programs, plans, research, requirements, etc., and along with the References in Section III, well-document the community scientific research and development that support these efforts. In this report review, we chose not to focus on duplicative scientific and technical analyses to these excellent works, but to develop additional insight that complements and enhances the effectiveness of NOAA's ongoing efforts, as well as garner additional support and collaboration across the larger Earth System community.

Urgency: The growing importance of S2S forecast and decision-making by leaders at every level of government as well as the private sector is well documented and has been amplified by recent subseasonal and seasonal extremes of temperature and precipitation, which have had catastrophic impacts on safety, security (including water and food), and economic prosperity across the nation and around the globe. As stated in the NOAA S2S Report, this has led to steadily increasing demand for S2S information, as well as the need for greater skill and effectiveness of S2S products. The various programs and plans described in the NOAA S2S Report to Congress provide an excellent framework to continue advancing S2S forecast products and decision-support services, and to influence larger federal policies and fiscal appropriations to meet these growing needs.

Conclusion: The official report to Congress, submitted in October 2020 and entitled *Subseasonal and Seasonal Forecasting Innovation: Plans for the 21st Century*, "is a summary of a comprehensive analysis, which is available for more detailed information and reference." This review therefore included the "comprehensive analysis" that is encapsulated in a separate document entitled *Supplement for Report to Congress*, which was provided by NOAA to the review team. **Our review concludes that the official report, in tandem with its supplement, is responsive to the Congressional tasking and sufficiently addresses the specific information requested.** The term "NOAA S2S Report" used in this review includes both the *official report to Congress* and the *supplement* for conciseness.

We concur with the following summary statement in the NOAA S2S Report: “Our society continues to change and become more vulnerable to impacts from extreme S2S influenced weather events, including tornadoes, hurricanes, snow, blizzards, heat, cold, drought, fire, and floods. Improved subseasonal to seasonal prediction is a critical component to enable decision makers to make informed decisions to address extreme events ranging from drought to flooding and heat to cold. As our S2S predictive capability improves, decision makers at all levels will have better information to make informed decisions to save lives and property.”

C. Summary Findings and Recommendations

The overarching findings and recommendations below are included in the Executive Summary as they relate to the overall S2S Program as described in the NOAA S2S Report. More specific findings and recommendations in the following section of this report are aligned with the NOAA S2S Report sections. The recommendations in this report are not prioritized. A list of all recommendations is provided in Appendix II for easy reference.

1. Availability of the Report *Supplement*

Summary Finding: The NOAA S2S *summary* report alone does not reflect the extensive effort by NOAA to answer Congressional tasking and can lead to erroneous assumptions or inferences if considered in isolation from the *supplement*. The report *supplement* fully describes NOAA’s S2S products, plans, requirements, etc., in all aspects, and must be considered alongside the summary report for any detailed analysis or review of NOAA’s S2S programs. However, the *supplement* is not readily available to the public for download in the same manner as the summary report, which unnecessarily impedes public analysis and review.

Recommendation 1: NOAA should make the *S2S supplement report* publicly available for download alongside the official report. Language should also be included on the download site that describes the relationship between the two reports. Annotating the reports with dates on which they were published would also be beneficial, especially in referencing the reports.

2. “S2S” Periodic Definition/Terminology

Summary Finding: Congressional language uses the terminology “Subseasonal and Seasonal Forecasting Innovation” with corresponding definitions of subseasonal (the time range between 2 weeks and 3 months) and seasonal (the time range between 3 months and 3 years). These definitions do not specify the inclusive or exclusive nature of these time period definitions (e.g., are “Week-2 Outlooks” part of S2S?), but do indicate that both timeframes should be considered together in the report by using “and.” NOAA assigned the acronymic abbreviation “S2S” to represent “Subseasonal

and Seasonal” in this case, although other organizations (e.g., the National Academy of Science, the World Meteorological Organization) use different timeframes to define S2S. NOAA also defined S2S as “week two to three months” in a fiscal year 2022 budget initiative. Additionally, the NOAA S2S Report defines and uses the terms “short range” and “long range” forecasts (in *supplement* Section III Plans for Improving S2S Products and Services) in the following statement: “The National Weather Service issues forecasts and outlooks from the short range (on the order of hours to days) to the long range (on the order of 1 year). Longer term prediction (interannual to decadal) and projections (decades or longer) fall outside the purview of the NWS.” The overlap of these terms with multiple S2S definitions adds confusion.

Recommendation 2: NOAA should develop, publish, and maintain a standardized index of the various definitions that exist (nationally and internationally) for the terms subseasonal, seasonal, S2S, interannual, decadal, short range, medium range, long range, etc., to help eliminate potential confusion around these widely used terms.

Recommendation 3: NOAA should ensure consistency in its use of “S2S” and associated/related terminology across all products, services, programs, projects, budget requests, correspondence, etc.

3. S2S Strategic Goal(s)

Summary Finding: In addition to the “specific plans and goals” described in Section III of the NOAA S2S Report, we conclude that a larger strategic goal (or goals) regarding the overall use of S2S products by a Weather and Climate Ready Nation is warranted. The National Academies of Sciences, Engineering, and Medicine (NAS) *Next Generation Earth System Prediction: Strategies for Subseasonal to Seasonal Forecasts* report from 2016 includes a vision for the future that “S2S forecasts of environmental conditions will be as widely used a decade from now as weather forecasts are today.” A visionary goal along these lines would be valuable to guide and cohere the complex, myriad efforts across NOAA (and partner agencies) toward greatly enhanced S2S products and services, and their impact on decision-making by public and private stakeholders across all domains.

Recommendation 4: NOAA should adapt the vision from the NAS (2016) S2S Report: “S2S forecasts of environmental conditions will be as widely used a decade from now as weather forecasts are today” (or a similar vision) to develop a strategic, time-bound goal (or goals) for its S2S overall program that encompasses the entire Earth System and all associated offices.

4. S2S in Advancing Earth System Prediction

Summary Finding: As discussed at numerous points throughout the NOAA S2S Report, the importance of understanding and predicting the combined interactions and

influences of the various components of the Earth System are crucial to accurate predictions of atmospheric conditions, trends, and potential impacts at S2S scales. In addition, the S2S scale impacts of the Earth System on the health of the environment, including fisheries, hydrologic and cryospheric cycles, synoptic weather patterns, etc., suggest that every line office in NOAA has a significant stake in advancing S2S capabilities and support functions. While the National Weather Service (NWS) and Oceanic and Atmospheric Research (OAR) offices are deeply involved and well-coordinated toward advancing S2S capabilities, a true cross-NOAA strategic approach will be necessary to realize the potential value of S2S predictions in coming years. This also represents an opportunity to use the burgeoning Earth Prediction Innovation Center (EPIC) as a means to advance trans-discipline, community research and development toward S2S enhancements in multiple aspects.

Recommendation 5: NOAA should highlight S2S as a true Earth System effort with correspondingly cross-office approaches in NOAA's strategic planning, prioritization, and budgeting efforts to include regional offices.

Recommendation 6: NOAA should emphasize S2S predictions in projects that are solicited and funded under NOAA's Earth Prediction Innovation Center (EPIC) program.

5. Interagency and International Collaboration

Summary Finding: There are numerous research, development, and operational efforts by multiple federal agencies to provide and improve S2S forecast capabilities, products and associated decision-making at many levels. The National Earth System Prediction Capability (ESPC) has been a successful effort to cohere federal agency partners toward enhanced capabilities for S2S prediction, including ensembles and coupled Earth System modeling. The National ESPC effort was largely led and resourced by NOAA and the U.S. Navy for many years, but it has been recently integrated into the Interagency Council for Advancing Meteorological Services (ICAMS) which is co-led by the Office of Science and Technology Policy (OSTP) and NOAA under the Executive Office of the President, elevating its ability to influence interagency programs and resources. The alignment of National ESPC (and other related S2S programs and offices) under ICAMS represents an opportunity to further enhance the efficacy and efficiency of S2S plans, programs, and fiscal resource investments across the federal agencies. The inclusion of the Department of State in ICAMS and the stated ICAMS objective to advance "U.S. Global Leadership in meteorological services" also provide an opportunity to increase the overall effectiveness of U.S. collaboration with international S2S-related efforts such as the S2S Prediction Project under the WMO.

Recommendation 7: NOAA should use the co-leadership role of NOAA in ICAMS, prioritize S2S-related interagency collaboration, including the initiatives under National Earth System Prediction Capability (ESPC).

Recommendation 8: NOAA should capitalize on the Interagency Council for Advancing Meteorological Services (ICAMS) objective to coordinate, help prioritize, and execute activities for “U.S. global leadership in meteorological services” to cohere and increase overall international engagement and program support in areas related to S2S forecasting.

II. SPECIFIC REVIEW RESULTS – FINDINGS AND RECOMMENDATIONS

This section of the report describes review results related to specific parts of the NOAA S2S Report that correspond to the three specific requests from Congress on information to be provided:

- How NOAA S2S information “is utilized in public planning and preparedness”
- Specific plans and goals for the continued development of S2S forecasts and related products
- Identification of research, monitoring, and observing requirements to meet the specific goals

A. NOAA Report Section II. *Current S2S Products and Services*

(Addresses Congressional language to describe: “How NOAA S2S Information is used in public planning and preparedness.”)

Finding: The NOAA S2S Report sufficiently describes current S2S products at the time of the report, and it is complemented by the updated list of S2S products on the NOAA/NWS Climate Predictions Center (CPC) website. The NOAA S2S Report also describes how S2S products are used by stakeholders to support decision-making and provides specific examples of use by agencies and public entities. The following recommendations are provided to enhance the visibility and usefulness of all S2S products and services.

Recommendation 9: NOAA should maintain a true S2S Product “Internet clearinghouse.” The Weather Act (2017) directs NOAA to “develop an Internet clearinghouse” to provide S2S forecasts and associated information on their impacts, at both national and regional levels. We recommend the current S2S forecast products and information available on the CPC webpage be expanded and titled/described as a “clearinghouse” to fully meet this direction and include all national and regional S2S forecasts and impact-based products.

Recommendation 10: NOAA should provide additional product verification and use metrics to enhance user awareness of forecast skill usefulness. The Forecast

verification pages on the CPC website provide Heidke Skill scores and associated data archives for S2S temperature and precipitation forecasts. We recommend the verification pages be expanded and upgraded to:

- 10.1. Ensure all verification tools and information are accessible to the public.
- 10.2. Provide summarized verification information on all S2S products, including hurricane seasonal outlooks.
- 10.3. Include long-term changes and trends in verification scores that indicate changes in skill of specific products, types, regions, etc. over time.
- 10.4. Make updated product use and download metrics publicly available (e.g., aggregate “web hits” as provided in the NOAA S2S Report)
- 10.5. Develop and publicize comparative skill metrics with S2S products from other sources such as almanacs and commercial weather organizations (e.g., news media) that develop seasonal predictions based on “analog” past years with global weather patterns and trends that resemble current year.

Recommendation 11: NOAA should maintain an updated, online version of the “Potential Future Products List” that is provided in Appendix B of the official NOAA S2S report. This will enable stakeholders to better plan for the use of these products as they become available.

Recommendation 12: NOAA should collect, publicize, and maintain an online catalog of “best practices” regarding the use of S2S products in public planning and preparedness. This will enable regional planners and decision-makers to share and gain knowledge regarding product use as well as support collaboration with NOAA regional organizations and other federal/regional/local partners.

B. NOAA Report Section III. *Current Plans for Improving S2S Products and Services*

(Addresses Congressional language to provide “Specific plans and goals for the continued development of S2S forecasts and related products.”)

Our review examined the current plans to meet the two main goals for improving S2S products and services as stated within the NOAA S2S Report: (1) improving the skill of S2S forecast products, and (2) enhancing the value of S2S products and services to stakeholders.

1. Additional Specificity

Finding: The overarching two goals (improving forecast skill and enhancing stakeholder value) meet Congressional direction, but there are varying levels of detail in the plans and goals provided in the NOAA S2S Report. There are also no clear priorities provided in this overall analysis. More specific plans and goals that include updated milestones

are needed to help prioritize research, R2O transition planning, new product development, and associated S2S budgetary increases.

Recommendation 13: NOAA should develop and maintain (more) specific plans, goals, and priorities under both overarching goals (improving forecast skill and enhancing stakeholder value) that can be mapped to budget requests, EPIC project initiatives, collaboration efforts with “core partners,” etc. Goals that are specific, measurable, achievable, relevant, and time-based (SMART) would help increase community support and potentially drive successful budgetary increases.

Recommendation 14: NOAA should maintain holistic roadmaps for the two overarching goals (increased forecast skill and enhanced stakeholder value) that include SMART goals and priorities along with desired end states. Frequently updated, publicly available roadmaps with critical path elements would provide additional transparency into status, progress and evolving requirements that would help garner public support and engagement around NOAA’s S2S programs and initiatives.

2. Forecast Skill Improvement

Finding - To address this goal, the NOAA S2S Report states that “A coupled numerical weather-climate prediction system is the primary tool used to produce S2S forecasts and outlooks for the NWS.” Our review concurs with this approach and agrees with the detailed description of NOAA’s plans to advance the Next Generation Global Prediction System (NGGPS) infrastructure in concert with the community-based Unified Forecast System (UFS) for S2S Earth System predictions at global and regional scales.

The NOAA S2S Report accurately describes the relative importance of ocean, ice, and land observations, and addresses the current sparsity of these observations as compared with the network of atmospheric observations. The NOAA S2S Report also correctly highlights the need for improved Coupled Data Assimilation (CDA) algorithms across all domains. Additional information provided by NOAA during the review process indicates that the plans presented in the NOAA S2S report remain effective and are well aligned with research efforts as well as research-to-operations (R2O) transition plans.

3. Stakeholder Value

Finding: The NOAA S2S Report identifies increased forecast skill and improved communication of risk and uncertainty as means to enhance stakeholder value and highlights the needs for additional efforts related to social and behavioral sciences to better understand and enhance decision-making processed by myriad categories of

stakeholders¹. We concur with these assessments and further conclude that the development of methods to accurately and consistently assess and measure stakeholder value for all S2S products as they relate to specific categories of use cases should be a specific goal. Examples of potential categories are:

- “Core Partners” (as defined in the Introduction section of the NOAA S2S Report)
- Financial capital organizations (investors, reinsurance, developers)
- Small business owners and entrepreneurs
- Underserved populations (rural, tribal, impoverished)
- Emergency managers & responders

As an example, NOAA’s Chief Scientist – Dr. Sarah Kapnick – (at JP Morgan at time of interview and formerly NOAA Geophysical Fluid Dynamics Laboratory) has conducted in-depth research and analyses of the value of S2S predictions in the use case of financial organizations that guide investments. Her research exemplifies potential means to measure/assess changes in the value of S2S predictions over time for this specific category of users. Additional coordination with regional NOAA activities, “core partners,” and other stakeholder groups could inform the development of additional value metrics for user categories that address diverse societal needs and impacts.

Recommendation 15: NOAA should develop a framework, using social/behavioral sciences and direct coordination with stakeholders, to establish value metrics and assessment processes for key categories of S2S product stakeholders. This could include well-coordinated communication and coordination with stakeholders by NOAA’s various regional offices (e.g., NWS Regional Headquarters, Regional Climate Centers, Regional Integrated Science and Assessment activities). These coordinated efforts should consider multiple sectors of the weather/climate/earth science enterprise, to include the many local/state/regional public and private weather organizations that provide S2S forecasts and decision-making support (including news media). Consultation with other entities within the Department of Commerce, such as the Office of Native American Affairs and the Minority Business Development Agency, may also prove valuable in developing this framework.

Recommendation 16: NOAA should increase interagency collaboration around social and behavioral sciences, to include how S2S products and services can be more effective toward influencing public behavior and responsiveness, to include planning and preparedness by all levels of government. Given the growing impact

¹ Note: An FY2022 increase submitted in the President’s Budget for S2S Decision Support with increased social and behavioral science resources at NOAA was not funded by Congress with additional appropriations; however, NOAA was directed in appropriations language to “report how these priorities will be augmented with resources provided in the IJA and the Disaster Relief Supplemental Appropriations Act, 2022.”

of extreme conditions on public safety and security, collaboration with organizations within the Intelligence and Homeland Security communities such as the National Geospatial Agency (NGA) and Federal Emergency Management Agency (FEMA) is strongly recommended.

C. NOAA Report Section IV. *Requirements for Improving S2S Products and Services*
(Addresses Congressional language associated with the “Identification of research, monitoring, and observing requirements to meet the specific goals.”)

The section of the NOAA S2S Report that addresses these requirements is the longest section of the *report supplement* and goes into great detail as it “focuses on the identification of longer-term research, monitoring, observing, and forecasting requirements to fill knowledge, understanding, and capability gaps identified in the analysis of the portfolio of current subseasonal and seasonal products.” It also states that “this section focuses on capabilities that will not be met through the specific plans for the continued development of the subseasonal and seasonal forecasts and related products. These research and development requirements for the advances in scientific knowledge and mission capabilities are needed to ensure NOAA can provide the information needed on S2S timescales.”

The NOAA S2S Report further categorizes the three areas stated in the Congressional directive into the following sections:

- Forecasting Requirements
- Research Requirements
- Observational Requirements
- Monitoring Requirements
- Advancing S2S Forecast Capabilities and Products
- S2S Information Dissemination and Delivery
- Regional Pilot Projects

In developing these requirements, NOAA used specific recommendations from the NAS 2016 Report as a foundation. We consider this an excellent approach, given the in-depth analysis and recommendations in the NAS report that were based on a predominance of scientific research at that time, including social scientific research.

1. Requirement Prioritization

Finding: The extensive information provided in this section is valuable toward understanding the breadth and scope of the numerous requirements and ongoing efforts to support long-range enhancement of S2S products and services. However, there is no overall prioritization of requirements (individual or categorical), no process described for how priorities and associated investments are determined and reviewed, and no approach suggested on how to rank-order these longer-term requirements. A

clearly described process for prioritization would help guide investment strategies and integration with innovation efforts such as EPIC.

Recommendation 17: Using the SAB Priorities for Weather Research (PWR) Report as an initial reference, NOAA should develop a process for the establishment and periodic review, validation, and prioritization of longer-term S2S research and development requirements priorities. This would help the SAB and its working groups (e.g., EISWG and CWG) provide valuable assistance around the development/enhancement of requirements prioritization based on their breadth of expertise and experience.

2. Forecast Requirements – Sources of Predictability

Finding: The NOAA S2S Report describes well specific requirements to address predictability at various timeframes within the S2S period (two weeks to two years). It describes well the numerous atmospheric, ocean and land-based phenomena as they relate to predictability at these timeframes. It also identifies the knowledge gaps around these phenomena that need to be filled in to improve predictability, especially at “long range” S2S timeframes (“13-24 months”). These requirements are well-supported and they are complemented by the *SAB-CWG Advancing Earth System Prediction (ESP) Report* and the *SAB-CWG Subseasonal-to-Seasonal-to-Decadal (S2S2D), A Pathway to Improved Prediction White Paper*, which could also be used to further refine and validate research prioritization and future research investments.

We further believe that the limits of S2S predictability, geographic and temporal variability of predictability (including the impact of climate change on predictability), and even the ability to predict changes in predictability are topics that deserve additional, basic research emphasis.

Recommendation 18: In addition to the extensive research needs described in the NOAA S2S Report, NOAA should support additional basic research across the Earth System research enterprise into the limits and variability of Earth System predictability.

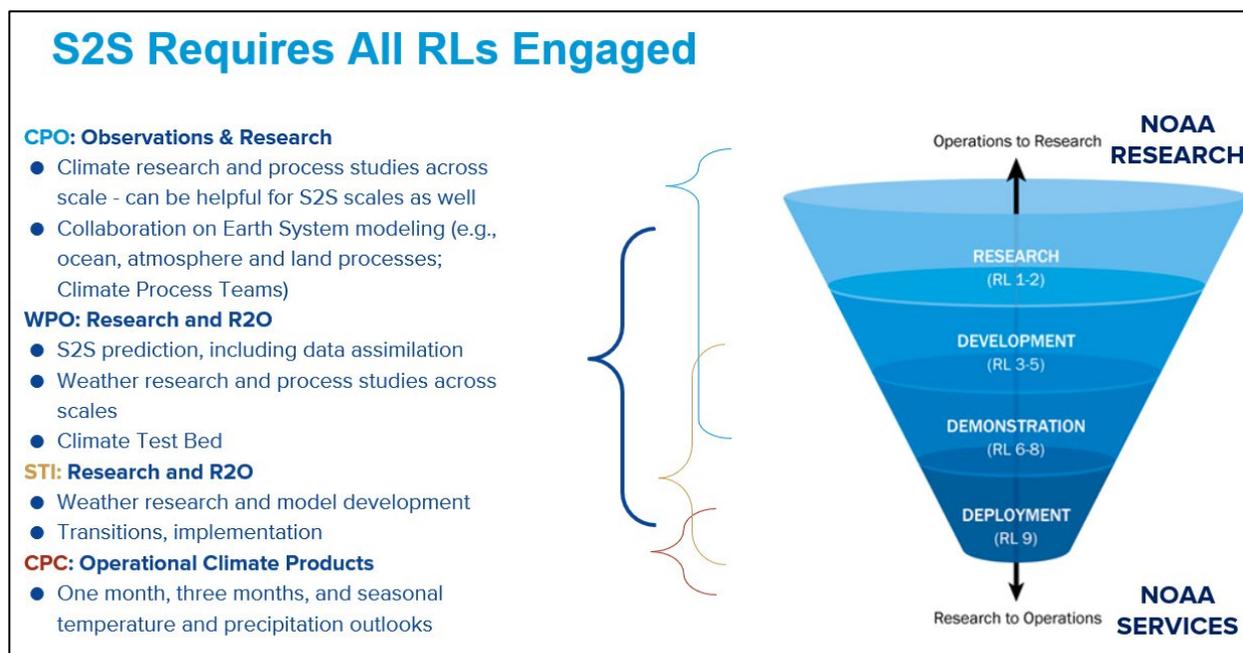
3. Research Requirements – Coordination Across NOAA Offices

Finding: Even though the S2S prediction is distinct from climate prediction, the two share common processes and mechanisms that interact across time and space scales. The section in the NOAA S2S Report on Research Requirements describes well specific R&D needs to better understand physical processes that can then be incorporated into algorithms for S2S portions of the Unified Forecast System (UFS). These are corroborated by many of the priorities in the PWR Report, and include:

- Coupled Earth System data assimilation
- Coupled ensemble predictions systems

- Uncertainty quantification
- Earth System reforecasting capability

Ongoing efforts to advance these and other areas described in the NOAA S2S Report were confirmed in interviews and reviews by the Review Team. We found that research, development, and R2O transitions involving both NWS and OAR are well-coordinated and productive. We also found that there is significant overlap in S2S research programs between the Weather Program Office (WPO) and Climate Program Office (CPO) under OAR. This is not surprising, given the Congressionally-defined S2S timeframe that overlaps with traditional weather prediction and climate prediction scales. However, these overlaps can appear redundant to NOAA-external organizations and researchers. We believe the below diagram, used in a presentation to the review team, is an excellent means to describe the differing roles of the WPO and CPO, as well as NWS offices (STI and CPC) regarding the R&D and Transition of S2S capabilities based on designated R&D Readiness Levels (RL) defined within NOAA Policy



Recommendation 19: NOAA WPO and CPO should foster a stronger synergistic relationship and clarify their respective roles to the research community as well as interagency partners. Confirm the validity and accuracy of the diagram above and then use it to guide and publicize cross-office R&D and R2O transition efforts regarding S2S capabilities.

4. Observation and Monitoring Requirements – Collaboration around Ocean Observing

Finding: The NOAA S2S Report describes well the importance of observations (and monitoring) of Earth System parameters toward enhanced S2S analyses prediction systems. The requirements delineated in these sections are supported by the conclusions and priorities addressed in the PWR Report related to observations and data assimilation, as well as in the SAB-CWG ESP Report and the S2S2D White Paper. The NOAA S2S Report specifically highlights the importance of ocean observations toward increased knowledge of the ocean state, considered “the dominant source of skill for S2S forecast lead times beyond 30 days.” The Tropical Pacific Observing Systems (TPOS) 2020 Report further specifies observation (as well as related assimilation and modeling) needs in the Tropical Pacific Ocean area. It’s necessary to address these needs in order to enhance S2S prediction skill in the United States and can help prioritize specific ocean observational requirements as they relate to S2S needs. Additional collaboration with the ocean observing enterprise, to include activities supported by the Integrated (U.S.) Ocean Observing System (IOOS) and the (international) Global Ocean Observing System (GOOS) initiatives would help to address these needs.

Recommendation 20: NOAA should increase collaboration with Integrated Ocean Observing System (IOOS) leadership and the myriad IOOS and Global Ocean Observing System (GOOS) organizational activities to help address ocean observing and monitoring gaps as they relate to S2S requirements.

5. Continuation of Pilot Projects

Finding: Four potential regional pilot projects are described in the NOAA S2S Report:

- Winter S2S precipitation forecasts for water management in the western U.S.
- Spring and summer S2S precipitation forecasts in the central U.S.
- S2S forecasts of Arctic sea ice
- S2S forecasts of tropical cyclone activity

We concur with the NOAA S2S Report that pilot projects such as these provide a means to accelerate the improvement of S2S prediction skill. They also provide unique opportunities to develop partnerships and engage stakeholders/users around specific needs and opportunities that can lead to more effective S2S products and services. None of these projects have been completed to date for several reasons (e.g., resource constraints, inclusion in larger program initiatives such as the Precipitation Prediction Grand Challenge). The need for such projects, however, remains valid and we are pleased that S2S pilot projects such as these are still being considered. We are especially pleased that the Senate developed a budgetary initiative for NOAA-OAR in FY22 around specific research funding for the first project (Winter S2S precipitation forecasts for water management in the western U.S.) as indicated in the following excerpt from the Senate FY2022 appropriations report:

Subseasonal to Seasonal Weather Prediction. —Within funding for the U.S. Weather Research Program, the Committee provides \$5,000,000 above the fiscal year 2021 enacted level for a subseasonal to seasonal research program to seed innovative research testbeds. Such efforts shall include a pilot project for subseasonal to seasonal precipitation forecasts for water management in the western United States recommended in NOAA’s report to Congress pursuant to section 201 of the Weather Research and Forecasting Innovation Act of 2017 (Public Law 115–25). The pilot project should be carried out in coordination with the National Weather Service and should be focused on achieving measurable objectives for operational forecast improvement, including forecasts of seasonal mountain snowpack accumulation and total seasonal precipitation.

Although this initiative was not included in the final Congressional appropriations bill, it does indicate the interest that Congress maintains in S2S predictions and the contents of the NOAA S2S report.

Recommendation 21: NOAA should continue to develop and prioritize funding for S2S pilot projects that involve Earth System prediction and the application of associated products to decision-making involving specific use cases (e.g., underserved populations).

III. REVIEW METHODOLOGY

As indicated in the Executive Summary, the EISWG formed a review team that included EISWG members as well as supporting members from the CWG given the influence of climate conditions and knowledge on Subseasonal and Seasonal timeframes as defined in the Weather Act, Title II, Section 201 (between two weeks and two years). In addition to extensive reviews of the report and associated references, the review team received briefings from NOAA (NWS and OAR line offices) on the NOAA S2S Report and related, ongoing programs, and consulted with external subject matter experts.

In addition to the detailed sections of the NOAA S2S Report and associated references, we also reviewed and concur with the *Process and Consultation* information in the report. It is evident that NOAA included extensive internal and external expertise in the development of the report and sought input from myriad federal agencies as well as the public. As indicated in the report, “the public was encouraged to provide feedback on the scope of the outline and potential utility of subseasonal and seasonal information. Nearly 100 respondents from academia, state government, water resource agencies, and the Federal Government provided comments that were addressed in the report.”

A. Members of the S2S Review Team:

- **Jon White**, RADM USN (Ret.), Oceanographer/Meteorologist (Ret.) (SAB EISWG member)

- **Ilse Gayl**, VP of Corporate Development, Advanced Environmental Monitoring (SAB EISWG member)
- **Michael Anderson**, PhD., State Climatologist, CA Dept. of Water Resources, (SAB CWG member)
- **Cecilia Bitz**, PhD., Professor and Chair, Department of Atmospheric Sciences, University of Washington (SAB CWG member)
- **Rong Fu**, PhD., Professor, Department of Atmospheric and Oceanic Sciences, Director, the Joint Institute for Regional Earth Science and Engineering, The University of California – Los Angeles. (SAB CWG member)

B. Subject Matter Experts Consulted for this Report

In addition to the substantial expertise represented by the members of the review team, including the exceptional scientific acumen of the CWG representatives, we consulted with the following individuals:

NOAA:

David DeWitt, PhD., Director, Climate Prediction Center, NWS-CPC

Jessie Carman, PhD., CAPT, U.S. Navy (Ret.), S2S Program Director, OAR-WPO

External:

Doug Kammerer, Chief Meteorologist, NBC-4, Washington, DC

Sarah Kapnick, PhD., NOAA Chief Scientist (JP Morgan at the time of the interview)

Susan Wijffels, PhD., Senior Scientist, Woods Hole Oceanographic Institution

C. References Used for this Report:

1. NOAA Science Advisory Board, 2021: A Report on Priorities for Weather Research. NOAA Science Advisory Board, 119 pp. https://sab.noaa.gov/wp-content/uploads/2021/12/PWR-Report_Final_12-9-21.pdf
2. Kessler, W.S., S. Cravatte and Lead Authors, 2021: Final Report of TPOS 2020. GOOS-268, 83 pp. <https://tropicalpacific.org/tpos2020-project-archive/reports/>
3. Climate Working Group, 2021: Advancing Earth System Prediction. NOAA Science Advisory Board Report, 22 pp. https://sab.noaa.gov/wp-content/uploads/2021/08/SAB_Report_Advancing-ESP_02April2021_Final.pdf
4. Climate Working Group, 2019: Subseasonal-to-Seasonal-to-Decadal (S2S2D), A Pathway to Improved Prediction. NOAA Science Advisory Board, 24 pp. https://sab.noaa.gov/wp-content/uploads/2021/08/SAB_S2S2D-White-Paper_12-17-19_Final-1.pdf

5. National Academies of Sciences, Engineering, and Medicine, 2016: Next Generation Earth System Prediction: Strategies for Subseasonal to Seasonal Forecasts. The National Academies Press, 350 pp. <https://doi.org/10.17226/21873>
6. National Oceanic and Atmospheric Administration, 2016: NOAA Administrative Order 216-105B - Policy on Research and Development Transitions. 11 pp. <https://www.noaa.gov/sites/default/files/legacy/document/2021/Jan/NAO%2520216-105B%2520UNSEC%2520Signed.pdf>
7. Interagency Council for Advancing Meteorological Services, 2020: Charter of the Interagency Council for Advancing Meteorological Services. 6 pp. https://www.icams-portal.gov/resources/signed_icams_charter.pdf

APPENDIX I

WEATHER ACT TITLE II, SECT. 201. IMPROVING SUBSEASONAL AND SEASONAL FORECASTS

SECTION 201 OF THE WEATHER RESEARCH AND FORECASTING INNOVATION ACT OF 2017, PUBLIC LAW 115-25, INCLUDED THE FOLLOWING LANGUAGE

“(c) FUNCTIONS.—The Under Secretary, acting through the Director of the National Weather Service and the heads of such other programs of the National Oceanic and Atmospheric Administration as the Under Secretary considers appropriate, shall—

- (1) Collect and utilize information in order to make usable, reliable, and timely foundational forecasts of subseasonal and seasonal temperature and precipitation;*
- (2) Leverage existing research and models from the weather enterprise to improve the forecasts under paragraph (1);*
- (3) Determine and provide information on how the forecasted conditions under paragraph (1) may impact—*
 - (A) The number and severity of droughts, fires, tornadoes, hurricanes, floods, heat waves, coastal inundation, winter storms, high impact weather, or other relevant natural disasters;*
 - (B) Snowpack; and*
 - (C) Sea ice conditions; and*
- (4) Develop an Internet clearinghouse to provide the forecasts under paragraph (1) and the information under paragraphs (1) and (3) on both national and regional levels.”*

Further, under Title II, Section 201(h) Congress requests a report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives. This report shall include:

- “(A) An analysis of how information from the National Oceanic and Atmospheric Administration on subseasonal and seasonal forecasts, as provided under sub-section (c) [quoted above], is utilized in public planning and preparedness;*
- (B) Specific plans and goals for the continued development of the subseasonal and seasonal forecasts and related products described in subsection (c) and*
- (C) An identification of research, monitoring, observing, and forecasting requirements to meet the goals described in subparagraph (B).”*

APPENDIX II

TABLE OF RECOMMENDATIONS

Summary Recommendations
Availability of the Report Supplement
<u>Recommendation 1:</u> NOAA should make the S2S supplement report publicly available for download alongside the official report. Language should also be included on the download site that describes the relationship between the two reports. Annotating the reports with dates on which they were published would also be beneficial, especially in referencing the reports.
“S2S” Periodic Definition/Terminology
<u>Recommendation 2:</u> NOAA should develop, publish, and maintain a standardized index of the various definitions that exist (nationally and internationally) for the terms subseasonal, seasonal, S2S, interannual, decadal, short range, medium range, long range, etc., to help eliminate potential confusion around these widely used terms.
<u>Recommendation 3:</u> NOAA should ensure consistency in its use of “S2S” and associated/related terminology across all products, services, programs, projects, budget requests, correspondence, etc.
S2S Strategic Goal(s)
<u>Recommendation 4:</u> NOAA should adapt the vision from the NAS (2016) S2S Report: “S2S forecasts of environmental conditions will be as widely used a decade from now as weather forecasts are today” (or a similar vision) to develop a strategic, time-bound goal (or goals) for its S2S overall program that encompasses the entire Earth System and all associated offices.
S2S in Advancing Earth System Prediction
<u>Recommendation 5:</u> NOAA should highlight S2S as a true Earth System effort with correspondingly cross-office approaches in NOAA’s strategic planning, prioritization, and budgeting efforts to include regional offices.
<u>Recommendation 6:</u> NOAA should emphasize S2S predictions in projects that are solicited and funded under NOAA’s Earth Prediction Innovation Center (EPIC) program.
Interagency and International Collaboration
<u>Recommendation 7:</u> NOAA should use the co-leadership role of NOAA in ICAMS, prioritize S2S-related interagency collaboration, including the initiatives under National Earth System Prediction Capability (ESPC).

Recommendation 8: NOAA should capitalize on the Interagency Council for Advancing Meteorological Services (ICAMS) objective to coordinate, help prioritize, and execute activities for “U.S. global leadership in meteorological services” to cohere and increase overall international engagement and program support in areas related to S2S forecasting.

NOAA Report Section II. *Current S2S Products and Services*

Recommendation 9: NOAA should maintain a true S2S Product “Internet clearinghouse.” The Weather Act (2017) directs NOAA to “develop an Internet clearinghouse” to provide S2S forecasts and associated information on their impacts, at both national and regional levels. We recommend the current S2S forecast products and information available on the CPC webpage be expanded and titled/described as a “clearinghouse” to fully meet this direction and include all national and regional S2S forecasts and impact-based products.

Recommendation 10: NOAA should provide additional product verification and use metrics to enhance user awareness of forecast skill usefulness. The Forecast verification pages on the CPC website provide Heidke Skill scores and associated data archives for S2S temperature and precipitation forecasts. We recommend the verification pages be expanded and upgraded to:

- 10.1. Ensure all verification tools and information are accessible to the public.
- 10.2. Provide summarized verification information on all S2S products, including hurricane seasonal outlooks.
- 10.3. Include long-term changes and trends in verification scores that indicate changes in skill of specific products, types, regions, etc. over time.
- 10.4. Make updated product use and download metrics publicly available (e.g., aggregate “web hits” as provided in the NOAA S2S Report)
- 10.5. Develop and publicize comparative skill metrics with S2S products from other sources such as almanacs and commercial weather organizations (e.g., news media) that develop seasonal predictions based on “analog” past years with global weather patterns and trends that resemble current year.

Recommendation 11: NOAA should maintain an updated, online version of the “Potential Future Products List” that is provided in Appendix B of the official NOAA S2S report. This will enable stakeholders to better plan for the use of these products as they become available.

Recommendation 12: NOAA should collect, publicize, and maintain an online catalog of “best practices” regarding the use of S2S products in public planning and preparedness. This will enable regional planners and decision-makers to share and gain knowledge regarding product use as well as support collaboration with NOAA regional organizations and other federal/regional/local partners.

NOAA Report Section III. *Current Plans for Improving S2S Products and Services*

Additional Specificity

Recommendation 13: NOAA should develop and maintain (more) specific plans, goals, and priorities under both overarching goals (improving forecast skill and enhancing stakeholder value) that can be mapped to budget requests, EPIC project initiatives, collaboration efforts with “core partners,” etc. Goals that are specific, measurable, achievable, relevant, and time-based (SMART) would help increase community support and potentially drive successful budgetary increases.

Recommendation 14: NOAA should maintain holistic roadmaps for the two overarching goals (increased forecast skill and enhanced stakeholder value) that include SMART goals and priorities along with desired end states. Frequently updated, publicly available roadmaps with critical path elements would provide additional transparency into status, progress and evolving requirements that would help garner public support and engagement around NOAA’s S2S programs and initiatives.

Stakeholder Value

Recommendation 15: NOAA should develop a framework, using social/behavioral sciences and direct coordination with stakeholders, to establish value metrics and assessment processes for key categories of S2S product stakeholders. This could include well-coordinated communication and coordination with stakeholders by NOAA’s various regional offices (e.g., NWS Regional Headquarters, Regional Climate Centers, Regional Integrated Science and Assessment activities). These coordinated efforts should consider multiple sectors of the weather/climate/earth science enterprise, to include the many local/state/regional public and private weather organizations that provide S2S forecasts and decision-making support (including news media). Consultation with other entities within the Department of Commerce, such as the Office of Native American Affairs and the Minority Business Development Agency, may also prove valuable in developing this framework.

Recommendation 16: NOAA should increase interagency collaboration around social and behavioral sciences, to include how S2S products and services can be more effective toward influencing public behavior and responsiveness, to include planning and preparedness by all levels of government. Given the growing impact of extreme conditions on public safety and security, collaboration with organizations within the Intelligence and Homeland Security communities such as the National Geospatial Agency (NGA) and Federal Emergency Management Agency (FEMA) is strongly recommended.

NOAA Report Section IV. Requirements for Improving S2S Products and Services

Requirement Prioritization

Recommendation 17: Using the SAB Priorities for Weather Research (PWR) Report as an initial reference, NOAA should develop a process for the establishment and periodic review, validation, and prioritization of longer-term S2S research and development requirements priorities. This would help the SAB and its working groups (e.g., EISWG and CWG) provide valuable assistance around the development/enhancement of requirements prioritization based on their breadth of expertise and experience.

Forecast Requirements - Sources of Predictability
<u>Recommendation 18</u> : In addition to the extensive research needs described in the NOAA S2S Report, NOAA should support additional basic research across the Earth System research enterprise into the limits and variability of Earth System predictability.
Research Requirements - Coordination Across NOAA Offices
<u>Recommendation 19</u> : NOAA WPO and CPO should foster a stronger synergistic relationship and clarify their respective roles to the research community as well as interagency partners. Confirm the validity and accuracy of the diagram above and then use it to guide and publicize cross-office R&D and R2O transition efforts regarding S2S capabilities.
Observation and Monitoring Requirements – Collaboration around Ocean Observing
<u>Recommendation 20</u> : NOAA should increase collaboration with Integrated Ocean Observing System (IOOS) leadership and the myriad IOOS and Global Ocean Observing System (GOOS) organizational activities to help address ocean observing and monitoring gaps as they relate to S2S requirements.
Continuation of Pilot Projects
<u>Recommendation 21</u> : NOAA should continue to develop and prioritize funding for S2S pilot projects that involve Earth System prediction and the application of associated products to decision-making involving specific use cases (e.g., underserved populations).