Subseasonal and Seasonal Forecasting Innovation: Plans for the Twenty-First Century

Annotated Outline

12 July 2018

The full report is to be submitted to Congress in accordance with
Section 201 of the Weather Research and Forecasting Act of 2017, Public Law 115-25

Prepared by

The National Oceanic and Atmospheric Administration

Draft Executive Summary

Within the past 20 years, the demand for subseasonal-to-seasonal (S2S) forecast information has been steadily increasing as Federal, State, local, and Tribal authorities seek to prepare for and reduce risk from meteorological events well in advance. *Subseasonal* is defined as the period from 2 weeks to 3 months, and *seasonal* ranges from 3 months to 2 years.

This document will serve as a guidepost for NOAA planning and execution, as well as to inform the public and NOAA's stakeholders on its efforts on subseasonal and seasonal forecasting. This document traces the continuum of effort for S2S, working backwards from products and services to the innovations needed to enable and improve them. Two main goals are identified: (i) improving the skill of the S2S forecasts, and (ii) enhancing the value of S2S products for stakeholders.

A central theme of this report is the use of NWS S2S products by its deep-relationship core partners. NOAA continues to learn from these interactions to improve the usability and transference of data, information, and forecasts. The coordination and communication of S2S related information is quite active and remains critically important in continuing to build the NOAA Climate Weather Enterprise. Research and development requirements for the advances in scientific knowledge and mission capabilities are needed to ensure NOAA can provide the information needed on sub-seasonal and seasonal timescales to support decision making for public planning, preparedness, early warning and meet rapidly expanding applications for subseasonal and seasonal forecasts and related products.

To produce forecasts and outlooks NWS relies on numerical earth system models to provide guidance. Given the small signal and large noise, S2S forecasts are inherently probabilistic and forecasters rely on post-processing of ensemble forecast systems to extract information to inform the forecast. The identification of sources of S2S predictability rely on the analysis of variance using a combination of observations, process-oriented studies and various types of modeling approaches to isolate the relative role and importance of individual components. The research and development needed to fully exploit potential sources of S2S predictive skill requires a seamless integration of efforts to advance observations in terms of both type and use, to better initialize coupled forecast systems, to improve parameterization of unresolved physical processes, to enhance coupled model forecast system capabilities, to produce the needed coupled re-analyses and re-forecasts, and leverage modern and evolving computer architectures. Observations are also needed to improve understanding of the critical processes on S2S timescales, to evaluate S2S model forecast system fidelity and guide model development, to enable the accurate initialization of S2S forecast systems, and to quantify S2S prediction skill and reliability.

Research and development will need to focus on identifying opportunities to better exploit regional influences impacting S2S predictability and forecast skill. Prediction systems will need to be improved to better model the sources of known S2S predictive skill. Opportunities for improvement include more carefully estimating the initial state of the ocean, the land surface, and polar ice conditions. Advances are needed for forecast systems to be able to predict the evolution of the coupled land-atmosphere-ocean-sea ice system, correctly providing an estimate of the most likely state and the uncertainty in the forecast. S2S forecast verification and evaluation research will be important to better understand forecast limitations and identify forecast opportunity, where we can expect enhanced skill and reliability. In order to function most effectively, there will need to be changes in how the components of the S2S enterprise (operational, research, and private sector) work together.

Diverse populations/sectors/decision makers absorb and understand and use information differently. Social and behavioral science research is critical to provide a better understanding of how to communicate this information effectively. As the forecasts have improved, so has our understanding of some of the needs of decision makers as well as how to deliver this information. In order to continue to increase impact and use these data, NOAA understands that they must incorporate methods uniquely available through the social and behavioral sciences to best communicate risk and uncertainty. NOAA social scientists are working on more advanced ways to understand communities' needs such as conducting studies on community risk perception and the value of scientific information. Future activities tying these societal aspects will enhance the use and applicability of weather data, forecasts and information.

1.0 Introduction

The *Subseasonal and Seasonal Forecasting Innovation: Plans for the Twenty-First Century* report is provided in response to the requirement under Title II, Section 201(h)(1) of United States Congress enacted PL115-25, with the short title, “Weather Research and Forecasting Innovation Act of 2017,” enacted on April 18, 2017. In addition to meeting the reporting requirement requested by Congress, this document will also serve as a guidepost for NOAA planning and execution, as well as to inform the public and NOAA’s stakeholders on its efforts on subseasonal and seasonal forecasting.

This annotated outline is intended to give the public and key stakeholders a sense of this report as it is being prepared for submission to Congress.

1.1 Background

Within the past 20 years, the demand for subseasonal to seasonal information has been steadily increasing as Federal, State, local, and Tribal authorities seek to prepare for and reduce risk from meteorological events well in advance. Additionally, many industries, such as tourism, insurance, commerce, water management, agriculture, financial markets, and transportation, are looking to NOAA for “extended weather” information to help them in their decision making for planning and to ensure their economic advantage.

The operational entity within NWS who’s mission is to produce products on subseasonal to seasonal timescales is the Climate Prediction Center (CPC). One avenue of dissemination of these products are through the NWS field structure (which includes Regional Headquarters, thirteen River Forecast Centers, and one-hundred and fifty Weather Forecast Offices nationwide), who in turn provide services to regional and local stakeholders. Another important outlet for dissemination of the current NWS operational subseasonal to seasonal (S2S) products from CPC are through deep relationship core partners that obtain the information directly from CPC and in which CPC provides interpretation and when necessary value added products and services.

Within NOAA there are a number of additional organizations and programs that provide S2S information products and services such as: the Regional Integrated Sciences and Assessments (RISA) Program, the National Integrated Drought Information System (NIDIS), the National Centers for Environmental Information (NCEI), the Regional Climate Centers (RCCs), the River Forecast Centers (RFCs), and the NOAA Research Laboratories. Collectively these organizations support CPC operational S2S responsibilities by working with the public, academic, and private user communities to: advance understanding of context and risk, support knowledge to action networks; and innovate services, products and tools to enhance the use of science in decision making.

1.2 Scope

The scope of the effort described in this report is defined by the operational services provided by the NWS's CPC. As noted above, the CPC is the NOAA NWS organizational entity charged to provide the operational services described and defined and authorized by Title II of the Weather Research and Forecasting Innovation Act of 2017. Within NOAA there are a number of additional organizations and programs that provide S2S information products and services. Collectively these organizations support CPC operational S2S responsibilities by working with public and private user communities to: advance understanding of context and risk, support knowledge to action networks; and innovate services, products and tools to enhance the use of science in decision making. The scope of this report encompasses these efforts and focuses on current operational products and services, as well as research and development efforts to carry NOAA into the future.

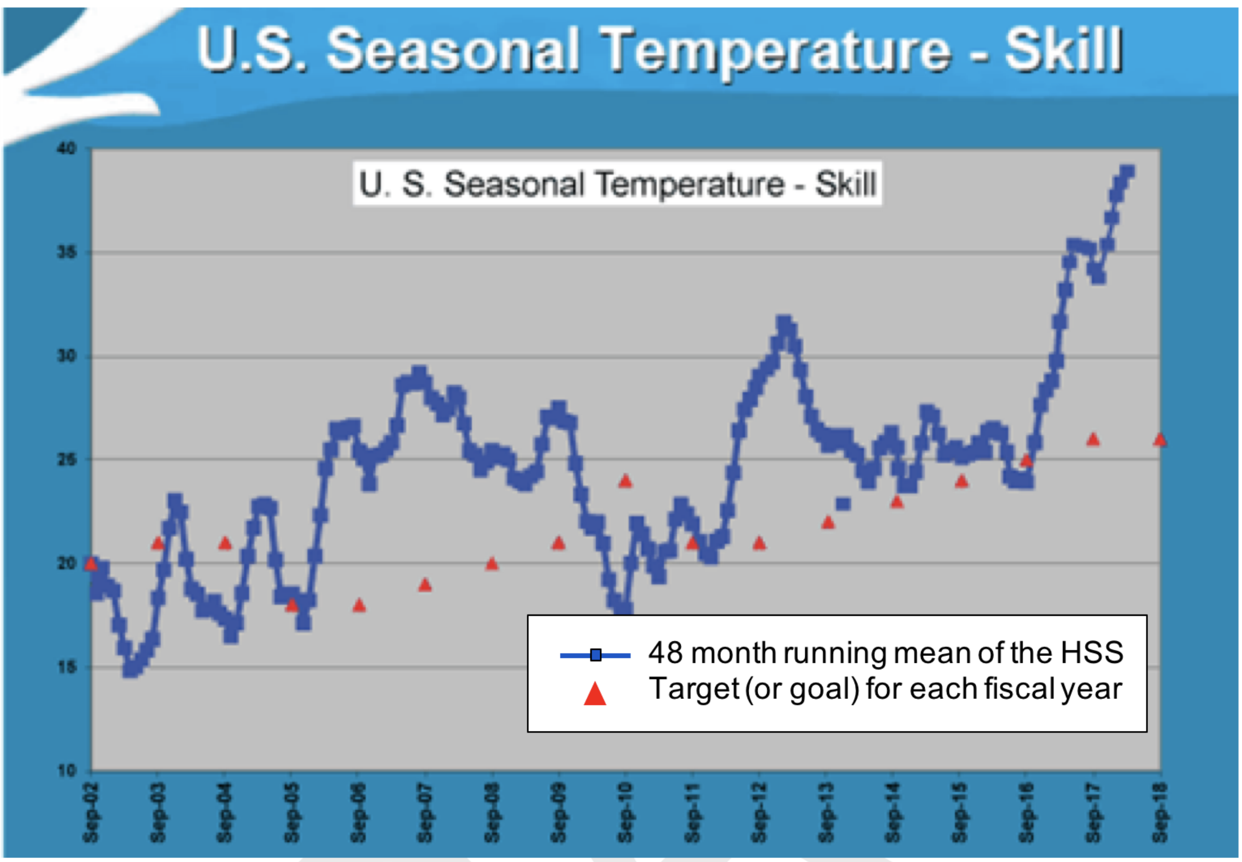

Figure 1: Heidke Skill Score (HSS) for U.S. seasonal temperature outlooks over the period from Fiscal Year (FY) 2002 through the first portion of FY 2018. The specific calculation of the metric is a 48 month running mean of the HSS (blue line). The HSS ranges from -50 to 100 with values of 0 or less (negative) indicating no forecast skill, while positive values depict forecast value over a climatological benchmark. The greater the positive values shown the higher the forecast skill. The red points are the given goal for each fiscal year over the period.

1.3 Enhancing S2S Forecasts and Products: Measuring Success

In recognition of the advancing state of the science, new metrics and baselines are needed to gauge improvement in forecast skill. Two main goals are identified: (i) improving the skill of the S2S forecasts, and (ii) enhancing the value of S2S products for stakeholders. Within each goal a number of compelling and quantifiable milestones are identified. In each case, a baseline will need to be established, and reasonable targets will need to be identified. Figure 1. illustrates one important metric, the Heidke Skill Score (see caption), which is an official Government Performance and Results Act (GPRA) measure.

1.4 Organization of this Report

The document is laid out in a straightforward manner, following the information requested by Congress in the Weather Act of 2017. It traces the continuum of effort for S2S, working backwards from current products and services to the innovations needed to enable and improve them. The report is broken up into five sections: Introduction; Current S2S Products and Services; Plans for Improving S2S Products and Services; Requirements for Improving S2S Products and Services; and Process and Consultation for Developing this Report.

2.0 Current S2S Products and Services

This section summarizes key components of the CPC S2S product suite in the prediction and monitoring areas. Considerably more detail is provided for each product listed in an appendix of the full report, where additional specifics related to product (a) type and purpose, (b) scientific basis (including guidance products used), (c) stakeholder usage for planning and preparedness and (d) planned future work to improve the products are given.

2.1 Summary of Current Products

Table 2.1 outlines high level information for the CPC suite of official operational outlook products with additional details provided in Appendix C in the full report.

Product Name	Forecast Variable(s)	Forecast Period	Release Frequency	Additional Information
Extended Range Forecast	Probabilities of different tercile classes of weekly mean temperature and total precipitation	Days 8-14	Daily	A Days 6-10 5-day mean forecast is also operationally produced at the current time
Week 3-4 Forecast	Probabilities of 2 classes (above-/below-normal) of	Days 15-28	Once per week	Released on Friday

	two-week mean temperature and total precipitation			
Monthly Forecast	Probabilities of different tercile classes of monthly mean temperature and total precipitation	~30 day period of upcoming month	Near mid-month, last day of month	An updated forecast for the upcoming month is released on the last day of each month
Seasonal Forecast	Probabilities of different tercile classes of 3-month mean temperature and total precipitation	~90 day period of upcoming 13 overlapping 3-month seasons	Near mid-month	The 13 overlapping seasons (3-months) result in a series of forecasts that extend out to ~1 year
U.S. Hazards Outlook	Potentially hazardous extremes related to temperature, precipitation, wind, flooding, severe weather and fire weather	Days 8-14	Daily	
Global Tropics Hazards and Benefits Outlook	Potentially hazardous/beneficial weekly tropical rainfall and temperature, elevated odds for tropical cyclogenesis	Week 1 and Week 2	Once per week	Released on Tuesday; Product updated on Friday's for northern Pacific and Atlantic areas during hurricane season.
Monthly Drought Outlook	Net change in drought category as defined by the U.S. Drought Monitor	By the end of the upcoming month	Once per month	Released on last day of the month
Seasonal Drought Outlook	Net change in drought category as defined by the U.S. Drought Monitor	By the end of the upcoming 3 month season	Once per month	Released near mid-month
MJO Outlook	Briefing package (PDF file format of images and text) summarizing MJO current strength and forecast	Next 2 weeks	Once per week	Released on Monday
ENSO Diagnostic Discussion	Briefing package (PDF file format of images and text) summarizing current ENSO status and forecast	Next 8 overlapping 3-month seasons	Once per month	Released 2nd Thursday of each month
Seasonal Hurricane Outlook	Number of named storms, hurricanes and major hurricanes; Probability of seasonal activity overall (above-, below-, or near-normal) as defined by ACE	June through November	Late May, updated in early August	Outlook is produced for the northern Central and Eastern Pacific and the Atlantic Ocean

Monthly Sea Ice Forecast	Arctic monthly mean sea ice extent, sea ice concentration, sea ice melt and freeze dates; Both deterministic and probabilistic formats	Next 9 months	Once per month	
Seasonal Sea Ice Forecast	Arctic seasonal mean sea ice extent, sea ice concentration, sea ice melt and freeze dates; Both deterministic and probabilistic formats	Next 9 months	Once per month	
Famine Early Warning System (FEWS) Products	Outlooks for regions outside the U.S.: Regional hazards outlooks, seasonal temperature and precipitation outlooks, and ITCZ forecast	Week 1 and 2; upcoming season; weekly	Once per week; once per month; once per week, respectively	Additional critical information provided by FEWS includes satellite rainfall estimates, and dynamical model data and derived products
Office of Foreign Disaster Assistance (OFDA) Products	Similar to FEWS products but products primarily are post-processed dynamical model data that specifically focus on potential extreme events	Week 1 and 2; upcoming season; weekly	Once per week; once per month; once per week, respectively	

Table 2.2 outlines high level information for several CPC operational climate monitoring products with additional details provided in Appendix C in the full report.

Product Name	Parameters Monitored	Update Frequency	Additional Information
U.S. Drought Monitor	Drought intensity categories	Weekly	Drought categories are: DO abnormally dry, D1 moderate drought, D2 severe drought, D3 extreme drought, D4 exceptional drought
CMORPH Global Precipitation	Precipitation estimation globally	30 minutes	Horizontal resolution is 8 km. Incorporates both Geostationary and low earth orbit satellite information in the product preparation
Unified Gauge Analysis	Precipitation; Global land areas only; Rain gauge data only.	Daily	CONUS horizontal resolution is ⅛ degree while for other regions it is ½ degree.
Outgoing Longwave Radiation (OLR)	Outgoing Longwave Radiation; Global coverage	5-day and monthly mean data produced in real-time	Horizontal resolution is 2.5x2.5 degrees

Extratropical Teleconnection Patterns (recurring and persistent air pressure and wind patterns that span vast geographical areas, such as entire ocean basins and continents)	Arctic Oscillation; North Atlantic Oscillation; Pacific-North America Pattern; Antarctic Oscillation (NOTE: Not all patterns monitored listed here)	Daily and monthly	Teleconnection patterns have a strong seasonality to their structure, duration, and impacts
Climate Reanalysis (R1, R2, NARR and CFSR)	Many atmospheric, land, and oceanic variables are analyzed as part of these systems	6-hourly	Daily, monthly and seasonal averages are prepared and disseminated to various stakeholders

2.2 Usage in Planning and Preparedness

The NOAA suite of S2S products are used by stakeholders to support decision making in a variety of public planning and preparedness contexts. Each stakeholder has their own unique risk tolerance and therefore utilizes those products that can effectively and efficiently inform their decisions. The S2S prediction problem is characterized by a small signal and large noise leading to limited predictive skill beyond two weeks for some fields such as precipitation.

A number of examples are provided of the use of the NOAA S2S prediction products for public planning and preparedness by major federal and state stakeholders: United States Department of Agriculture (USDA) Climate Hubs; NWS Fire Weather Forecasts; US Navy; federal use of Arctic Sea Ice Forecasts; United States Agency for International Development (USAID) Office of Foreign Disaster Assistance (OFDA) and Famine Early Warning System Network (FEWSNET); Federal Emergency Management Agency (FEMA); the US Forest Service (USFS); Bureau of Land Management (BLM); the United States Army Special Operations Command (USASOC); use of seasonal forecasts of hydrology (ESP and HEFS) by the New York City Department of Environmental Prediction (NYCDEP), the United States Army Corps of Engineers (USACE), and the United States Bureau of Reclamation (USBR); use of S2S precipitation forecasts by state and local water resource managers; U. S. Drought Monitor (USDM); use of the CPC Unified Daily Gauge Analysis (UDGA).

2.3 Dissemination, Communication, and Coordination

A brief summary on the primary NWS product dissemination methods and coordination approach is outlined in this section. Current NWS operational S2S products and services are reliably disseminated by several avenues. CPC S2S operational services are securely provided to the NWS regional and local field structure via a secure network termed the Advanced Weather Interactive Processing System (AWIPS). In addition to this governmental internal secure network, NWS operational S2S products and services are available via other platforms such as the WWW and NOAA Weather Radio for example. Considerable communication and coordination of NWS operational S2S products and services are undertaken by a critical set of local and regional experienced short term climate related experts and workers.

3.0 Plans for Improving S2S Products and Services

This section documents efforts currently underway to improve the underlying numerical guidance and pre- and post-processing, improvements to our efforts to communicate our findings, and some near-term research priorities.

3.1 Modeling

To produce these forecasts and outlooks NWS relies on numerical earth system models to provide guidance. Improvements in these will lead to improved forecast products.

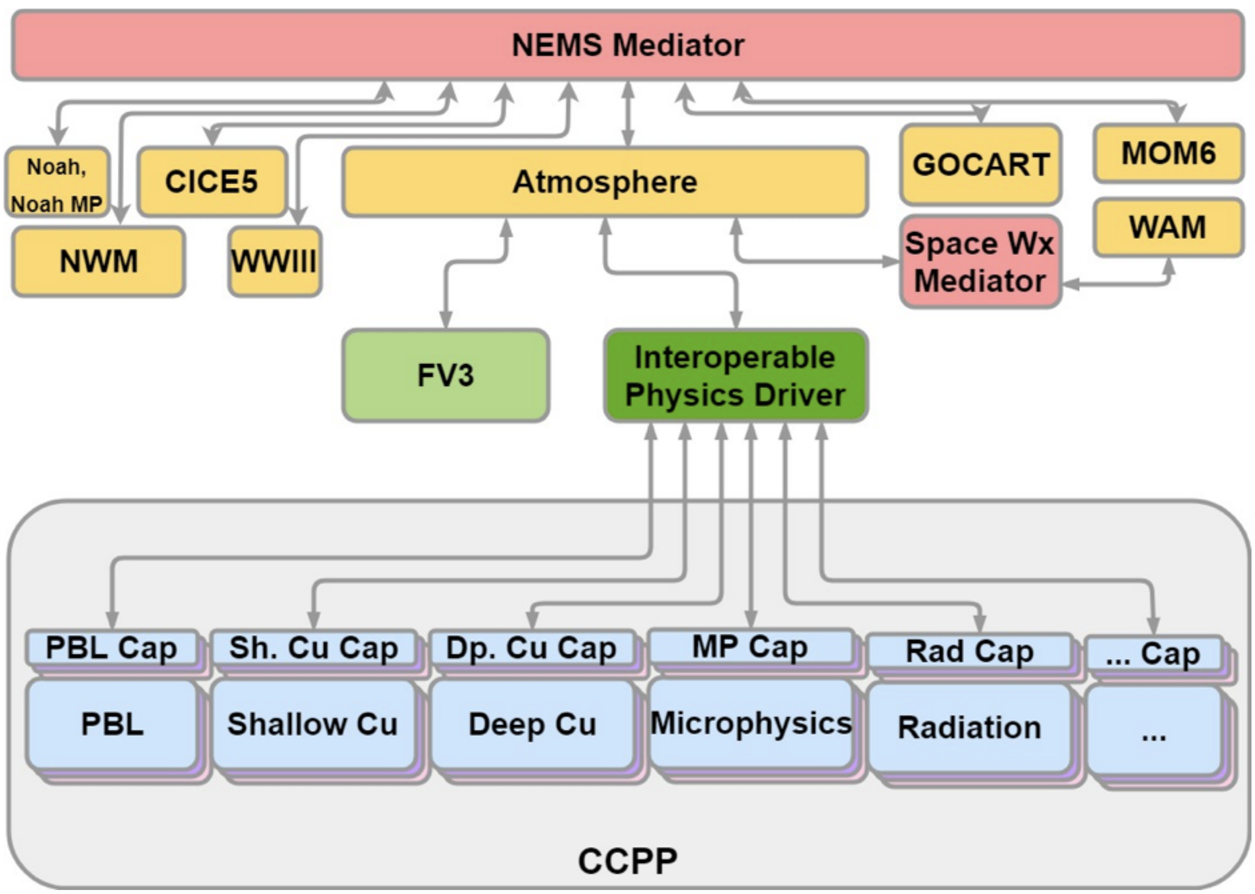

Figure 2: Schematic of the system architecture of the Unified Forecast System for operational Earth system prediction. The framework is based on NEMS/NUOPC architecture, which enables unified global and regional coupled modeling and DA, and broad community engagement.

Earth system models have been used successfully to provide predictive capabilities for the National Weather Service for over 50 years now. They continue to improve through continuous science and technology advances (e.g., increased understanding of physical processes) from academia, research laboratories, and operational centers, combined with significant advances in computational capacity and capability. The scientific development of these earth system models that power the NWS operational forecasting suite is a NOAA-wide endeavor, with key partners in NOAA Research and the broader scientific community.

The modeling section covers component Earth system models, coupling infrastructure, data assimilation, ensemble design, reanalysis and reforecasting, multi-model ensembles, statistical tools and hybrid systems. Much of this work derives from the development of the NOAA Unified Forecast System (UFS) which is documented in Figure 2.

3.2 Communication

In the past few decades, through interactions between scientists and decision makers, we have learned that various populations, sectors, and/or decision makers absorb, understand, and use information differently. We have come to understand that the social and behavioral sciences are able to provide tools and methodologies that help provide a better understanding of how to communicate this information effectively. As the forecasts have improved, so has our understanding of some of the needs of decision makers as well as how to deliver this information. In order to continue to improve impact and use of these data, NOAA understands that they must incorporate methods uniquely available through the social and behavioral sciences to best understand the communities with which they are working, and to communicate risk and uncertainty.

3.3 Near Term Science Goals

This section lists NOAA's near-term science goals for science and modeling including sea ice, data assimilation, coupled ensembles, reanalyses and reforecasts, and physics. It also provides recommended pathways to utilizing social and behavioral scientific methods to better communicate risk and uncertainty derived from NOAA's foundational forecasts.

4.0 Requirements for Improving S2S Products and Services

This section of the report 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 and services utilized in public planning and preparedness. Note in particular that this section focuses on capabilities that will not be met through the current near-term plans (as described in

Section 3) 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 to support decision making for public planning, preparedness, early warning and to meet rapidly expanding applications for subseasonal and seasonal forecasts and related products. The scope of research and development includes, not only needed foundational scientific advancements, but research and development efforts that are in progress but not mature enough to be implemented for operational delivery of S2S information products and services within the next 5 years.

This section derives from sources of S2S predictability that are inherent in the Earth system, many of which are nicely illustrated in the Figure 3.

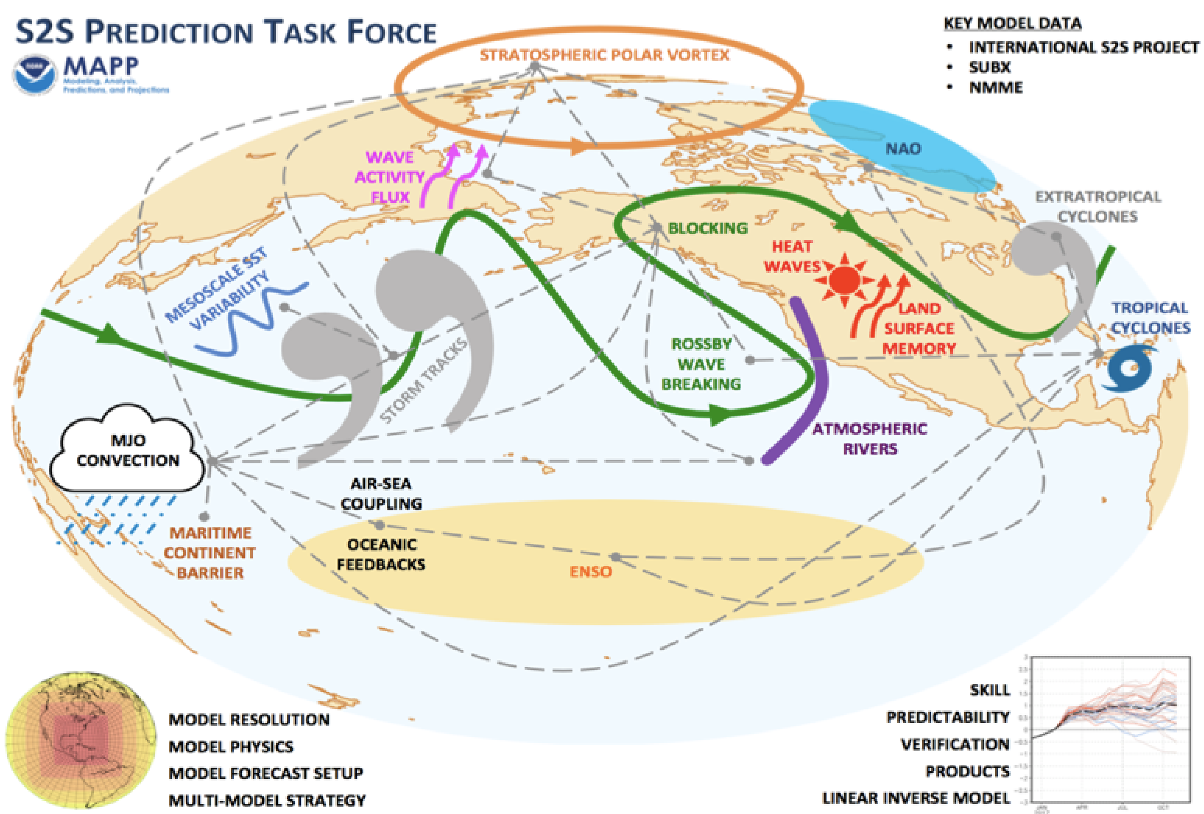

Figure 3: A conceptual illustration of the complex interconnections between weather phenomena and various low-frequency sources of variability. Figure prepared by Cory Baggett, Colorado State University, with input from the NOAA/CPO/MAPP S2S Prediction Task Force.

4.1 Background

The "Background" section references a number of reports have been produced over the past decade that provide a strong foundation for the current understanding of the pathways forward and the types of research and development required for advancements in S2S science understanding resulting in substantial improvement in weather forecasting and prediction of high impact weather events.

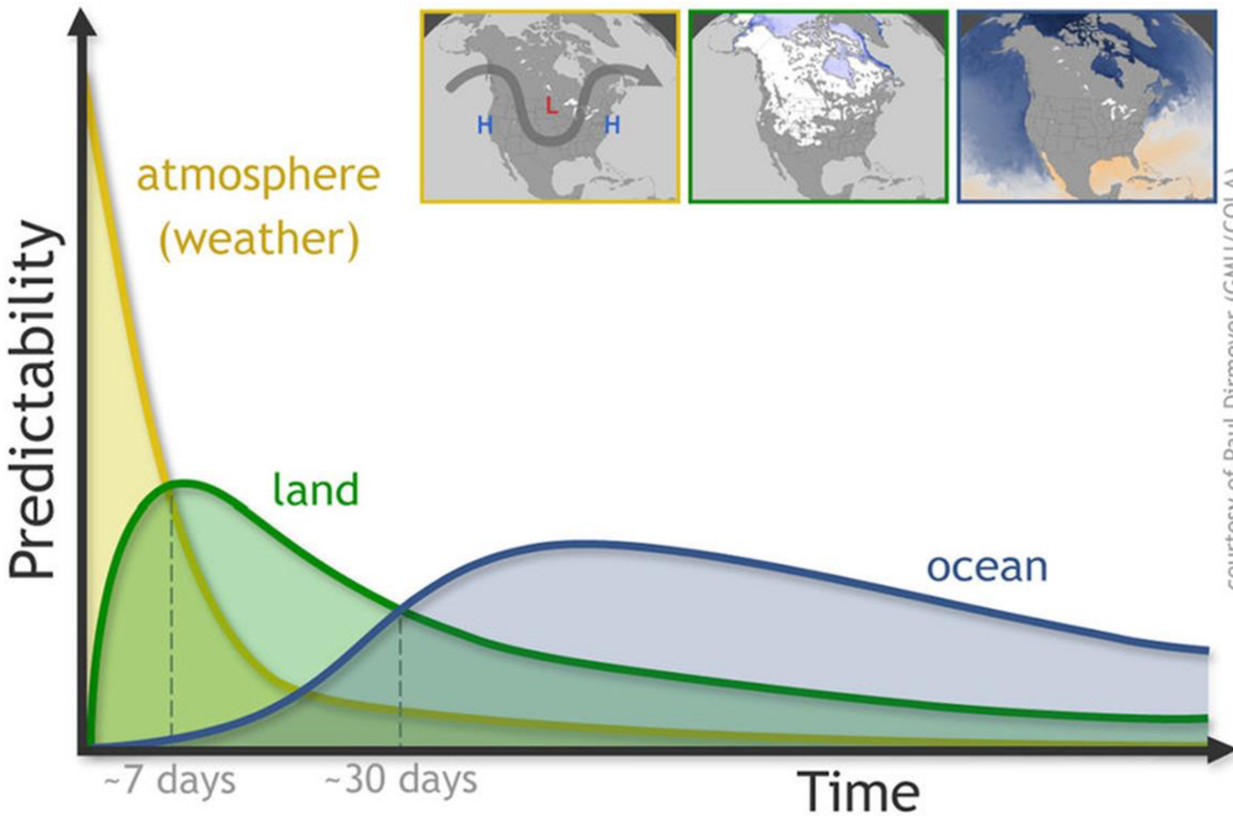

Figure 4: It illustrates several potential sources of predictive skill (vertical axis), from the atmospheric state (yellow), the land-surface state (green), and the ocean state (blue) over various forecast lead times (horizontal axis). At shorter lead times, the initial state of the atmosphere has the greatest impact. Beyond a week the state of the land surface (including things like soil moisture, snow cover, and vegetation) is a significant source of predictive skill. At lead times of about 30 days and more, knowledge of the state of the ocean, such as variations in the sea surface temperature are dominant. Credit: NOAA Climate.gov graphic, adapted from original by Paul Dirmeyer.

4.2 Forecast Requirements

The identification of source of S2S predictability for a given process or phenomena commonly rely on the analysis of variance using a combination of observations, process-oriented studies and various types of modeling approaches to isolate the relative role and importance of individual components. At time scales of interest for S2S prediction, there are many potential sources that will modulate the climate mean and variability. A description of several of the anticipated sources of S2S predictive skill are described in this section in the report, including atmospheric sources, boundary forcings and external forces, and are illustrated in Figure 4.

4.3 Research Requirements

The research and development needed to fully exploit potential sources of S2S predictive skill requires a seamless integration of efforts to advance observations in terms of both type and use, to better initialize coupled forecast systems, to improve parameterization of unresolved physical processes, to enhance coupled model forecast system capabilities, to produce the needed coupled reanalyses and reforecasts, and leverage modern and evolving computer architectures. This section addresses coupled initialization of the S2S forecast system, physical parameterization improvement, and coupled model ensemble prediction. The need for coordination of research efforts across the enterprise is identified.

4.4 Observational Requirements

Observations and monitoring networks provide the foundation for an enhanced S2S prediction system and the operational delivery of S2S information products and services. Observations are needed to improve understanding of the critical processes on S2S timescales, to evaluate S2S model forecast system performance and guide model development, to enable the accurate initialization of S2S forecast systems, and to quantify S2S prediction skill and reliability. The existing network of remotely-sensed and in situ observations plays a fundamental role in current and future S2S prediction capabilities, yet research and development is required to not only optimize use of the full spectrum of available data streams but to ensure all the important components of the ocean, land surface and cryosphere are sufficiently observed to advance S2S prediction.

4.5 Monitoring Requirements

Subseasonal to seasonal prediction leads to a unique set of monitoring requirements, which has three main foci. These are: (1) diagnostics of recent events, especially extreme events to understand their forcing and evaluate how well or poorly the forecasts for these events verified, (2) construction of gridded fields of key observed quantities for the hydrologic cycle such as precipitation, surface temperature, and soil moisture, and (3) overarching requirements for foundational datasets for S2S monitoring.

4.6 Towards Improving S2S Capabilities, Usage, and Value

Research and development will need to focus on identifying opportunities to better exploit regional influences (Arctic, tropical North Atlantic, tropical Pacific, Indian Ocean) impacting S2S predictability and forecasting. S2S forecast verification and evaluation research will be important to better characterize forecast limitations and understand them, as well as for the clarification of opportunistic forecasts for events with potentially enhanced skill and reliability. Likewise, research and development efforts are needed to determine dynamical aspects of forecast improvements (e.g. spatial scales) that can reduce long-standing systematic errors in dynamical properties (e.g. stationary wave amplitude, storm tracks, tropical cyclone paths). In addition to scientific advances resulting from the research and development needed to fully exploit potential sources of S2S predictive skill, there will need to be significant changes in how the S2S research community works and partners internally, with the operational community and the private sector.

5.0 Process and Consultation for Developing this Report

Congress asked when developing this report that NOAA consult with relevant Federal, regional, State, tribal, and local government agencies, research institutions, and the private sector. This section documents that process and provides documentation with whom was consulted.

The process for developing this report, which is currently a work in progress, was to establish a team comprised of senior leaders and senior scientists representing relevant NOAA line offices. The team functioned as a panel to identify key issues to be addressed, developed an outline for a plan, collected and reviewed existing plans and documents, solicited briefings from various subject matter experts (SMEs), held a workshop, and queried deep relationship core partners via a questionnaire. Public “town hall meetings” were also held at several national meetings of the American Meteorological Society and the American Geophysical Union.

Under the auspices of the full panel, a writing team has been formed to develop the document, taking inputs from the team and inputs received from this solicitation. The NWS will manage the public input , vetting, and approval of the document.