NOAA Response

NOAA Science Advisory Board
Climate Working Group Report:

Advancing Earth System Prediction

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Introduction

The National Oceanic and Atmospheric Administration (NOAA) received the final report of the Science Advisory Board (SAB) on *Advancing Earth System Prediction* in April 2021. This report makes 22 specific recommendations on ways to enhance the quality and value of NOAA's Earth-system prediction efforts. NOAA thanks the members of the SAB and the Climate Working Group for their work on this important task and for providing their collective insight on the agency's scientific endeavors.

This document provides NOAA's response to these recommendations. For each recommendation, the actions taken since the report was delivered to NOAA are detailed, as well as intended actions. A listing of acronym definitions is at the end of this document.

Background

With NOAA being the only federal agency with "prediction" in its legislative and operational mandates and the converging climate, weather, and Blue Economy needs for informed decision-making, NOAA has been building its Unified Forecast System (UFS) toward a coupled Earth-system approach to modeling and data assimilation to advance Earth-system prediction. NOAA's Earth-system prediction approach is evident in the NOAA Strategic Plan's focus on Climate and the Blue Economy, the NOAA Precipitation Prediction Grand Challenge, the NOAA Climate, Ecosystems, and Fisheries Initiative (CEFI), the Hurricane Forecast Improvement Project, its study of Coastal Inundation on Climate Timescales, and the NOAA Science Advisory Board's *Priorities for Weather Research Report* (December 2021). Internally, NOAA has implemented its Weather, Water, Climate Board to integrate across Earth-system components. NOAA's Earth-system approach aligns with national-level guidance and priorities, of particular note is the *Earth System Predictability Research and Development Strategic Framework and Roadmap* report (October 2020) by the Fast Track Action Committee on Earth System Predictability Research and Development (ESP-FTAC) of the National Science and Technology Council. Other NOAA efforts towards implementing an Earth-system approach for predictions include the legislated Earth Prediction Innovation Center (EPIC), as well as contributions to such international efforts as the United Nations' Decade of Ocean Science for Sustainable Development.

The SAB report examines ways to enhance the quality and value of NOAA's Earth-system prediction capabilities, focusing on increasing sources of predictability, thus enhancing predictive skill to address decision-making across timescales. The recommendations span observations and modeling, notably highlighting operational oceanography and forecasting needs, as well as increasing accessibility to data, improving coordination with partners, and strengthening the alignment and integration of decision-maker needs and scientific capabilities. The 22 recommendations that the SAB offered in its white paper are detailed below, along with NOAA's responses to each. The breadth of the SAB recommendations is deeply appreciated. These are broadly consistent with the ESP- FTAC and internal NOAA initiatives.

General Comments

In the context of predictions, within this report there is confusion in distinguishing between the Finite-Volume Cubed-Sphere Dynamical Core (FV3), the FV3-based Global Forecast System (FV3-GFS), and the Unified Forecast System (UFS), none of which refer to the same thing. There is a significant absence of reference to the prediction system currently in existence in OAR, the Flexible Modeling System (FMS), which predates the UFS and is the progenitor of many components presently used in UFS (indeed, FMS is used in the FV3 dynamical core, the current dycore in UFS applications). In particular, the FMS Seamless System for Prediction and

Earth System Research (SPEAR), documented in peer-reviewed publications, is far-ranging and being used for predictions/projections over a wide swath of time frames - from seasonal to centennial timescales. Since these predictions are delivered routinely, e.g., seasonal predictions delivered each month to the North American MultiModel Ensemble, in addressing NOAA's Earth-system prediction capabilities, the collective capabilities of the FMS and UFS need to be considered.

The emphasis on land processes and atmospheric chemistry measurements in the context of Earth-system Prediction, as reflected by Recommendations 1-4, is timely and speaks to important, yet underexplored, research directions. A number of research initiatives within OAR aim to elucidate the roles of atmosphere-land interactions and aerosol/cloud/radiation interactions with respect to Earth-system prediction. A concerted effort to assimilate these measurements into prediction models is critical and requires greater investment.

The SAB report has a singular focus on the Modular Ocean Model Version 6 (MOM6), specifically with respect to ecological applications at scales from deep ocean to the coastal applications, and short-term forecasts to climate applications. The SAB report advocates a massive acceleration of the operational applications associated with this. NOAA agrees with focusing on MOM6 for appropriate applications. As an open-development community-based model, the MOM6 is fully in accord with NOAA's emerging policy with respect to Software Governance and Public Release, as is required by Congressional directives to NOAA. NOAA's stance is that all software that is used in its research or operations or developed with Federal funds is strongly encouraged to be in alignment with this Congressionally mandated transparent approach. As a natural extension of previous MOM development, MOM6 has been the focus of seasonal to centennial applications at GFDL, particularly bringing in capabilities of the HYCOM model. Moreover, these GFDL applications are more and more applied to shorter time-scale applications. The MOM6 also is a focal model in the UFS, where the UFS community is actively moving towards unifying shorter time horizon applications, up to seasonal time scales, in coupled physical environmental modeling applications. Prototype testing of coupled physical models, including MOM6, is moving rapidly toward pre-operational testing. NOAA, however, does not concur with the singular focus on MOM6 for the broad range of ocean applications and challenges:

1. The singular focus on MOM6, with associated massive increase in resolution, forecast horizons, and resource requirements, is inconsistent with a balanced approach for the entire NOAA mission. For instance, the ecological focus is not consistent with most effectively addressing the NWS mission of saving life and property. A reasonable question is what model(s) should be implemented for ecological modeling, integrating finer-resolution physical processes with the biogeochemical state and processes. Thus, NOAA has concerns with the specification of a single solution (MOM6) for addressing its challenges.

2. NOAA has previously identified that effectively addressing NOAA's coastal missions requires unstructured grid models in 2D and 3D to resolve physical processes at the appropriate local spatial scales. This capability is not available in MOM6, making MOM6

less preferable for high-resolution applications. Explicitly using NOAA testbed facilities, NOAA previously selected ADCIRC as a focal 2D model for total coastal water level, and the 3D FVCOM model for focusing on water quality in the Great Lakes.

There appears to be an absence in the report of any focus on verification, evaluation, or overall measuring of model performance.

Land Observations

Recommendation 1:
Lead the coordination, through multi-agency collaborations, of the observation of surface, deep soil and groundwater, as well as the atmospheric boundary layer and free troposphere, clouds and precipitation profiles, which are mostly available, but not coordinated in space and time.

NOAA Response

NOAA agrees.

It is important to note that surface precipitation observations, versus precipitation profiles, are most important for land applications. Land surface satellite products (vegetation index (VI), land surface temperature (LST), albedo, soil moisture, evapotranspiration, leaf area index (LAI), etc.) are generated, but they are not coordinated with the production of other data that may be related to developed surface products, e.g. deep soil moisture or groundwater, much less atmospheric boundary layer variables. The first step needed is consistency of land surface products, prior to their being capable of use in operational models. Current missions have support for only individual product development, not all the needed product coordination or consistency checks. To partially address this challenge, NESDIS's strategy is to build enterprise algorithms for satellite observation products. A high-spatiotemporal-resolution surface-type-dynamics data product is also critical for consistency checks of other land products and model parameters, in particular to address temporal variability limitations when current weather, water, and climate models employ static surface-type look-up tables.

Increased observations of land surface and lower-atmosphere conditions could yield increased skill and reliability, if targeted at better predictive understanding of critical air-land fluxes and processes. Exploiting these observations through the use of a strongly-coupled ensemble-based data assimilation system that can use the observations of all components together to update land surface and atmospheric boundary layer components simultaneously would enhance predictive skill. Currently, the kinematic and thermodynamic properties of the boundary layer are not well defined, especially those associated with surface fluxes and land surface properties (vegetation cover, soil moisture, etc.). The major climate regions of the U.S. require new coordinated observations that should be used in conjunction with current and forthcoming satellite observations to develop and enhance spatial and temporal coverage of the land surface. It is suggested that a framework for improved land observations could sit with the Interagency Council for Advancing Meteorological Services (ICAMS) Observational Systems Committee.

What NOAA has done:

- Nothing specific to note.

What NOAA intends to do:

- NOAA anticipates leveraging the ICAMS for this coordination effort, and encourages ICAMS to step into an interagency coordination role as the Office of the Federal Coordinator for Meteorology (OFCM) did.
- NOAA will continue its engagement with the U.S. Global Change Research Program (USGCRP), which includes a U.S. Water Cycle group, through NOAA's Precipitation Grand Challenge.

Recommendation 2:

Develop and improve gridded snow mass datasets, including investment in quality check of the citizen science measurements, over U.S. and globally for improving model initialization in weather and S2S prediction, especially for stream and river flows and floods over snow-covered regions.

NOAA Response

NOAA agrees.

Since the benefit of gridded snow-mass observations is not limited to weather and S2S model initialization, NOAA notes:

- Developing higher-quality snow-mass data also improves and drives hydrologic modeling, drought monitoring, climate monitoring, and the assessment of long-term trends, enabling optimal use of resources (crop selection, river flows and floods, reservoir operations, fire season preparedness, management of anadromous species, etc.). This benefit increases as the dataset ages. NESDIS can help transform this real-time data into climate-actionable data.
- Citizen science measurements are very valuable for calibrating and improving satellite snow products for gridded snow mass datasets (where quality control and new data fusion algorithms are required). However, they are not consistently distributed for geographical coverage; consequently, satellite remote sensing and improved airborne and drone remote sensing are critical to getting better observations.
- The potential exists for improving snow-mass estimates through blending passive microwave, visible, synthetic aperture radar, and ground measurements, with the synthesis addressing gaps and limitations of the individual sources.

Increased observations of snow mass and coverage could yield increased skill if the observations better constrain the modeling of key processes and assimilation into the model forecast systems. Snow observations include snow cover, snow depth, and snow water equivalent, with snow mass depending on snow depth and snow density. NESDIS produces satellite products that can contribute to snow-mass datasets, including Snow Water Equivalent, Snow Depth, and Snowfall Rate. NOAA's Microwave Integrated Retrieval System delivers the snow water equivalent, which equals snow mass. Accurate snow retrieval is challenging because of large spatial variability within a short time window, aerosol deposition on snow that changes its albedo, and heterogeneity of snow cover across different types of vegetation. Snow mass can be estimated by keeping track of snowfall (e.g. satellite snowfall rate developed by NESDIS), such as is done with the National Water Model with modeled snowfall. Understanding historical variability in snow mass, along with observations that improve its predictability, can impact the ability of NMFS to describe changes in salmon habitat and survival.

What NOAA has done:

- In FY21 WPO funded NWS CPC work to improve snowfall/snowpack datasets. As part of the FY22 NOFO competition, WPO is funding a 3-year project on enhancing S2S predictions of precipitation and drought via improved representation of snowpack processes. This work should improve UFS seasonal snow predictions.
- NESDIS is developing a blended satellite-in situ snow-water-equivalent product. It has already developed and published a blended satellite-in situ snow-depth research (not operational) product.

What NOAA intends to do:

- Improve coordination of modeling and data assimilation efforts from hydrological through to fully coupled applications.
- Develop techniques to better leverage novel observations, such as those from citizen science.
- Properly steward and use gridded snow-mass observations to service climate-scale understanding and use.
- NWS and OAR aim to develop data assimilation and analysis systems that can ingest the highest-quality snow-mass data and use them for product development and model initialization in UFS-based systems.

Atmospheric Chemistry Observations

Recommendation 3:
Enhance land observations with focus on land impacts on atmospheric boundary layer structure, and biogenetic, dust and biomass burning aerosols, and their interaction with clouds and precipitation, either by initiating NOAA's own or contributing to joint efforts; and realign some of the "chemistry" measurements capabilities to address the issue of boundary layer meteorology that will enhance weather prediction, deposition process understanding, and climate change science.

NOAA Response

NOAA agrees.

NESDIS highlights that capabilities for observing atmospheric composition/chemistry need to be enhanced and extended from the surface to the top of the atmosphere (ground, aircraft, and satellite) to study deposition, anthropogenic, biogenic, biomass burning emissions, air quality, climate, and their linkages, including physical and chemical processes. Recognition of pending new observations is needed, e.g., NOAA's GeoXO mission observations. NESDIS notes that surface winds, ocean-atmospheric fluxes, and ocean waves strongly influence boundary layer meteorology, highlighting the need for winds and wave remote sensing. Intensive and comprehensive studies on land observation impacts on modeling should be carried out to understand how to use which land observations to improve numerical Earth-system prediction models, including water models. NWS recognizes that boundary layer physics need to be improved in the operational prediction systems. Moving to an Earth System approach to account for human decision-making that impacts vegetation cover is a high priority. Improving equity in providing critical information on air quality also is a priority. NMFS notes that improved data on atmospheric deposition of dust to the ocean surface would help reduce uncertainties in the micronutrients supplied to ocean ecosystems. Micronutrients supplied by dust and ash can have a substantial impact on the composition of phytoplankton communities, the foundation of the marine food chain.

Enhanced observations of boundary layer structure, biogenetics and aerosols, and their interaction with clouds and precipitation can improve the modeling of land-atmosphere interaction, energy fluxes, convective and large-scale precipitation processes, and, ultimately, overall model prediction accuracy. Enhanced observations of dust and biomass burning aerosols can also improve air quality and wild fire modeling capabilities within NOAA's operational prediction systems. NOAA notes that more science is needed to demonstrate how biogenic (and other) aerosols influence weather, both observations and models. Just increasing focus on the boundary layer is not sufficient. More science also is needed to assess whether the influence warrants a computationally cost-effective method to incorporate them in our forecast systems. This science cannot be based on observations alone, but requires extensive work with models and observations and must be done collaboratively with other agency partners.

What NOAA has done:

- NOAA conducted Bedrock-to-Boundary Layer (B2B) Workshops in April 2019 and June 2021 and expects to exploit the findings and recommendations from those boundary latter coordination efforts at NOAA Labs.
- NESDIS developed a biomass burning emissions product that is ingested by NWS operational global (GEFS-Aerosol) and regional aerosol (CMAQ) models.
- The CMAQ model used for NOAA's air quality products includes a comprehensive set of aerosols including biogenics. The CMAQ is being coupled to the regional system (RRFS) and the science team is beginning to examine feedbacks between chemistry and weather.
- The OAR Air Resources Laboratory (ARL) developed FENGSHA, a dust emission model that has been implemented into the FV3GFS-Chem global aerosol model. Additionally, ARL conducts process studies of boundary layer structure using tower-based observations and uncrewed aircraft systems (UAS).

What NOAA intends to do:

- NOAA will continue its long collaboration with NASA and the larger community to obtain the most up-to-date land and biomass emission observations and derived products for improving EMC's modeling suites for weather and S2S predictions.
- NESDIS aims to utilize the fire radiative power, aerosol and trace gas products from geostationary satellite imagers and atmospheric composition sensors to contribute to air quality, cloud physics, chemistry, and climate modeling. NOAA anticipates starting this work with the NASA TEMPO mission, subsequently exploiting NOAA's GeoXO Program.
- To address the prediction of air quality in operational systems, NWS and OAR intend to: develop assimilation capabilities for enhanced land observations and improved observations of emissions; improve the representation of boundary layer physics; introduce radiatively active aerosols and chemistry into the prediction systems as predictands; and transition innovation from research and development partners into operational applications based on the Unified Forecast System.

Recommendation 4:
Enhance and refocus the NOAA infrastructure (people; heavy-lift aircraft; chemical, aerosol, and radiation measurements, etc.) to improve weather forecast, emission quantification to inform societal action, climate change quantification to inform mitigation and adaptation, and reducing impacts of wildland fires.

NOAA Response

NOAA agrees.

NOAA notes that capabilities need to be enhanced and extend from surface to the top of the atmosphere to observe atmospheric composition/chemistry from ground, aircraft, and satellite to study deposition, anthropogenic, biogenic, biomass burning emissions, air quality, climate, and their linkages, including physical and chemical processes. Moving to an Earth-system approach to account for human decision-making that impacts emissions is a high priority. Improving equity in providing critical information on air quality is also a priority. NOAA's Earth-system prediction modeling components need to recognize that the pending GeoXO satellite observing system provides underlying infrastructure for such capabilities.

Surface and atmospheric column measurements of aerosols and chemical species are crucial to inform, develop, and tune both global and regional air quality models. Datasets collected from observational campaigns, such as NASA's Atmospheric Tomography Mission (ATom), have been key to evaluating spatial and size distributions of predicted global aerosols, which influence the meteorology upon enabling radiative feedback. Current representations of convective and large-scale scavenging processes could also be improved if adequate datasets were available.

What NOAA has done:

- With respect to improving emission quantification to inform societal action and climate change quantification, NOAA has developed plans to: 1) rebuild and enhance regional greenhouse gas (GHG) observing systems; 2) initiate transformative network development to enable a step change in data analysis and spatial and temporal sampling of GHGs for satellite, model and emissions evaluations; 3) develop and apply enhanced Earth-system models to inform policy makers about the feasibility and implications of meeting or not meeting different future climate targets; 4) build out a transformative measurement network to enhance network detectability by using commercial aircraft, fossil fuel tracers, boundary layer supersites for model and satellite evaluation and process understanding; and 5) develop a near-real-time GHG data assimilation system coupled with NOAA's Unified Forecasting System transport to provide global to local 4-D estimates of atmospheric GHG concentrations, emissions and sinks.

What NOAA intends to do:

- NWS and OAR are improving their capabilities to use community-based innovations in its modeling systems. This includes planned upgrades to data assimilation capabilities for satellite, ground-based, and ocean-based observing systems, through implementing the Joint Effort for Data assimilation Integration (JEDI) being developed by the Joint Center for Satellite Data Assimilation (JCSDA). This software compartmentalizes the code that aligns with specific observing systems, making possible rapid assimilation of data from upgraded or new observing systems and capabilities. All UFS-based applications will use JEDI.

- NWS and OAR also are in the process of implementing next-generation operational global and regional, high-resolution aerosol and air quality coupled prediction systems with a more detailed representation of the underlying physical and chemical processes, including contributions from wildfires plumes. These systems aim at better informing societal action through more-accurate quantification of surface pollutants and wildfire emissions.
- OAR Labs and Programs will continue current (SABRE) and planned (AEROMMA) field missions which implement NOAA and partner infrastructure (people; heavy-lift aircraft; chemical, aerosol, and radiation measurements, etc.) to improve quantification of emissions and climate change in the stratosphere and troposphere.
- The OAR Climate Program Office plans to continue its investments in characterizing emissions and chemistry resulting from wildfires and fires at the Wildland-Urban Interface (WUI), continuing, in part, a collaboration between OAR Laboratories and NESDIS.
- A geostationary atmospheric composition sensor coupled with a high-spectral resolution sounder for NOAA's GeoXO mission is proposed to help improve diurnally and vertically resolved atmospheric chemistry measurements. Such measurements will build upon NASA's TEMPO mission developments

Ocean and Coastal Shelf Observations

Recommendation 5:
Target major gaps in the ocean observing system (shelf seas, deep and polar oceans, and living ocean). Expand the use of new and improved drifters, buoys, and autonomous instruments to facilitate a cost-effective expansion of the observing network below the ocean surface.

NOAA Response

NOAA agrees.

NOAA's Earth-system prediction modeling and data assimilation activities welcome these recommendations. Overall, the ocean subsurface is severely under-sampled and has large gaps. Operational prediction applications will leverage the observations discussed here via JEDI, as described in the response to Recommendation 4. Improved climate and ocean forecasts will not only require expansion of subsurface observations, but also observations at the air-sea interface. NOAA observes that observations should focus on addressing model systematic errors and should be leveraged to transform improved predictive understanding into improved modeling of critical fluxes and processes. NOAA notes that more observations will become available through enhanced satellite communications provided by the Argos system for in situ environmental observations. This recommendation also will enhance the validation of existing and new satellite observations. NOAA highlights the need to encompass biogeochemical parameters, as well as physical parameters, to support NOAA's Earth-system prediction objectives.

NOAA notes the report contains no mention of new autonomous surface vehicle technology in the report, even though the data from these platforms are already flowing into the Global Telecommunications System (GTS), e.g. the current saildrone project with the European Centre for Medium-Range Weather Forecasting (ECMWF).

What NOAA has done:

- NOAA recently released a five-year Strategic Plan for Uncrewed Systems (UxS) with the objective of coordinating and expanding operation of NOAA's uncrewed aircraft and marine systems across the agency. This plan describes how NOAA will coalesce the different UxS components across the organization into relationships that maximize the collection and utilization of critical, high-accuracy, and time-sensitive data by increasing the application UxS to improve the quality and timeliness of NOAA science, products, and services. This agency-wide effort centers around five goals: 1) coordination and uncrewed system support at an enterprise level; 2) expanded autonomous applications across NOAA's mission portfolio; 3) accelerated transition of autonomous platforms from research to applications; 4) strengthened and expanded partnerships through the National Oceanographic Partnership Program (NOPP), (including with academia, the private sector, and other agencies; and 5) workforce proficiency in using autonomous platforms. Implementing this plan depends on the availability of resources.
- Autonomous vehicles, such as Saildrone and underwater gliders, continue to be evaluated for mission-specific purposes. For example, this past year, Saildrones intercepted a hurricane for the first time. The assimilation of saildrone data is being advanced in NOAA operational prediction systems.
- NOAA has increased deep ocean observations through the Deep Argo program. An additional 20 floats were deployed in the last year (FY21), along with deploying 12 BGC Argo floats for regional pilot studies.
- NOAA operational ocean prediction modeling systems (e.g., RTOFS) ingest all such observations of shelf-sea, deep, and polar waters that are available on the GTS.
- The ability to assess the living components of the coastal and deep ocean and understand their variability is closely linked to understanding changes in the physical and biogeochemical conditions of the environment. NMFS continues to maintain a portfolio of regionally focused fisheries-independent surveys of commercial and protected species and the environments that support them (e.g., CalCOFI, EcoMon, EcoFOCI, SEAMAP). The integration of data from autonomous platforms, including airborne drones, saildrones at the ocean surface, gliders, and floats, has accelerated in recent years, a consequence of seagoing restrictions associated with the COVID pandemic. While autonomous floats offer promise for improving NOAA's sampling of the open ocean, the vast majority of the country's fishery landings are harvested from the continental shelves. To aid in sampling the coastal ocean, NOAA has supported academic collaborators, as well as US IOOS Office partners, for the development and maintenance of a coastal glider network (https://gliders.ioos.us/), along with associated data dissemination. For example, in the southern portion of the California Current, this network complements ecological data collected by NMFS fisheries surveys, offering nearly constant assessment of physical and biogeochemical conditions in the water column along key transects over the continental shelf.

What NOAA intends to do:

- US IOOS will expand its existing network of multi-purpose mooring technology and add new mission-required sensors for ecosystem management purposes. NOAA's grant partners will address the critical need to develop a baseline capability infrastructure for the ecosystem monitoring required for climate-based living marine resource management, along with necessary added measurements (e.g. acidity, nutrients, acoustics, and genomics) for targeted regional needs and applications.
- As part of the proposed NOAA CEFI, NOAA will coordinate with IOOS on data management, modeling, and new technology deployments. NOAA also will coordinate with partners to improve the collection of useful ecosystem data in poorly sampled

habitat areas (e.g., subsurface conditions that are not regularly observed by satellites and coastal areas that may have reduced satellite coverage and poor sampling by autonomous floats). Recognizing the need to include biological data in the suite of ocean observations, NOAA will establish a Marine Life Program within the IOOS Office and develop a 5-year deployment plan that identifies planned ecosystem moorings, including new moorings and/or enhancements to existing moorings, as well as operations and maintenance plans to ensure continuous operations.

- Plans for the 2022 hurricane season include further testing/evaluation of the Saildrone system, and may include additional testing of other technologies.
- NESDIS plans to provide complementary new and improved satellite observations and derived data products for focus areas, e.g., the CEOS-COAST project co-led by NESDIS (https://ceos.org/ourwork/ad-hoc-teams/ceos-coast/). In conjunction with NWS and NOS, NESDIS plans to develop data products, tools, and techniques to effectively assimilate geostationary ocean color data into NOAA's ocean biogeochemical models and applications. Exploiting the higher temporal, spatial and spectral resolution offered by geostationary ocean color sensors (including OCX on the GeoXO operational mission and GLIMR a non-NOAA experimental mission) will improve NOAA's ability to observe and track more transient coastal processes, observe coastal areas impacted by clouds, and better support operational ecological forecasting efforts at NOAA. NESDIS will also facilitate and support NOAA's exploitation of ocean color observations from non-NOAA polar-orbiting satellite missions that feature additional spectral coverage and increased spectral resolution (Sentinel-3 OLCI, GCOM-C SGLI and the upcoming NASA PACE mission which will be hyperspectral) necessary for refining biological and biogeochemical water constituents which in turn enable, for example, identification of harmful algae or phytoplankton types as the basis for ecological communities. NESDIS plans enhanced collection of atmospheric chemistry observations to better quantify the transfer of material between the atmosphere and ocean. Direct and indirect deposition of atmospheric constituents contribute substantial input to the ocean, and the ocean emits numerous substances that affect the atmosphere and its properties, e.g., dimethylsulfide (DMS). These observations are needed to evaluate output of the NOAA's ocean predictions (Recommendation #12).
- Implementation of the UFS JEDI data assimilation framework will enhance the extensibility of the UFS operational prediction systems and accelerate the assimilation of new and enhanced ocean observations.

Recommendation 6:
Ensure capability through robust observing system design projects and implement experiments to design networks of integrated observations and platforms including satellites, ships, floats, gliders and moorings for both physical and biogeochemical parameters.

NOAA Response

NOAA agrees.

NOAA notes that, for the ocean domain, the United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Ocean Observing System (GOOS and the Intergovernmental Panel on Climate Change (IPCC), as well as feedback to the State of the Climate report, provide important guidance for observing system design. NOAA emphasizes the complementary need to observe interface parameters, such as surface winds, ocean waves, and sea ice that inform ocean-atmosphere fluxes of heat, moisture, and momentum and which are critical for coupled Earth-system predictions.

What NOAA has done:

- The Tropical Pacific Observing System 2020 (TPOS 2020) Project completed its final report in 2021, providing recommendations developed through expert consultation, quantitative observing system design studies, early assessments of alternate technologies, and extensive public feedback. The TPOS 2020 report recommends several paths for integrating observational approaches (e.g. moorings, satellites, gliders, ships) and further development and evaluation of promising observational technologies. Some of these recommendations are already being implemented in FY22. OAR climate modeling has been extensively involved in developing the Tropical Pacific Observing System (TPOS) design. The TPOS 2020 engagement substantially addresses this Recommendation with respect to the tropical Pacific.
- The National Data Buoy Center (NDBC) supports and provides data from ocean observing systems, including buoys (fixed arrays, tsunami detection), high-frequency radar, and ships.

What NOAA intends to do:

- NOAA intends to address stakeholder requirements by filling priority gaps for global ocean and coast observations. These investments will focus on advancing NOAA's understanding and prediction capabilities for: 1) climate and weather prediction, 2) ecosystems, 3) decision support for coastal communities, and 4) extreme weather and climate events. The goal is to address strategic needs for better observations and knowledge products, increase the uptake of ocean information in NOAA's models that lead to improved forecasts, and utilize new technologies to develop an efficient and effective observing enterprise. The NOAA Observing System Council (NOSC) may be a natural home for this effort.
- As part of the proposed CEFI, NOAA will expand efforts to design and prioritize ocean and marine-life observing capabilities and the capacity to deliver and use this information in assessments and decision making. In partnership with OAR, NMFS plans to identify observations of highest priority for data assimilation to support ecosystem applications through observation impact studies or Observing System [Simulation] Experiments, as conducted by NOAA's Quantitative Observing System Assessment Program (QOSAP).
- NOAA has begun targeting the development of a global high-resolution ocean "nature" run to enable NOAA's QOSAP to support Observing System Simulation Experiments (OSSE) used in designing and optimizing ocean, and coastal observing systems, as well as understanding the impact of pending new observing capabilities on ocean, coastal, and coupled Earth-system prediction modeling.

Recommendation 7:
Assess the utility of a nationwide shallow-water network of autonomous platforms (like gliders and floats) for physical and biogeochemical measurements for the shelf and coastal oceans and under-ice.

NOAA Response

NOAA agrees

Coastal/shallow waters are severely under-sampled, and such a network needs to include Blue Sea observations as well, since off-shore ocean currents and dynamics have a large influence on coastal conditions. It is anticipated that the U.S. IOOS partners will notably contribute to this recommendation. NOAA recognizes that, with the proven potential of glider measurements, use of the IOOS glider dataset should be expanded. Funding and training are needed to help other groups contribute observations, as well as more broadly improve the accessibility and usability of glider data. Such a glider network would enhance coastal ocean observations relevant to NMFS work.

What NOAA has done:

- The California Current Ecosystem has several underwater gliders that are maintained throughout the year and provide physical characteristics (temperature and salinity), as well as some biogeochemical information.
- Through various field campaigns, gliders have demonstrated the capability to provide the subsurface observations needed for better understanding physical and biogeochemical processes. The IOOS Regional Associations have conducted numerous glider missions in coastal areas for various coastal ocean observing applications, including hurricane forecasting improvements, oil spill response, ocean acidification, harmful algal bloom (HAB) mapping, ecosystem dynamics, and climate monitoring. The gliders measure physical and biogeochemical variables, and the data are delivered to the IOOS Glider Data Assembly Center for public access.

What NOAA intends to do:

- IOOS, OAR, and NWS are coordinating to strengthen the value chain between glider observations and NOAA's models, aiming to ensure gliders contribute data in areas that will optimize ocean model performance. Specifically, IOOS is coordinating with OAR and NWS/EMC on an underwater glider field campaign that will contribute physical oceanographic observations to the operational and experimental models with the goal of improving hurricane intensity forecasts.

Recommendation 8:

Build out the Argo network, including deep Argo and floats with biogeochemical sensors. Plan to enhance the fleet of global ocean observing ships.

NOAA Response

NOAA agrees.

NOAA recognizes that the One-Argo system that incorporates profiling floats for the upper ocean, deep ocean, and those equipped with biogeochemical sensors are vital for NOAA's mission, and foundational for Earth-system prediction of ocean biogeochemical and biological parameters and their impacts on ocean ecosystems. The build-out of revolutionary robotic sensors and platforms, such as One-Argo, gliders, and uncrewed surface vehicles, requires concurrent enhancement of campaigns on traditional platforms (ships) and improved shipboard and shoreside analytical capabilities for calibration purposes.

What NOAA has done:

- Recognizing the value of the Argo float data for NOAA's mission, the NOAA Argo Program Office held a cross-line-office workshop in June 2022 to demonstrate the utility of core Argo, deep Argo, and biogeochemical Argo for NMFS applications. The current US Argo array includes over 2000 floats (core floats, Deep Ago floats, and biogeochemical (BGC) floats). NOAA deployed several floats in key areas (Tropical Pacific) to enhance NOAA's understanding of that region and enable more accurate predictions (e.g., El Niño events). However, the trend in deployments has been fewer deployments in recent years, and regional gaps are becoming more frequent. Float costs increased dramatically, up to 25% in FY22, largely due to vendor price increases.

- NOAA has a significant investment in the international Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP). GO-SHIP works in partnership with One Argo by providing indispensable opportunities to deploy floats in the remote ocean, validating float data through referenced climate-quality observations, and providing discrete measurements that are correlated with the float-based measurements to expand their utility. Recent GO-SHIP cruises in 2019 and 2022 were unfortunately canceled, but planning is underway for possible GO-SHIP cruises in FY23 and beyond.

What NOAA intends to do:

- OAR aims to maintain NOAA's contribution of 1200 active core Argo ocean profiling floats and continue to deploy more Deep (6000 meters) Argo floats, with the long-term goal of 600 active deep floats. NOAA will also increase the number of BGC floats to supplement NSF's contributions, as well as continue to develop scientific data processing and product development capacity. With this continued investment in Argo, NOAA will expand coverage in priority areas, such as the tropical Pacific, North Atlantic, Gulf of Mexico, and off southern California.
- NOAA currently has one global class ship, the *Ronald H Brown*, that has been used to good effect in GO-SHIP and other global research campaigns that have improved Earth-system prediction. The *Ronald H Brown* is scheduled for a major mid-life refit starting in FY23 that serves to refurbish critical systems, as well as provide machinery control system enhancements, propulsion system enhancements, improved ship-to-shore connectivity, improved sensors, sonars, data management, telepresence capability, scientific data transfer improvements, an extensive CCTV camera system for remote observation, improved Bridge Management systems, navigational components and upgraded radar system. Aside from improvements in operating days and ship-based measurement and sampling capabilities to accommodate increased water observation needs, NOAA needs to increase the seagoing capabilities though chartering from a capable and, sometimes, underutilized non-NOAA research fleet, including international charters. In the long term, increasing the number of NOAA global class ships to regain lost capacity and accommodate the needs of the Global Ocean Observing System and its role in earth system prediction is imperative.

Ice and Inundation:

NOAA appreciates that Recommendations 9 and 10 emphasize coupling sea ice and ice sheets into the global model and recognizes the need for greater investment to address associated challenges for accurately forecasting coastal inundation, maritime safety, and icebreaking parameters, etc.

Recommendation 9:
Create a strategic plan to implement global predictions, projections, and scenarios coupling dynamical sea ice and ice-derived runoff components with the atmosphere, ocean, and land in global models. Sea ice and ice sheet components must have high quality initializations for ice sheet and sea ice mass and coverage through advanced data assimilation means.

NOAA Response

NOAA agrees, recognizing that the task spans multiple relevant timescales for predictions and projections (near-real-time, medium-range, subseasonal-to-seasonal, and longer). NOAA notes that accurate seasonal forecasting requires better physical descriptions of the slowly changing sea-ice processes. Significant developments in land vegetation and groundwater, sea-ice growth and melt, ocean mixing, and atmospheric ozone model components are critical. Data assimilation improvements for the land, ocean and sea ice states are needed in order to more accurately represent the initial states of those model components that provide the long-term memory of the Earth System. Sea-ice and ice-sheet observations are comparably critical to NOAA's near-real-time Earth-system predictions. NMFS notes that sea-ice dynamics are important for some of the most valuable fisheries; consequently, NMFS would be a user of such improved model output.

What NOAA has done:

- NOAA continues developing its Unified Forecast System (UFS) global coupled model for the oceans, atmosphere, and sea ice (using CICE6, which has dynamical sea ice), accounting for ice-derived runoff as part of sea ice-ocean coupling. NOAA is pursuing activities on many other fronts for coupled sea-ice/ocean/atmosphere assimilation and prediction (UFS, JCSDA, NOAA-NASA Modeling Team).
- Through the NOPP, NOAA is partnering with the Office of Naval Research (ONR) to support higher-resolution global ocean and tide modeling, which should improve modeling of Arctic ice mechanics by providing information needed for assessing flexure.
- NESDIS is closely coordinating with the NWS to support the UFS Coupled Model through new satellite sea-ice observations and products for assimilation for enhanced coupling of ocean, atmosphere, and sea-ice interfaces. NESDIS is building new sea-ice observing capabilities spanning multiple phenomenologies (infrared, passive microwave, altimetry, and synthetic aperture radar) to provide robustness to new products for sea-ice concentration, thickness, motion, and dynamics, building toward a sea-ice dynamics integrated system (Dynamice). NESDIS notes that these observations significantly leverage partner satellite observations. Some of these developmental satellite sea-ice products are already available for evaluation for assimilation.
- OAR's OM4, CM4, and SPEAR model efforts are providing a path for coupling dynamical sea ice and ice-derived runoff components. OAR is actively working on developing ice-sheet components.

What NOAA intends to do:

- NOAA plans to utilize new technologies to develop an efficient and effective observing enterprise, investing in new deployments of ocean observing technologies. NOAA will deploy buoys and other observing technologies for Arctic ice information. These steps will enable new Arctic observations and research targeting improvement of NOAA's forecasts of sea ice and coupled ocean-atmosphere-sea ice response. NOAA aims to better understand and assess these components and associated coupling within the Earth system and NOAA's modeling.
- The NOAA Modeling Board Modeling Strategy Working Group aims to include long-range plans for implementing and improving components of the UFS; specifics such as dynamical sea ice and runoff are expected to be included. Data assimilation plans also are expected to expressly state the goal of incorporating these components into coupled data assimilation.
- NWS will support strategic and tactical ice analysis services by leveraging data from foreign satellite data purchases and providing support for the International Arctic Buoy

Program. NWS products will provide upgraded operational inundation maps, upgraded probabilistic storm surge guidance, and operational weekly, monthly, and seasonal sea-ice outlook guidance products for the Arctic Ocean. NOAA aims to establish a Seasonal Forecast System (SFS) forecast capability with improved skill, lead time, and breadth of weather and environmental predictions that address the gap between shorter-range weather forecasts and longer-term climate-change projections.

- NESDIS is developing a sea ice dynamics product suite that includes ice motion, divergence/convergence, deformation rate, and sea ice leads (fractures).

Recommendation 10:
Work towards using an ensemble of predictions from a global model for stakeholder products. Regional modeling for calculating inundation should be nested within boundary conditions from global model simulations with coupled sea ice and ice sheets for consistency in treating variability and meltwater and its influences on ocean stability and circulations.

NOAA Response

NOAA agrees.

Development of an experimental ensemble global and nested capability to forecast and predict coastal inundation and sea level rise will provide needed information on the location and timing of impacts, and how risk varies from month to month and year to year. NOAA envisions greater use of ensemble forecasting to reduce model-specific issues and to provide better estimates of forecast uncertainties.

What NOAA has done:

- NOAA already produces such predictions, using global models (CFS and SPEAR), with the exception of integrating ice sheets.
- The 2020 realignment of USNIC into NCEP's Ocean Prediction Center (OPC) positions NWS to start planning implementation of a full spectrum of integrated analyses and predictions of polar maritime weather and ice, including improved sea-ice predictions and hazards, and polar seasonal outlooks.

What NOAA intends to do:

- As noted in the NOAA Blue Book (NWS-57) NWS will operate NOAA's component of the interagency U.S. National Ice Center (USNIC) to support sea ice analysis and prediction, offering operational sea-ice forecasts.
- The NOAA CEFI will develop regionally focused models nested within global models that, for the Arctic and Alaskan domains, will include sea-ice simulations.
- NOAA anticipates developing horizontal coupling and downscaling strategies for ocean models, as for atmosphere models, and including them in the NOAA Modeling Board modeling strategy to serve the various needs of coastal modeling across NOAA in an internally consistent fashion. Subsequently, NOAA aims to connect hydrology runoff with those coastal models, and back to global ocean models. Integration between data assimilation tools/algorithms and ocean and coastal models shall be included as part of the NOAA Modeling Board's modeling strategy. Such integration will be valuable, both at longer time scales (climate) and for extreme events at shorter time scales (e.g., hurricanes).

Operational Oceanography and Forecasting

NOAA concurs that it is important to have clarity on “who has the ultimate leadership for the development of ocean forecasting at NOAA.” Addressing this concern, to some degree, NOAA recently established the NOAA Modeling Board, which, in turn, has initiated a working group for “Enhancing Operational Ocean Forecasting.” Also as noted, given NOAA’s mandate for environmental forecasts, NOAA is clearly positioned to take the lead in developing a national, open access, high-resolution forecasting system. With the Nation’s and NOAA’s strategic priority focus on the Blue Economy, in conjunction with the United Nations Decade of Ocean Sciences and Sustainable Development, NOAA recognizes that the opportunity exists now to coalesce its operational oceanography enterprise and to apply Earth-system prediction tools and approaches to its operational oceanography endeavors.

Recommendation 11:
Implement an open-source operational ocean forecast system using MOM6 as soon as possible (on an accelerated timeline, i.e. not waiting until 2025). Include Earth system prediction benchmarks that quantify ocean pH, carbon, nutrients, with the intent of enabling consistent regional downscaling of ocean transport and ecosystems.

NOAA Response

Please see the general comment at the beginning of this response. The recommended accelerated NOAA timeline likely is challenging given that coupled and long-term prediction, as well as biogeochemical prediction capabilities, have long development lead times relative to near-term forecasting within the UFS milieu. The long-lead-time for NOAA’s recruitment and hiring process inhibits dramatic acceleration of efforts. However, with the resources and commitment detailed in the CEFI Implementation Plan, NOAA’s capabilities would be substantially advanced by 2025.

NESDIS notes that planned satellite ocean color instruments will enable regional ecological forecasting, contributing to addressing this recommendation (See response to Recommendation 5).

What NOAA has done:

- Development is underway on assimilating satellite ocean color observations of chlorophyll-a into NOAA’s Unified Forecast System’s (UFS) Real-Time Ocean Forecast System (RTOFSv2) to inform both biophysical feedback and ecosystem representativeness in conjunction with working to implement BLINGv2 biogeochemical modeling within the global RTOFSv2.
- Through a project funded by the Integrated Ocean Observing System (IOOS) Coastal and Ocean Modeling Testbed (COMT), NOS initiated research on assimilating satellite ocean color observations of chlorophyll-a for regional coastal ecological forecasting, notably targeting supporting harmful algal bloom forecasts and National Marine Fisheries Service (NMFS) bycatch avoidance guidance.
- The MOM6 is the ocean model of choice for UFS-based applications, the framework for future NWS operational modeling systems, which includes fully coupled models for medium-range, subseasonal, and seasonal forecasts. As requirements warrant, NWS will expand its capability to include biogeochemical cycles into its ocean models. Preliminary work on using biogeochemical model components developed in OAR within operational systems is already complete.
- On a global scale, the SPEAR climate prediction system, which includes the MOM6 ocean model has been published and is routinely delivering seasonal physical ocean

forecasts to the North American Multi-Model Ensemble and corresponding decadal prediction efforts. On a regional scale, recent and ongoing investments through the Climate Program Office and the Climate Portfolio associated with preparation for the CEFI have established prototype high-resolution (1/12th-degree) regional MOM6 implementations covering the east coast, west coast and the Arctic that include both physical and biogeochemical capabilities. NOAA has called for investments that would accelerate the development of MOM6 to offer ecological forecasts and facilitate advice on improved strategies for management of living marine resources.

What NOAA intends to do:

- Pending funding for the CEFI, NOAA plans to implement a cross-line-office effort that includes an end-to-end, operational modeling and decision support system that will provide the information and capacity stakeholders and resource managers need to reduce impacts and increase resilience in a changing climate. Regional ocean modeling teams will use the national ocean modeling framework offered by MOM6 to produce and deliver regional ocean hindcasts, forecasts, and projections that are intended for use by NMFS science centers to accelerate the production of climate-informed assessments and management guidance. In support, GFDL intends to implement the Carbon Ocean And Lower Trophics (COBALT) model within OAR's SPEAR model. The ongoing investments that would be provided by the CEFI would allow NOAA to develop a regional MOM6 system that delivers seasonal to multi-decadal physical and biogeochemical predictions and projections to the operation standards required by NOAA Living Marine Resource mandates.
- NESDIS intends to develop the infrastructure to enable assimilating planned observations from hyperspectral ocean color sensors (NASA PACE) and geostationary ocean color sensors (NASA GLIMR and NOAA GeoXO/OCX), as well as enable more frequent observations of water quality and biological assemblages (e.g., phytoplankton types) and biological processes (e.g., primary productivity) made possible through ocean color measurements. NESDIS desires to explore exploiting satellite sea-surface salinity observations as proxies/predictors for ocean acidification parameters.
- The UFS community is actively working on establishing foundations for future global coupled forecast systems (via an Earth System Modeling approach) for operational prediction, which includes MOM6. The use of MOM6 for S2S time scales has been well established by OAR/GFDL, but challenges remain on using MOM6 for shorter weather time scales. The broader research community, including NOAA, is actively pursuing these challenges. These efforts could be accelerated.

Recommendation 12:
The NOAA ocean forecast system (based on MOM6) should include development and implementation of ocean data assimilation, ocean reanalysis and the framework for coupled ocean-atmosphere assimilation & reanalysis.

NOAA Response

NOAA agrees.

NOAA notes that a strongly coupled data assimilation approach is critical to initializing model prediction systems, as well as that the ocean forecast system also must be paired with large ensemble, high resolution, multidecadal reanalyses. Significant investment in global and regional MOM6 development and evaluation is needed to accelerate the predictive capabilities needed to address NOAA priorities, such as climate change, fisheries, marine ecosystems (e.g., CEFI), and coastal inundation/sea level rise.

What NOAA has done:

- NWS recently completed a 40-year ocean reanalysis employing JEDI-based data assimilation in conjunction with the operational Real-Time Ocean Forecast System (RTOFS), which is based on HYCOM. MOM6-based prediction systems currently are under development.
- Using MOM6 with JEDI, NOAA is working on adding new capabilities for ocean DA and coupled DA, while also working on similar capabilities for ROMS, in conjunction with JEDI, to help advance current operational systems.

What NOAA intends to do:

- NOAA is developing a UFS-based Seasonal Forecast System (SFS) that employs MOM6 and CICE6 as components. JEDI-based ocean data assimilation and a new ocean reanalysis will set the stage for fully coupled data assimilation, initially weakly coupled, with the target being strongly coupled data assimilation.
- NESDIS aims to improve the assimilation of satellite altimetry observations into the UFS's modeled ocean's interior through better constraining surface density, thereby enhancing the representativeness of modeled ocean heat content and cascading influences on coupled ocean-atmosphere interactions.

Recommendation 13:
Current NOAA capability in regional ocean forecasting benchmarks and skills test should be applied to evaluate MOM6 global and regional simulations to accelerate transition to robust climate-relevant timescale boundary conditions.

NOAA Response

NOAA agrees.

- While this recommendation focuses on the MOM6 in the context of global and regional simulations and the need to consolidate and improve ocean forecasting efforts with nested structured-mesh ocean models, NOAA explicitly notes that the highly unstructured mesh coastal models, such as those currently used operationally by NOS, will continue to play an indispensable role in local ocean forecasts and downscaling (even if they are much less efficient for the larger scales) because they are better at resolving critical complex bathymetric and topographic features. Refined-structured-mesh nesting within MOM6 (similar to that in FV3) could help bridge differences between the two approaches, and should be developed. NOAA recognizes that greater pan-NOAA coordination between these global- to basin-scale ocean modeling approaches and coastal- to local- scale unstructured ocean modeling approaches would be highly beneficial. See also the general comment on the use of MOM6 at the beginning of this response.

What NOAA has done:

- As part of future UFS-based operational applications, global and regional MOM6 simulations are being actively evaluated for future operational use with help from the larger UFS-community. NOAA has other well-established regional ocean operational systems built with other models (e.g. ROMS and FVCOM at NOS) that can be considered for climate-scale relevant applications as well.

- As a step towards implementation of the CEFI, NOAA's Climate Program Office (CPO) has established prototype, high-resolution (1/12 degree) regional MOM6 implementations covering the east coast, west coast and in the Arctic that include both physical and biogeochemical capabilities. NOAA has proposed improving these capabilities and developing operational predictions and projections.

What NOAA intends to do:

- The long-range UFS vision includes evolving the near-real-time global RTOFSv2 from HYCOM to the MOM6, once the MOM6 has been validated for use at the RTOFSv2 spatial and temporal resolutions. NOAA will leverage the development of regional MOM6 systems in its UFS-based Hurricane Analysis and Forecast System (HAFS) and its Rapid Refresh Forecast System (RRFS) regional prediction systems for hurricanes and severe weather respectively, demonstrating the seamlessness of weather and climate prediction using regional ocean models. NOAA's CEFI will develop regional MOM6 model grids with the objective of simulating ocean and ecosystem conditions at a range of timescales. The modeled regions will cover all US Exclusive Economic Zones (EEZs) and will be coupled to global models. Regional ocean modeling teams will consist of both NMFS and OAR scientists. OAR will lead the development of these models, with NMFS leading model application, evaluation, output tailoring for user-defined needs, and production of forecasts and projections.
- NOS will continue to expand and enhance its Operational Forecast System (OFS) and is planning an East Coast Operational Forecast System, in addition to developing and improving OFSs in the Northeast, Northwest, Southeast, and Gulf of Mexico. NOS will collaborate with the MOM6 modeling community in its regional modeling efforts.

Decision-Maker Needs

Recommendation 14:
Enhance product specifications to include the distinctive dimensions of decision requirements for infrastructure and investment decision making that are influenced by progressive and abrupt change in climate processes and timescales and how advances in Earth system prediction can meet those needs across sectors.

NOAA Response

NOAA agrees.

NOAA recognizes the need for extracting knowledge from Earth-system observations to support informed decision-making with respect to infrastructure and investments, particularly those components sensitive to progressive and abrupt changes. When developing Earth-system prediction capabilities, NOAA aims to incorporate these considerations into sector-specific support. Working to establish continuity of Earth-system prediction capabilities across time scales, NOAA seeks to address infrastructure and investment decision-making needs across sectors. Incremental development and enhancements enable near-term support.

Within NESDIS, the National Centers for Environmental Information (NCEI) serves as a well-established NOAA locus for climate-related products and services, the temporal and spatial scales of which directly support infrastructure and investment decision-making. NCEI, along with NOAA CoastWatch/OceanWatch/PolarWatch led by the NESDIS Center for Satellite Applications and Research (STAR), are well-established at collecting

Earth-system observation needs and requests from a broad spectrum of external users, spanning commercial, academic, and international partner needs. Vetted user needs serve as data and product requirements for guiding the exploitation of NOAA observations to address predictions and decision-making within sectors. NOAA Earth-system data and products encompass both numerical modeling predictions and situational awareness products.

NMFS agrees with this recommendation and strives to maintain ecosystems in a healthy, productive, and resilient condition that continue to provide human communities with services that they want and need. To accomplish this mission, management plans must be adaptive to changing ocean conditions, recognize trade-offs between different stakeholder priorities by balancing social and ecological needs. Integrating understanding derived from enhanced earth system prediction capabilities, coupled with a good baseline against which to measure changes, is necessary to provide scientists and decision-makers with the information necessary to implement these resource stewardship responsibilities. The NOAA CEFI is specifically designed to help those seeking tools for climate-informed management of marine resources over a range of temporal and spatial scales.

NOS agrees with this recommendation and strives for healthy ecosystems, resilient coastlines and understanding threats from storm surge and coastal inundation. Changing climate threatens infrastructure and ecosystems throughout the US coastline. To prepare for these threats, NOS 3D coastal models must: cover the geographical coastline; successfully and accurately couple with hydrologic models to understand inundation and compound flooding; and should include data assimilation, which will allow the models to be iterative and adapt to environmental changes over time. A growing need is computing power and opportunities to advance existing models.

What NOAA has done:

- NOAA leverages the U.S. Integrated Ocean Observing System (IOOS) and associated Regional associations and partners in identifying user requirements for decision making across temporal and spatial scales and across user sectors.
- Spanning shorter to climate timescales, UNESCO/GOOS, the IPCC, and feedback on the State of the Climate report provide important inputs with respect to information needed in support of infrastructure and investments. The NESDIS National Centers for Environmental Information (NCEI) also has a well-established User Helpdesk, which collects requests identifying needs from a broad spectrum of external users, e.g., the commercial sector, the academic sector, and even foreign governments, each of which have their own longer-term infrastructure and investment needs and objectives.
- Metrics to evaluate coupled systems, particularly ones that are capable of predicting abrupt changes in precipitation and temperature regimes, are being discussed through UFS-based workshops.
- NOS has worked, and is working with the modeling community to fill coastal modeling gaps, advance storm surge models, and advance data assimilation capabilities of ocean models. The West Coast Operational Forecast System (WCOFS), which uses data assimilation to improve accuracy, was transitioned to NOS operations in 2021 .

What NOAA intends to do:

- Supporting this recommendation, the NWS and OAR are developing UFS-based fully coupled subseasonal and seasonal prediction systems to capture processes leading to extreme phenomena, which are of critical importance to infrastructure and investments, including floods/droughts, heat waves, and basin-scale hurricane activity.

- NOS is working to improve models through improved observational and bathymetry data. NOS also is working with the modeling community, the Office of Water Prediction, and OAR to expand and enhance coastal modeling efforts in key waterways, as well as to couple coastal models with hydrologic models to better predict compound flooding. NOS is working with the modeling community to enhance data assimilation algorithms so that models may exploit a wider range of observations to improve model accuracy.

Recommendation 15:
Develop plans to foster the continued refinement of model information and derived products, at multiple time scales and spatial scales. In order to better characterize decision spaces, the Earth system prediction model output should be made available in combination with other decision-relevant information.

NOAA Response

NOAA agrees.

NOAA notes that decision makers will need useful tools to access and synthesize information from Earth-system prediction models in conjunction with contextual information. NOAA's Earth-system observations enable NOAA's predictive modeling, as well as provide situational information for decision making. Model data and products need to be made available in an equitable user-friendly manner, which will require investment in data infrastructure, especially for exploiting high-resolution real-time data.

What NOAA has done:

- NWS and OAR, in collaboration with community partners, established key verification and validation metrics for UFS-based applications. These metrics, derived from input by the broader community, including researchers, developers, and operational forecasters, will be applied to evaluating UFS research products, helping guide their transition from research to operations.
- OAR has developed the FV3-based System for High-Resolution Prediction on Earth-to-Local Domains (SHiELD) to generate improved weather-scale products at increased spatial resolutions. SHiELD can be configured for a variety of forecast modeling applications — high-resolution short-range (0–60 hour), global medium-range (2–10 days), hurricane, and subseasonal (10–40 days) — in the same modeling system. Physical models that incorporate the new approaches in high-resolution modeling are able to exploit the spatial data for improved prediction of weather extremes.
  OAR's SPEAR has been developed as a next-generation OAR FMS-based coupled modeling system for seasonal-to-multidecadal predictions and projections, superseding the OAR/GFDL FLOR models. Since early 2021, SPEAR real-time seasonal predictions (50-km atmosphere, 1-degree ocean resolution) have been available as part of the North American Multi-Model Ensemble. SPEAR decadal predictions are available through the UK Met Office as part of the international (WCRP) decadal prediction program.
- NESDIS has developed satellite product line plans for refining existing, as well as developing new, satellite observations for assimilation into NOAA's Earth-system prediction models. The satellite product line plans include corresponding contextual information captured in decision-relevant situational awareness data and products spanning spatial and time scales. Examples include lightning strikes, airborne volcanic ash, flooded terrain, sea ice, and ocean oil spills.

- Metrics to evaluate coupled systems are being discussed through UFS-based workshops. It is anticipated that these discussions will continue.
- NOAA has developed an Implementation Plan for the CEFI that will support climate-informed decision making for the marine environment.

What NOAA intends to do:

- Pending funding availability, NOAA's CEFI, designed to support climate-informed decision-making by multiple sectors involved in managing and using marine and coastal resources, aims to deliver essential forecasts (seasonal-to-decadal scales), projections (decadal-to-centennial scales), and assessments of climate, ocean, and marine ecosystems. This NOAA effort, in collaboration with existing programs and external partners, will establish expert teams to accelerate the production of climate-informed assessments and management advice designed to sustain fisheries, conserve protected resources, and maintain ecosystem services. Operational delivery of ocean forecasts and projections will aid climate-informed management decisions by NMFS and others, with the objective of decreasing climate-associated risks and increasing the resiliency of resources and the communities which those resources support. A substantial component of the initiative includes a comprehensive "Information Hub" that will provide scientists, managers, and other decision makers with access to the broad suite of information on changing climate and oceans needed for climate-informed management of fisheries and protected resources. This suite of accessible information will include high-spatial-resolution reanalysis, hindcasts, predictions, and projections optimized for management applications, as well as existing living-marine-resource-relevant climate and biological information.
- NESDIS will support NOAA's need for consistently processed multiple-mission long-term time-series datasets, initially focusing on mature satellite ocean observations (SST, Ocean Color, altimetry/SSH). NESDIS/STAR will lead the development of innovative derived products that fuse satellite observations of multiple geophysical parameters to meet user needs, exploiting AI/ML learning techniques when appropriate. With IIJA funding, NESDIS will extend flood inundation forecasts to provide an observation-based early-response system for flood inundation, integrating satellite flood imagery (optical and SAR) into a mapping service, leveraging satellite imagery from NOAA, Partner, Commercial, and aircraft observations. These observation-based flood inundation maps will provide the basis for flood inundation forecast model initialization.
- The OAR SHiELD system will deploy at high spatial resolutions for both global and global-regional nested modeling, including a capability to efficiently zoom-in over regions of interest, extending simulations and forecasts of extreme weather from the current 1–2 day lead-time limitation into the medium range and beyond, as desired by many societal sectors. The OAR SPEAR system will target higher spatial resolution for the atmosphere and ocean to yield improved coupled atmosphere-ocean information on climate anomalies at county scales, including predictions based on scenarios of greenhouse gas and aerosol concentrations.
- NWS will continue engaging the R&D and operational communities on refining measures of model skill and valuation of derived products. Of particular importance is the development of derived ensemble model products for probabilistic weather prediction in support of improving the delivery of impacts-based, decision-support services.
- NOS will continue working with the modeling community and the IOOS regional associations to improve model skill and resolution.

Recommendation 16:
Develop a framework for incorporating research and development needs as informed by the end user decision spaces. This should include systematic, regularized opportunities for collaborative exploration based on decision-centric benchmarks of data and product performance of new components of Earth system prediction.

NOAA Response

NOAA agrees.

NOAA aims to deliver world-class numerical environmental prediction systems supporting NOAA through the development of the Earth Prediction Innovation Center (EPIC) that targets leveraging community modeling efforts to inform and advance NOAA's Unified Forecasting System (UFS). EPIC seeks to accelerate scientific research and modeling contributions through continuous and sustained community engagement, spanning government, industry, and academia, to produce the most accurate and reliable operational modeling system in the world.

What NOAA has done:

- NOAA has initiated EPIC, a facilitating organization that leverages resources to better coordinate the weather research and modeling community. EPIC combines: (1) being a roadmap for research and model priorities, (2) being a development environment, (3) code management, (4) cloud-ready code, (5) observational data and tools, (6) community support, and (7) community engagement.
- NOAA also engages the operational forecast community to establish forecast goals. These goals are used in strategic planning (e.g., the UFS Strategic Plan) to focus R&D on modeling system improvements to achieve those goals.

What NOAA intends to do:

- Through the CEFI and activities of the Climate Program Office, NOAA will fund a robust collaborative research program to use observations, laboratory experiments, reanalyses, and model hindcasts/predictions to understand the responses of marine ecosystems to past climate variability and change and assess NOAA's capacity to predict responses. Priorities for these collaborative efforts include enhancing ocean and ecological predictions and decision-support tools, improving scientific understanding of earth-system changes reflected in marine ecosystems, and evaluating alternate resource management strategies that will increase the resilience of fisheries and coastal communities to changing climate conditions.
- NESDIS will leverage NOAA CoastWatch/OceanWatch and PolarWatch user engagement to inform and guide NESDIS research efforts and capabilities.
- Metrics to evaluate coupled systems are being discussed through UFS-based workshops. It is anticipated that these discussions will continue.

Recommendation 17:
In conjunction with planning for the implementation of the Service Delivery Network, evaluate the appropriate level of specialist support needed to maximize benefits of advanced Earth system predictions. Coordinate these activities within NOAA so they can integrate feedback from decision makers and users' applications into continuing Earth system prediction improvements.

NOAA Response

NOAA agrees.

NOAA acknowledges the good example provided by the European Center for Medium-range Weather Forecasting (ECMWF), which publishes very clear information about each model upgrade and its products, including extensive metadata, helping end-users optimally use the data without needing extensive support from specialists.

What NOAA has done:

- For the ocean domain, satellite products, decision-making aids, and specialist support are coordinated, in part, through NOAA CoastWatch/OceanWatch/PolarWatch and the NOAA CoastWatch/OceanWatch/PolarWatch Annual Science Meeting.
- For coastal ocean products and decision aids, the NOS IOOS Program Office contributes to maximizing user benefits through planning and coordinating specialist support and improvements to NOAA's Earth-system predictions.
- NOAA engages the operational forecast community to establish forecast goals. These goals are used in strategic planning (e.g., the UFS Strategic Plan) to focus R&D on modeling system improvements to achieve those goals.
- Metrics to evaluate coupled systems are being discussed through UFS-based workshops. It is anticipated that these discussions will continue.

What NOAA intends to do:

- As guided by the Service Delivery Framework, NOAA's CEFI will establish a process to continue soliciting input from internal and external user communities during the initiative's development and implementation, thereby ensuring that the system effectively responds to the needs of target audiences. Within the first year, the Initiative will host the Climate and Ocean Information for Living Marine Resource Science and Management Workshop of scientists and managers to gather operational requirements for climate and ocean information and identify existing products and gaps. After assessing needs, the CEFI will convene an Ocean Modeling, Reanalysis, and Prediction Workshop to refine the pathway toward an integrated, regional ocean-modeling system that robustly delivers climate and ocean information across timescales and within operational requirements. The Interim Executive Steering Committee of the CEFI currently is working to evaluate the number and types of positions needed within the agency to facilitate delivery of these products to users and partners.

Enhancing Coordination

Recommendation 18:

Every NOAA Strategic Implementation Plan related to Earth system prediction should include a line that addresses the goals, objectives, responsible parties and metrics of assessment relevant to the collaboration and coordination between:

1) Responsible line offices within NOAA
2) NOAA and other Federal agencies
3) NOAA and State agencies
4) NOAA and other partners – academic and industry
5) NOAA and stakeholders

NOAA Response

NOAA agrees.

What NOAA has done:

- NOAA is a member of the Interagency Council for Advancing Meteorological Services (ICAMS), which coordinates priorities across the diverse agencies that make up the Federal meteorological services enterprise. The ICAMS Committee on Research and Innovation hosts a Joint Action Group on Earth System Predictability, in which NOAA is actively engaged. NOAA co-chairs the US Global Change Research Program that is key to interagency coordination on Earth system process research and climate predictions. ICAMS and USGCRP play complementary interagency coordination roles.
- NOAA actively participates in (and is a principal funder of) the Unified Forecast System, which brings together collaborators from other Federal Agencies and the academic and private sectors, leveraging the entire numerical weather prediction enterprise to improve NOAA's operational numerical environmental prediction systems.
- NOAA engages the operational forecast community to establish forecast goals, and develops metrics to evaluate modeling system performance through UFS-based workshops. These goals are used in strategic planning (for example, the UFS Strategic Plan) to focus R&D on modeling system improvements to reach those goals. Metrics to evaluate coupled systems are being discussed through UFS-based workshops. It is anticipated that these discussions will continue.

What NOAA intends to do:

- The NOAA Modeling Board's overarching Modeling Strategy working group expects to work closely with the Earth-system prediction components of relevant Strategic Implementation Plans to ensure the UFS implementation continues steering toward being a benefit to multiple line offices, as well as the relevance of an overarching plan. The UFS Strategic Plan has some gaps concerning broader NOAA modeling needs. The NMB Modeling Strategy working group envisions mapping the different components of NOAA and the Enterprise working on components of Earth-system modeling for NOAA, tracking progress of those components, potentially building a new Earth-system modeling plan for NOAA. Similarly, a well-connected, detailed strategy with long-term modeling goals, connecting the broad NOAA strategy with near-term implementation plans, will help competitions more effectively assess research project relevance to NOAA's needs.

Model Technology

Cloud Computing

Recommendation 19:

Establish agreements with Cloud Service Providers and members of the Earth system value chain to realize benefits of cloud technology for advancing predictions.

NOAA Response

NOAA agrees

NOAA notes that significant strides are underway for evolving NOAA's exploitation of Cloud computing across the spectrum of NOAA's Earth-system observations value chains. Supporting this vision and consistent with emerging open access tools to analyze "Big Data", a potential enabling NOAA effort would be to host the model data behind the projections, thereby supporting analysis for diverse applications, including improved understanding of predictability. NOAA recognizes that this effort requires deliberate resourcing to effectively create the workforce needed and equipped to successfully implement this vision. Current resources are insufficient.

What NOAA has done:
- The NOAA Office of the Chief Information Officer (OCIO) has developed a NOAA Cloud Strategy. Cloud computing and data contracts/programs have been established at OCIO and across NOAA line offices.
- NESDIS is moving intelligently to the cloud, with the NESDIS Common Cloud Framework (NCCF) providing a good example of cloud computing. NESDIS has been migrating and developing the enterprise algorithms to generate the products in the cloud, aiming to subsequently provide the NCCF data and products to numerical modeling users.
- NWS initiated multiple projects to run UFS-based applications in the cloud, including the operational Global Forecast System, the ensemble-based Rapid Refresh Forecast System, and Model Evaluations Tools, which provide the basis for all UFS-based model evaluations.
- OAR has engaged all three cloud providers in conjunction with the EPIC program. OAR also is moving its UFS applications to the cloud for easier community engagement and to broaden options for experimentation and development.

What NOAA intends to do:
- EPIC plans to continue fostering collaboration, enabling access to high-performance computing output by porting UFS-based applications to cloud platforms.

Artificial Intelligence / Machine Learning
Recommendation 20:
Establish accurate, high-quality, historical training datasets and indicators for trust in applying Artificial Intelligence/Machine Learning technologies to advance Earth system predictions.

NOAA Response

NOAA agrees.

NOAA recognizes that establishing the data readiness, IT, and computing infrastructure to enable innovations and leverage progress in this fast-developing field is critical. These challenges include modernization of data to be AI/ML/Analysis-ready, model and analysis codes and scripts, developing cloud-ready interfaces and data protocols to take advantage of Artificial Intelligence (AI)/Machine Learning (ML) capabilities that are emerging on cloud platforms. OAR notes that the training datasets for earth-system prediction require the production of large-ensemble, high-resolution, multidecadal reanalyses and reforecasts. The NESDIS National Centers for Environmental Information (NCEI) routinely produce high-quality historical datasets suitable for training AI/ML applications. Relevant AI/ML efforts include supporting hurricane predictions, the assimilation of ocean color observations for bio-physical feedback and marine biological modeling, and water surface conditions (e.g., floods, oil, ice). Improved coordination is needed to leverage the AI/ML that currently is funded in NOAA, thereby reducing isolated efforts, as well as focus on providing infrastructure and access to the raw datasets that can be transformed into AI/ML-friendly data for particular user and application needs. NMFS notes its critical need for long, consistent datasets due to the low-frequency variability evident in marine ecosystems and fisheries. NMFS agrees that

AI/ML techniques are promising and are being applied for habitat characterization, fisheries assessments, and environmental modeling.

Pursuant to Section 5 of Executive Order 13960, "*Promoting the Use of Trustworthy Artificial Intelligence in the Government*", NOAA identified over 260 current and planned AI/ML efforts, spanning Readiness Levels and spanning NOAA.

Examples of what NOAA has done:
NOAA has begun to broadly use AI/ML for Earth-system applications, spanning from the retrieval of geophysical parameters to identifying and exploiting Earth-system predictors.

- OAR's Geophysical Fluid Dynamics Laboratory (GFDL) currently engages AI for machine learning and atmospheric model parameterization development, including:
    - Information from GIS on the heterogeneity of land vegetation and land cover for use in global models;
    - Post-processing of model predictions of hurricane simulations to obtain finer regional details;
    - Usage of ML to represent marine ecosystem population dynamics;
    - Supervised ML for diagnosing subsurface ocean circulation regimes from high-resolution models, as precursors for prediction of ocean state;
    - In partnership with Schmidt Foundation and Princeton University, development of ML algorithms for physical oceanography; and
    - In partnership with Allen Institute for Artificial Intelligence (AI2), machine-learned parameterization of moist processes simulated in a Global Storm Resolving Model for applications in climate model predictions (e.g., regional precipitation).
- The NWS began using AI/ML techniques in 1995, when it used a neural network (NN) algorithm to enhance satellite retrievals. Currently, NWS is pursuing the application of AI/ML techniques in the following areas:
    - Radiosonde processing
    - Satellite Data Thinning
    - Physics emulation
    - Improved Background
    - Background Error Covariances
    - Accelerated Transport of atmospheric constituents
    - Atmospheric Chemistry Emulator
    - Physics Suite Emulation
    - Radiation Parameterizations
    - Great Lakes Wave Emulation
    - Rip Currents
    - Air Quality Bias Correction
    - Sub-Seasonal/ Seasonal forecast products
- NESDIS has been utilizing AI/ML in many capacities. Two recent efforts of note are:
    - NOAA is exploring digital twin technologies to enable NOAA to enhance its ability to process, monitor, quality-control, consolidate, fuse, and assimilate environment observations and streamline the satellite data ground processing and dissemination to users and applications. NOAA's recent Broad Agency Announcement: "Digital Twin for Earth Observations Using Artificial Intelligence" was posted in May 2022.
    - The NOAA Center for AI (NCAI) is working with the Earth Science Information Partners (ESIP) Data Readiness cluster to develop an AI-ready data standard for open environmental datasets. A preliminary checklist has been released as

"Checklist to Examine AI-readiness for Open Environmental Datasets" (doi.org/10.6084/m9.figshare.19983722.v1).
- NMFS currently is applying AI/ML to acoustic event classification.

Examples of what NOAA intends to do:

- NESDIS intends to pursue AI/ML for:
  - Data fusion for assessing environment and storm structure using multi-platform data;
  - Event detection, such as fires, volcanic eruptions, and hazardous low clouds affecting safe and efficient transportation;
  - Enhanced retrievals of precipitation, harmful algal blooms; and,
  - Data assembly, notably for uncrewed systems, and AI/ML training data sets, e.g. FathomNet.
- OAR envisions using AI/ML for:
  - Exploring a future hybrid modeling system that includes dynamics and AI/ML statistics working side by side;
  - Quantifying the relationship between fire radiative power and atmospheric variables;
  - Establishing a physics-guided approach to model parameterization;
  - Improving soil moisture estimates for modeling; and
  - Developing high-resolution large-ensemble probabilistic forecasts of precipitation.
- NWS numerical environmental prediction applications of AI/ML include planning for a wide variety of projects, including:
  - Neural network (NN) emulation of GFS physics, in particular for tangent-linear/adjoint use in data assimilation systems (4DVar Hybrids), forecast sensitivity, and observation impact;
  - Satellite thinning, data selection and quality control for the global data assimilation system;
  - Improved bias correction; and
  - Downscaling of S2S outlooks for hydrologic applications.
- NMFS aims to use AI/ML to:
  - Understand marine heatwave impacts on species,
  - Project the daily habitat of highly mobile species,
  - Autonomously tracking lower trophic levels for improved ecosystem monitoring and assessment,
  - Automated fish and invertebrate detection in Habcam images, and
  - Automated post-processing of multibeam bathymetry data.
- NOS plans to exploit AI/ML for:
  - Detecting rip currents with coastal imagery,
  - Quality-control water-level observations,
  - Coastal change analysis, and
  - Automated post-disaster vessel and debris mapping from remotely sensed imagery.
- The NOAA Center for Artificial Intelligence (NCAI) will continue collaborating, through the Earth Science Information Partners (ESIP) cluster, to mature the AI-ready data standard to support diverse open environmental data user needs.

Advanced Remote Sensing Technology
Recommendation 21:
Accelerate acquisition and assimilation of commercial sources of data and delivery systems along with development of Earth Science Decadal recommended observing systems.

NOAA Response

NOAA agrees.

NESDIS currently has a commercial weather program that successfully acquires commercial GPS radio-occultation (RO) data, with up to 6000 soundings per day. The program can procure other commercial weather data when they become available and meet performance requirements. NWS recommends that the private sector share in supporting user readiness for the private sector observing systems being developed.

Additional investment is needed in "continuous optimization" to extract maximal information from the observations now received and will receive in the future. Operational data assimilation is not a "last mile" problem, but rather an endeavor that requires continuous optimization. Additional efforts on cost/benefit/risk analysis of government programs versus commercial data buys are also needed.

What NOAA has done:

- The NESDIS Office of Satellite and Product Operations (OSPO) currently ingests commercial RO data in the NCCF and provides RO data to NCEP for assimilation. NESDIS has issued Broad Area Announcements to explore developing new technologies. NESDIS OSPO is working to acquire more data sets for hazard mitigation.
- NWS operational forecast systems assimilate commercial radio occultation data, data from commercial aircraft, and ground-based precipitable water from Global Navigation Satellite Systems (GNSS).

What NOAA intends to do:

- With the advanced GEO instrumentation and significantly improved navigation and registration, NOAA and NASA are working closely to further develop a stereo capability (GEO-GEO; GEO-LEO) to offer a direct method of cloud height and wind-vector assignment that relies only on the geometric parallax observed from two different vantage points. NESDIS also will explore the technological development of hyperspectral microwave soundings and 3D winds.
- NWS plans to continue upgrading its observation processing to accommodate new observing systems, including those from commercial vendors, e.g., smallsat microwave observations and saildrones.
- NESDIS will facilitate and support Line Office needs for imagery and products for coastal ocean observations derived from high-resolution non-NOAA satellite missions, including Sentinel 2, Landsat and from commercial satellite missions, including synthetic aperture radar missions, "cube sats", "planet", and others.

Recommendation 22:
Benchmark performance quality, productivity, and cost using proven methodologies to quantify improvements to close gaps, identify root causes for deficiencies, and inform actionable improvement opportunities.

NOAA Response

NOAA agrees.

Metrics of what NOAA deems as successful should be stated. One aspect in this regard is peer-reviewed publication, important assessments attesting to the quality of the findings, recognizing its deficiencies and limitations, such that the information can be considered 'actionable' in Earth System predictions and projections.

What NOAA has done:

- NESDIS monitors and validates the quality and performance of remote sensing data including commercial data.
- NOAA engages the operational forecast community to establish forecast goals, developing metrics to evaluate modeling system performance through UFS-based workshops. These goals are used in strategic planning (e.g., the UFS Strategic Plan) to focus R&D on modeling system improvements to reach those goals. Metrics to evaluate coupled systems are being discussed through UFS-based workshops. It is anticipated that these discussions will continue.

What NOAA intends to do:

- Nothing specific to note.

ACRONYMS

2D	Two dimensional
3D	Three dimensional
ADCIRC	Advanced Circulation Model
AEROMMA	Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas
AI	Artificial Intelligence
ARL	Air Resources Laboratory
ATom	NASA's Atmospheric Tomography Mission
B2B	Bedrock-to-Boundary Layer
BGC	Biogeochemical
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CCTV	Closed-Circuit Television
CEFI	Climate, Ecosystems, and Fisheries Initiative
CEOS-COAST	Committee on Earth Observation Satellites - Coastal Observations, Applications, Services, and Tools
CFS	Climate Forecast System
CICE6	Community Ice CodE, Version 6
CM4	NOAA/OAR Climate Model, Version 4
CMAQ	Community Multiscale Air Quality Modeling System
COBALT	Carbon Ocean And Lower Trophics
COMT	Coastal and Ocean Modeling Testbed
COVID-19	Coronavirus Disease 2019
CPC	NOAA/NWS/National Centers for Environmental Prediction/Climate Prediction Center
CPO	NOAA/OAR/Climate Program Office
ECMWF	European Centre for Medium-Range Weather Forecasting
EcoFOCI	Ecosystems and Fisheries - Oceanography Coordinated Investigations
EcoMon	Ecosystem Monitoring

EEZ	Exclusive Economic Zone
EMC	NOAA/NWS/National Centers for Environmental Prediction/Environmental Modeling Center
EPIC	Earth Prediction Innovation Center
ESIP	Earth Science Information Partners
ESP-FTAC	Fast Track Action Committee on Earth System Predictability Research and Development of the National Science and Technology Council
FENGSHA	Dust emission model scheme - an English analog of the Mandarin term for wind-blown dust
FLOR	Forecast-oriented Low Ocean Resolution
FMS	Flexible Modeling System
FV3	Finite-Volume Cubed-Sphere Dynamical Core
FV3-GFS	FV3-based Global Forecast System
FVCOM	Finite Volume Community Ocean Mode
FY	Fiscal Year
GEO	Geostationary Earth Orbit
GeoXO	NOAA's Geostationary Extended Observations (GeoXO) satellite system
GFDL	NOAA/OAR Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast System
GHG	Greenhouse Gas
GLIMR	Geostationary Littoral Imaging and Monitoring Radiometer
GNSS	Global Navigation Satellite Systems
GOOS	Global Ocean Observing System
GO-SHIP	Global Ocean Ship-based Hydrographic Investigations Program
GPS	Global Positioning System
GTS	Global Telecommunications System
HAFS	Hurricane Analysis and Forecast System
HYCOM	Hybrid Coordinate Ocean Model
ICAMS	Interagency Council for Advancing Meteorological Services

IIJA	Infrastructure Investment and Jobs Act
IPCC	Intergovernmental Panel on Climate Change
JCSDA	Joint Center for Satellite Data Assimilation
JEDI	Joint Effort for Data assimilation Integration
LAI	Leaf Area Index
LEO	Low Earth Orbit
LST	Land Surface Temperature
ML	Machine Learning
MOM6	Modular Ocean Model, Version 6
NASA	National Aeronautics and Space Administration
NCCF	NESDIS Common Cloud Framework
NCEI	NOAA/NESDIS/National Centers for Environmental Information
NDBC	NOAA/NWS/National Data Buoy Center
NESDIS	NOAA National Environmental Satellite, Data, and Information Service
NMFS	NOAA National Marine Fisheries Service
NN	Neural Network
NOAA	National Oceanic and Atmospheric Administration
NOFO	Notice Of Funding Opportunity
NOPP	National Oceanographic Partnership Program
NOS	NOAA National Ocean Service
NOSC	NOAA Observing System Council
NWS	NOAA National Weather Service
OAR	NOAA Office of Oceanic and Atmospheric Research (“NOAA Research”)
OCIO	NOAA Office of the Chief Information Officer
OCX	GeoXO Ocean Color Observations (OCX) instrument
OFCM	Office of the Federal Coordinator for Meteorology
OFS	Operational Forecast System
OM4	NOAA/OAR Ocean Model, Version 4

ONR	Office of Naval Research
OPC	NOAA/NWS/National Centers for Environmental Prediction/Ocean Prediction Center
OSPO	NOAA/NESDIS/Office of Satellite and Product Operations
OSSE	Observing System Simulation Experiments
PACE	NASA's Plankton, Aerosol, Cloud, ocean Ecosystem mission
QOSAP	NOAA's Quantitative Observing System Assessment Program
R&D	Research and Development
RO	Radio-Occultation
ROMS	Regional Ocean Modeling System
RRFS	Rapid Refresh Forecast System
RTOFS	NOAA's Real-Time Ocean Forecast System (v2 - Version 2)
S2S	Subseasonal-to-seasonal
SAB	Science Advisory Board
SABRE	Stratospheric Aerosol processes, Budget and Radiative Effects
SFS	Seasonal Forecast System
SHiELD	System for High-Resolution Prediction on Earth-to-Local Domains
SPEAR	Seamless System for Prediction and Earth System Research
STAR	NOAA/NESDIS/Center for Satellite Applications and Research
TEMPO	NASA's Tropospheric Emissions: Monitoring of Pollution Mission
TPOS 2020	Tropical Pacific Observing System 2020
UAS	Uncrewed Aircraft Systems
UFS	Unified Forecast System
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGCRP	United States Global Change Research Program
U.S. IOOS	United States Integrated Ocean Observing System
USNIC	United States National Ice Center
UxS	Uncrewed System(s)
VI	Vegetation Index

WCOFS	West Coast Operational Forecast System
WPO	NOAA/OAR Weather Program Office
WUI	Wildland-Urban Interface