NMME: Meeting Future Needs Workshop Report

June 21-22, 2023

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Table of Contents

Executive Summary

The North American Multi-Model Ensemble (NMME) emerged in 2011 as a collaborative initiative among prominent North American climate modeling centers, including institutions like the National Center for Atmospheric Research (NCAR), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), Environment and Climate Change Canada (ECCC). Recognizing the limitations of individual climate models, the NMME initiative aimed to enhance seasonal and climate prediction accuracy by leveraging the strengths of ensemble forecasting. By combining outputs from diverse models, the ensemble approach aimed to reduce individual model system biases and increase prediction reliability. Through subsequent updates, the NMME has incorporated more models and refined its methodologies, resulting in improved seasonal predictions of temperature and precipitation for North America. Beyond prediction enhancement, the NMME has facilitated research into the sources of climate predictability and has informed advancements in individual model development. The ensemble's outputs are now widely utilized across sectors such as agriculture, water management, and energy for informed decision-making.

The NMME: Meeting Future Needs Workshop took place over two days, from June 21-22, 2023. Organized into a series of structured sessions, the workshop welcomed participants from academic institutions, governmental agencies, and various stakeholders from the sectors affected by climate predictions. The primary objectives were twofold: firstly, to review and evaluate the current capabilities and advancements of the NMME in addressing the challenges of seasonal climate predictability; and secondly, to identify actionable recommendations for the future direction and enhancement of the NMME project. The structure allowed for presentations, discussing the latest research and findings, and breakout sessions, facilitating in-depth discussions and collaborative brainstorming among attendees.

Workshop discussions and outcomes predominantly revolved around two main themes: 1) enhancing NMME's forecasting accuracy on the subseasonal to seasonal (S2S) timescale to address user-specific requirements and 2) facilitating a seamless connection between NMME outputs and end-user stakeholders. Forecasting accuracy and reliability increases are emergent from the structure of the NMME, with the NMME system’s architecture and data assimilation techniques uniquely suited for evaluating and implementing model enhancements, serving as an ideal platform for refining S2S forecasting algorithms. NMME’s calibration processes have been adeptly configured to handle complex S2S dynamics, though there was a mention of synchronicity challenges that could influence prediction precision. Additionally, the importance of refining the initial state assessments of various climate influencers, like oceanic conditions, terrestrial surfaces, and polar ice configurations, was underscored, highlighting a key potential venue for further improvements.

A significant portion of the discourse was focused on determining the future trajectory of NMME enhancements in two major areas: 1) broadening and supporting the expansive array of research needs in order to reach top-tier operational accuracy on the S2S timescale and 2) meeting the wide range of user-specific needs. It was emphasized that analyzing website interaction metrics could provide valuable insights into NMME’s most impactful areas on this

timescale, but currently, there's a resource gap in gathering this vital data. A consensus emerged suggesting that for optimizing NMME's utility on the S2S timescale, there's a need to reconfigure the collaborative dynamics between operational, research, and private entities.

The workshop brought to light a broader spectrum of sectors that are leveraging NMME outputs on the S2S timescale than was perceived. Stakeholders from domains such as agriculture, hydrology, energy, environmental conservation, and research/model validation are utilizing the NMME forecasts for informed situational assessments, strategic planning, and in certain scenarios, critical decision-making processes. A notable point was the absence of user interaction data on the NMME platform, potentially leading to missed opportunities for understanding specific model utilities or identifying emerging user demographics. A resonating sentiment among attendees was the imperative to translate intricate S2S forecasting data into comprehensible information for partners and stakeholders who may not possess a background in the specifics of the S2S domain.

Challenges and Recommendations

The NMME workshop provided a platform for experts to discuss the present capabilities and potential limitations inherent to the system, specifically targeting subseasonal to seasonal (S2S) predictions. Deriving insights from extensive analytical sessions that reviewed NMME's core methodologies, performance metrics, and potential enhancement routes, a set of prioritized recommendations has emerged. These recommendations are oriented towards improving NMME by bolstering NMME's scientific rigor and expanding its relevance to a diverse array of stakeholders.

1. **Strengthen Cross-Sector Collaboration:** NMME's evolutionary trajectory in the S2S domain would gain momentum through an integrative strategy that fosters collaboration across operational, research, and private sectors. Pooling insights and resources from these diverse echelons, NMME can embark on pioneering initiatives and diversify its service portfolio.
2. **Revisit Initialization Frequency**: The cadence of model initialization is instrumental in shaping S2S forecast outcomes. There's a compelling case for revisiting the prevailing initialization frequency of NMME models. By optimizing this frequency and championing a unified initialization protocol across all member models, NMME can further refine its predictive granularity and timeliness.
3. **Refine Initial State Assessments:** A salient component of S2S predictions pertains to the meticulous representation of initial state conditions—oceans, land surfaces, and polar ice regions. It is paramount to fortify research and techniques that can enrich and fine-tune these initial conditions, which would directly influence the prognostic efficacy of the NMME system.
4. **Extend Hindcasts to 1982**: A recommendation with pronounced implications for retrospective analysis, extending NMME hindcasts back to 1982 would significantly augment the model's utility. This temporal expansion not only provides a more extensive dataset for researchers but also paves the way for more rigorous validation and calibration exercises, thereby strengthening the model's predictive competence.

5. **Develop a Comprehensive User Guide:** To bridge the potential comprehension gap among diverse NMME users, a rigorous user guide is advocated. This guide would clarify NMME's core modeling attributes, its intrinsic forecasting tenets, and offer a structured approach to data interpretation. A guide of this caliber would empower users, ensuring they harness the full potential of forecast outputs.

Conclusively, the NMME framework demonstrates significant operational capability, forming the definitive blend of models in the subseasonal to seasonal space, in its current configuration. By integrating the proposed recommendations, there is potential to enhance the robustness and utility of NMME in the domain of S2S forecasting. Adopting these strategies is paramount to ensuring the system meets the evolving needs of the scientific community and broader stakeholder groups.

Welcome and Opening Remarks

Goals and expected outcomes | Dr. Jessie Carman

Dr. Jessie Carman (NOAA WPO) welcomed all the attendees and opened the workshop with an overview of the workshop's goals and agenda for the next two days. Dr. Carman emphasized that the primary goals of this workshop were to 1) establish current uses of North American Multi-Model Ensemble (NMME) across forecast data users and 2) explore some of the potential data needs, what decisions that data might inform, and the required infrastructure and cost to support those data needs.

Dr. Carman also provided a brief overview of the NMME, noting its decade-long history that originated from the 2010 National Research Council (NRC) recommendations for forecast strategies. The NMME forms an important international and interagency partnership (Table 1) to mutually address similar needs by leveraging existing model development infrastructure, providing continuity, improving model accuracy and quality, and potentially identifying and diagnosing model errors. Dr. Carman noted that both research and operational models are members of NMME and include NCEP CFSv2, GFDL SPEAR, ECCC CanCM4, NASA GEOS5, and NCAR CESM. Nonetheless, the protocol outlined in the 2021 agreement was developed under a different model, hardware, and communication constraints. Consequently, this workshop was organized to bring the NMME community together to discuss how decision needs and research goals could be better met in subsequent agreements.

Dr. Carman concluded by asking that over the course of the workshop participants consider what output variables and at which frequency would be useful for stakeholders, how new technological developments could support enhanced NMME activities, and the technical challenges faced in the current NMME.

Table 1. Participants in the 2021 NMME Cooperation Arrangement

Federal Partners
• NASA Earth Science Division (ESD) • NOAA Geophysical Fluid Dynamics Laboratory (GFDL) • NOAA National Center for Environmental Information (NCEI) • NOAA National Center for Environmental Prediction (NCEP) • NOAA Weather Program Office (WPO)
Academic Partners
• Columbia University International Research Institute for Climate and Society (IRI) • University of Miami
International Partners
• Environment and Climate Change Canada (ECCC)

Workshop structure and logistics | Dr. Mark Olsen

Dr. Mark Olsen introduced the workshop agenda, providing an overview of planned workshop activities including keynote presentations from NOAA and interagency perspectives, the history and current state of the NMME, improvements in constituent models, research and operational end user activities, and observed gaps in the current framework. Dr. Olsen also introduced the logistics and topics for the following breakout sessions: 1) Data Needs and Access, 2) Model Improvements, 3) Prediction/Predictability Testbed, 4) Operational Gaps, 5) Modeling Center Challenges, and 6) Initialization Frequency: Requirements and Limitations.

Keynote Speakers

Building seasonal predictions for purpose: How the NMME supports early warnings, climate adaptation, and commerce | Dr. Sarah Kapnick

Dr. Sarah Kapnick presented the first keynote presentation, which primarily focused on how the NMME could support early warnings, climate adaptation, and commerce. Dr. Kapnick emphasized that the demand for seasonal outlooks predates the NMME, drawing on the development of the 2000 NOAA Atlantic Hurricane Outlook as an early example of a seasonal product. Since then, the NMME has become critical infrastructure for seasonal outlooks, providing monthly variables such as 200 hPa geopotential height, total precipitation, sea surface temperature, maximum and minimum temperatures, and reference temperatures. She also highlighted subsequent seasonal products for El Niño Southern Oscillation (ENSO), winter outlooks for December through February, and improved hurricane outlooks. However, Dr. Kapnick noted that as our climate continues to change, dynamical models are increasingly important for ocean temperatures and ENSO products.

Dr. Kapnick argued that climate change increases the need for NMME in an emerging climate economy, defined as the mitigation and adaptation activities that are shifting current and driving new financial flows. She noted that NMME serves as an invaluable function for both of these activities by providing forecasts for numerous sectors from energy to agriculture. NMME data and products can inform and support risk management by providing seasonal predictions based on observations and modeling, pre-disaster support through early warning systems, disaster and post-disaster support through rapid response and planning for restoration activities, and long-term advanced operations and investment planning when an event unfolds.

Dr. Kapnick emphasized that expectations of increased climate change impacts indicate that the need for these warnings and systems will only continue to expand as we begin to feel and will be accelerated by traditional investment drivers like regulation, technological innovation, and demographics. She outlined three important aspects of information in the climate economy: acquisition, access, and application (Table 2) and provided two examples of these concepts in practice: 1) U.S. Agency for International Development (USAID) investing in early warning systems for climate-related disasters to save lives and 2) NOAA's Climate Prediction Center's (CPC) International Desk efforts to build capacity and products since 1995.

Dr. Kapnick concluded with how our use of NMME might change in the future. She hypothesized that we will see improved data assimilation and models to improve forecast skill with critical investments from the Inflation Reduction Act (IRA). She noted that some upgrades have likely already happened (i.e., new models and more variables). She also suggested that future products and derivatives will likely be a combination of multiple types of climate data and conditions, as well as combinations with other models to produce macroeconomic data to forecast potential damages using catastrophe models or empirical losses. She concluded with remarks on how the current El Niño will likely highlight the need for seasonal predictions of global surface temperatures and other climate variables.

Table 2. Aspects of Information in the Climate Economy
Acquisition
• Observations (*in situ* and satellite) • Models to monitor, forecast, predict, and project the Earth System • Sector-specific environmental intelligence
Access
• Integrating climate data from multiple sources or translating it into usable products (i.e., cloud computing, mapping and imaging, and artificial intelligence/machine learning)
Application
• Products that derive new information from climate data to develop new insights • Risk and asset management • Renewable energy development • Carbon markets and carbon dioxide removal

Progress in federal coordination to advance meteorological science and services | Dr. Scott Weaver

Dr. Scott Weaver introduced the Interagency Council for Advancing Meteorological Services (ICAMS) and its goal to lead the world in meteorological services via an earth system approach, providing societal benefits with information spanning scales from local weather to global climate. Dr. Weaver highlighted recent improvements in hurricane track forecasts and emphasized that while the NOAA National Hurricane Center (NHC) issues the forecast products, the entire meteorological community participated in improving our ability to generate these products.

Dr. Weaver noted that the increase in billion-dollar disasters (even after adjusting for inflation) will drive the need for continued interagency coordination to improve products and services. He highlighted recent policy achievements aimed at improving products and services such as the Weather Act (2017), the ICAMS charter, and the numerous federal agencies

participating under ICAMS. Dr. Weaver also broke down the four committees, which are as follows: 1) Observational Systems; 2) Cyber, Facilities, and Infrastructure; 3) Services; and 4) Research and Innovation. He emphasized that ICAMS is important because it represents the first major restructuring of the Federal meteorological enterprise to meet national needs since the 1960s and that it elevates meteorological coordination to the White House level, working with relevant National Science and Technology Council (NSTC) bodies. Finally, Dr. Weaver stated that ICAMS aims to fill gaps and streamline interagency coordination while also adopting a comprehensive Earth-system approach.

Dr. Weaver concluded with several examples of recent successful ICAMS efforts. Included in these efforts are:

- Hurricane hunters flying into coastal storms earlier than ever
- National winter seasons operations plans
- National hurricane operations plan
- Wildland fires

Dr. Weaver elaborated further on wildland fire efforts, highlighting both the recent Wildland Fire Workshop, where the ICAMS Observational Systems collaborated with U.S. Group on Earth Observations (USGEO) on interagency science recommendations to inform FY24 agency budget planning, as well as the Committee on Research and Innovation series of interagency wildland fire workshops. These efforts have culminated in the preparation of a BAMS paper that will be published and then a copy provided to the NSTC.

State of the North American Multi-Model Ensemble (NMME)

NMME applications research | Dr. Benjamin Kirtman

Dr. Benjamin Kirtman presented the crucial role of NMME in advancing predictability and prediction research. He championed NMME as indispensable infrastructure, emphasizing its significance in pioneering novel methods for evaluating forecast skill. From its first iteration, NMME has evolved by integrating various models such as NCEP-CFSv1, NCAR-RSMAS-CCSM3, IRI-ECHAM4f, to more recent inclusions like GFDL's SPEAR model. The ensemble consistently updates, motivated by the need for better models and greater predictability. Dr. Kirtman raised a pertinent question: What is the ideal number of models required to achieve optimal prediction skill?

Dr. Kirtman also emphasized that real-time forecasts play an instrumental role in molding research, highlighting unseen challenges that arise in genuine operational contexts. By shedding light on real-time requirements, NMME encourages researchers to tailor their approach to meet dynamic needs. Dr. Kirtman cited an interesting case study on the 2015/16 West Coast ENSO Teleconnection anomaly, sparking debates on the reasons behind the unexpected precipitation patterns. He noted that there were two camps of thinking to explain this outcome: 1) This is a basic predictability problem and we oversold the expected amount of precipitation and 2) It may be that some of the details in global surface temperatures are not well-represented in the models.

Highlighting the evolution of NMME models, Dr. Kirtman showed a graphical representation demonstrating the frequent updates and integrations to NMME compared to other ensemble models. He concluded that the crux of NMME's philosophy revolves around enhancing forecast reliability, and its flexible architecture facilitates seamless ensemble size expansion. Individual model refinements contribute to the overarching enhancement of NMME, underscoring its role as a formidable platform for assessing model improvements, missing processes, prediction science, and in refining forecasts.

NMME prediction research | Dr. Emily Becker

Dr. Emily Becker highlighted the pivotal contributions of the NMME in advancing hydrological and climate prediction research. One of its most notable achievements is the Goddard Hydrological Forecast, which is part of NASA's Hydrological Forecast and Analysis System (NHyFAS). Developed with NASA's Earth science capabilities, it offers seasonal drought forecasts that are vital for USAID and U.S. Army Corps of Engineers (USACE) operations in the Middle East and Africa. Furthermore, by integrating NMME forecasts with regional climatological data, a Region-Specific Seasonal Climate Forecast tool was devised. Dr. Becker shared that this tool has been instrumental for the U.S. Army Corps of Engineers in Detroit, particularly for operational water-level forecasting in the Great Lakes region.

Dr. Becker also highlighted work in the marine environment where NMME is a critical tool. In marine ecosystem research communities, NMME is used to inform forecasts on marine heatwaves. The NMME plays a crucial role in characterizing, understanding, and predicting these heatwaves. It offers a 70-member forecast ensemble, utilizing six global climate models, with lead times of up to a year, ensuring comprehensive and up-to-date information. Another example of areas where the use of NMME is critical to research and forecasting is in collaboration with agencies like NASA and USAID, where NMME underpins the SERVIR Global initiative, which enables developing countries to harness satellite data to address challenges in sectors like food security, water resources, and climate. The ensemble forecasts are rigorously bias-corrected, downscaled, and extended up to 6 months, ensuring their applicability and relevance across various domains.

Looking ahead, Dr. Becker outlined numerous applications where the NMME is poised to expand into new applications, emphasizing data-driven solutions for contemporary climatic and hydrological challenges, setting a roadmap for future advancements in the field. She highlighted several potential applications spanning numerous areas. For instance, in the Colorado River Basin, it is used to enhance the accuracy of streamflow predictions, aiding stakeholders in decision-making processes. She also noted that a hybrid dynamical approach, emphasizing atmospheric forcings, has been employed for seasonal sea-level prediction, presenting significant advancements over existing models. This holds great promise for coastal flood risk predictions, as does the NMME's role in analyzing winter temperature fluctuations. Overall, Dr. Becker concluded that the NMME's advancements offer multifaceted solutions for many of today's pressing climatic and hydrological challenges.

NMME operations | Mr. Matthew Rosencrans

Mr. Matthew Rosencrans provided a snapshot of NMME in NOAA's CPC operations. He stated that at CPC, there is a monthly routine of data collection and processing of CPC website traffic. The CPC's metrics showed a record of 3,900 uses in one month and a cumulative total of around 135,000 downloads. Of these, metrics indicate that NMME is the most visited landing page, followed by CPC's international desk NMME page. The most accessed product pages include the NMME ENSO Plumes, the seasonal and monthly product landing pages.

However, Mr. Rosencrans mentioned that the center has faced recent challenges like fixing numerous broken verification links, repairing a lot of the hindcast data, and initiating a transition to the new National Center for Environmental Prediction (NCEP) infrastructure. When discussing 2022-2023 updates, it was highlighted that while no new models were introduced during this period, there are ongoing efforts to address hindcast inconsistencies and discrepancies between CPC and IRI data files. They're also in the process of establishing a quality control routine and devising new figures or outputs for improved customer-facing products. Importantly, the NMME has been recognized as a pivotal input for the seasonal forecast process at CPC, but there's acknowledgment of the need for enhancements. The talk emphasized the importance of discussions and collaborations for the upcoming NMME cooperative agreement renewal.

At the presentation conclusion, a question was posed by Dr. Andy Robertson regarding NMME data's presence at IRI since its inception and the serving of Subseasonal Experiment (SubX) data, highlighting the considerable and growing demand for subseasonal forecasts. For context, for the year 2022, the IRI Data Library recorded 2.6 million hits for NMME data, with 13,000 unique visitors downloading 12TB of data. In comparison, SubX data registered 2.5 million hits, attracting 3,500 unique visitors who downloaded a total of 18TB of data. Mr. Rosencrans concluded that these data emphasize not only the growing importance and reliance on NMME datasets but also highlight the increasing engagement of the community and stakeholders in making informed decisions for the future.

Model Improvements

Future evolution of the NCEP operational prediction systems | Dr. Vijay Tallapragada

Dr. Vijay Tallapragada opened his presentation with an update on the current status of the state of the NOAA NCEP Production Suite. In order to meet stakeholder requirements, NCEP operates more than 38 distinct modeling systems. He noted that this assemblage of models was developed to meet the service needs over a long period of time and that the simplification of the NCEP Production Suite is critical to reducing redundancy and improving efficiency. Nonetheless, Dr. Tallapragada suggested that we are currently moving into a new era of the Unified Forecast System (UFS) and its application in the context of Medium-Range Weather (MRW) and Subseasonal-to-Seasonal (S2S) forecasting. The plan to make this transition spans five years and involves transitioning to UFS applications within an S2S framework.

Dr. Tallapragada emphasized that the UFS Community plays a pivotal role and is supported by various NOAA Programs such as the National Weather Service (NWS) Office of Science and Technology Integration (OSTI), the Weather Program Office (WPO) Earth Prediction Innovation Center, and Disaster Supplementals passed through Congress. Moreover, the UFS initiative also includes a three-year project (FY20-23) within the broader five-year vision aimed at developing advanced global and regional forecast systems, targeting a transition to NOAA operations by FY23. Key components of this development will involve coupled model components like WW3 (FV3GFS), CHEM (FV3GFS), HYCOM (FV3GFS), MOM6/CICE, and SFSv1, focusing on enhancing initializations, reducing drift, and improving forecast uncertainties. The UFS community will also prioritize physics/dynamics improvements, reduced biases, enhanced forecast skills, and seamless incorporation of SFS developments into UFS repositories.

Finally, Dr. Tallapragada summarized that the future evolution of NCEP Production Suite is expected to be simplified using UFS Coupled Applications, with GEFSv13 and SFSv1 becoming the flagship NCEP Operational Application for ensemble-based S2S predictions. Dr. Tallapragada concluded, however, that in terms of operational seasonal forecasting, the NMME remains a valuable tool and UFS is expected to foster greater collaboration within the broader community.

Recent advancements on the community Unified Forecast System | Dr. Neil Jacobs

Dr. Neil Jacobs' presentation highlighted key insights and strategies for addressing future needs within the NMME. He emphasized the key difference between Earth Prediction Innovation Center (EPIC) and UFS, where EPIC is a program that supports the export of code exchange and UFS operates as an open-source software with multiple applications that use a common code base. The focus of Dr. Jacob’s discussion centered on the UFS Matrix, Roles, and Touchpoints, aiming to enable community innovation through platforms like Github releases. He also emphasized the need for community involvement from academia, industry, individuals, and government labs.

Dr. Jacobs underlined the importance of community input and governance. He proposed the establishment of a Community Modeling Board (CMB) composed of 15 members with representation from participating stakeholders that would enhance communication, collaboration, and coordination of resources to the UFS from public, private, and academic sectors. The CMB also would serve as a conduit for communication between NOAA's Modeling Team, the EPIC Program Team, and various stakeholders. The CMB could also provide strategic advice to the UFS Steering Committee (UFS-SC) on the UFS and help prioritize its advancement by defining goals and objectives, and identifying barriers. Finally, a CMB would provide a means to continuously exchange feedback about research modeling innovations through various channels such as Environmental Information Services Working Group (EISWG), ICAMS, American Meteorological Society (AMS), and American Geophysical Union (AGU).

Looking ahead, Dr. Jacobs concluded by summarizing the next steps for UFS, including process mapping, designing community governance, and enhancing outreach efforts through

platforms like AGU and AMS. He also mentioned plans for revising charters and developing teaching materials. In conclusion, Dr. Jacobs highlighted longer-term goals for the UFS that included soliciting community input to help solve key challenges, developing a more coordinated approach for releases, developing additional toy models and idealized cases, and expanding UFS coupling and applications.

Morning Q&A Summary

During the workshop Q&A session, the suitability of daily outputs from NMME for hydrologic seasonal forecasting systems was discussed. Dr. Becker suggested they are ideal, while Dr. Kirtman offered that it depends on the means of resolving seasonal predictability. When seeking an analogy between NMME and UFS, Matt described NMME as a research tool and UFS as its dynamical core, with UFS being a more simplified version of the research operational tool. The session also highlighted the importance of allocating resources for code implementation and management for advancing UFS/SFS. The EPIC CMB could play a pivotal role in determining the extent and aspects of code availability.

Further, a reminder was provided about the development of SFS v1, highlighting collaboration across NOAA's Oceanic and Atmospheric Research (OAR), Environmental Modeling Center (EMC), and Development Testbed Center (DTC), and seeking contributions from the academic and private sectors. The code management for this project will be cloud-based, with more chances for community involvement. Finally, Jerry Cotter inquired about the integration of research into operations across the weather community. Dorothy Koch mentioned that EPIC encourages community participation and mentioned the Testbed framework between WPO and NWS that welcomes community input. Hendrick added that there are differences in dycore and physics between research and operational models.

End User Activities

Climate information: user needs and user uses (Keynote) | Dr. Walter Baethgen

Dr. Walter Baethgen provided the opening keynote presentation for the afternoon session and focused his talk on user needs and uses. Dr. Baethgen primarily focused his discussion on five lessons learned at the Columbia University's IRI: 1) Understanding the system and challenges, 2) Identifying the role of climate information, 3) Exploring tools and products to inform solutions, 4) Translating climate data into agronomic data, and 5) Identifying intermediaries and next users, as opposed to simply "end users".

Dr. Baethgen noted that one of the major challenges of using forecasts is the reliability of seasonal forecasts and cited a scale used to describe their utility: perfect, still useful, marginally useful, not useful, or dangerous. He observed that regions with no ENSO signal tend to find seasonal forecasts ranging from marginally useful to dangerous. Furthermore, Dr. Baethgen highlighted that, at times, just monitoring climate variables (e.g., soil water content) could provide enough information, citing the Uruguay drought in 2015 as one successful example of monitoring efforts. Grasping the role of and delivering pertinent climate information substantially bolstered Uruguay's ability to respond to the drought. Dr. Baethgen also emphasized that the

pinnacle of success in this case was having a well-organized decision system in place with a person or agency designated as the primary decision maker. Dr. Baethgen also delineated the evolution of IRI's crop simulation tool from "dangerous" and not user friendly to a new online tool called SIMAGRI with a much easier to use interface.

In his concluding remarks, Dr. Baethgen posited that subseasonal forecasting could act in tandem with seasonal forecasts. In this structure, product users might utilize seasonal forecasts for preliminary planning and make requisite adjustments based on subseasonal forecasts. Such subseasonal forecasts could offer pertinent insights about pivotal climate markers, such as the onset of the rainy season and the probability of extreme weather phenomena, be it torrential rainfall or intense heat waves. He wrapped up by stating that access to this type of data can empower decision-makers to establish preemptive warning systems, thereby bolstering forecast-based operations.

CPC use of NMME and Sub-Seasonal to Seasonal (S2S) Prediction Challenges | Dr. David DeWitt

Dr. David DeWitt offered a summary of how NOAA's CPC is currently using the NMME in operations, noting that it is a critical component of CPC research and operations, both for domestic and international applications. However, he suggested that CPC would greatly benefit from having reforecasts for all NMME models dating back to 1982. Dr. DeWitt provided notable examples of CPC utilization of NMME for domestic monthly and seasonal ENSO predictions. CPC also provides access to real-time global and regionalized weather and climate forecasts, facilitating forecast-based decision-making in agriculture and water management worldwide. Dr. DeWitt also cautioned, however, that all models failed to predict drought amelioration in the western United States when the region received especially heavy precipitation resulting from a large number of atmospheric river events.

Dr. DeWitt also summarized some of the most pressing scientific challenges for S2S forecasting. He proposed that it might be the case that models are not accurately capturing regime transitions. He also pointed out that NMME models struggle to predict monthly precipitation variability beyond the canonical ENSO response. He used December 2016 as an example, where the southwest United States was in the fifth year of a drought when it received above-normal precipitation from a substantial number of atmospheric rivers by the end of January 2017. He also indicated that other scientific limitations of S2S forecasts include the inability to predict below-normal temperatures, S2S variability beyond ENSO responses, and predicting the spatial distribution of tropical convection variability and sea surface temperature anomalies outside of the central and eastern Equatorial Pacific.

Dr. DeWitt stressed the indispensable role the NMME plays within the operational framework of CPC, emphasizing that it is a foundation upon which much of CPC's domestic and international research and forecasting activities are built. The NMME's vast contributions to the field underscore its importance, and the countless benefits it provides to diverse sectors around the world make it an invaluable asset. Therefore, as Dr. DeWitt articulated, it is imperative for the community to support the continuation and expansion of the NMME, ensuring its potential is fully harnessed for the betterment of global forecasting capabilities in the coming years.

Leveraging the NMME for marine ecosystem prediction | Dr. Mike Jacox

Dr. Mike Jacox from NOAA's Southwest Fisheries Science Center (SWFSC) provided insights into the growing interest within fisheries science towards using forecasts for fisheries management. These forecasts aid in crucial decisions related to monitoring marine habitats, implementing fishing closures, and setting annual catch limits. The tools and methods for these forecasts span from global to regional and even ecosystem-specific models, each playing a unique role. A key tool in this process is the NMME, which is invaluable for predicting phenomena like marine heatwaves (MHWs), which can drastically affect marine life, from altering water quality to shifting ecosystem dynamics.

Dr. Jacox emphasized that the NMME, with its advanced capabilities, allows for the generation of global maps predicting MHW probabilities for up to a year. These forecasts, updated monthly, provide projections with lead times of up to a year. An interesting practical application of these forecasts is the Temperature Observations to Avoid Loggerheads (TOTAL) tool, which uses temperature readings to preemptively detect the migration patterns of loggerhead turtles. When unusual warmth is detected in areas like the California bight, it signals the potential arrival of loggerhead turtles. As a response, fishing closures can be implemented to prevent inadvertent captures of these turtles. Such anticipatory measures, had they been in place during warm periods like those in 2015 and 2016, could have offered the fishing industry a beneficial six-month warning.

Dr. Jacox also touched upon the ongoing comparison between the utility of downscaling versus global models. While both methodologies have their advantages, the takeaway is that both are essential tools in the arsenal of marine forecasting. Dr. Jacox concluded that as the field evolves, there's a clear emphasis on refining these tools, integrating new datasets, and expanding the forecasting range to consider variables like ocean biogeochemistry, ensuring informed decisions for sustainable fisheries and marine conservation.

Chesapeake Bay Vibrio seasonal prediction | Mr. Bob Daniels

On behalf of Dr. John Jacobs, Mr. Bob Daniels presented a perspective on ecological forecasting from NOAA’s National Center for Coastal and Ocean Sciences (NCCOS), with a particular focus on priority areas and geographies of interest. Mr. Daniels highlighted several ecological challenges, including Harmful Algal Blooms (HABS), hypoxia, pathogens, habitat degradation, and notably *Vibrio vulnificus* and *Vibrio parahaemolyticus*. *Vibrio*, a naturally occurring bacteria in coastal waters, is of significant concern. An estimated 80,000 cases occur annually, with *V. vulnificus* accounting for 95% of seafood-related mortality. These infections lead to health care costs exceeding $300 million each year. Moreover, the economic implications stretch beyond healthcare due to consequences like shellfish bed closures, product recalls, and avoidance of recreational activities.

Mr. Daniels provided an in-depth overview of current *Vibrio* forecasting tools, which depict the concentration of the bacteria in water and rely substantially on NMME for their accuracy. The ten-year illness data compilation became the foundation for assessing the 2016 anomaly. Notably, precipitation during the months of May, June, and July was predominantly

above average across the local region and the Chesapeake Bay watershed. While there was an initial interest in connecting these patterns to the El Niño and Arctic Oscillation (AO) transition, it became evident that a more extended data record was necessary for conclusive insights. Examination of 1-month and 2-month lead times from NMME forecasts resulted in fragmented data with a low r^2 (<40%). However, when employing the model selection/dredge technique, the GFDL model emerged as particularly apt for *V. parahaemolyticus*, and NASA's model performed well for both *V. vulnificus* and *V. parahaemolyticus*.

As future directions, Bob Daniels emphasized the promise seen in the April 1-month lead models. Some models, even those for March with a 2-month lead for total *Vibrio* species, exhibited strength. It was further observed that *Vibrio* illnesses were at their peak following the strong El Niño of 2016, underscoring the potential for the continued enhancement of seasonal *Vibrio* prediction tools.

Reservoir adaptive management: What weather forecast enhancements are needed in Texas? | Dr. Jerry Cotter

Dr. Jerry Cotter provided an overview of how the USACE uses NMME for adaptive reservoir management in Texas. Dr. Cotter noted that USACE inundation map endeavors and reservoir management have been the focal points of their efforts, investing as much as $8 billion to the development of multi-purpose reservoirs across the nation. Projections indicate that the population of Texas is projected to increase to between 30 and 54 million people and so the need to effectively manage water resources across the state is critical to supporting the state's population expansion and economic growth.

Dr. Cotter outlined USACE's Forecast Informed Reservoir Operations (FIRO) reservoir operations, which follow the WCM Plan of Operation for reservoir systems. He also noted that water is stored in conservation pools and that flood inflow is stored temporarily to maintain safe operational conditions. Dr. Cotter stated that USACE FIRO operations leverage NWS products, particularly during extreme storm periods. The objectives of FIRO forecasting are to maximize water availability without major infrastructure expenses and minimize water pumping. However, FIRO faces challenges, such as the extended water travel times, precipitation complexities, and a forecasting lead time that's three weeks longer than California's.

Dr. Cotter summarized his presentation underlining the need to address several challenges. Some of the most pressing challenges USACE faces are long travel times between reservoirs and the large amount of time to empty flood storage. Consequently, in order to implement FIRO in Texas in the same manner as has been accomplished in California would require a forecast lead time of three or more weeks. He concluded with his optimism that NMME might be able to fill this gap in future iterations.

What is usable skill for water management? (Keynote) | Ms. Jeanine Jones

Ms. Jeanine Jones delivered the closing keynote presentation of this session. Ms. Jones reiterated the significance of NWS operational products in California and their wider implications. The CPC graphics, which provide seasonal outlooks for air temperature, are

particularly valuable for water resource management in the United States. To illustrate this point, she recounted the severe drought in California in 2016, emphasizing that factors beyond ENSO played a role. She noted that during the winter of 2023, there was a contrasting situation with a long drought followed by atmospheric rivers, marking a shift from October 2022 being the driest to February 2023 being the wettest.

Ms. Jones suggested that, drawing from the NOAA 2020 report to Congress on S2S skills, the rationale behind the S2S focus was sufficiently highlighted. The S2S perspective aids in managing risks associated with impacts and financial exposure, assists local water agencies in project financing, and aids in contract negotiation in anticipation of water extremes. Ms. Jones has since taken the initiative to organize an S2S group, urging non-federal employees to support efforts in securing necessary funding, which might diverge from traditional congressional appropriations.

Ms. Jones concluded her remarks, suggesting that while precipitation and prior drought conditions are essential, the emphasis should be on both seasonal and subseasonal timeframes. While the current skill levels in models don't allow for setting specific targets, the goal is to achieve much-improved skill levels, particularly in predicting regime shifts, for adaptive management in the near future. She opined that currently, NMME's utility for a broader audience is very low, with no usable skill for precipitation in western watersheds and no identified path forward for improving skill. She suggests that perhaps the best way to improve the utility of NMME-provided S2S forecasts is to develop a comprehensive work plan with performance metrics that can track the evolution of NMME and its ability to meet user needs.

Operational Gaps Discussion Panel

This discussion panel centered on improving the NMME's ability to forecast extreme weather events. Mr. Jon Gottschalck (CPC) emphasized the importance of NMME in understanding extreme weather patterns. Dr. Benjamin Kirtman (University of Miami) talked about transitioning NMME to operational S2S and climate model capabilities. He stressed the importance of higher frequency observations, especially in the context of extreme weather events. Kirtman also highlighted an operational gap in resolution, suggesting that it's time to move beyond the 1-degree model that has been prevalent for the past decade.

Dr. Samantha Kramer (Sonoma Tech) addressed the growing concern about air quality and forest fires. She noted the increase in air quality issues due to climate change and extreme weather events, emphasizing the need for local departments to make informed decisions based on large-scale and long-term evaluations of air quality. Dr. Mike Jacox (Southwest Fisheries Science Center) discussed the challenges in linking global phenomena to regional oceanography and fisheries dynamics. He pinpointed gaps in operational models and advocated for the inclusion of ocean biogeochemistry in models, suggesting that fisheries should not be the only end users in mind, but also offices like National Marine Fisheries Service forecast centers.

The panel discussion touched upon several aspects of NMME, from its capability to forecast certain events to potential improvements. Several questions revolved around improving

model capabilities, the practicalities of using specific observation/modeling outputs, the importance of high-frequency and resolution data, and the potential for cross-disciplinary and cross-agency collaboration. The discourse also touched upon the financial aspects of advancements in forecasting, with mentions of budgets, and funding avenues. In particular, Dr. DeWitt pointed out potential funding opportunities for coastal prediction, while Dr. Merryfield directed attention to available hindcast data.

Research Needs Discussion Panel

During this session, panelists provided insights and comments on how the NMME is utilized within the research community, highlighting current gaps and challenges. Dr. Nathaniel Johnson (GFDL) spotlighted the development of innovative seasonal forecast prototypes using GFDL models that have participated in the NMME. He discussed a current research focus on developing seasonal forecasts of extreme weather, including for U.S. extreme summertime heat and tropical cyclones. He also showed how a version of a GFDL coupled climate model with horizontal resolution higher than the version participating in the NMME can produce seasonal forecasts of major hurricanes. Dr. Johnson also discussed research efforts into methods with lower computation cost for generating seasonal forecasts, with a focus on model analog-based ENSO forecasts that have showcased comparable skill, sometimes even outperforming standard SPEAR forecasts. Emphasis was placed on GFDL's insights regarding model-analog ENSO forecasts.

Dr. Bill Merryfield (ECCC) detailed the enhancements in the ECCC's seasonal forecasting. He noted the addition of five variables to their climate site, the integration of interactive maps, and the expansion of global data. When queried about the NMME's impact on the ECCC's group, Dr. Merryfield highlighted its value in monitoring systems and in facilitating a higher volume of publications. Another inquiry about western precipitation in Canada revealed that while Canada’s west coast doesn't face the same challenges mentioned by Ms. Jones in her presentation, temperature and ENSO influences remain crucial. Dr. Michael Tippett (Columbia University) elaborated on the potential of specific research questions. He championed the importance of models in predicting rare or previously unobserved events, underscoring that while traditional records are indispensable, they aren't exhaustive. He brought attention to the UKMET office's UNSEEN method and stressed the relevance of CAT models, which convert climatic events into potential financial losses. He advocated for archiving more than just predictable events, accentuating the necessity for accessible and diverse data.

Panelists fielded numerous questions centering on the real-time application and validation of the showcased models. A recurring theme was the primacy of real-time data in bolstering research. Additionally, there was pronounced interest in the Arctic's influence on seasonal forecasting and the intricacies of appraising models from both research and operational perspectives. The conversation underscored the multifaceted nature of model evaluation, with multiple panelists accentuating the probabilistic essence of forecasts. Several comments from attendees further delved into the operational and research hurdles, the potential of the EPIC platform, and the nuances of model verification. The prevailing sentiment

underscored the significance of collaboration, ongoing research, and the quest for groundbreaking methods in the field of ecological forecasting.

Breakout Session Report Out and Discussion

Participants, both in-person and virtual, were broken out into six breakout groups over the course of two hour-long sessions. Each group focused their discussions on one of the following aspects of NMME: 1) Data Needs and Access, 2) Model Improvements, 3) Prediction and Predictability Testbed, 4) Operational Gaps, 5) Modeling Center Challenges, and 6) Initialization Frequency: Requirements and Limitations. Groups selected a representative to present a high-level summary of their group's discussion and any resulting recommendations for reducing barriers and enhancing the ability of NMME to meet a broader range of user needs.

Session 1: Data needs and access

The discussion in this session emphasized the importance of a centralized User Guide, standard terminology, and user-friendly data portals for the NMME datasets. With the conclusion of the SubX project, discussions focus on whether NMME can fill the resultant gaps, and the specific data needs and accessibility issues of different user groups. The main discussion points are as follows:

User Guide and Feedback Mechanisms: There's a need for a comprehensive User Guide detailing the location of various datasets (e.g., IRIDL/CPC ftp). A feedback system, perhaps through a GitHub issues tracker, would be beneficial to address and record data access issues, ensuring that all complaints are centrally noted.

Data Variables and Quality: A survey to determine additional desired variables, such as soil moisture, is suggested. The existing Google Doc listing these variables could be utilized more efficiently. There's confusion about the correct use of "bias correction" in data sets, emphasizing the need for standard terminology.

Data Access and Usability: Data portals need to be user-friendly, with IRI DL and C3S cited as positive examples. There's a demand for more processed data (e.g., bias corrected forecasts, skill masks) and not just raw daily data. Cloud storage should be considered for data accessibility, ensuring it fits into a seamless workflow for users.

SubX's Conclusion and NMME's Role: The SubX project is ending, prompting discussions on whether NMME can fill the gaps left, especially since NMME provides forecasts less frequently than SubX. There's a distinct need for data covering weeks 3-4, with requests for more variables and frequent updates.

Data Needs and Accessibility for Specific Users: There's a need for daily timescale data to assess specific weather patterns, like the onset of rainy seasons. The capability of server-side subsetting, especially for bandwidth-limited regions like certain African countries, is crucial. Direct access to all NMME fields (dods access) would be beneficial, but currently, some data accessible at CPC aren't available on the IRI DL.

Session 2: Model improvements

This discussion emphasized the challenges of modern modeling techniques, the significance of understanding and addressing biases in forecasting models, and the complexities of balancing computational feasibility with the demands of accurate and frequent forecasting. The main discussion points are as follows:

Modeling Shifts: NCEP is adopting Earth System Modeling with challenges in re-analysis and re-forecasting. Key questions surround complexity, initialization, and ensemble strategies.

Model Complexity: The balance between model complexity and computational cost is crucial. Feedback from NMME highlights critical biases that guide solution directions.

Bias vs. Performance: While bias correction can improve some aspects of models, the overall skill might remain unchanged, emphasizing the role of systematic errors.

Resolution Insights: High-resolution modeling benefits specific components, like oceans, but the operational impact varies. Other complex processes, such as vertical resolution, need attention.

Initialization Concerns: Early biases can lead to data wastage. The frequency of model cycles, like NCEP's 6-hour cycle, and ensemble member considerations are debated.

Session 3: Prediction/predictability testbed

The discussions in this session focused on refining research methods, strengthening inter-agency collaborations, and enhancing forecast accuracy through various technical advancements. The main discussion points are as follows:

Research Coordination and Clarifications: Emphasis on coordinated research to prioritize unanswered questions, with possibilities of hypothesis numerical experiments. UFS and NMME collaboration will enable idealized sets for the numerical weather model.

Inter-Agency Collaboration: Agencies are urged to synchronize efforts, especially when predicting extreme weather events. Furthermore, there's a strong inter-agency effort in coordinated sensitivity experiments and understanding impacts like ENSO teleconnections under a changing climate.

Verification and Data Assimilation: Projects with CPC are targeting the establishment of verification capabilities using METplus. Data assimilation was identified as a key area to reconsider, especially concerning improving forecasting skills for longer time scales.

ENSO Modeling & Understanding: ENSO errors arise from initializations rather than the model itself. However, the distinction is clear only for ENSO, indicating a gap between climate and weather communities in forecasting. Different centers yield different results due to varied model conceptualizations.

Terminology and Implementation: A shift in terminology from 'testbed' to 'Innovation Laboratory' is proposed. Discussions also touched on how to incorporate varied observations into modeling systems and the relevance of coupling weather/climate models with land-surface models, particularly in coastal regions.

Session 4: Operational gaps

Discussions in this session prioritized refining model resolution, understanding service viability, rigorous quality control, hybrid data methods, user-friendly interfaces, the necessity of long hindcasts, and timely data provision to the CPC. The main discussion points are as follows:

Model Resolution and Ensemble Size: While the benefits of increasing model resolution are debated, the importance of a larger ensemble size for accurate forecast uncertainty is clear. Balancing this with computational demands is a concern.

Operational Utility and Forecast Quality: The GEFS community, primarily USACE, evaluates the utility of services for NOAA, with NMME possibly serving as an interim solution. For accurate forecasting, data as far back as 1982 may be used, despite data quality concerns, necessitating significant post-processing.

Model Variables and Quality Control (QC): SST, precipitation, and 2mTemp are the core elements, with additional variables suggested for the stratosphere, hurricanes, and more. Rigorous QC is essential, especially for these core variables.

Hybrid Approaches and Operational Needs: Combining NMME capabilities with statistical methods offers cost-saving opportunities. Meanwhile, the CPC seeks earlier model data delivery, and storage requirements, especially with NOAA's NOAA Open Data Dissemination (NODD) program, should be met.

User Interface, Calibration, and NHC Perspective: A tailored user data retrieval system, developed collaboratively, is advised. Long hindcasts are crucial for rare events calibration. The NHC suggests more granular, possibly monthly, forecasts supported by downscaling data.

Session 5: Modeling center challenges

This session emphasized the imperative for more comprehensive final testing, the conceptualization of innovative retrospective forecasting methodologies to elevate model outcomes, preserving continuity in hindcast scenarios, the indispensability of timely reforecasts, reducing biases through model improvements and run-time tendency corrections, pioneering rapid calibration techniques for the latest model variants, and fortifying land initialization, especially in platforms akin to SPEAR. The main discussion points are as follows:

Testing and Forecasting: Focus on refining forecasting strategies with hindcasts as far back as 1982, and improving temperature predictions despite model challenges.

Retrospective Forecasts: Emphasize consistency with hindcast conditions, explore Machine Learning's potential, and address calibration delays in new models.

Variable Initialization: Highlight the importance of less observed variables, especially sea surface salinity and soil moisture, and address challenges in platforms like SPEAR.

Initialization Frequency: Prioritize frequent initializations for S2S forecasting, discuss resource allocation, and consider varied forecast durations.

Timeliness and Hindcast Value: Stress timely forecast deliveries with NMME, explore larger ensemble sizes, and recognize the significance of extended hindcasts.

Session 6: Initialization frequency: Requirements and limitations

This discussion revolved around optimizing the NMME for S2S forecasting, considering both research and operational perspectives. There was a strong emphasis on balancing resources, meeting frequency requirements, and ensuring the relevance and timeliness of forecasts. The main discussion points are as follows:

Initialization Frequency: There was agreement on the need for frequent S2S initializations, with SubX disseminations in view and CPC offering higher frequency alternatives.

Resource and Duration Preferences: Debates centered on redirecting NMME resources towards the CPC's needs and the forecast durations, with varied preferences between 16 and 24 months.

Technical Considerations: Discussions included the balance between ensemble size and model resolution, the relevance of certain variables, and the potential for staggered initialization impacting hindcast databases.

Hindcast and Timing: The value of real-time and longer hindcasts was emphasized, along with suggestions to standardize initialization timings by month-end.

Ensemble Size and Frequency Requirements: A push for larger ensemble sizes, ensuring timely monthly model outputs, and addressing issues with mid-month NMME and the length of hindcasts for current needs.

Meeting Outcomes: Informing the Evolution of the NMME

During the concluding session, panelists provided insights and comments on the challenges and future directions of the NMME. Dr. David DeWitt (CPC) highlighted the inherent challenges with S2S due to its low signal-to-noise ratio, which makes it challenging to establish a cohesive community focused on it. He also underscored the efficiency of NMME in delivering S2S-style products and pointed out that there are scaling issues with Operations-to-Research (O2R) in NMME. Furthermore, he emphasized that users often lean towards forecasts with shorter lead times.

Dr. Benjamin Kirtman (University of Miami) offered several suggestions for NMME's future evolution. He touched on the potential consideration of changing ensemble size while weighing it against computational costs. He noted that extending forecasts beyond a 12-month period might be unfeasible, but collaboration with ongoing efforts, especially at the CPC, is

possible. Moreover, Dr. Kirtman emphasized the need for coordinated efforts to boost model predictability.

Dr. Brian Gross (EMC) clarified that EMC does not intend to replace NMME with the upcoming SFSv1, assuring that the NMME will maintain its role for operational use. Dr. Dorothy Koch (WPO) provided a broader perspective, positioning NMME as a crucial component of the S2S program under WPO. She hinted at potential future avenues, such as revitalizing the climate testbed. Furthermore, Dr. Koch acknowledged the broader societal and outreach benefits NMME outputs provide.

Finally, there was a general consensus on the importance of NMME in specific regions, like the US west coast, and its potential role in addressing challenges like coastal inundation driven by climate change. Dr. Jessie Carman (WPO) posed questions about trade-offs in model development and application, spurring discussions on differentiating between stakeholder perspectives and research needs, the potential of higher vertical resolution in Numerical Weather Prediction (NWP) for better S2S predictability, and the broader challenges in estimating earth system states. The dialogue concluded with reflections on NMME's invaluable contributions to NOAA's operational needs and the acknowledgment that NMME might not fully cater to all broader decision-making needs.

Closing Remarks

Mr. Rosencrans provided the closing remarks, acknowledging the presenters, participants, and workshop organizers. He assured workshop participants that the discussions that occurred over the course of the workshop would inform upcoming conversations to renew the NMME Agreement. Finally, he announced that presentation slides would be accessible on the workshop website and that the final workshop summary report would also be distributed to participants upon its completion.

Appendix A: Acronyms

AGU	American Geophysical Union
AMS	American Meteorological Society
AO	Arctic Oscillation
CanCM4	Canadian Coupled ocean-atmosphere general circulation Model
CESM	Community Earth System Model
CFS	Climate Forecast System
CMB	Community Modeling Board
CPC	Climate Prediction Center (NOAA)
DTC	Developmental Testbed Center (NOAA)
ECCC	Environment and Climate Change Canada
EISWG	Environmental Information Services Working Group (NOAA)
EMC	Environmental Modeling Center (NOAA)
ENSO	El Niño-Southern Oscillation
EPIC	Earth Prediction Innovation Center (NOAA)
ESD	Earth Science Division
FIRO	Forecast-Informed Reservoir Management
GEFS	Global Ensemble Forecast System
GEOS	Goddard Earth Observing System
GFDL	Geophysical Fluid Dynamics Laboratory
HABS	Harmful Algal Blooms
ICAMS	Interagency Council for Advancing Meteorological Services
IRA	Inflation Reduction Act
IRI	Columbia University International Research Institute for Climate and Society
MHW	Marine Heatwaves
MRW	Medium-Range Weather
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCCOS	National Center for Coastal and Ocean Sciences (NOAA)
NCEI	National Center for Environmental Information (NOAA)
NCEP	National Center for Environmental Prediction (NOAA)
NHC	National Hurricane Center (NOAA)
NHyFAS	NASA Hydrological Forecast and Analysis System
NMME	North American Multi-Model Ensemble
NOAA	National Oceanic and Atmospheric Administration
NODD	NOAA Open Data Dissemination
NRC	National Research Council
NSTC	National Science and Technology Council
NWP	Numerical Weather Prediction
NWS	National Weather Service (NOAA)
OAR	Office of Atmospheric Research (NOAA)
OSTI	Office of Science and Technology Integration (NOAA)

S2S	Subseasonal-to-Seasonal
SFS	Seasonal Forecast System
SubX	Subseasonal Experiment
SPEAR	Seamless System for Prediction and Earth System Research
SWFSC	Southwest Fisheries Science Center (NOAA)
TOTAL	Temperature Observations to Avoid Loggerheads
UFS	Unified Forecast System
USACE	US Army Corps of Engineers
USAID	United States Agency for International Development
USGEO	U.S. Group on Earth Observations
WPO	Weather Program Office

Appendix B: Workshop Agenda

Day 1: Wednesday, June 21, 2023

8:00 AM COFFEE

8:30 AM Welcome and Opening Remarks

Goals and expected outcomes | 20 min

Jessie Carman, Ph.D., NOAA WPO

Workshop structure and logistics | 10 min

Mark Olsen, Ph.D., NOAA WPO

9:00 AM Keynote Speakers

Building seasonal predictions for purpose: How the NMME supports early warnings, climate adaptation, and commerce | 20 min

Sarah Kapnick, Ph.D., NOAA Chief Scientist

Progress in federal coordination to advance meteorological science and services | 20 min

Scott Weaver, Ph.D., White House Office of Science and Technology Policy

9:40 AM BREAK

10:00 AM State of the North American Multi-Model Ensemble (NMME)

NMME applications research | 20 min

Benjamin Kirtman, Ph.D., University of Miami

NMME prediction research | 20 min

Emily Becker, Ph.D., University of Miami

NMME operations | 20 min

Matthew Rosencrans, NOAA Climate Prediction Center (CPC)

11:00 AM Model Improvements

Future evolution of the NCEP operational prediction systems | 15 min

Vijay Tallapragada, Ph.D., NOAA Environmental Modeling Center (EMC)

Recent advancements on the community Unified Forecast System | 15 min

Neil Jacobs, Ph.D., University Corporation for Atmospheric Research (UCAR)

11:30 AM Morning Q&A

12:00 PM LUNCH

1:30 PM End User Activities and Needs

Climate information: user needs and user uses (Keynote) | 20 min

Walter E. Baethgen, Ph.D., Columbia University International Research Institute for Climate & Society

CPC use of NMME and Sub-Seasonal to Seasonal (S2S) Prediction Challenges | 15 min

David DeWitt, Ph.D., NOAA Climate Prediction Center (CPC)

Leveraging the NMME for marine ecosystem prediction | 15 min

Michael Jacox, Ph.D., NOAA Southwest Fisheries Science Center

Chesapeake Bay Vibrio seasonal prediction | 15 min

John Jacobs, Ph.D., NOAA National Center for Coastal and Ocean Sciences

Reservoir adaptive management: What weather forecast enhancements are needed in Texas? | 15 min

Jerry Cotter, Ph.D., U.S. Army Corps of Engineers

What is usable skill for water management? (Keynote) | 20 min

Jeanine Jones, California Department of Water Resources

3:15 PM BREAK

3:30 PM Operational Gaps Discussion Panel

Panelists

Jon Gottschalck, NOAA Climate Prediction Center
Michael Jacox, Ph.D., NOAA Southwest Fisheries Science Center
Benjamin Kirtman, Ph.D., University of Miami
Samantha Kramer, Ph.D., Sonoma Tech

Moderator

Matthew Rosencrans, NOAA Climate Prediction Center

4:45 PM ADJOURN

Day 2: Thursday, June 22, 2023

8:00 AM COFFEE

9:00 AM Research Community Needs Discussion Panel

Panelists

Emily Becker, Ph.D., University of Miami
Neil Jacobs, Ph.D., University Corporation for Atmospheric Research (UCAR)
Nathaniel Johnson, Ph.D., NOAA Geophysical Fluid Dynamics Laboratory
Bill Merryfield, Ph.D., Canadian Centre for Climate Modeling and Analysis
Michael Tippett, Ph.D., Columbia University

Moderator

Benjamin Kirtman, Ph.D., University of Miami

10:30 AM BREAK

10:45 AM Breakout Session Instructions

11:00 AM Breakout Session 1: Scientific Challenges

Group 1A: Data Needs and Access

Lead: Andrew Robertson, Ph.D.

Group 1B: Model Improvements

Lead: Vijay Tallapragada, Ph.D.

Group 1C: Prediction/Predictability Testbed

Lead: Wanqui Wang, Ph.D.

12:00 PM LUNCH

1:00 PM Breakout Session 2: Technical Challenges

Group 2A: Operational Gaps

Lead: Matthew Rosencrans

Group 2B: Modeling Center Challenges

Leads: Bill Merryfield, Ph.D. and Andrea Molod, Ph.D.

Group 2C: Initialization Frequency: Requirements and Limitations

Leads: Emily Becker, Ph.D. and Benjamin Kirtman, Ph.D.

2:00 PM Breakout Session Report Out and Discussion

Moderators

Emily Becker, Ph.D., University of Miami
Benjamin Kirtman, Ph.D., University of Miami
Matthew Rosencrans, NOAA Climate Prediction Center

3:00 PM BREAK

3:30 PM Meeting Outcomes: Informing the Evolution of the NMME

Moderators

Dorothy Koch, Ph.D., Weather Program Office
Brian Gross, Ph.D., NWS Environmental Modeling Center
Benjamin Kirtman, Ph.D., University of Miami
David DeWitt, Ph.D., NOAA Climate Prediction Center

4:30 PM Closing Remarks
Wrap-up | 15 min
Matthew Rosencrans, NOAA Climate Prediction Center

4:45 PM ADJOURN