Community Modeling review Committee Report

Based on August 9-10, 2018 Meeting

Delivered 14 December, 2018

The Community Modeling review Committee (CMC) operates as an independent, ad hoc review committee aligned with Modeling Programs in the NWS and OAR

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Community Modeling review Committee (CMC)

August 9-10, 2018
Boulder, CO

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1. Introduction

The Community Modeling review Committee (CMC), which is a committee convened at the request of the National Oceanic and Atmospheric Administration Office of Oceanic and Atmospheric Research (OAR) and National Weather Service (NWS) to review the NOAA modeling program (see Charter in Appendix A), met on 9-10 August 2018 at the NOAA offices in Boulder, CO, hosted by the Earth System Research Laboratory (ESRL). Because of the breadth and complexity of the NOAA modeling program, the meeting was focused on four primary aspects:

- Principles for NOAA organization of research and development (R&D) and the transition from research to operations (R2O)
- Accelerating advancements in NOAA's data assimilation (DA) capabilities
- Unifying NOAA's convection-allowing/resolving modeling (CAM) approach
- Advancing NOAA's subseasonal to seasonal (S2S) forecasting skill

The full charge for the August 2018 meeting is provided in Appendix B. Other aspects of the NOAA modeling program will be reviewed in subsequent meetings. The CMC heard presentations from NOAA on all 4 areas and held vigorous discussions of these topics.

The individual CMC members (see Appendix C) have formulated preliminary findings and recommendations for NOAA to consider as it develops its plans for integrated R&D and R2O, DA, CAM and S2S. The members' findings and recommendations are provided in Section 3. A summary of common themes from the individual members' remarks is provided in Section 2. Our rule is that if a comment/finding/recommendation was mentioned two or more times, it could be included as a common theme. Two consequences of this style of report are (a) there may not be feedback on all the topics on which the committee was briefed, and (b) there may be differences of opinions among the CMC members' contributions. *Thus, it is very important for NOAA to carefully read the individual comments in addition to the common themes.*

2. Summary and Common Themes

The primary result of the CMC meeting in August 2018 is a set of individual findings and recommendations from each of the members, which are provided in Section 3. During the discussion and the preparation of this report, many common themes emerged that were mentioned by two or more members. This section summarizes those common themes. Section 2.1 summarizes two overarching topics of interest to all CMC members. The next 4 sections present the common themes for the four primary topics assigned for this meeting (listed above).

2.1. General Aspects

Unified Forecast System and Community Engagement

Finding: The joint commitment by NWS and OAR for collaboration at the highest level is a very positive development that has tremendous potential to help NOAA achieve its mission.

Finding: NOAA's transition toward a unified approach to developing and implementing models to provide guidance for its operational products and services is already delivering dividends in terms of exciting the community, focusing planning efforts and revealing risks and barriers to progress.

Finding: The collaborative, unified approach, which includes the Unified Forecast System (UFS) and the Strategic Implementation Plan with its community-based working groups, all of which is directed at bridging the gap between research and operations, is highly beneficial but has not been embraced uniformly by all relevant parts of NOAA.

Computing

Finding: A major roadblock is a lack of computational resources for research and development. The problem of limited high-performance computing (HPC) resources available for (i) increasing the fidelity, complexity and resolution of forecast and DA systems, (ii) engaging in the necessary experimentation/testing of modeling systems, and (iii) providing compute resources for an expanding community of user/developers, is a pressing challenge for all subject areas addressed in this report.

Recommendation: NOAA, OAR and NWS should develop holistic short-term and long-term plans for meeting and managing their operational and research-oriented computing and storage needs. In the long-term, this may need to include the articulation of a "cloud-forward" strategy for considering the use of cloud (or virtual machine) computational resources and data-hosting in conjunction with traditional HPC. In the near-term there is a need to set realistic priorities -- *which may effectively mean a reduction in expectations* -- in order to help NOAA employees manage within available computing and data resources.

2.2. Organizational Principles for Research and Development and the Transition from Research to Operations

Note that this section is organized according to a document provided to the CMC by OSTI titled "Core Principles for Organizing an Enterprise Operational Model Development Capability". These 8 Principles were not specifically discussed in any session but if any of them were addressed multiple times in the CMC comments in Section 3, the relevant findings and recommendations are provided below.

2.2.1. Operational Requirements and Outcomes shall drive the enterprise

Finding: Serving NOAA's and NWS's mission demands that operational outcomes drive research and development (R&D) and implementation.

Recommendation: NOAA should clearly prioritize development strategies and identify funding streams to address specific prediction capabilities.

2.2.2. Accept NGGPS and the NGGPS-based Unified Modeling System as the technological foundation for infusing new science

Finding: Engaging the broader community in the evolution of the UFS is a positive development.

Finding: Greater emphasis on scientific excellence (see Appendix E) in U.S. operational numerical weather prediction (NWP) is needed. This requires a highly integrated research-and-development (R&D) structure that includes clear responsibility for model components, allocation of resources, internal scientific expertise, and the effective entrainment of the external scientific community.

Recommendation: NWS and NOAA should better and more effectively communicate the grand challenges in weather, climate and environmental prediction.

Finding: Documentation and community liaisons are critically important technical strategies for engaging the community.

Recommendation: In order to encourage the transitions from Research to Operations (R2O) and use Operational codes and facilities to support Research (O2R), the UFS should be a true community modeling system, including user support, such as tutorials, workshops, support desks, and comprehensive model (and other code) documentation.

Recommendation: NOAA should better define the "community" and the incentives and expectations for engagement. NOAA should build trust relationships with members of the R&D community, e.g., by establishing longer-term funding mechanisms and enhancing O2R support.

Recommendation: As an investment strategy, NOAA should devote substantial resources to support community engagement.

Recommendation: NOAA and other agencies potentially could benefit from applying the "climate process teams" approach to NWP.

2.2.3. Accept the joint NCAR-NOAA infrastructure to enable community modeling for O2R/R2O

This principle was not discussed specifically by CMC as the NCAR-NOAA MOA on this topic had not been signed. However, there was much discussion and agreement in the CMC on the following related issues:

Finding: NOAA support for FV3 is currently split between EMC and the DTC at UCAR, and is under-resourced, with many support activities not yet occurring. EMC isn't well-structured to perform this function, but the DTC does not yet have the charge, personnel, or resources to provide support for all FV3 (UFS) components.

Recommendation: NOAA should develop a plan to train and support the community in all UFS components (e.g., documentation, training courses, model help desk, data sets for model execution and analysis, provision of computing resources, easy-to-use workflow, etc.) This support function should be organized/coordinated under one entity (although not necessarily in one location – take advantage of where the expertise is). Strong consideration should be given to NOAA Deputy Administrator Neil Jacobs' vision with respect to the community support entity.

2.2.4. Accept and Maintain the multi-Agency Joint Center for Satellite Data Assimilation unique mission for accelerating the implementation and use of satellite data operationally

Specific findings and recommendations related to the JCSDA and the JEDI project are provided below in the individual comments section.

2.2.5. NOAA Research Funnel should be used to identify/describe/define roles and responsibilities

Finding: A significant amount of OAR research funding is now programmed for helping to implement the FV3 and other UFS components over the next year or so; i.e., funding at the Technical Readiness Levels 6-7-8. While this is laudable to help ensure the successful implementation of FV3, a consequence is a decrease in funding higher in the research funnel, thus leading to a decrease in R&D for UFS improvements in the 3-5 year time frame.

Recommendation: NOAA should rebalance its research priorities in OAR to ensure that sufficient funding is available for TRL 3-4-5 R&D that will provide improvements to the UFS in the 3-5 year time frame.

Finding: Better organization of NOAA capabilities, including precise definitions of quantitative metrics of success, is required to achieve the goal of providing the best numerical weather and climate predictions in the world. Coordination between OAR and NWS research has improved recently but more can be done.

Recommendation: NOAA should continue to re-organize its R&D enterprise to provide a more integrated R&D capability that benefits the UFS mission.

2.2.6. Accept the UFS Governance as already implemented

Finding: Leadership transitions, slowness to fill key positions, and general uncertainty about "who's in charge?", "who is accountable?", and "where will resources come from?" represent potential brakes on progress.

Finding: Although greater integration of R&D with operations is occurring within NOAA, responsibility and resources are still divided over several entities.

Recommendation: NOAA should establish a supervisory, advisory and decision-making body that can prioritize R&D activities and implement the recommendations in the SIP. That is, define a process for helping the Working Groups work together more effectively. See comments/recommendations on this in Section 3.7.

2.2.7 EMC needs to remain science based, and collocated with service centers

This principle was not discussed by CMC nor mentioned by any individual members.

2.2.8 Close collocation of Operations and Development activities, e.g., EMC-NCO, is essential

This principle was not discussed by CMC nor mentioned by any individual members.

2.3. Data Assimilation

Note: Sections 2.3 to 2.5 were organized according to a suggestion in the Charge for the 2018 Review that the CMC consider, for each topic area, NOAA's technical strategies, priorities, resource requirements, developmental approaches, investment strategies, and scientific/technical challenges while conducting this review. There is considerable overlap in these categories, so more importance should be given to the recommendations themselves than to its category location.

Technical Strategies

Finding: Good progress and promise exists with the development of the Joint Effort for Data Assimilation Integration (JEDI) software framework, but there appears to be a lack of strategic planning to engage research towards data assimilation (DA) advances that will be implemented in the future UFS system.

Finding: There appear to be serious disconnects between the JEDI software development team employed by the joint center of JCSDA, and the NOAA algorithm development and future implementation team at EMC. EMC is under-resourced for the science and algorithm development; there is a general lack of plan to enhance the workforce and science at the top of the funnel for DA development.

Finding: The JEDI team under JCSDA has a broad mission, with portfolio and objectives that are not necessarily aligned with priorities and requirements for NOAA's unified modeling system development under NGGPS. The limits of EMC's involvement in the development of the JEDI software framework and computing architecture poses a risk for the effective transition of JEDI developments into NOAA operations.

Recommendation: NOAA should take the lead in creating a decision-making body to advise, evaluate and enforce a clear scientific excellence plan for data assimilation, which should include JEDI.

Finding: The roadmap for long-term migration to coupled DA accurately articulates the primary technical and scientific challenges, but it remains unclear what mechanism/resources will be used to address them.

Recommendation: Technical and scientific challenges that require significant research should be communicated by NWS in a formalized fashion to OAR; funding lines to address these challenges should be developed or strengthened

Recommendation: NWS should engage scientists from the NOAA labs and other R&D groups experienced with coupled DA research and implementation.

Priorities

Finding: It is not clear if JEDI has sufficient concurrent science development for advanced DA algorithms, all-sky radiances and other under-utilized data sources.

Recommendation: NWS should assign more DA scientists at the Environmental Modeling Center (EMC) to be involved with JEDI development, so there is not a significant spin-up as this system becomes operational. EMC DA scientists need to be involved in the JEDI priority setting and algorithm development from the beginning.

Resource Requirements

Finding: DA R&D resources for science and algorithm development are not allocated so as to optimally support all DA requirements (global, CAM, coupled etc.). There is no plan to enhance the workforce and support scientific research at the top of the funnel.

Finding: There is no clear plan for how to accomplish what is needed for transition, testing, evaluation and inspiring new development in the face of HPC and other limitations.

Recommendation: NOAA should consider creating partnerships with institutions that have DA expertise in order to address the human resource issue. Such partnerships would need to have concomitant training capabilities.

Development Approaches

Recommendation: NOAA should develop a suite of operationally-relevant simplified prototype models that the community could use to test new DA advances within the JEDI framework. This approach also requires support from OAR and NWS programs.

Finding: The status of data assimilation and initialization of the land surface is not clear.

Investment Strategies

Recommendation: NOAA should invest in a comprehensive R&D consortium on DA that taps a broad range of expertise across all communities.

Recommendation: NOAA needs to better integrate and strategize the hurricane-specific model development including novel use of advanced sensors such as those from all-sky microwave and infrared sensors into the DA science development, and the eventual transition to the global convection-permitting NWP and DA.

Recommendation: NOAA should strategize the development of atmospheric composition DA for improving both NWP and air quality modeling, as these components will be scientifically and technically challenging.

2.4. Convection-Allowing Modeling

General Aspects

Finding: The CAM SIP group is working effectively together, as its co-leaders are also leaders of the 5 organizations that are doing most of the work: EMC, GSD, GFDL, NSSL, AOML.

Finding: The CAM effort is a large one, since UFS equivalents are needed for the following current operational forecast systems: NAM, NAM nests (4+), HIResW (5+), FireWxNest, RAP, RAP-Alaska, HRRR, HRRR-Alaska, SREF, HREF2, HWRF, HMON and perhaps others - most of these have different domains, resolutions, run cadence, physics, etc.

Recommendation: The CMC (and the community at large) would appreciate a mapping of how all the above forecast products are going to be replaced by UFS systems. The resulting chart should include the system name, domain, resolution, cadence, projection time, physics suite and other relevant information.

Finding: There are great benefits in moving to convection-allowing models (CAM) from regional to global scales. In addition to the obvious advantage of employing CAM for mesoscale weather prediction, convection-allowing modeling potentially has large benefit on the global scale, including improved tropical convection and global teleconnections.

Recommendation: A global CAM model needs to be evaluated and a plan needs to be developed for moving it to operations.

Technical Strategies

Finding: Dynamics and physics are often treated as independent components.

Recommendation: NOAA should evaluate how this paradigm needs to be revised as NWP moves to higher resolution.

Priorities

Finding: Current U.S. convection-allowing ensemble operational prediction is too limited (HREF2, 7 members, 3-4 km, small domain) to provide reliable probabilistic guidance.

Recommendation: Although some efforts are being made to provide a larger/more capable CAM system over the U.S (HRRRE), NOAA should give more priority to this effort, including the necessary computer resources and data assimilation/perturbation approaches.

Recommendation: NOAA should enhance the organizational expertise in CAM-scale DA, and better capture and incentivize such expertise from broader communities.

Finding: While the FV3 can do global nests, the time required by CAM forecasts precludes use of the global version since it takes too much time to do the global analysis. Thus a Stand-Alone-Regional (SAR) model is being developed by EMC, GFDL, GSD and NSSL. This model can replace both the 12-13 km NAM-RAP regional models and also serve as the ≤ 3 km CAM model.

Finding: A regional, long-range (72-84 hrs) CAM ensemble is desirable to replace the SREF. Use of HREF2 or HRRRE or its FV3 replacement is not possible now because of the enormous computer resources CAM resolution needs for the SREF domain and 84 hr projections. The short-term replacement for SREF is challenging. In principle, the FV3GEFS would be the replacement, since its resolution will be at least as good as the current SREF. However, the SREF runs require good surface/PBL analyses and physics to enable good forecast sounding thermodynamics, and the GEFS will be using the GFS PBL physics in its initial configuration, with no surface data being used in the analysis - this leads to the well-known inadequate GFS surface and PBL sounding forecasts that do not meet SPC minimum requirements. Another possible solution is to use the new regional version of FV3 (SAR) to accomplish this, but work on SAR has just started and no ensemble research with SAR has been done to date.

Recommendation: NOAA should quickly create and execute a plan to decide how to implement an equivalent of SREF for operational use that has satisfactory PBL thermodynamics. It is not recommended to continue use of NAM and RAP beyond 1-2 years. Hence we recommend the formation of a short-term task force or "tiger-team" to quickly incorporate surface data into the analysis system and test different combinations of surface and PBL physics in FV3GEFS. EMC already has experience, via the ARW and NMMB NAM runs, of what PBL schemes work well, and people at CAPS have already been testing these same schemes in the FV3. Perhaps this task force could do a trial run of Neil Jacob's "surge experimentation in the cloud" concept. The goal would be to get good sounding thermodynamics in 6 months. A second option would be to quickly acquire HPC resources for a HRRRE-based system with a larger ensemble size than HREF2.

Resource Requirements

Finding: Effective testing and R&D will require significant new HPC resources and highly capable and motivated personnel.

Development Approaches

Recommendation: NOAA should perform systematic numerical tests to resolve whether the FV3 C-D grid is adequate to predict the details of convection compared to a model employing a C-grid.

Scientific/Technical Challenges

Finding: Discussion in the community is ongoing on whether the CAM version of FV3 can forecast convection as well as other community models (C vs D grid issue). However, a more relevant concern w.r.t. grid structure may be how the CAM FV3 performs during the rapid-cycling DA mode that the HRRR and HRRRE currently utilize for their runs.

Recommendation: Test CAM FV3 performance in hourly (rapid-cycling) DA runs to assess stability, noise generation, analysis accuracy, etc. in the hourly analyses and subsequent forecasts.

Recommendation: FV3 developers should be encouraged to form closer collaborations with CAM R&D groups.

Open question: How should ocean feedback be incorporated into hurricane nests? Does this mean that FV3-GFS/GEFS is going to be a coupled model or just within the nests? If the latter, what does that mean for the GFS/GEFS roadmap?

2.5. Sub-seasonal to Seasonal Prediction

General Aspects

Finding: Society now embraces the importance of sub-seasonal to seasonal (S2S) prediction, which remains a very challenging problem.

Recommendation: There should be an analysis of the strengths, weaknesses, opportunities and challenges, including risks and benefits, of S2S prediction.

Technical Strategies

Finding: Coupled modeling for S2S is advancing and there is considerable engagement among different parts of NOAA, but NOAA has not fully embraced applying the UFS paradigm to coupled modeling across the entire organization.

Recommendation: NOAA's S2S effort should strive for internal coherence, collaboration and implementation planning extending across the OAR labs and the NWS development and implementation groups, to avoid straining resources and putting the strategic vision at risk.

Finding: There is some confusion over the forecasting time range associated with S2S prediction. The Weather Bill calls for prediction in the range of 2 weeks to 2 years lead-time, while the EMC plan only extends to 9 months.

Finding: There is a lack of clarity about whether the primary vision for S2S is a single (best) model or a combination of multiple models.

Finding: Multi-model approaches are currently used by the Climate Prediction Center (CPC) for S2S prediction. An important research topic is the evaluation of using a single modeling core with stochastic physics and varying initial conditions as an alternative approach.

Recommendation: NOAA should determine whether the long-term scientific strategy will actively support a multi-model/multi-institutional ensemble (with a diversity of models, configurations, and initialization strategies), and, if so, how this meshes with the UFS goal of having a single "best" model.

Recommendation: If the S2S strategy is to benefit from multiple models (e.g. the North American Multi-Model Ensemble - NMME - and the Subseasonal Prediction Experiment - SubX), then the OAR Office of Weather and Air Quality (OWAQ) should be making explicit commitments to long-term (10+ years) research support for these efforts in the research community.

Priorities

Recommendation: As in other areas, NOAA should determine the priorities of S2S research issues as informed by intended uses and outcomes.

Resource Requirements

Finding: NOAA's view of the resource requirements for advancing the science of seasonal prediction is not clear.

Development Approaches

Recommendation: NOAA should establish a SIP Working Group (WG) that will focus on S2S prediction.

Recommendation: NOAA should take the lead in creating an institutional structure for coupled model evaluation and improvements that will govern interactions with the other NOAA labs and academia collaborators, with clear and transparent definitions of the process, metrics and goals and responsibilities. NWS should develop a vision for the model they want to have 5 to 10 years from now based on the outcomes NOAA must deliver to the users.

Recommendation: NOAA should create a concrete plan for high-resolution coupled testing, including computing resources.

Scientific/Technical Challenges

Finding: The inability to capture timing and spatial structure of tropical convection in global coupled models is a key obstacle to skillful predictions.

3. Committee Members' Individual Findings and Recommendations

3.1. Comments from Cecilia Bitz

Cecilia Bitz is professor of Atmospheric Sciences and director of the Program on Climate Change at the University of Washington. Her research focus is on ice and climate interactions, especially involving sea ice. Her group is actively investigating Arctic sea-ice subseasonal to seasonal prediction and mechanism of climate change. The primary tools for her work are a variety of climate models, from simple reduced models to sophisticated Earth system models. She has been involved with the CESM project for two decades.

Subseasonal-to-Seasonal Forecasting

Finding: The S2S presentation was hard to follow, probably too little time was allowed for the presentation and more people should have been asked to speak. For this reason, it was hard to understand the S2S strategy and the rationale behind the priorities was hard to follow, and thus it is hard to offer recommendations.

Finding: It appeared that the staff were unsure about the future of the MME approach. It was unclear if they were asking for our view about it or if they were reviewing their need to create a long-term plans and strategies themselves.

Finding: A great many model configurations are being run now, some apparently for testing and some to produce products. The number of components that have tested NUOPC caps is impressive, but it also suggests an uncertainty about which components are needed and whether partially coupled configurations are needed in the long run.

Finding: The planned scheduled for UFS development is underway, despite an expectation that the DA system would not be ready for several years. It would seem that the metrics of success would depend on good initialization and the plan to use pure observations now for initialization seems problematic.

Finding: A set of priorities were given, which is a good sign. The plan to execute the priorities was not offered. The questions to the CMC listed in the presentation reveal the areas that need further effort, such how to improve communication and cooperation across the line offices and what are the best ways to meet priorities.

Recommendation: Spend time planning and responding to the questions prepared for the CMC. These seem to be the most important to me too. They include: discuss (1) how to improve coordination across the line offices, (2) what determines priorities, (3) what is the liability of waiting for DA to be developed and what to do if the schedule slips.

Finding: The back-and-forth about model capabilities with GFDL staff on the phone gave the appearance that cooperation is sub optimal.

Recommendation: Clarify the future support of a separate S2S model at GFDL and how it fits with the UFS.

<u>Other matters:</u>

Finding: The "community" modeling paradigm that is being promoted by management is not well articulated. As a newcomer to CMC, I gleaned from the presentations that NOAA wants the models to be available to the community to use and desires some input and team-work during the development, especially from the SIPs. We learned in the talks that engagement within NOAA, EMC especially, and of outside members on the SIP teams is sub-optimal. Engagement from university researchers in general in the NGGPS development process appears to be rare despite funding calls for this purpose; a possible reason is that codes are too immature and plans are undocumented. How output from prediction systems would be made available to the community was never discussed and seems to be an essential element of having an engaged community. The community can offer a great deal of diagnostic analysis that will help NOAA better understand its systems.

Recommendation: The meaning of "community" needs to be made clear, and then mechanisms need to be created to ensure engagement. To make models useful to others, documentation, tutorials, and liaison between the developers and users are needed. Model output needs to be made available with information about the model configurations from which they came. These need to be in-place during the development phase to allow the community to evaluate and scrutinize the developing components. This will help with by-in of the final model configuration choices.

Recommendation: A reward structure is needed to ensure engagement. We were told that funding is good, so it should be put to good use now to create collaborations and acquire resources and new hires to excite development teams. Ask the teams what they need and try to provide it.

Finding: Concerns about computing came up frequently. Staff thought there is a lack of planning about future computing expansion to keep pace with the increase in model resolution and complexity and intended new products.

Recommendation: Create a 5- and 10-year plan for computing and share it with staff. Encourage model developers to incorporate the plan for computing into their goals for model capabilities.

Finding: The phase-out of old products appears to be very conservative and is spreading resources and workforce thin during this development phase.

Recommendation: A cost benefit analysis regarding less-used products in the operational suite should be undertaken, recognizing that a cost of their production is slower and more limited development of NGGPS. Ask product consumers if a gap is acceptable if it results in a better future product.

Finding: JEDI promises a considerable opportunity to advance the DA capability. However, the JEDI development milestones are not well-aligned with NOAA's needs, and there is a significant risk that the JEDI project will not deliver some of the needed capability on time.

Recommendation: Understand the risks associated with JEDI development and the consequences to the NGGPS program.

3.2. Comments from Fred Carr

Fred Carr is McCasland Foundation Professor Emeritus, University of Oklahoma. He received his PhD in Meteorology from Florida State University under Dr. T. N. Krishnamurti, was a post-doc for Dr. Lance Bosart at SUNY-Albany, and has been at the University of Oklahoma since 1979. His research areas include numerical weather prediction, data assimilation, mesoscale meteorology and observing systems impacts. He served as Director of the School of Meteorology for 14 years, and has also served on the UCAR Board of Trustees and as the President of the American Meteorological Society in 2016. He is the past Co-Chair of the 2009 Major NCEP Review, the resulting UCACN and the UMAC.

NOAA Organization for Modeling R&D and R2O:

Finding: The NGGPS/UFS program (hereafter called UFS) has created a needed structure and governance to organize the development of an operational Unified Forecast System. It is led by a 26-member Steering Committee, and has 14 large Working Groups (WG) assigned to provide Strategic Implementation Plans (SIPs) to guide the development of the UFS. The community involvement implied by the 200+ members of the SC and WGs is impressive and desirable.

Finding: There is some concern that the SC's size prevents it from being as agile as it needs to be to move the UFS program forward as quickly as it could be. It also has a policy not to direct the actions of the WGs, leading to questions about who actually does the necessary priority-setting and who makes the final decisions on UFS development.

Finding: The WGs are not all equally effective, with some very active and progressive, and some almost inactive. Since all components of the UFS are important, this will lead to an ineffective UFS development, with progress being held up by the weak links. Also, in some cases the model developers at EMC (and elsewhere) and WGs are working closely, with well-coordinated plans, and in other areas the development work is not closely coordinated with WG plans.

Finding: There is now a useful hierarchy of strategic plans and roadmaps, from NOAA and NWS HQ levels to the SIPs and EMC Implementation Plan. The important tasks now are priority-setting, experimental design to resolve scientific or technical questions, and decision making.

Recommendation: The SC should assess its own membership on a continuing basis, and if some members prove to be inactive, they should be replaced by someone who will make significant contributions to the UFS program.

Recommendation: The SC should be very proactive in tracking the progress of the WGs. If they are not contributing in a timely and significant manner, new leadership should be found that will achieve the WG mission.

Recommendation: Each of the WGs should continually check to see if their group contains both the nation's best scientific talent in their area as well as the NCEP/NWS/NOAA personnel who are responsible for making progress on their topic.

Recommendation: The WGs should be charged with priority-setting responsibilities, including providing a recommended order of experimentation; they should help design the R&D experiments necessary to inform the decisions on operational implementations. The decision-making process should be articulated (e.g. – relative roles of the GMTB, JEDI, WG, SC, EMC and NCEP Directors, etc.)

Finding: Some components of the infrastructure needed for an effective community UFS are coming together, especially w.r.t. common infrastructure such as the CCPP. OAR personnel are making strong contributions. However, a support infrastructure for outside users is still lacking.

Recommendations: Support infrastructure (documentation, tutorials, workshops, workflow tools for easy use of UFS, help desk, computing resources, etc.) need to be made available as soon as possible. The support center should be at one location; - not all expertise has to reside there, but should be easily accessible. EMC should not be asked to be the support center. Serious consideration should be given to moving the support center outside of NOAA to facilitate cloud computing purchase, rapid security clearances, visitor support, etc. Efforts should be made to incentivize community participation in UFS development.

Finding: There is significant funding from NWS and OAR for research at the "low-end" of the technology funnel (TRL 6,7,8); e.g. NGGPS, JTTI, USWRP, HWRF, DTC, CSTAR, some NCEP testbeds, etc. Since NSF continues to support only research at the "high end" (TRL 1,2), there appears to be a funding gap at the middle levels (TRL 3,4,5) which would support research needed to make improvements to the UFS in the 3-5 year time frame.

Recommendation: NOAA leaders (especially in NWS and OAR) of the above and related funding programs should examine their total research and R2O program portfolio and coordinate them such that it is clear which ones should support efforts that provide an immediate (1-2 year) benefit and which ones should support longer-term goals. EMC leaders should play a prominent role in this effort to improve R&D and R2O/O2R coordination.

Convection-Allowing Modeling

Finding: The CAM SIP group is working effectively together, as its co-leaders are also leaders of the 5 organizations that are doing most of the work: EMC, GSD, GFDL, NSSL, AOML.

Finding: The CAM effort is a large one, since they need to find UFS equivalents to the following current operational forecast systems: NAM, NAM nests (4+), HIResW (5+), FireWxNest, RAP, RAP-Alaska, HRRR, HRRR-Alaska, SREF, HREF2, HWRF, HMON and perhaps others - most of these have different domains, resolutions, run cadence, physics, etc.

Recommendation: The CMC (and the community at large) would appreciate a mapping of how all the above forecast products are going to be replaced by UFS systems. The resulting chart should include the product name, domain, resolution, cadence, projection time, physics suite and other relevant information.

Finding: While the FV3 can do global nests, the start time required by CAM forecasts precludes use of the global version since it takes too much time to do the global analysis. Thus a Stand-Alone-Regional (SAR) model is being developed by EMC, GFDL, GSD and NSSL. This model can replace both the 12-13 km NAM-RAP models and serve as the ≤ 3 km CAM model.

Finding: The short-term replacement for SREF is problematical. In principle, the FV3GEFS would be the replacement, since its resolution will be at least as good as the current SREF. However, the SREF runs require good surface/PBL analyses and physics to enable good forecast sounding thermodynamics, and the GEFS will be using the GFS PBL physics in its initial configuration, with no surface data being used in the analysis - this leads to the well-known inadequate GFS surface and PBL sounding forecasts that do not meet SPC minimum requirements. Another possible solution is to use the new regional version of FV3 (SAR) to accomplish this, but work on SAR has just started and no ensemble research with SAR has been done to date. Use of HREF2 or HRRRE or its FV3 replacement is not currently possible because of the enormous computer resources a CAM resolution needs for the SREF domain and 84 hr projections - unless new HPC is acquired to address this issue.

Recommendation: Another possible option is to get decent surface-layer and PBL schemes into the FV3GFS and FV3GEFS as soon as possible, without waiting for the next major upgrade, which is 1-2 years away. That is, form a short-term task force or "tiger-team" to quickly incorporate surface data into the analysis system and test different combinations of surface and PBL physics in the FV3GEFS. EMC already has experience, via the ARW and NMMB NAM runs, of what PBL schemes work well, and people at CAPS have already been testing these same schemes in the FV3. Perhaps this task force could do a trial run of Neil Jacob's "surge experimentation in the cloud" concept. The goal would be to get good sounding thermodynamics in 6 months.

Finding: Discussion in the community continues on whether the CAM version of FV3 can forecast convection as well as other community models (C vs D grid issue). However, a more relevant concern w.r.t. grid structure may be how well the CAM FV3 performs during the rapid-cycling DA mode that the HRRR and HRRRE currently utilize for their runs.

Recommendation: Test CAM FV3 performance in hourly (rapid-cycling) DA runs to assess stability, noise generation, etc. in the hourly analyses and subsequent forecasts.

3.3. Comments from Alicia Karspeck

Dr. Alicia R. Karspeck is a Climate Scientist and Associate Director of Research Partnerships at Jupiter – a private company providing data and analytics services for the management of climate and weather related risk. Dr. Karspeck was formerly a research scientist in the Climate and Global Dynamics Laboratory at the National Center for Atmospheric Research, where she led the development of the ensemble data assimilation system for the Community Earth System Model. Her specific areas of expertise are ocean and coupled ocean-atmosphere data assimilation using state-of-the-art global climate models, and the extension of that work to probabilistic near-term climate prediction. Dr. Karspeck has served on a number of national and international science working groups, has served as a content-expert editor for the Journal of Geophysical Research, and publishes in academic journals on data assimilation and decadal climate prediction. In addition to her work in climate, Dr. Karspeck also collaborates with researchers in the field of public health and is co-founder of SK Analytics – commercializing real-time influenza forecast technology developed at Columbia University. Dr. Karspeck holds bachelors and master's degrees in Mechanical Engineering, and holds a Ph.D. in atmospheric science and oceanography from Columbia University.

Overall finding/recommendation:

Finding: The problem of limited HPC resources available for i) increasing the fidelity/complexity/resolution of forecast and DA systems, ii) engaging in necessary experimentation/testing of modeling systems, iii) providing compute resources for an expanding community of user/developers was mentioned as a pressing challenge for multiple subject areas *(resource limitations)*.

Recommendation: NOAA OAR and NOAA NWS should be developing a holistic short-term and long-term plan for meeting and managing their operational and research-oriented computing and storage needs. In the long-term this may need to include the articulation of a "cloud-forward" strategy for gradually increasing their use of cloud (or virtual machine) compute and data-hosting in conjunction with traditional HPC. In the near-term there appears to be a need to set realistic priorities -- *which may effectively mean a reduction in expectations* -- in order to help NOAA employees manage with limited compute.

Improving O2R and R2O

Finding: NOAA EMC was clear/consistent in their view that there would be a long-term payoff from leveraging the talents and research energies of a broader academic/research community. The reorientation toward a smaller suite of models, and a unified forecast modelling framework (including standardized coupling infrastructure and modular physics packages) is an aspect of community modelling that appears to have been embraced across groups and management levels. The materials presented and the discussion during the CMC meeting suggested that most of the work toward unified and community modeling was focused on the infrastructure ("plumbing") aspects of this endeavor as a necessary condition. However, except when raised by the committee, there was little acknowledgment of the cost (in terms of human resources, workflow and software development/management/support), increasing access to computing resources) of community engagement and management of the O2R tech transfer or which programs within (or outside) NOAA would bear that cost.

Recommendation: NOAA EMC and NOAA OAR should be budgeting for the costs of community engagement, designating specific programs (or employees) that are accountable for building a community and articulating the incentives that will drive NOAA programs and employees to orient their activities in this new direction.

Finding: It is unclear whether NOAA OAR or NOAA NWS has a clear vision of how (or if) other US agencies (who are contributing to research funding in the US) will participate in this community effort. The possibility of further fracturing the U.S. climate modeling enterprise was not addressed.

Recommendation: NOAA should be developing MOA/MOU with any U.S. funding agency that currently supports ocean/atmosphere modeling/forecasting that is relevant to the unified modeling system. To the extent possible, these should clearly outline who is financially responsible for one-time and ongoing infrastructure investments and maintenance.

Finding: OAR is committed to supporting the research that is being prioritized by the line offices and aims to understand those requirements through frequent high-level coordination.

Recommendation: In a community modeling paradigm, OAR program officers should be increasingly cognizant of whether NWS is providing sufficient access to software engineering/compute/working code releases/documentation to allow academic grantees to successfully contribute to the enterprise.

Finding: A "gatekeeping" process is necessary to ensure that the O2R process results in *high-qualit*y tech-transfer from research to operations. It was acknowledged that a key element of this is the establishment and *public exposure* of *common metrics and testing/evaluation processes* for each model (or system) that hopes to benefit from community engagement. It was noted that the V&V working group is responsible for this activity.

Recommendation: NWS should put forth a clear statement of who (or what entity) is the ultimate arbiter of what becomes part of the operational suite, and what criteria (objective or subjective) play into those decisions. Transparency of process and governance to long-term community engagement.

Data Assimilation

Finding: Regarding coupled data assimilation roadmap: The materials accurately articulate the primary challenges associated with coupled DA - but it remains unclear what mechanism/resources will be used to address these, which of these issues will be prioritized, "for what explicit purpose" coupled DA would be employed (e.g. what is the prioritized timescale?), and where the authority and accountability for progress on these will reside.
Recommendation: In the DA roadmap document (in development), NWS should be explicit about what outcomes it hopes to achieve by engaging in coupled data assimilation. These articulated

outcomes should be used to prioritize the infrastructure and research topics that need to addressed, and where the authority and accountability for progress on these outcomes will reside and where funding will come from.

Recommendation: NWS project/program leads should explicitly communicate a *limited set* of critical coupled-DA priorities to OAR program leads as well as actively engage existing NOAA expertise in coupled DA (within NCEP, within GFDL). NWS and OAR should refrain from requiring research explicitly within the JEDI framework until the JEDI framework has mature/supported interfaces for coupled DA or unless the research funding is earmarked for "JEDI development"

Finding: A long-term (10-year) goal to have one "unified" DA team within NWS is an important and laudable goal for the advancement of multi-component ("coupled") data assimilation.

Comment/Recommendation: Determination of what coupled DA method and configuration set is adequate/appropriate for a specific application (e.g. global S2S vs. regional/continental CAM) suggests that even if there is one "unified DA team," there will be a need to support a variety of systems.

Finding: The success of the DA enterprise is critical to the overarching goal of improving weather/climate forecasting in the US. This activity is particularly vulnerable to the problem of insufficient HPC resources to accomplish internal evaluation, testing, tuning and comparison of methods.

Recommendation: In the short term, there is a need to prioritize (and perhaps scale back) the DA activities in light of these limited resources.

Finding: The idea of virtual (cloud-based) machines to provide "burst" computing to accomplish some of the most critical DA experiments is promising. However, these virtual machines will not be out-of-the-box EC instances -- but specialized machines that will have to be built as part of a negotiated process with cloud providers.

Recommendation: The compute, communication and data-movement needs of DA (specifically) need to be articulated to any NOAA decision makers that negotiating the specifications of virtual machines.

Findings (related to JEDI): The JEDI concept (modern programming, standardization, separation of concerns) is a positive direction for NOAA.
Incremental implementation of the JEDI components (e.g. UFO; as they become available) into current operations is rational plan to avoid pitfalls associated with a full forklift.
It was unclear how NOAA NWS would staff their interactions with JEDI and transition to a JEDI infrastructure without crippling the current DA efforts.
As posed in these discussions, JEDI is now in the critical path of core improvements to the GSI (The 4DVar and 4DEnVar intercomparisons that will lead to an operational roll-out). Clear timelines as to when co-development will begin at EMC and the number of FTEs that will be

assigned would be useful. We understand that these will be in the planning document that D. Kleist will provide.

Recommendations (related to JEDI):
It would be very valuable if the NOAA DA team could put in place a science plan that can act as a "plan-B" regardless of what transpires with JEDI.
More NWS DA should be contributing to the JEDI development now, so there is not a significant spin-up as this system becomes operational.
If the JEDI framework is going to be the preferred by the NOAA community, it would benefit from a more transparent governance structure and a clear sense of how it is accountable to NOAA/NWS goals.
In order to attract an academic community to use the JEDI system in a way that is useful to R2O, the NWS DA should *articulate, expose, and support* a set of "simplified models" that they believe will be relevant to any operational products
The inclusion of ensemble management software and ensemble-based DA algorithms will become increasingly valuable when there is movement toward rapid prototyping.
Clarity on who will lead the community engagement on behalf on NOAA is needed. JEDI includes community as part of its mission and orientation -- is NOAA relying on this?

Subseasonal-to-Seasonal Forecasting

Finding: For S2S, it is not clear whether the *long-term* scientific strategy included active support of a multi-model/multi-institutional ensemble (with a diversity of models/configurations/initialization strategies), or whether the goal was to have a single "best" model developed within NWS.

Recommendation: If the strategy is to benefit from multiple models, then OAR should be making explicit commitments to *long-term* (10+ years) of support into coupled-climate model research and quasi-operational seasonal forecasting.

Finding: NCEP and GFDL did not appear to be moving toward a "unified" seasonal prediction strategy. GFDL and NCEP expressed very different objectives when it comes to climate prediction.

Comment: While similar model component sets are being used, it is unclear whether they are using the same "infrastructure" for S2S.

Comment: Regarding S2S, there was a clear tension between the value of research and value of operationalization. One interpretation of this is that S2S science is not sufficiently mature to warrant a NOAA-wide orientation toward operational constraints and objectives. Quote from Jessie Carman: "Skill of S2S leaves much to be desired."

Finding: It is likely that the diversity of models within the NMME will dry-up if OAR puts "higher weights on projects that use the unified forecast system."
Recommendation: NOAA should reconsider whether S2S outcomes will truly benefit from being included in a unification effort. A key part of the current S2S operational strategy (NMME) is

reliant on diverse groups running their own modelling systems, with their own assimilation systems, etc.

3.4. Comments from Jim Kinter

Jim Kinter is the Director of the Center for Ocean-Land-Atmosphere Studies (COLA), and Professor and Chair in the department of Atmospheric, Oceanic, and Earth Sciences (AOES) at George Mason University. After earning his doctorate in geophysical fluid dynamics at Princeton University in 1984, Dr. Kinter has conducted or supervised research in climate variability and predictability as well as serving on many review and advisory panels for both national and international organizations.

Organizational Principles for Research and Development and the Transition from Research to Operations:

Finding: The NWS and OAR commitment to collaboration at the highest level is a very positive development that has the potential to help NOAA achieve its mission.

Finding: There has been tremendous progress in the areas of organizing research and development (R&D) within NWS, within NOAA, and across a broad range of partners including other operational entities within the Federal government, academic institutions, and, to a lesser extent, the private sector.

Finding: NOAA's transition toward a unified approach to developing and implementing models to provide guidance for its operational products and services is already delivering dividends in terms of exciting the community, focusing planning efforts and revealing risks and barriers to progress. The recent effort to involve the community external to NCEP in the development of NOAA models through the NGGPS-sponsored Strategic Implementation Planning (SIP) process has been especially positive in terms of engaging the community, accelerating development, and improving the flow of ideas toward operational implementation.

Finding: This progress in organizing R&D has occurred against the backdrop of resistance to change that is systemic within NOAA due to its separation of research in OAR from the development and implementation activities in NWS and other line offices. NOAA is addressing this issue through good will on the parts of OAR and NWS, including various coordination mechanisms such as memoranda of agreement (MOA) and service level agreements (SLA).

Finding: NOAA has been very proactive and responsive to the advice it has received from the University Corporation for Atmospheric Research (UCAR) Community Advisory Committee for NCEP (UCACN) and its subcommittee, the UCACN Model Advisory Committee (UMAC).

Recommendation: NOAA should find more lasting and fundamental ways to facilitate more effective and efficient transition from research to operations and from the research community to those responsible for transitioning methods and products to operations.

Finding: A structure has evolved through the SIP process, composed of a large number of Working Groups (WG) that all operate on several organizing principles: (1) evidence-based decisions with metrics and benchmarks; (2) a common scientific/technical base that is the FV3-based Unified

Forecast System (UFS); and (3) a common shared infrastructure built on the Earth System Modeling Framework (ESMF), the National Unified Operational Prediction Capability (NUOPC) and National Environmental Modeling System (NEMS). This structure has been initially effective at engaging and enabling people within and outside NCEP and exposing issues that need attention. The common shared infrastructure was recommended by the National Research Council in its 2012 report on a national strategy for climate modeling.

Finding: A memorandum of agreement (MOA) is under development between NOAA and NCAR to provide infrastructure support for UFS. The relationships between (parts of) NOAA and other entities, as shown in the Community Modeling diagram, particularly relating to scientific aspects of UFS development, are not as well defined.

Finding: There are aspects of the SIP organization that are cumbersome, with possibly too many WGs and improper alignment of R&D issues with WGs – these issues are being addressed in the SIP and WG meetings.

Finding: While the technical aspects of building the UFS and the WGs that are dedicated to technical issues are making good progress, the structure of, and coordination across, the WGs lacks a scientific focus.

Recommendation: NOAA should develop a process or institution whereby the scientific aspects of UFS R&D can be addressed, including the formulation of scientific questions to drive innovation and the scientific review of plans and progress.

Finding: Another issue with the WG structure is that the large number and diversity of topics of the WGs demands a firm guiding hand that has real authority and resources to allocate. Whether or not this should be the role of the UFS Steering Committee (UFS-SC) is an open question.

Recommendation: The UFS-SC should be given authority to review individual WGs as well as the overall structure of the WGs and their interactions, with a clear set of review criteria published in advance, in order to more effectively organize SIP activities.

Finding: The principle that R&D is driven by operational requirements and outcomes is positive, because it can provide a basis for defining success and planning progress toward success. However, the final transition to operations, involving cyber-security and other considerations by the NCEP Central Operations (NCO), remains a bottleneck.

Recommendation: NCEP and NWS should take steps to establish and continually improve two-way communication of requirements and decision processes between stakeholders, operations, and R&D teams.

Finding: Other important elements of supporting a community modeling initiative include (1) sufficient computational resources for research and development; and (2) user support (training, liaisons, documentation and sample workflows). This has been recognized by several community modeling efforts, notably the Community Earth System Model (CESM) hosted by the National Center for Atmospheric Research (NCAR).

Recommendation: NOAA should seek, identify and allocate resources for these important aspects of supporting the community, adopting best practices from other such efforts.

Finding: The schematic diagram labeled UFS NWS Operational Applications is a clear and better organized plan for providing model guidance for operational products at various lead times than its predecessor, often referred to as "the Quilt".

Finding: The linkage from the UFS global model and DA to the regional applications – the Rapid Refresh Forecast System (RRFS), Warn on Forecast System (WOFS) and National Water Model (NWM) is a one-way flow of information. There may be relevant and valuable information that could flow from the regional applications, particularly the NWM, to the global model.

Recommendation: NWS and the UFS-SC should more fully engage the Office of Water Prediction (OWP), its advisory committee, and the developers of the NWM in the UFS planning and evaluation process.

Finding: The Environmental Modeling Center (EMC) has re-organized into a model and DA group and a validation and verification (V&V) group. There are plans for model testing being developed by EMC, ESRL and the broader community. There is a SIP WG focusing on V&V. It is not clear how all these efforts are being integrated and coordinated.

Recommendation: NOAA should ensure that the plans for testing that are being developed by the various groups are well coordinated and that duplication of effort is minimized. There should be an external peer review of the scientific and technical aspects of test plans.

Subseasonal to Seasonal Prediction:

Finding: Coupled modeling for Subseasonal-to-Seasonal prediction (S2S; where sub-seasonal is defined as lead times from 2 weeks to 3 months, and seasonal is defined as lead times of 3 months to 2 years) is advancing, and the SIP process for developing the UFS is working. This is particularly apparent in the work being done on infrastructure to support the coupled model.

Finding: This recent progress is in contrast to the last several years during which progress toward the next generation coupled model for S2S was slow or stalled. Progress on S2S has been slow for many reasons, including lack of scientific understanding of the sources of predictability and how to exploit them, uncertainty about how best to address the scientific questions (e.g. should convection-allowing models be applied to sub-seasonal forecasts?), over-reliance on a long, serial and taxing vetting process that entails years of testing and evaluation, overemphasis on metrics that are not necessarily the only or best choices for advancing the coupled model, some discontinuities in the "funnel" from basic research to applied research to implementation and operations, and internecine disagreements.

Finding: The organization across NOAA has not fully embraced the UFS paradigm, and the cooperation among labs is not yet fully functional.

Recommendation: NOAA, both NWS and OAR, should make a systematic assessment of the scientific and technical barriers to progress in S2S prediction and develop a single plan that addresses these barriers.

Recommendation: NOAA, across its line offices and laboratories and vertically within each part of the organization, must fully embrace the notion of a single modeling framework that all operational and research entities employ.

Finding: As recommended by Congress in the S2S prediction section of the "Weather Bill" of 2017, there are many NOAA S2S planning efforts underway, including the UFS SIP process, S2S planning to exploit the Hurricane Supplemental funding, a NOAA white paper for a "joint center" approach, and others. It is not clear how these various planning efforts are being coordinated or evaluated.

Finding: The operational generation of S2S forecast products has for several years relied on the availability of multi-model ensembles – the North American Multi-Model Ensemble (NMME) for seasonal prediction and an experimental sub-seasonal multi-model ensemble called SubX. The plan going forward is to focus on the development of UFS applications for sub-seasonal and seasonal prediction, while exploiting quasi-operational activities by other agencies that are producing S2S forecast guidance in real time. It is not clear if the Geophysical Fluid Dynamics Laboratory (GFDL), which is developing its own model called SPEAR that is not a UFS-based system, is viewed as "another agency" in this regard.

Recommendation: NOAA should develop a long-term scientific strategy that determines whether the goal for S2S prediction is a multi-model/multi-institutional ensemble (with a diversity of models, configurations, and initialization strategies), or a single "best" model developed within EMC.

Recommendation: Whichever strategy is adopted by NOAA, the Climate Program Office (CPO) and the Office of Weather and Air Quality (OWAQ) of OAR should make explicit commitments to long-term (10 years) research support for these efforts in the research community**.**

Finding: The plans for developing and testing the next generation coupled system for S2S are nearly mature. It is not clear what input from the scientific community was solicited or received in the development of the plans, especially the test plan.

Recommendation: The NWS and OAR should establish an institutional structure for coupled model improvement and evaluation that will govern interactions with the other NOAA labs and academic collaborators, with clear and transparent process, metrics and goals and responsibilities. The NWS should develop a vision for the coupled model needed in 5 to 10 years based on operational outcomes.

Other Aspects:

Finding: There are separate but parallel developments of infrastructure and code for the UFS and the JEDI-based DA system.

Recommendation: NOAA should better coordinate these efforts.

Finding: There are aspects of ocean-atmosphere interaction in the development of the convective-allowing model (CAM).

Recommendation: NOAA should ensure that design, testing and implementation efforts in S2S and CAM are well coordinated.

3.5. Comments from Cliff Mass

Cliff Mass is a Professor of Atmospheric Sciences at the University of Washington and he directs the real-time modeling of the NW Regional Modeling Consortium. He has a B.S. in Physics from Cornell University and a Ph.D. in Atmospheric Sciences from the University of Washington.

NOAA Organizational Principles for Modeling R&D and R2O

Finding: Major improvement of cooperation between NWS/EMC and NOAA ESRL. There has been a notable and important improvement in the level of cooperation between the National Weather Service and NOAA research efforts, many of which are in ESRL.

Finding: Lack of organization and wasted resources for R&D for NOAA NWP. There is no effective overall planning and organization for U.S. NWP. Responsibility and financial resources are divided over a number of entities within NOAA. Strategic planning is superficial and inadequate.

Recommendation: Need an organizational structure to prioritize and fund research and development gaps.

Finding: Acute lack of computer resources for both operational NWP AND R&D. Problems are apparent in the procurement of NOAA/NWS computer resources (e.g., lack of storage and data transfer bandwidth.

Finding: The NWS lacks the computer resources necessary for its core mission. Enough resources to run a large (~50 members) global hydrostatic-scale (e.g. 12km) ensemble and a CAM ensemble (30-50 members) over the U.S. Model development groups need vastly more resources. Operational capacity should be at least 100 times greater than current (current about 5 Pflops, need 500); there is a similar need for research HPC.

Recommendation: NOAA/NWS needs to give more priority to computer resources for research. Operational NWP could profitably use 100X more computer resources then possessing today.

Finding: The SIP groups have been provided useful discussion venues, but it is not clear whether they are effective tools for prioritization and community organization.

Recommendation: Standing committees of NOAA and other scientists should be established for every major aspect of operational modeling. They should provide strategic planning and oversee R&D in their respective areas.

Convection-Allowing Modeling

Finding: The performance of FV3 for convection-permitting resolution is not clear.

Recommendation: Careful evaluation for a range of events is required.

Finding: The operation HREF CAM system is too small and non-optimal.

Recommendation: The U.S. requires a far larger national CAM ensemble system with more realistic spread characteristics.

Finding: CAM has potentially great promise on the global scale. Initial results suggest that having sufficient resolution to remove convective parameterizations could result in substantial improvement in global skill at subseasonal and greater time scales. This should be explored, leading to operational implementation if beneficial.

3.6. Comments from Rohit Mathur

Rohit Mathur is a Senior Scientist in EPA's Office of Research and Development, where he is responsible for developing and executing an interdisciplinary research program to produce advanced models that can simulate the transport and fate of air pollutants. His research deals with the development of methods to represent the physical and chemical behavior of atmospheric pollutants in comprehensive modeling frameworks. He has served in numerous leadership and science management positions and has been involved with the development of several large-scale air pollution modeling systems.

NOAA Organization for Modeling R&D and R2O

Finding: The NWS and OAR commitment to collaborate and to engage the external community is a very positive step in the development, deployment and evolution of the unified modeling system. Both R2O and O2R would benefit from a more deliberate plan to engage the broad external community.

Recommendation: Develop a plan and devote resources to enhance community engagement and "training" (e.g., tutorials and training courses, model help desk, data sets for model execution and analysis).

Recommendation: Collaboration between NWS and OAR could be enhanced through creation of temporary detail opportunities which enable OAR model developers to work at NWS on targeted R2O projects that help meet specific operational implementation and testing targets.

Data Assimilation and Convection-Allowing Modeling

Finding: Both the DA and CAM evolution in the UFS can benefit from more explicit (rather than an after the fact) consideration of atmospheric composition in their overall designs. Modulation of radiation during episodic dust outbreaks and wildfires can significantly impact temperature predictions and consideration of aerosol burden, optics, and/or radiation in the data assimilation system could be beneficial. Assimilation of lightning information can not only help constrain NO_x emissions but help improve model skill in placement and duration of convective activity and atmospheric deposition amounts. Aerosol aware cloud scheme are now also being shown to be beneficial for numerical weather prediction applications.

Recommendation: A more explicit consideration of coupling atmospheric composition treatment with the dynamics will be beneficial for the long-term evolution of the UFS. The design of the data assimilation system and the CAM schemes should consider linkages with atmospheric composition. This could be facilitated through greater interactions with the Unified Modeling Strategic Implementation Plan (SIP) working group on Aerosols and Atmospheric Composition.

Subseasonal to Seasonal Prediction

Finding: The S2S program presents many exciting but challenging opportunities and several efforts devoted toward exploring forecasting on timescales from weeks to multiple years are underway across NOAA. Given the broad scope inherent across these disparate time scales, these efforts as presented at the meeting came across as being somewhat disjointed.

Recommendation: R2O efficiencies and coordination in the S2S program could be further improved through clearer identification of the key end applications that the program should target. For instance, approaches to forecast seasonal precipitation amounts (for use in agriculture applications) could be distinctly different from that needed to forecast incidence and frequency of wildfire outbreaks (for land management and human exposure). Identification of specific key applications and end users could help better define both short- and long-term strategies for the model infrastructure (single, multi-model, multi-institutional), science needs and component models/sub-models, metrics to measure progress and success, and help streamline efforts across NOAA.

3.7. Comments from Richard Rood

Richard Rood is a Professor in the Department of Climate and Space Sciences and Engineering CLaSP) at the University of Michigan. Prior to joining the University of Michigan, he worked in modeling and high-performance computing at the National Aeronautics and Space Administration (NASA). He presently serves as the Co-chair of the Unified Forecast System – Steering Committee. Rood is an ex-officio member of the CMC.

Principles for NOAA organization of research and development (R&D) and the transition from research to operations (R2O)

It is positive to see OAR and NWS talking about better alignment of research with operational priorities. It remains to be seen if there will be substance in the statements. The potential of significant turnover in key positions in middle management requires development of plans and practice to assure continuity and execution of sentiments for increased coordination. There is opportunity and risk in these changes in leadership.

The MOA with NCAR is important, and it needs to be signed. Continued delay in signing the MOA detaches it significantly from its authors and leadership at the time. Further, continued delay sends a negative message about NOAA's commitment. Details of the agreement need to be developed by technical experts and line managers. The expectations associated with the MOA need to be tempered by its implementation.

The Unified Forecast System needs to emerge as the centerpiece of NOAA predictive modeling strategy and implementation. This meeting was an opportunity for NOAA to take credit for some of its successes in the past 3 years with the dynamical core selection and the major transition to FV3-GFS. It was an opportunity to discuss the emergence of coupled model capabilities, its testing, and its implications for the forecast suite. These opportunities were squandered at the meeting. Indeed, the absence of these successes (and more) in management presentations was demoralizing.

The Unified Forecast System – Steering Committee has recently published a description of R2O transition process. The R2O transition process must be better described before NOAA can make real progress on integrating research and operations. The R2O process needs to be considered in programmatic and organizational decisions at all levels in research and operational development spending. The Steering Committee's R2O document defines a framework suitable for work force planning and the execution of organizational goals. This description needs to be utilized and updated as we gain experience.
(http://www.earthsystemcog.org/site_media/projects/ufs-sc/2018.11.30_UFS-SC_Describing_the_Research_to_Operations_Interface.pdf)

NOAA has made significant progress with the SIP plan. This is important as there have been many years of planning, but seemingly, tabling the plans as if the planning documents were an end unto themselves. The continued use of vetted planning documents and development of community-based strategies and actions is critical. NWS and OAR need to stand up the executive function for the UFS-SC (Technical Oversight Board) so that the decisions and coordinating efforts of the UFS-SC can be resourced and implemented. The SIP process is a success in progress.

Accelerating advancements in NOAA's data assimilation (DA) capabilities

The Data Assimilation activities are the highest risk activities of the Unified Forecast System. NOAA has created an organizational purgatory with the Joint Center that separates the needs of the Unified Forecast Systems in the next three years from the long-term vision associated with JEDI. There is a reliance on JEDI that is unwarranted, given the lack of knowledge of JEDI's design and testing criteria. The JEDI project is difficult to engage; indeed, it is dismissive of the need to understand the requirements and architecture of the Unified Forecast System. This has the potential for system-scale failure.

NOAA needs to clarify the relationships between the operational mission, the evolution of the Unified Forecast System, JEDI, and the Joint Center. The Unified Forecast System – Steering Committee needs to develop a coherent and stable position on the needs for data assimilation and the co-development of data assimilation capabilities with community partners.

Unifying NOAA's convection-allowing/resolving modeling (CAM) approach

There has been significant improvement on the coordination of the activities associated with the stand-alone regional parts of the production suite. This was evident at the meeting and it has advanced since the meeting with a CAMDesign activity coordinated by the Unified Forecast Committee – Steering Committee. With regard to operations, the stand-alone regional model is central for the next 3 years. This includes both the CAM and non-CAM applications of the stand-alone regional model. These coordination activities need to be supported, and funds need to allocated as a work plan is developed.
(https://www.earthsystemcog.org/projects/ufs-sc/CAMDesign)

The model developments that focus on nesting and adaptive mesh refinement are in technical and organizational confusion. This is an activity that would benefit from active project and program management, as well as technical and scientific based projects focused on specific goals.

Advancing NOAA's subseasonal to seasonal (S2S) forecasting skill

As presented at the meeting, this activity revealed deep organizational divisions within NOAA. The meeting was dominated by the research activities at GFDL being, seemingly proffered, as an alternative to the Unified Forecast System. There was no real consideration of how such an alternative would fit into the operational suite or, indeed, make the transition to operations. Therefore, this presentation was, fundamentally, divisive. Unfortunately, this discussion came at the expense of burying important progress and testing with the coupled model that has and is occurring at EMC.

This is situation where it is critical for NOAA to 1) Define the R2O process and consider that process in its evaluation of modeling capacity. 2) Provide a description so that research activities have a path to follow to operations, rather than being posed as disrupting alternatives. 3) Articulate a stable foundation of the UFS, FV3-GFS, systems architecture, etc. and focus and build on that foundation. 4) Align research and operational funding and strategy with more transparency and stability.

3.8. Comments from Elena Shevliakova

Elena Shevliakova is a senior climate modeler in the Ecology and Evolutionary Biology group at the Geophysical Fluid Dynamics Laboratory of NOAA. She is the co-chair of the Land Model Development Team.

Subseasonal to Seasonal Prediction

My comments are based on the slides, including supplementary materials from the S2S panel members, and the SIP appendixes provided before the meeting. The main presentation did not give a clear OAR/ NWS vision for future S2S goals, challenges, tactics, and strategies to address them, nor intended outcomes, short-term and long-term specific model biases-improvements.

Findings

1. NOAA S2S portfolio presently includes different types of internal projects and collaboration with other agencies and academic institutions:

- Operational GEFS week 3&4 forecasts;
- OAR labs and external to NOAA research/operational models, e.g. Numerical Multi-Model Ensemble real time seasonal prediction with 8 models CFS; GFDL/CM2.1, FLOR; NASA/GEOS-S2S; NCAR/CESM1, CCSM4; CanCM3
- Sub-seasonal prediction eXperiment (i.e. SubX) with 6 models: CFS, GEFS, Navy, NASA/GEOS5, NCAR/CCSM, Canadian model;
- OAR lab development of sub-seasonal-seasonal-decadal prediction
- External to NOAA research projects funded previously by CPO and now by OWAQ;
- Service Level Agreement (SLA) projects (not described);
- R2O projects.

2. NWS/OAR is transitioning to the Unified Forecast System (UFS) capabilities which has been actively developed in NOAA OAR labs (particularly by ESRL labs), EMC, NCAR, NASA, and Navy.

3. While development of UFS capabilities are coordinated through the Strategic Implementation Plan (SIP) working groups comprised of a variety of academic, government, and private sector researchers, the resources for implementation have been mostly requested by NOAA OAR labs, NCAR, and EMC.

4. It appears that the academic community at large is not yet involved in the development of capabilities for the S2S applications based on the UFS and does not have access to the S2S applications code.

5. There is a difference of opinion among NOAA labs about the strategies necessary to vet the applications intended for the seasonal prediction. NOAA/GFDL is advocating an approach previously adopted in CM2.1 and FLOR-based coupled-climate prediction systems and advanced by the new GFDL SPEAR system, which requires a prior vetting of a coupled-climate model on

the decadal to century times scale to obtain initial climate model conditions, particularly for the deep ocean. NOAA/EMC's and NOAA/ESRL's view is that the UFS-based seasonal (i.e. 9 months) predictions could be initialized the same way as 3-4 week sub-seasonal predictions aided by improved data assimilation.

6. My understanding is that seasonal prediction is defined as up to 2 years by the recent congressional documents. The EMC plans for the SFS system appear to be up to the 9 months only.

Recommendations

1. NOAA OAR/NWS needs to develop a vision for how their S2S portfolio may change as UFS capabilities come on line, and taking into account the implications for partners involved in NMME and SubX.
2. The scope and the process by which the larger academic and public sector community can participate in the UFS development needs to be clearly articulated.
3. It appears that SIP working group participants from NOAA labs, NCAR, and other agencies became the majority of the Core development partners and Trusted super-users. There is a need to establish an independent review process to assure that the UFS-based application developments result in the world-class S2S prediction capabilities grounded in the latest advancement from the broader academic community.
4. There needs to be a more explicit discussion and perhaps evaluation of different approaches to initialize seasonal climate model predictions. It's not clear that the proposed coupled data assimilation will be sufficient for initialization of subsurface ocean state and it's not clear how the ocean model ensemble perturbations will benefit the coupled system predictive skills.
5. There needs to be a discussion in OAR/NWS how to advance predictions beyond the currently planned 9-month capabilities.

3.9. Comments from Ryan Torn

Ryan Torn is an Associate Professor at the University at Albany, SUNY specializing in predictability, data assimilation, and ensemble forecasting. He is the co-author of 43 peer-reviewed publications and has been a principal investigator on research that has been funded by NSF, NOAA, and ONR. He earned his PhD from the University of Washington in 2007.

Data Assimilation

Finding: Given the inherent limitations of the current GSI code and transition to coupled data assimilation approaches, I endorse the JEDI strategy. While this will lead to some short-term issues and DA development may be limited, this new framework allow for more fundamental long-term DA advances once JEDI is fully built out, which includes the ability to carry out coupled DA.

Recommendation: All data assimilation resources appear to be directed toward the development of the JEDI framework; however, it appears that all new advances in DA techniques (i.e., testing of 4DENSVar vs. 4DVAR) are on hold until JEDI is ready. As a consequence, it appears that the UFS atmospheric data assimilation system will not see any substantial advances until JEDI is built out. OAR/OSTI need to make sure there are sufficient human resources available to carry out both the JEDI development and to test new DA advances while JEDI is being developed (resource requirement). This could include using supplemental funds.

Recommendation: EMC should develop a list of operationally-relevant simplified models and configurations that the external community (i.e., outside of NOAA) could use within proposals to demonstrate new DA methods (i.e., research at the top of the funnel). This could increase community participation in DA since many in the external community have difficulty using the operational DA systems due to lack of documentation and computational resources. Moreover, OAR/OSTI should be able to identify and fund projects that intent to make use of these configurations.

Recommendation: It is critical for EMC personnel to be involved in the development of the core JEDI infrastructure now and not wait to be involved in the code development until JEDI is ready for an operational transition. Having EMC people involved now will reduce the “spin-up” time needed for EMC personnel to understand the code.

Convection-Allowing Modeling

Finding: I strongly endorse the strategy of consolidating the NAM/SREF/HWRF capabilities into the FV3 GFS/GEFS and prioritizing FV3 developments that would accomplish this.

Recommendation: ESRL/EMC personnel should reach out to other NCEP centers (i.e., beyond SPC) to determine their usage of the legacy models (NAM/SREF/HWRF) and prioritize FV3 development around addressing the FV3 shortfalls that would allow for the discontinuation of the legacy models.

Recommendation: EMC/HRD and UFS personnel need to consider how to handle ocean coupling for TCs. Currently, the GFS/GEFS plans seem to suggest an uncoupled to the ocean. Adding ocean coupling for TCs will have impacts on other aspects of the model; therefore, this should be addressed soon.

Other Matters

Recommendation: NOAA leadership needs to develop a clear S2S strategy that (i) clearly defines the applications and metrics for such a modeling system and (ii) makes best use of the limited resources. Given the inherent funding limitations, this should include consolidating the S2S efforts at multiple NOAA labs.

Recommendation: EMC & management needs to develop the proper set of "carrots and sticks" that encourage EMC personnel to work closely with OAR lab personnel to enhance the R2O and O2R process (i.e., science and operations problems informing each other, with joint work throughout the process). Furthermore, OAR should prioritize funding toward lab activities that have a clear R2O path and incentivize work within the labs that occurs in conjunction with operational personnel.

Recommendation: OAR/OSTI need to increase funding toward the top of the funnel, rather than just at the middle of the funnel (i.e., work that is 3-5 years away from operational implementation). This will encourage more in the university community to engage in research that is beneficial to the operational model since many in the university community work on longer timescales.

3.10. Comments from John Wilkin

John Wilkin is active in ocean modeling and remote sensing of coastal ocean and boundary current processes, using variational methods for data assimilation, sensitivity and predictability analysis, the design of observing networks, and real-time forecast systems. He serves on the GODAE OceanView Science Team, co-chairs the Ocean Observation Physics and Climate panel (OOPC) of the UNESCO/IOC Global Ocean Observing System (GOOS), and is an associate developer of the Regional Ocean Modeling System (ROMS).

I was unable to attend the meeting in person due to other professional commitments, which also limited the time available for me to participate remotely. Of the talks I was able to monitor remotely I have remarks only on the presentation by Ming Ji on Research to Operations considerations, and these are more forward-looking and strategic than specific to the presentation.

Research activity in coastal oceanography is predominantly within the academic community, with innovation in applied coastal prediction (including sustained real-time operations) driven by the NOAA IOOS Regional Associations. But IOOS RA modeling functions in a very different environment with respect to data streams than does NCEP, and much of RA regional model skill assessment (notably in estuaries and marginal seas/gulfs) exploits data sources that may be held locally. To better facilitate experimentation amenable to future R2O implementation the IOOS RA research community needs exposure to the NCEP operational environment so that R&D can deliver solutions that acknowledge practical constraints on NCEP operations (data latency and QA/QC) while helping inform priorities for transitioning coastal data streams to the national data assembly centers. This would be an important step toward inviting greater expert input from the active research community, rather than prioritizing R&D steps to be taken within NCEP itself.

When future reviews turn to issues of coastal ocean model downscaling and land/ocean interactions in the coastal zone I anticipate having more to contribute to the CMC.

3.11. Comments from Fuqing Zhang

Fuqing Zhang is a professor in the Department of Meteorology and Department of Statistics at the Pennsylvania State University. He is also the director of the Penn State Center on Advanced Data Assimilation and Predictability Techniques. He has authored over 200 peer-reviewed journal publications with a h-index of 51. He also served on various advisory boards and expert panels for numerous organizations which include NOAA, NASA, ONR, NSF, NCAR, American Meteorological Society, World Meteorological Organization, UK Met Office, China Meteorological Administration, and the US National Academies. He has received numerous awards for his research which include the 2009 American Meteorological Society's Clarence Leroy Meisinger Award, the 2015 American Meteorological Society's Banner I. Miller Award, and the 2018 Penn State Faculty Scholar Medal. He is an elected Fellow of the American Meteorological Society and the American Geophysical Union.

Data Assimilation

Findings:

1. There are encouraging progresses and promises in the development of JEDI software framework. NOAA has invested enormous funding and resources for the JEDI development with high expectations which appears to leave no alternative to not go with JEDI. However, there is an apparent lack of efforts or strategic plans to advance the DA science and algorithm development before JEDI matures while the readiness of JEDI for such development is a moving target.

2. There appear to be strong disconnects between the JEDI software development team employed by the joint center of JCSDA, the NOAA algorithm development and future implementation team at EMC. EMC is under-resourced for the science and algorithm development; there is a general lack of plan to enhance the workforce and science at the top of the funnel for DA development.

3. The JCSDA/JEDI team has too broad a mission with portfolio and objectives that are not necessarily aligned with priorities and requirements for NOAA's unified modeling system development under NGGPS. EMC is not heavily involved or consulted in the software framework development, computing architecture, urgent DA algorithm and solution needs, etc.

4. Given that JCSDA and JEDI receive support from various agencies, it is not apparent how NOAA can ensure the accountability for its investment, priority, and expectations being met at JCSDA.

5. There are no clear plans and sufficient resources within NOAA and in particular EMC on how to accomplish what is needed for the testing, evaluation, transition for existing and future DA algorithm development in the face of HPC limitations.

6. There is a general lack of specific plans for hurricane-specific DA development, in particular with regards to using new observations from radars and satellites for the likely nested domain CAM version of the hurricane analysis and prediction.

Recommendations:

1. Need to consider creating partnerships with selected universities (and NCAR?) who have DA expertise in order to address human resource issue; would need to have concomitant training capabilities

2. There is an urgent need to form a decision making body (beyond the DA SIP) to advise, evaluate and enforce a clear scientific excellence plan for the DA algorithm development as well as more targeted, intense development of certain functionalities that are crucial to the future NOAA operational DA system.

3. There should be concurrent science development for advanced DA algorithms, all-sky radiances and other under-utilized data sources. This explains the most of the skill performance difference between the current NOAA operation global NWP and the leading centers (ECMWF and UKMet).

4. EMC DA scientists need to be involved in the JEDI priority setting and algorithm development from the beginning. EMC knows best the priorities in terms of operationally relevant research, and is ultimately responsible for the operational DA milestones, implementation timelines, and HPC restrictions. They are to ensure that JEDI is operational ready.

5. NOAA needs to consider creating long-lasting and productive partnerships and possibly forming a DA consortium with selected universities (and academics at large) who have DA expertise through dedicated computing and funding resources to augment the DA science development at different readiness levels, and to train future DA experts.

6. NOAA needs to better integrate the hurricane-specific development including novel use of advanced sensors such as those from all-sky MW and infrared sensors into the DA science development, and potentially think long-term DA strategies in which the global model becomes a CAM.

Convection-Allowing Modeling

Findings:

1. Convection-allowing resolution potentially has large benefit on the global scale, including improved tropical convection and global teleconnections.

2. Current U.S. convection-allowing operational prediction is limited (HREF, 7 members, 3-4 km) and too small to provide reliable probabilistic guidance.

3. Effective testing and R&D is going to require significant new HPC resources and highly capable and motivated personnel

Recommendations:

1. NOAA should evaluate the feasibility and requirements for a global CAM and rapidly move to global CAM operations if it fits the science and computing requirements.

2: NOAA should enhance the organization expertise in CAM-scale DA, and better capture and incentivize such expertise from broader communities. The hurricane-specific and CAM DA should be coordinated with a task team that aims at future global CAM operations.

3. NOAA needs to evaluate whether regional FV3 can handle rapid cycling associated with the current HRRR system through closer collaboration of FV3 developers with CAM groups.

Other Matters - Organizational aspects

Findings:

1. NOAA's current grant and funding, in particular under R2O, to the broad modeling and DA development communities are rather short-term (2 years) which does not allow university researchers to contribute more longer-term science and development.

2. The current NOAA R&D under the CI framework may be too restrictive in attracting and promoting fresh science and new talents.

Recommendations:

1. NOAA's funding shall create tiers of modeling and DA development, one aim at short-term R2O transition in 1-2 years, and the other relatively longer-term 3-5 years. NOAA should coordinate NSF and NASA to fund even longer term model and DA development to form a concerted pipeline in science and human resources.

2. NOAA shall explore the option of a more flexible modeling or DA consortium with talented university professors at large who can closely collaborate with NOAA scientists in shared development, shared student and postdoc supervision.

Appendix A: CMC Charter

1. Background

As NOAA is moving toward a unified modeling approach for its operational model development, it is recognized that communication with the broad research community on NOAA's efforts in operational weather and climate prediction modeling programs is essential. Therefore, NOAA will sponsor an ad hoc Community Model review Committee (CMC) consisting of members of the research community with individual expertise in various key modeling areas.

2. Charge to CMC

The CMC will operate as an independent, ad hoc review committee aligned with Modeling Programs in the NWS and OAR. The scope of the CMC includes weather across time and space scales, out to and including sub-seasonal to seasonal prediction, as well as space weather, air quality, and water modeling, including surge modeling. Members of the CMC provide individual technical expertise of relevant subject-areas to review NCEP's Production Suite, and NOAA's operational modeling research and development programs and activities, for the improvement of operational products and services. The objective of the CMC is to represent the NOAA research community and gain a comprehensive understanding of NOAA's operational weather and climate modeling strategy, priorities, resource requirements, developmental approaches, investment strategies, and scientific/technical challenges through the reviews and communicate this information throughout the community.

The CMC will meet annually and provide a written summary of its findings and recommendations by individual members and communicate the summary to NOAA. This summary will aggregate and document the individual expert comments and recommendations of the CMC members, and may include a preamble summarizing the findings, for NOAA's consideration. For each annual meeting, NOAA will recommend specific focus areas for CMC to review, seeking CMC comments on areas of mutual interests as needs and priorities evolve.

3. Roles and Responsibilities

The CMC participates as a representative of the NOAA community, and is provided information on projects that are works in progress. It is understood and agreed that the CMC has access to information that might be transient and incomplete in nature and should be treated as confidential. To ensure the non-disclosure of confidential information, Members and Ex-officio Members of the CMC agree to the following rules:

a. The Recipient of information in updates and briefings shall consider that information for use in CMC's group discussions, deliberations, assessments, evaluations, recommendations, and findings. Whether information is confidential or public will be stated at meetings. In the absence of direct statements of confidentiality, information not in the public domain shall be considered confidential.

b. CMC Members shall not disclose confidential information from updates and briefings.

c. CMC Members and Ex-officio Members understand that their membership on the CMC imbues them with the potential imprimatur of the Committee as a whole. Therefore, public statements on the NCEP Production Suite and OSTI and other NOAA programs by CMC members have the potential to appear as Committee statements as well as to influence the ability of the Committee to carry out its charge. Therefore, Committee members will exercise due diligence to assure that confidentiality is maintained and to avoid the appearance of conflict of interest or influence.

d. Members are free to express their opinions outside of the committee as long as they make it clear that they are not speaking for the Committee in any official role.

These rules represent values by which the CMC and its members and ex-officio members conduct themselves. The rules are intended to support open and productive communication on the development of NCEP's Production Suite and planning within the NWS and OAR, with particular focus on strategic planning.

4. Composition

The CMC will consist of 12 – 14 members who are established subject matter experts in earth system numerical modeling (atmosphere, water/ocean, space weather and air quality considered), drawn from academia, non-governmental organizations, the private sector and Federal and state agencies.

Initial appointments will be for terms of 2, 3 or 4 years, equally apportioned, or until the CMC is terminated or otherwise reconstituted, whichever comes first. As members rotate off, new members will have 3-year terms. All members are eligible for a second term.

The Director, NWS/OSTI, and Director, OAR/OWAQ, will select the members, including Co-Chairs, of the CMC. CMC membership will be reviewed for adjustments on an annual basis, at a minimum, by the same leadership. An initial review of membership at six months after establishment may be used to stagger/refresh membership assignment. The Co-Chairs of the UFS Steering Committee will serve as Ex-Officio members.

There is no dedicated funding associated with the CMC for federal employees. Compensation for other participants will be considered on a case-by-case basis and provided, as applicable, in accordance with relevant contracts.

5. Duration

This CMC will be formally established from the date this Charter is signed, until terminated or reconfigured by NOAA. Review and revision of this charter may be conducted as deemed necessary by NOAA or the CMC Co-Chairs at any time. The latest date of amendment constitutes the new effective date unless some later date is specified.

Appendix B: CMC Charge for the August 2018 Meeting

NOAA has implemented a unified modeling approach for its operational model development (the Unified Forecast System), developed a set of detailed, comprehensive, and coordinated plans development and governance (both strategic and visionary), and strengthened its programmatic coordination across the Line Offices. To further strengthen NOAA's approach to unifying operational weather and seasonal modeling development, the Community Model review Committee (CMC) has been formed and aligned with the NWS and OAR Modeling Programs.

The stated scope for the CMC includes space weather, air quality, and water modeling including surge modeling); inclusive of the Office of Science and Technology Integration (OSTI) modeling programs, NCEP's Production Suite, and NOAA's operational modeling research and development programs for improvement of operational products and services.

Within this broad and diverse portfolio, recognizing the current exigencies of the Agency, OSTI and the OAR Office of Weather and Air Quality (OWAQ) request that the CMC focuses on the following areas:

1. "Core Principles for Organizing an Enterprise Operational Model Development Capability" (see below) for improving modeling research and development and transition to operations
2. Accelerating advancements in NOAA's data assimilation capabilities
3. Unifying NOAA's convection-allowing/resolving modeling (CAM) approach
4. Advancing NOAA's subseasonal to seasonal (S2S) forecasting skill

Aspects of these four areas that the CMC is asked to consider include NOAA's technical strategies, priorities, resource requirements, developmental approaches, investment strategies, and scientific/technical challenges while conducting this review.

<u>Core Principles for Organizing an Enterprise Operational Model Development Capability</u>

1. Operational Requirements and Outcomes shall drive the enterprise
2. Accept NGGPS and the NGGPS based Unified Modeling System as the technological foundation for infusing new science
3. Accept the joint NCAR-NOAA infrastructure (defined by the draft NOAA-NCAR Agreement) to enable community modeling for O2R/R2O
4. Accept and Maintain the multi-Agency Joint Center for Satellite Data Assimilation unique mission for accelerating the implementation and use of satellite data operationally
5. NOAA Research Funnel should be used to identify/describe/define roles and responsibilities
6. Accept the UFS (Unified Forecast System) Governance as already implemented
7. EMC needs to remain science based, and collocated with service centers.
8. Close collocation of Operations and Development activities, e.g., EMC-NCO, is essential

Appendix C: CMC Membership

Name	**Institution**
Cecilia Bitz	University of Washington
Fred Carr	University of Oklahoma (Co-Chair)
Alicia Karspeck	Jupiter Inc.
Jim Kinter	George Mason University (Co-Chair)
Cliff Mass	University of Washington
Rohit Mathur	Environmental Protection Agency
Lorenzo Polvani	Columbia University
Ricky Rood	University of Michigan (ex officio)
Elena Shevliakova	NOAA Geophysical Fluid Dynamics Laboratory
Hendrik Tolman	NOAA National Weather Service (ex officio)
Ryan Torn	University of Albany
John Wilkin	Rutgers University
Eric Wood	Princeton University
Fuqing Zhang	Penn State University

Appendix D: Acronyms

AOML	Atlantic Oceanographic & Meteorological Laboratory
ARW	Advanced Research WRF
CAM	Convection-Allowing Modeling
CanCM	Canadian Climate Model (e.g. version 3: CanCM3)
CAPS	Center for the Analysis and Prediction of Storms
CCPP	Common Community Physics Package
CCSM	Community Climate System Model (e.g. version 4: CCSM4)
CESM	Community Earth System Model
CFS	Climate Forecast System
CM	Coupled Model
CMC/CMrC	Community Modeling review Committee
CPC	Climate Prediction Center
CPO	Climate Program Office
CSM	Climate System Model
CSTAR	Collaborative Science, Technology and Applied Research
DA	Data Assimilation
DTC	Developmental Testbed Center
EC	Elastic Compute
ECMWF	European Centre for Medium-range Weather Forecasts
EPA	Environmental Protection Agency
EMC	Environmental Modeling Center
ESMF	Earth System Modeling Framework
ESRL	Earth System Research Laboratory
4DVar	Four-Dimensional Variational
4DEnVar	Four-Dimensional Ensemble Variational
FireWxNest	Fire Weather Nested Model
FLOR	Forecast-oriented Low Ocean Resolution
FTE	Full-Time Equivalent
FV3	Finite Volume cubed-sphere dynamical core (e.g. version 3: FV3)
GEFS	Global Ensemble Forecast System
GEOS5	Goddard Earth Observing System model (e.g. version 5: GEOS5)
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast System
GMTB	Global Modeling Test Bed
GSD	Global Systems Division
HIResW	High-Resolution Window
HMON	Hurricanes in a Multi-scale Ocean-coupled Non-hydrostatic
HPC	High-Performance Computing
HRD	Hurricane Research Division
HREF2	High-Resolution Ensemble Forecast (e.g. version 2: HREF2)
HRRR	High-Resolution Rapid Refresh
HRRRE	High-Resolution Rapid Refresh Ensemble
HWRF	Hurricane Weather Research and Forecasting
IOOS	International Ocean Observing System

JCSDA	Joint Center for Satellite Data Assimilation
JEDI	Joint Effort for Data assimilation Integration
JTTI	Joint Technology Transfer Initiative
MME	Multi-Model Ensemble
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MW	Microwave
NAM	North American Mesoscale
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NEMS	NOAA Environmental Modeling System
NGGPS	Next Generation Global Prediction System
NMMB	Nonhydrostatic Multiscale Model on the B-grid
NMME	North American Multi-Model Ensemble
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NUOPC	National Unified Operational Prediction Capability
NWM	National Water Model
NWS	National Weather Service
O2R	Operations to Research
OAR	Office of Oceanic and Atmospheric Research
ONR	Office of Naval Research
OSTI	Office of Science and Technology Integration
OWAQ	Office of Weather and Air Quality
OWP	Office of Water Prediction
PBL	Planetary Boundary Layer
Pflops	Peta (10^{15}) floating-point operations per second
QA	Quality Assurance
QC	Quality Control
RA	Regional Associations
RAP	Rapid Refresh (model)
RAP-Alaska	Rapid Refresh for Alaska
R&D	Research and Development
R2O	Research to Operations
RRFS	Rapid Refresh Forecast System
SAR	Stand-Alone Regional
SC	Steering Committee (of the UFS)
S2S	Sub-seasonal to Seasonal Prediction
SIP	Strategic Implementation Plan
SLA	Service Level Agreement
SPEAR	Seamless system for Prediction and EArth system Research
SREF	Short-Range Ensemble Forecast
SubX	Subseasonal prediction eXperiment
TRL	Technical Readiness Level

UCACN	UCAR Community Advisory Committee for NCEP
UCAR	University Corporation for Atmospheric Research
UMAC	UCACN Modeling Advisory Committee
UFS	Unified Forecast System
UKMet	United Kingdom Meteorological Office
USWRP	United States Weather Research Program
V&V	Validation and Verification
WG	Working Group
WOFS	Warn on Forecast System
WRF	Weather Research and Forecasting (model)

Appendix E: Measures of Excellence in U.S. Numerical Weather Prediction

Excellence in U.S. operational numerical weather prediction can be measured in several ways.

First, one can compare the skill of U.S. operational global modeling against other major international efforts, such as those of ECMWF and UKMET, both for deterministic and probabilistic (ensemble-based) forecasts. There are a number of websites that provide such comparisons, with the general finding that the NCEP's global modeling lags both ECMWF and UKMET, and is roughly equaled by the Canadian effort (CMC).

Second, another evaluation of U.S. NWP skill is a comparison is between the post-processed model output produced by the NOAA/NWS and private sector firms. Such evaluations generally show that U.S. post-processing is behind that of the private sector.

Third, another measure of excellence is whether the U.S. operational effort is state-of-the-science, evaluating and adopting the most advanced numerical methods, parameterizations, and other components in its modeling systems. Such evaluation is shows uneven progress for U.S. operational systems, lagging in data assimilation (U.S. 4DENVAR versus ECMWF 4DVAR) physics (e.g., Zhao-Carr microphysics, which has only recently been replaced in operations by the GFDL microphysics after remaining in the operational code for nearly 20 years), statistical post-processing, convective-allowing ensembles, and effective use of satellite information, while state-of-science is evident in areas such as high-resolution rapid-refresh analyses/forecasts and land-surface modeling.