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High-level NOAA Unified Modeling Overview

Prepared by

NOAA Unified Modeling Task Force

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Abstract: The emphasis of unified modeling is to establish a common framework for model interoperability and to more efficiently integrate systems across disciplinary boundaries. It should not be interpreted as development of a unitary modeling system. By pursuing a unified modeling approach, NOAA provides a business model where modeling costs and resources are minimized, critical mass for model development is more easily reached, and modeling community efforts can be leveraged effectively. This report identifies key elements of unified modeling and provides high-priority recommendations to adopt a unified modeling approach, from a broad disciplinary perspective, as a means to facilitate collaboration among a wide range of NOAA modelers and to promote modeling collaborations beyond NOAA. If implemented these recommended actions could significantly advance unified modeling within NOAA.

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Vision Statement: Effective modeling in support of NOAA's Mission - NOAA models are interoperable and accessible, optimally interface with observations, and are efficiently integrated into a prudent set of scalable systems that cross disciplinary boundaries and serve the full suite of mission-driven applications.

1. What does Unified Modeling mean

Unified modeling[1] implies that a (group of) organization(s) uses the most effective (i.e. typically smallest) number of actual models for a set of similar tasks, as is consistent with the necessary model diversity to support scientific advancement, while providing an efficient application of the models for both *science and operations*. This approach results in a lean business model, with the capability to build critical mass for model development across organizations. It does ***not*** imply unitary modeling where only a single model for each application type is allowed. It is also not limited to NOAA alone, but by definition includes research and operations throughout the government and academia, both domestically and internationally (see inset Examples of Unified Modeling).

Unified modeling also implies that models are increasingly coupled, as appropriate, to ensure that the information flowing from one thematic area appraises modeling in other related thematic areas. Be they chemistry models coupled with global circulation models, or climate models downscaled to force regional oceanographic models, or ecosystem models coupled to economic models, NOAA models need to be coordinated such that the information is exchanged across the suite of models to provide more accurate feedbacks between model components and to support an increasing array of applications. Unified modeling also implies that a framework exists for flexible and interoperable development, so that for a given thematic area new process models can be readily tested to replace existing ones with minimal impact to downstream applications.

Finally, unified modeling implies that across model applications and across thematic areas of emphasis, best practices in model application are identified, shared, and utilized. The disciplinary focus of modeling should never preclude methodological advances of model practice from being shared across disciplines. Establishing means, mechanisms, and venues for such modeling practice exchanges is critical to a unified modeling approach.

2. What is in it for NOAA

Unified Modeling provides an efficient business model where modeling costs and resources are optimized, critical mass for model development is more easily reached, and (worldwide) modeling community efforts can be leveraged effectively. Optimizing operation and maintenance costs for NOAA and its customers can be achieved while accelerating the improvements of models (e.g., through data assimilation) with subsequent benefits for the general public. The skills, knowledge, and practice are leveraged across particular applications to improve all facets of the NOAA modeling enterprise.

[1] Whereas the theme in this section is unified *modeling*, it is implied that *data assimilation* is an integral part of many modeling efforts.

3. Elements of Unified Modeling

Some key elements for successful unified modeling are laid out in the following sections. This is by no means a complete list, but does address some overarching principles and key elements of unified modeling.

By 'unified', we again mean modeling that: minimizes redundancies with other efforts, efficiently uses available infrastructure and resources, includes multiple component models, takes advantage of modeling expertise in other disciplines, and is transparently coordinated.

3.1 Types of Unified Modeling

The January 2016 Research Council Retreat provided descriptions of unified modeling across NOAA as a starting point for a common vocabulary. Here we build on those concepts.

Disciplinary: Means that modeling is unified within a discipline to achieve greatest efficiency and to produce, through a rigorous R2X process,[2] the best well-defined suite of models (atmosphere, ocean, ice, chemistry, fish, etc.). This is inclusive of "end-to-end modeling" (from observations to suites of models to service delivery) within a discipline or NOAA mission line (e.g. Weather, Fisheries, etc.). From an organization's perspective, or within a mission area, this seems ideal. From a research perspective, striving for a limited set of standardized, operational models may suppress necessary innovation, so there needs to be a clear pathway from research to operations.

Interdisciplinary: Means that modeling is unified as focused on an end-to-end connection of interdisciplinary models, for instance in striving for connection from physics, through

Examples of Unified Modeling

Earth System Modeling Framework (ESMF)/ National Unified Operational Prediction Capability (NUOPC): *a unified framework for constructing an ensemble of the existing operational numerical weather prediction models. The participating model systems are constructed of separate end-to-end model suites from observations through service delivery; additionally, standards of verification, validation, and calibration are shared.*

National Center for Atmospheric Research (NCAR) Community Model: *at an organizational level a unified framework/modeling suite for exploratory Earth system modeling and applications spanning the physical, biological and socio economic disciplines.*

UK Met Office Weather to Climate Modeling Suite: *a unified modeling framework across time and space scales from local weather to regional and global climate.*

Full Ecosystem- Input Output bio economic model (Atlantis): *a unified model that has modules from sunlight to fisheries markets, capturing the key processes in each module in one of multiple functional forms, as parameterized for a given regional marine ecosystem.*

North American Multi-Model Ensemble: *a coordinated effort to bring together multiple centers for a single seasonal prediction.*

Geophysical Fluid Dynamics Lab (GFDL) modeling suite: *a unification of physical, chemical and ecological models in land, atmosphere and ocean in a single framework.*

NOS Coastal Ocean Modeling Framework (COMF*): an end-to-end set of common tools for NOS' operational three-dimensional hydrodynamic model-based coastal ocean forecast systems (OFS) that has been implemented to run on NOAA's High Performance Computing (HPC).*

FishSET: *fisheries spatial econometric toolbox, a set of modeling tools to predict fleet dynamics in a changing ecosystem.*

[2] R2X refers to the transition of research to operations, applications, commercialization, and other uses. Principles related to R2X are defined in NAO 216-105a.

biology to economics, or to connect the atmosphere (including ionosphere), hydrosphere, lithosphere, cryosphere and biosphere. Interdisciplinary unification in this context is also known as a form of coupled modeling. In the broader context, interdisciplinary approaches are also known as a system of systems approaches.

A special case of interdisciplinary unified modeling is evolving in operational modeling. Traditionally, ocean, ice, and other models are considered “downstream” from weather models: output from weather models is used as input to the downstream models. In fully coupled modeling, such as it has been done for decades in the context of climate models and more recently in Earth system models, information feedback between the ocean and atmosphere flows two ways between the components. While this results in a more complicated model, it also simplifies a model suite by reducing the number of models. It compacts the production suite by removing codes that have to be run serially, and it naturally enforces end-to-end evaluation of downstream models.

Process: Means modeling that is unified along the process lines (i.e. various process of models being conducted and executed), applying similar standards to how model verification, uncertainty, and calibration across disciplines are approached. This was the intent of the National Academies 2012 report: *Assessing the Reliability of Complex Models: Mathematical and Statistical Foundations of Verification, Validation, and Uncertainty Quantification.*

Unified modeling should consider the *disciplinary*, *interdisciplinary,* and *process* dimensions.

3.2 Partnerships

Unified modeling principles can be used within an organization, but becomes more powerful if applied across organizations at all levels, and is not limited to just NOAA. Partnerships and sustained engagement mechanisms are key to fostering a culture of unified modeling and enabling its effective implementation. Strong unified modeling efforts already exist among NOAA, the U.S. Navy, the U.S. Army Corps of Engineers (USACE), the U.S. Geological Survey (USGS), and others. In some cases, partnerships are underpinned by formal agreements between organizations.

National and international partnerships among agency research programs under the auspices of the World Meteorological Organization (WMO) (e.g. World Weather Research Programme (WWRP) and World Climate Research Program (WCRP)), Intergovernmental Panel on Climate Change (IPCC), and U.S. Global Change Research Program (USGCRP), have a legacy of fostering unified modeling and applications that enable Earth system understanding, modeling, prediction, and informed decision making. These partnerships support and coordinate a community of researchers, developers, and practitioners that share knowledge, models, and data across a variety of disciplines and timescales from days to centuries.

As an example, the National Earth System Prediction Capability (National ESPC) project coordinates efforts of federal agencies active in global analysis and prediction of the physical environment across time scales of a few days to a few decades. This partnership builds on key agency programs, including those that contribute to USGCRP and WMO, and each agency leverages the efforts of the other. For instance, the Navy’s operational Arctic cap modeling mission benefits NOAA’s coastal Arctic modeling mission, and sharing of model output and codes (e.g. shared ocean or shared wave models) enables efficient production and development of multi-model ensembles and coupled models.

The NOAA unified modeling efforts will be an important input to these partnerships and vice versa.

3.3 Community Modeling

Effective unified modeling both better enables and is accelerated by community modeling. In this, there is a subtle but important difference between a *community model* and *community modeling*. Some models are labelled as community models, only because they are made freely available to the general public. There is clear value in such a procedure for the public, as advanced simulation software is available for free. There is value for the modelers, as more eyes are put on model results.

A much bigger benefit can be obtained in community modeling. Community modeling implies a two-way exchange of information, where a group of users contributes back to the model and provides active and relevant evaluation. This requires dynamic code management with many groups contributing to the same code. It also requires a well-defined and implemented governance strategy to prioritize improvements and assure that diversity does not become a cancerous growth of competing options and features. A final critical aspect of community modeling is agreed-upon standardized metrics and test procedures. With this, community modeling becomes a powerful tool to accelerate model development while reducing costs. Note that there is a significant cost associated with code management and governance, but these costs are offset by a potentially much faster model development leveraging a wide range of funding sources.

Extending the community modeling concept, modeling frameworks have been developed that allow for easy addition or exchange of all model components (numerics, physics, etc.). Weather Research and Forecasting (WRF), Regional Ocean Modeling System (ROMS), and WAVEWATCH III are examples of models that have evolved into community modeling frameworks. These examples are technical in nature. Examples of community unification are NOAA OAR sponsored Climate Process Teams as part of Climate and Ocean-Variability, Predictability, and Change (CLIVAR). These teams have brought together observationalists, theoreticians, process modelers, and model developers to work closely on improving parameterizations of a particular process in one or more global models. Key to fostering community modeling and modeling unification across the community are grants programs and other funding opportunities that enable NOAA to engage the external community (academia and industry).

3.4 Multi Model Ensembles (MMEs)

The previous two decades have seen a shift in emphasis from running a single (deterministic) model to running an ensemble of models providing a probabilistic product including estimates of model (forecast) uncertainties. There is evidence that a multi-model approach to ensembles generally results in better probabilistic forecasts. It should be clear that the multi-model approach is not inconsistent with the push towards unified modeling, in fact as initially stated, model diversity is necessary to both address a diversity of applications and account for uncertainty in model results due to a range of different types of errors.

A good business model for meeting agency Unified Modeling goals *and* reaping the scientific benefit of MMEs is to apply community modeling concepts at the module level, creating MMEs by sharing output across organizations. This allows for rapid development inside organizations, while supporting the needed multi-model diversity across organizations for the best common scientific result.

The MME approach is well established in the weather and climate context. In the fisheries context, a few examples of MME exist, but MME is principally used to investigate model sensitivity to parameter priors or to alternative structural configurations within a selected modeling platform. The challenge to further use of MME has been the establishment of suitable criteria for such models to be included, as well as a clear set of protocols from which regulatory advice can be developed from the ensembles.

3.5 Computing Resources

Unified Modeling will require models of various Line Offices (LOs) to become more fully integrated. If these models have high computing and communication requirements, then coupling requires them to be run on the same machine. NOAA has adopted a one-NOAA[3] Research and Development High Performance Computer (RDHPC) environment, in which context the operational supercomputer of the NWS became the NOAA operational supercomputer.

As early as 2004, the Science Advisory Board (SAB) on ocean modeling at National Centers for Environmental Prediction (NCEP) recommended NOS move all its operational coastal ocean models to this operational supercomputer, resulting in a formal memorandum of agreement (MOA) between NOS and NWS NCEP Central Operations (NCO). This move has since been completed, and the basin-scale NWS ocean models and coastal NOS OFS have been unified using the NOS Coastal Ocean Modeling Framework (COMF). Such unification requires coordinating the operational time line and addressing run-time constraints between LOs. From a research and development (R&D) perspective, unifying the running of models on NOAA's R&D High Performance Computing (HPC) assets is notably constrained by run-time limits and quotas, as well as storage quotas and inter-system transfer rates for data. Run-time constraints will further hamper efforts as modeling unification evolves toward coupled modeling due to model size and complexity so recommendations on prioritization and criticality, forecast windows and run-time frequency will need to be negotiated.

With the ever-increasing scope and size of environmental models, storage and dissemination of results becomes both more critical and more difficult. In this, traditional roles of the NWS and National Centers for Environmental Information (NCEI) in data dissemination may need to be revisited, and new approaches such as "the cloud" are being explored.

While development can be accomplished on disparate platforms and code, effective R2X and X2R, and the community modeling approach, requires that research both internal and external to NOAA has access to up-to-date operational codes and the same, or mirror image, HPC platforms to minimize or eliminate transition differences, particularly for final transitions to operations/applications (NOAA Readiness Level 9). There are currently significant impediments to achieving this goal, which involve both lack of access to resources as well as computing time. These HPC impediments to unified modeling are greatest when external community partners are involved.

A unified modeling approach across NOAA will enable a more proactive approach to procuring and utilizing computer resources for both research and operations, as it allows for a holistic and well-founded assessment (request) of large-scale computing resources.

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[3] A one-NOAA approach refers to an integrated NOAA-wide approach as a opposed to a line office by line office approach.

3.6 Data Assimilation

Data assimilation (DA) is an established and rapidly evolving field, with advanced DA using 3D and 4D variational approaches that become situation dependent with the use of ensemble model data. Furthermore, the amount and types of satellite data in particular is rapidly growing, and availability of observations of essential environmental parameters is a critical aspect of DA. Furthermore, DA becomes increasingly coupled, particularly in climate applications. In a unified modeling environment, the rapid advances and maturity of DA in the atmosphere can be used for other DA needs that are not as mature.

The implementation of DA software is preferably organized according to generalized higher level considerations instead of low-level details, that is, it needs to be modular and object oriented. This allows both the developers and users to easily modify implementation details in a particular area of the software without affecting the functioning of the overall system, and to leverage developments in one field into other fields. Such an approach is presently spearheaded by the Joint Center for Satellite Data Assimilation (JCSDA) in the Joint Effort for Data assimilation Integration (JEDI) project.

A community repository for DA software components, e.g. object-oriented components, will extend development across the broader use community and provide more generalized solutions. A similar need exists for the observations used in DA approaches. Within such a repository, readiness levels can be employed for merging R&D and operational efforts.

Real-time data handling where needed to support DA presents a unique set of data-management requirements. Data must be transported between different systems, quality-controlled, and made available in consumable formats, all in a timely manner to ensure it is available for the next model run cycle. Typically these systems are purpose-built to support a particular application, and the data-management operations tend to be hardwired for a particular system. However, to support unified modeling these data-management functions need to support interoperability across NOAA, resulting in the broadest access to quality-controlled observations with minimal duplication of effort. In the area of numerical weather prediction, these capabilities are addressed by the NWS/NCEP/NCO data tanks and associated data processing capabilities, but at present the access to the data tanks is limited. For ocean data, the NOS Integrated Ocean Observing System (IOOS) Data Management and Communications (DMAC) effort results in a more open, virtual real-time data environment.

3.7 Common Modeling Frameworks, Architectures, and Platforms

The backbone of a successful unified modeling approach is a high-performance, flexible software infrastructure that can be used for building and coupling weather, climate, and related environmental science and human impact applications. For example, the Earth System Modeling Framework (ESMF) represents a leading community infrastructure for composing complex coupled modeling systems and includes data structures and utilities for developing individual models. As needed for interdisciplinary unified coupled modeling, a software infrastructure such as ESMF aims at breaking down complicated applications into components with standard calling interfaces. The adoption of this type of approach, such as NOAA Environmental Modeling System (NEMS) as part of the NWS suite, enables components to be easily replaced by new modules as needed (interoperability) or new components to be added as needed, and implements interagency ESPC principles.

While specific software infrastructures may vary among modeling groups and communities, the move towards common modeling architectures is key to enabling the use of components among different groups in support of unification, as interfaces can be built to enable communication if the architectures are common. The development of common modeling infrastructures in support of model development was recommended by the 2012 National Research Council (NRC) report on "A National Strategy for Advancing Climate Modeling."

Unified modeling is also fueled by an "open source" approach which is broadly seen as a way to make rapid advancement via community experimentation and enables interdisciplinary applications across communities. Additionally, key elements for effective virtual model development platforms include the availability of software and data to run experiments, good code management practices, and documentation. These features foster community involvement, experimentation, and model improvement to accelerate R2X (and X2R) and help promote accessible, documented, robust, and portable code that is essential to attain unification.

3.8 Venues and Mechanisms for Exchanging Best Modeling Practices

Unified modeling will require shared fora for the exchange of ideas, best practices, code, and platforms across the many organizational and disciplinary facets of the unified modeling enterprise. The development of this document, among the different classes and communities of modelers represented, highlighted that although there are common features of modeling, there are enough disciplinary distinctions and specific technical terminologies to make a common understanding of unified modeling and all the facets noted herein a challenge. Establishing a venue, both in person and virtually, to facilitate and broker continued exchange, is a necessity to gain efficiencies across modeling efforts.

For example, the NOAA Fisheries has established National Ecosystem Modeling Workshops (NEMoWs) and National Stock Assessment Workshops (NSAWs) that are held every few years to exchange ideas and modeling practices, usually centered around several core themes. Outcomes have included improved models, uptake of new methods, better modeling results, organizational changes, and similar results to improve the modeling enterprise. Similarly, OAR and NMFS have held joint modeling workshops to explore areas of synergy on topical facets of modeling where NWS and NOS modelers have even participated. Broadening this to a suite of topical areas across all NOAA LOs holds value. OAR programs have explored virtual venues for modeling communication and exchange, involving both NOAA staff and the external community. For example, the OAR Modeling, Analysis, Prediction and Projections (MAPP) program organizes several Task Forces that meet virtually and a monthly webinar series. Underpinning the success of such efforts are resources for projects that provide a practical mechanism for sustained engagement and collaboration. The NWS has developed the Virtual Laboratory (VLab) environment, to provide a virtual collaboration environment for exchanging ideas and model codes.

3.9 Model Review Protocols

Independent peer review of research findings is standard practice for all scientific publications. The federal requirement for peer review of our scientific products is embodied in the Information Quality Act and the Office of Management and Budget's (OMB) subsequent Peer Review Bulletin (PRB) (2004) that requires peer review for all "influential scientific information", and review that is more independent for highly influential products (above $500 million impact). Review of observing systems and analytical methods is already standard practice in the transition of research to operations, and hence is expected to be applied to unified models. This is particularly important in a regulatory context such as fisheries, where model results directly impact economic activities. Quoting from the National Academies 2012 report: *Assessing the Reliability of Complex Models: Mathematical and Statistical Foundations of Verification, Validation, and Uncertainty Quantification* (VVUQ) review protocols should seek to answer three key questions:

"*Verification*. How accurately does the computation solve the underlying equations of the model for the quantities of interest?

Validation. How accurately does the model represent reality for the quantities of interest?

Uncertainty Quantification (UQ). How do the various sources of error and uncertainty feed into uncertainty in the model-based prediction of the quantities of interest?"

Although the VVUQ report focused on physical and engineering models, they note that the principles apply to models of other systems. The need for and the capability and methods to do V, V, and UQ will vary from physical, to biological, to social systems, and will rely on the availability of observations. Whereas VVUQ is important for assessing the "value" of individual models, it becomes essential when unified modeling seeks to select a small number of target models to be used in a unified environment.
Models need to be reviewed at a level of rigor consistent with the intended use of their outputs. Some models, as in weather forecasts, have to be evaluated for scientific rigor but are used informationally. Other models, as noted above in fisheries assessments, are used in a regulatory manner. The venue, rigor, and level of reviews are different, so they need to be documented to ensure results can be repeated and compared. A unified modeling approach could learn lessons from both levels of intended use to gain efficiencies in the review process.

3.10 Data Management in Support of Unified Modeling

Unified modeling is by definition an integrative enterprise that depends on the flow of environmental data freely and openly throughout and within NOAA, as well as across agency boundaries to external partners. Data and information, in the form of observations, model guidance, and products, need to be discoverable and accessible both in real time to support forecast operations, as well as retrospectively to support model creation, validation, and ongoing skill assessment. This calls for interoperability among legacy data and modeling systems, as well as integrated planning in the development of new systems. Data management and long-term stewardship should therefore be considered an integral, core component of the infrastructure required to support unified modeling in NOAA.

NOAA has an active data management community and a reasonably mature set of best practices for the sound management of NOAA environmental data. Guidance on these practices has been developed by NOAA's Environmental Data Management Committee and published as a series of procedural directives. These practices address the full range of the data lifecycle from planning, to quality control, to long-term preservation, and are designed to facilitate full and open access, as well as ease of use. The key element in these practices is the use of standards, especially standard data formats and standard Web-based access protocols.

Interoperability of model data systems will enable distributed production of analyses and products, particularly as NOAA moves increasingly toward coupled modeling and data assimilation, and notably different user communities will need to access the outputs from the same modeling system. For example, storing the model output data on a unified access (virtual) server with a regional physical-biogeochemical model, the traditional hydrodynamic outputs could be accessed and routed to traditional dissemination products and paths, while associated biogeochemical outputs could be accessed by relevant entities for the production of focused analyses and products. The NOAA Operational Model Archive and Distribution System (NOMADS) and the Unified Access Framework (UAF) are two examples of these principles in action within NOAA, with particular application to model output. NOAA also participates in the international Earth System Grid Federation (ESGF) to make observational and model data widely available.

4. Themes for Unified Modeling and Data Assimilation

This section notes the importance of cross-cutting themes to advance unified modeling. It highlights a select few thematic areas that if addressed and further explored, will lead to significant progress in NOAA's Unified Modeling and Data Assimilation. These naturally build on an understanding of Unified Modeling from the previous section, and lead to a set of specific, recommended actions (Section 5).

4.1 Software, HPC, and Data Management Infrastructure

This theme focuses on the technical aspects of Unified Modeling and Data Assimilation. The list of thematic points elucidates the key, common needs to make the technical, software, hardware, and data interoperability facets of NOAA's modeling enterprise more suitable to unification.

1. *Modeling framework for sharing infrastructure, interoperability, and coupling utilities (including running baselined versions of operational models)*
2. *Shared common dynamical cores across NOAA (e.g. Modular Ocean Model, Finite Volume Atmosphere, Regional Ocean Modeling System)*
3. *Observation framework for model validation, output storage, and data assimilation*
4. *HPC platform architecture and access (one-NOAA approach to computing resources, with capacity, accessibility, and availability to the community)*
5. *Code version control and documentation; community accessibility*
6. *Maintain IT security while facilitating enhanced sharing of model material and information in a rapidly changing IT environment*
7. *Data management framework that effectively links data archives and real-time data streams across NOAA, for both observations and model output fields.*
8. *Models should have on-going (real-time when applicable) monitoring as an extension of verification and validation*

4.2 Modeling and Numerical Approaches

This theme focuses on the connections between the generation of new understandings of processes and implementation of those across the unified modeling landscape. The list of topics underscores the need to establish procedures to uptake research results into the modeling effort. It does not call out specific research themes per se, but notes that the fundamental and process-oriented research conducted across NOAA needs to understand its functional forms, parameter space, and relative significances, and needs to have a protocol to be "plugged into" the modeling in a systematic, unified manner.

1. *Process teams for incorporation of novel science into models through cooperative, interdisciplinary synthesis of observations, theory, models, and applications.*
2. *Scale-aware process representation for use across time and spatial scales*
3. *Dynamical core characteristics to delineate aspects of computational elements and functional form of key processes*

4.3 The Business Model for Effective R2X and X2R

This theme focuses on the organizational processes to link research and operations. This topical list notes that the modeling outputs need to be tested, and that the model testing efforts itself form a field of research building on the research noted above in 4.2. Ultimately for those model outputs to be used to inform decision making they need to go through an approach that establishes the validity of the modeling effort across unified model suites.

1. *NOAA modeling output availability, largely for reanalysis, predictions and projections (e.g. Coupled Model Intercomparison Project (CMIP), North American Multi-Model Ensemble (NMME))*
2. *Enhanced partnerships (e.g., U.S. IOOS Regional Associations) and testbeds to establish paths and procedures for bringing external R2X/X2R developments into NOAA unified modeling and data assimilation*
3. *NOAA operational codes and relative documentation availability, largely for code management needs (sharing/using common tools, e.g. wiki spaces, git hub, VLab; and best practices)*
4. *Business practices for developing and maintaining multi-model ensembles*
5. *Business practices to encourage model innovation while maintaining a succinct, pragmatic set of standardized operational models*

4.4 Communication and Community Engagement

This theme focuses on (subjects for) the interactions between people with a focus on, but not limited to NOAA. This topic list notes the need to communicate model outputs in a systematic and unified manner to all the end-users, partners, stakeholders and every other party that utilizes information from, and contributes to, the NOAA modeling enterprise. Of note are internal efforts to cross-pollinate modeling ideas among the different LOs.

1. *NOAA outreach and mechanisms enhanced to involve the external community and provide coordination on community modeling activities*
2. *NOAA Modeling Fora (such as meetings, webinars, and workshops) focusing on these core themes to facilitate modeling unification*
3. *Ability for external community expert input to support the NOAA mission*
4. *Internal and external (community) training*
5. *Model and product validation by users and stakeholders, at all stages of model development. (This requires open data access.)*
6. *Model user interfaces more widely developed, with suitable feedback from users to developers*

7. *Data visualization to facilitate broader use, uptake and operational application of unified modeling products*

4.5 Cross-Disciplinary Coupling

This theme expands Unified Modeling from disciplinary to interdisciplinary. This thematic list identifies the domains with respect to systems model and disciplines used, and calls for a significant increase in the degree of interdisciplinary facets of unified modeling, largely via model coupling, over what is occurring currently.

1. *Coupling between atmosphere (including ionosphere), hydrosphere, lithosphere, cryosphere, and biosphere domains*
2. *Coupling between physics, chemistry, biology, geology, ecology, and human interactions*
3. *A hierarchy of models with varying degrees of coupling for various applications. This includes coupling across spatial, temporal scales and nested boundaries*

4.6 Integration of Socio-Economics

Integration and consideration of socio-economics should occur early in model development and continue through the model life cycle, when appropriate. Often economics and other social science considerations are introduced towards the end of the process resulting in economic models being incompatible with other disciplinary model outputs due to scale or other issues. Early integration of socio-economics can also lead to enhanced model utility beyond its original purpose.

1. *Social science methodologies employed to unify model outputs (techniques, formats, content, etc.) to enhance dissemination and usability*
2. *Economic evaluation of the impacts of modeling to assist in prioritization and focus on model development*
3. *Emphasized coupled or bio-economic modeling as an extension of cross-disciplinary modeling to better link to performance measures, and model output expectations*

4.7 Governance and Best Practices for NOAA

NOAA's environmental modeling and prediction enterprise, comparable to NOAA's corporate enterprises for R&D and observations, stands alone in its lack of a corporate governance structure for unification, in particular for cross-NOAA strategic planning with respect to requirements and objectives, resource prioritization, and infrastructure coordination, as well as cross-NOAA integration and coupling. Thus, there is recognition that the NOAA modeling enterprise would benefit from high-level oversight. This theme addresses the governance and authority to move forward within NOAA. Cross-LO leadership, authority, and coordination are needed to better resource and advance unified modeling within NOAA.

1. *Recommended best practices identified for each of the themes above*
2. *Strategic planning and targeted resources*
3. *Clearly identified target model users and objectives*

5. Recommended Actions

The NOAA Research Council charged the Task Force with identifying strategic actions required to advance an agency-wide unified modeling practice in NOAA. There are many possible actions that could emerge from the themes identified above, both short-term and long-term, both resource neutral and resource requiring. Below are six recommendations to serve as a starting point for advancing Unified Modeling within NOAA. By their proposal, they are identified as relatively high priority areas that if executed, could significantly advance unified modeling within NOAA.

5.1 Establish a Formal Body to Coordinate Modeling

A governance/coordination body and representation at the NOAA Executive Panel (NEP)/ NOAA Executive Council (NEC) levels, comparable to NOAA's Research Council (RC) and the NOAA Observing Systems Council (NOSC), should be considered for NOAA corporate representation, particularly with respect to agency priorities, as well as accountability for achieving integrated agency objectives.

5.2 Establish a NOAA-Wide process for Information Exchange

An effective modeling information exchange approach needs to be considered to progressively advance the implementation of a unified modeling framework across NOAA and the community it engages with. This approach should be multi-pronged, certainly cross-LO, to enable different types of critical communication and preclude roadblocks. Regular NOAA modeling fora, such as meetings, webinars, training, and workshops, focusing on the core themes outlined in Section 4 will be key to facilitating modeling unification. While focused on NOAA modeling, these should involve key community experts or partners for input to help support of the NOAA mission, as appropriate. NOAA programs that already provide mechanisms for internal and external community outreach and coordination on modeling activities should be enhanced to serve broader roles such as the organization of the modeling fora.

5.3 Ensure Adequate Resources to Execute NOAA-Wide Modeling

NOAA should seek means to bolster cross-line office resources needed to conduct unified modeling. These additional resources should be developed cognizant of application-driven, requirements-based enterprise solutions that address the entire life-cycle of development and implementation (R2X). Leveraging partnerships with the modeling community in academia, the private sector, and other Federal Agencies to address topical priorities is warranted.

5.4 Define Best Practices in NOAA Modeling

A key question is how to apply a Unified Modeling approach within and across LOs. Unifying NOAA's environmental modeling enterprise into a prudent number of operational models requires a baseline of requirements that the unified enterprise is tasked to address. These requirements, in conjunction with NOAA's strategic priorities, resources, and available data, dictate the scope, scales, accuracies, process representations, coupling, etc., of the unified modeling suite. Traceability to current requirements can guide assessments for model retention, or elimination as redundant or out-of-date. Establishing a lightweight procedure for when to use a unified modeling approach relating back to theme areas identified above is needed. Alignment of schedules across offices and programs for model development and implementation would maximize efficiency towards unified modeling. Establishing a vetting process for preferred models/modeling approaches would also be beneficial. This includes the best approaches for model review that are legally and technically defensible. This could be used as a checklist of best practices.

5.5 Establish Regular Review for Model Redundancy and Retention

Related to but distinct from Unified Modeling best practices, a protocol to determine when models have neared the end of their life cycle is missing. Employing new social science methodologies, in addition to more conventional metrics and diagnostics, for assessing user perspectives and needs with respect to evolving NOAA's modeling suite is an important consideration, particularly with respect to discontinuing redundant or outdated models and associated products. It is important to know if some aspect of an old model or associated product that is valuable to a user is identified and understood, so that due consideration is given and informed decisions made with respect to continuity and substitution. Conversely, NOAA would need to discontinue old models and associated products for which the total costs outweigh the benefits for society. Basically, how would NOAA move its users of old models and products to more contemporary versions or updated or novel models and products, allowing NOAA to streamline its modeling outputs and services?

Consequently, NOAA's evolving enterprise modeling requirements will benefit from periodic formal updating and validation. In addition to addressing the specifics of user and stakeholder needs, these requirement updates would also need to evaluate and validate strategic objectives, ensure model development and updating, priorities, infrastructure requirements, and unification approaches.

5.6 Make HPC More Accessible to all of NOAA

NOAA should also develop easier, more intuitive user interfaces and other tools to facilitate widespread use of HPC; organize and host workshops across all of NOAA to foster bridge-building, reduce redundancy and duplication of effort, and to collectively address both technical and programmatic themes related to the use of HPC; increase awareness of NOAA's HPC portfolio; and develop mentoring programs (pairing experienced users with novice users) and enhanced support and training. NOAA should also develop a roadmap for HPC, which is strongly driven by this unified modeling roadmap.

Table 1: Recommended Actions vs. Theme

	Applicable Theme						
Action	**4.1**	**4.2**	**4.3**	**4.4**	**4.5**	**4.6**	**4.7**
5.1	✓	✓	✓	✓	✓	✓	✓
5.2	✓			✓	✓	✓	✓
5.3	✓	✓	✓	✓			
5.4	✓		✓	✓	✓	✓	✓
5.5			✓	✓		✓	✓
5.6	✓	✓	✓	✓			✓

Appendix A
Relevant documentation

NOAA Task Force on Unified Modeling Memo

Unified Modeling Discussion: Research Council Retreat

UCACN Model Advisory Committee Report

NOAA Holistic Climate and Earth System Model Strategy

Advancing Modeling Capabilities for the Coastal Ocean (IOOC Draft)

Assessing the Reliability of Complex Models: Mathematical and Statistical Foundations of Verification, Validation, and Uncertainty Quantification (VVUQ) Report

National Ecosystem Modeling Workshop

The National Earth System Prediction Capability: Coordinating the Giant

Appendix B
Glossary

CLIVAR	Climate and Ocean - Variability, Predictability, and Change	**NOAA**	National Oceanic and Atmospheric Administration
CMIP	Coupled Model Intercomparison Project	**NOMADS**	NOAA Operational Model Archive and Distribution
COMF	Coastal Ocean Modeling Framework	**NOS**	National Ocean Service
DA	Data assimilation	**NOSC**	NOAA Observing Systems Council
DMAC	Data Management and Communications	**NRC**	National Research Council
ESGF	Earth System Grid Federation	**NSAWs**	National Stock Assessment Workshops
ESMF	Earth System Modeling Framework	**NUOPC**	National Unified Operational Prediction Capability
ESPC	Earth System Prediction Capability	**NWS**	National Weather Service Line Office
FTEs	Full-time equivalent	**OAR**	Office of Oceanic & Atmospheric Research
FY	Fiscal Year	**OFS**	ocean forecast systems
GFDL	Geophysical Fluid Dynamics Lab	**OMB**	Office of Management and Budget
HPC	High Performance Computing	**PRB**	Peer Review Bulletin
IOOS	Integrated Ocean Observing System	**PRSS**	Performance, Risk & Social Science Office
IPCC	Intergovernmental Panel on Climate Change	**R&D**	Research and Development
JCSDA	Joint Center for Satellite Data Assimilation	**R2X**	Transition of research to operations, applications,

			commercialization, and other uses
JEDI	Joint Effort for Data assimilation Integration	**RC**	NOAA Research Council
LOs	Line Offices	**RDHPC**	Research and Development High Performance Computer
MAPP	Modeling, Analysis, Prediction and Projections	**ROMS**	Regional Ocean Modeling System
MMEs	Multi Model Ensembles	**SAB**	Science Advisory Board
MOA	Memorandum of Agreement	**STAR**	Center for Satellite Applications and Research
NCAR	National Center for Atmospheric Research	**UAF**	Unified Access Framework
NCEI	National Centers for Environmental Information	**UQ**	Uncertainty Quantification
NCEP	National Centers for Environmental Prediction	**USACE**	United States Army Corps of Engineers
NCO	National Centers for Environmental Prediction Central Operations	**USGCRP**	United States Global Change Research Program
NEC	NOAA Executive Council	**USGS**	United States Geological Survey
NEMoWs	National Ecosystem Modeling Workshops	**Vlab**	Virtual Laboratory
NEMS	NOAA Environmental Modeling System	**VVUQ**	Verification, Validation and Uncertainty
NEP	NOAA Executive Panel	**WCRP**	World Climate Research Program
NESDIS	National Environmental Satellite, Data, and Information Service	**WMO**	World Meteorological Organization

NFT	NOAA Fisheries Toolbox	**WRF**	Weather Research and Forecasting
NMFS	National Marine Fisheries Service	**WWRP**	World Weather Research Programme
NMME	North American Multi-Modal Ensemble	**X2R**	Transition from operations, applications, commercialization, and other uses to Research