A Strategic Vision for the NOAA's Physical Environmental Modeling Enterprise

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1 Purpose and scope

The purpose of this document is to provide a high-level vision for the NOAA's Physical Environmental Modeling Enterprise, which supports the forecast, analysis, and assessment missions of NOAA and its governmental, academic, private and commercial partners, both with respect to ***operations*** and ***research***. The main goal is to provide a vision to streamline and unify the Physical Environmental Modeling Enterprise so that available resources can be focused on becoming the best Physical Environmental Modeling Enterprise in the world within 10 years.

Traditionally, this enterprise has had a strong focus on weather modeling, and has focused mostly on modeling aspects of forecasting (creating products). The modeling aspects are rapidly moving to a more holistic (coupled) environmental approach, and serve an increasing set of requirements beyond traditional weather forecasting. Simultaneously, forecasting is moving to a holistic approach starting with customer needs and ending with decision support. The latter is evident in the Weather Ready Nation vision recently introduced by the National Weather Service (NWS).

The modeling enterprise remains the foundation of the forecasting enterprise and is the focus of this vision document. Other aspects of the forecast process are addressed only for as far as they directly influence the modeling enterprise, or the access and use of its

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products. Observing requirements are regularly addressed at the NOAA, national and international levels and are not considered here.

Accompanying this vision document is a Roadmap for this 10-year period, as well as a Strategic Implementation Plan (SIP) focusing on implementing this Strategic Vision (SV) and Roadmap in the next few years. Whereas the SV encompasses the entire Physical Environmental Modeling Enterprise, the Roadmap and SIP concentrate on the core operational Production Suite as run at the National Centers for Environmental Prediction (NCEP). This SV is fully aligned with, and draws on the recent NOAA whitepaper from the NOAA Unified Modeling Task Force (UMTF[3]) and the broader National Earth System Prediction Capability (National ESPC[4]) effort. Other facets of NOAA's modeling enterprise beyond the core NCEP operational production suite (ecological, chemical, socio-economic, oceanographic, etc.) are intended to be addressed in collaboration with the NOAA Unified Modeling Committee (UMC, permanent follow-up of the UMTF). The latter efforts are expected to result in roadmaps and implementation plans for these topic areas.

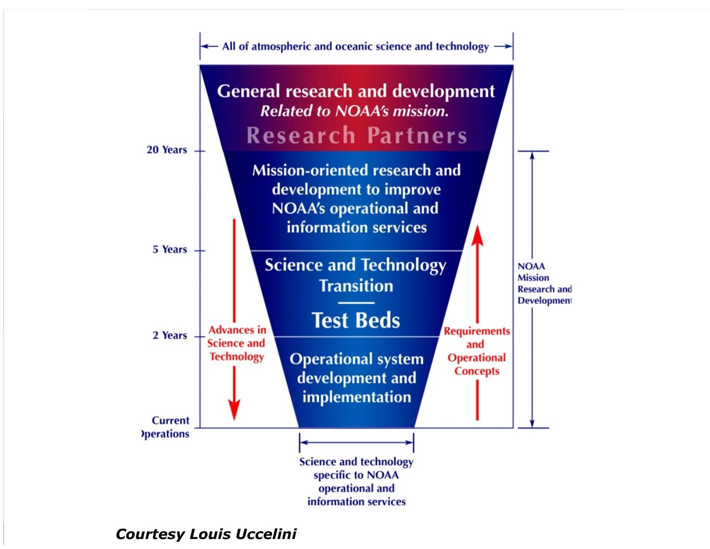

Figure 1: "The Funnel"

2 The Big Picture

NOAA's Physical Modeling Enterprise needs to serve a broad range of missions and associated applications, ranging from operations to fundamental research. Operations and

[3] ftp://ftp.library.noaa.gov/noaa_documents.lib/NOAA_UMTF/UMTF_overview_2017.pdf

[4] http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-16-0002.1

research occur at different time scales, and ideally form a funnel where broad research on large development time scales feeds into operations as is visualized in Figure 1.

Transitioning research into operations (R2O, left side of Figure 1) is essential to improve operations consistently and in a sustainable way. Focusing research on existing operations (O2R, right side of Figure 1) is a key element in rapid R2O and rapid improvement of operations. For rapid evolution of operations, research will continuously need to work today on tomorrow's envisioned operations (applications as well as models). Foundational research will also inspire new operations in support of the NOAA mission, currently not even envisioned. With this in mind, the NOAA modeling enterprise will be built around an integrated O2R-R2O approach with two caveats:

- ***Evolution versus revolution in operations***: An O2R-R2O approach implies an evolutionary development path for operations. Occasionally, a revolutionary approach may be needed, as will be indicated by results of fundamental research at the top of the funnel in Figure 1 that may not be directly linked to present day operations.
- ***Operations versus research***: Improvement of operations is critically dependent on linkage to research. However, not all research will be enabled by present day operations. The present vision is therefore to better link research to operations, but ***never to suppress (foundational) research*** within NOAA's mission, where research requires separation from present day operations.

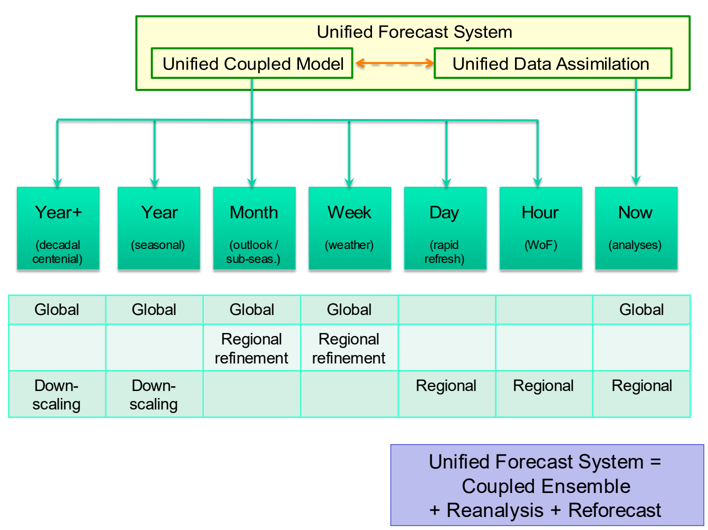

Figure 2: High-level design of a unified modeling system

The key element of a ***unified physical environmental modeling approach*** is the focus on ***products*** to provide ***services*** supporting mission ***requirements*** (including those of the research community). For the modeling enterprise, this implies being product-oriented rather than model-oriented. To move to a product-oriented modeling enterprise, several critical product ranges have been identified, as is illustrated in Figure 2. The discussion of these ranges focus on the presently dominant weather elements, but are generally applicable to most environmental sub-systems.

The "***Year +"*** element identifies modeling beyond the one year range. The "***Year***" element addresses seasonal forecasting. The "***Month***" element addresses the newly mandated services for week 3-4 (sub-seasonal) predictions. The "***Week***" element addresses traditional medium-range weather forecasting. The "***Day***" element addresses the rapid refresh short-range forecasts, with a focus on convection and severe weather. The hour element addresses envisioned Warn on Forecast approaches, with a forecast of only a few hours, produced (on demand) several times per hour. Finally, the "***Now***" range covers traditional global analyses, as well as envisioned rapidly updating full-atmosphere analyses. The "Now" element differs from the model initialization, as the former generally seeks to provide the best possible description of the state of the environment, whereas the latter seeks the model initialization that results in the best model forecast.

All key elements of the unified modeling enterprise are ***applications*** of a ***unified modeling*** and ***unified data assimilation*** system, with the understanding that unification should focus on the minimum (most effective) number of models and data assimilation approaches that can serve a complete Earth System Prediction Capability. Unitary modeling (only one model allowed) is ***not the goal***, but, where possible, provides a solid ***business model***. Economy of modeling suggests that each product in Figure 2 is produced by a unified model application with a different spatial resolution. However, if economy and accuracy allow, it is tentatively possible to create the products in this Figure with a smaller number of model applications.

Several additional considerations accompany the product-based high-level vision of the unified modeling enterprise.

Whereas the initial description of the modeling enterprise focuses on weather elements, the physical modeling enterprise already includes land, aerosol, ocean wave, sea ice, and space weather products at many of the identified forecast ranges. A unified environmental modeling enterprise has to be based on a ***coupled*** modeling approach, both in order to address the other non-weather elements and longer forecast ranges consistently, and because sustained improvement of all environmental modeling will require a more holistic environmental approach. A unified and coupled modeling approach is aligned with efforts of the NOAA Unified Modeling Committee (UMC), and The National Earth System Prediction Capability (National ESPC) project.

Forecasting is moving from a deterministic "model of the day" approach, to a probabilistic ***ensemble*** approach, where the forecast and its uncertainty are addressed simultaneously using an ***ensemble*** of possible model solutions, rather than a single ***deterministic*** model run. Ensembles are also a cornerstone of advanced data assimilation. All key elements of a unified approach should therefore be ***ensemble*** based, with all ensemble members run at the core resolution of the product element (i.e., no higher resolution deterministic control run).

Particularly for longer forecast ranges, ***reforecasts*** and ***reanalyses*** provide improved forecast skills through calibration of raw model output, and for Impact-based Decision Support Services (IDSS). When moving to full ensemble approaches for each element, traditional retrospective testing effectively attains the nature of a reforecast and reanalysis. Considering this, ***reforecasts*** and ***reanalyses*** will be considered as a core element of each implementation of an element of the NOAA environmental modeling enterprise.

Preprocessing of observations, ***postprocessing*** of model output, including ***calibration***, ***verification*** and ***validation***, and ***access*** of model results for stakeholders and the public also need to be unified to optimize the end-to-end modeling process. Unification of these aspects of the modeling enterprise is as important as those of the core modeling enterprise.

3 Basic Concepts

The previous section describes a unified approach based on products and requirements, unified coupled ensemble modeling, data assimilation, pre- and post-processing, reforecasts and reanalyses, validation and verification, data access, and data archiving. Several other key concepts are essential as outlined in the following sections.

3.1 Community modeling

Physical Environmental modeling is moving to a ***community modeling*** approach that involves NOAA, other federal partners and the research and academic communities at large (and any other interested partners). Only with appropriate contributions from the entire U.S. modeling community will we be able to build the best ***national*** [5] modeling system in the world.

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[5] A community modeling approach will move the NOAA effort to become a national effort.

The ***definition*** of "community" is important, and not all community efforts are identical. Prior community modeling efforts show both strengths and weaknesses of different approaches, and that one size does not fit all. The community approach will include training and support. Best practices suggest identifying groups of collaborators with different levels of contribution / interaction.

The community team has to include strong contributions from both ***operations*** and ***research*** groups, with different levels of partners. The unified modeling system will be built to support the needs of both ***operations*** and ***research***, with a well-defined path for transitioning research to operations (R2O), rooted in a preference for research performed with operational models (O2R). Without that linkage, the incentives for the research community to participate will be sub-optimal.

The unified modeling system has to be a national system where all core partners have true ***ownership***. As such, each core partner has to treat their role on the national team as a fundamental and enduring priority for their respective organization, supported where appropriate with internal core resources.

3.2 Evidence driven decisions

The physical environmental modeling community requires a rational, evidence-driven approach towards decision-making and modeling system development. Key decisions on architecture, scientific selection, etc. will therefore be based on objective validation and verification, not assertion. This requires establishment of ***requirements*** (including timeliness, run time, and reliability), agreement on ***validation metrics***, and a unified approach to computing such metrics. It also requires an ***effective*** and ***transparent*** process where testing and experimentation can be carried out effectively with the engagement of key partners.

3.3 Governance

With the community approach to modeling, all core partners will have a voice in making strategic decisions, not just the operational center(s). With the modeling enterprise being heavy on weather applications, the governance process for transition to operations will have to be aligned with the formal Line Office governance process for their Production Suite. For example for the NWS the formal governance process identifies three key steps.

1. Establish ***service requirements*** and associated products, where the products define the core of the Unified Production Suite.
2. Determine ***scientific requirement*** and possible solutions needed to have products meet (service) requirements.
3. The Mission Delivery Council (MDC) prioritizes solutions for requirements within the NWS.

Partner input is essential in all steps, both with respect to Line Offices contributing to the Production Suite, and with respect to partners co-developing elements of the Production Suite. Furthermore, the governance will need to acknowledge governance structures for other NOAA Line Offices (with coordination through the Research Council where needed), and to give proper consideration to both operational and research needs, which implies the need for a fully developed governance structure for research in parallel to the NWS governance structure.

3.4 High Performance Computing

Environmental modeling is critically dependent on High Performance Computing (HPC). In this context, NOAA needs to aggressively pursue HPC capacity in a holistic way, balancing compute power, storage and data access. Rather than being reactive, NOAA will project realistic HPC needs for the next 5-10 years as an essential tool to get access to such resources. Such estimates need to holistically address both operations and research needs.

With the expectation that Moore's law may no longer be applicable, and that we can therefore no longer expect to see rapidly increasing compute power with flat funding profiles, and considering that present models have systematically become less efficient relative to the processor capabilities (mostly due to changing hardware architectures, partially due to age and history of codes), optimization of models on new hardware is becoming of paramount importance. Unified modeling using a small (reduced) number of models will make the optimization process more efficient. However, as community modeling requires portability of models, portability and optimization will need to be balanced wherever this creates conflicting coding requirements. The insertion of portability in standards will be paramount to ensure smooth transitions are as agnostic as possible with advances of hardware.

Finally, rapidly increasing quantities of model (and observation) data and evolving data format standards move NOAA into a Big Data era. This will require NOAA to re-assess compute, storage, product (service) generation and dissemination paradigms, and focusing on Big Data best practices, that store and sequence data to optimize these services and capabilities.

4 Vetting and Approval

This documents has contributions of, and is vetted by all Centers, Regional Headquarters and Portfolio Offices of the NOAA's National Weather Service (NWS), all Laboratories and Program Offices of NOAA's Oceanic And Atmospheric Research (OAR), NOAA's Office of the Chief Information Officer (OCIO), all other NOAA Line Offices through their representatives in the NOAA Unified Modeling Committee (UMC), and has been socialized and discussed at many public fora during it's development.

This document is approved by:

4/16/2020

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Revision history

Date	Ver.	Author/Editor	Comment
Aug. 2018	1.0.3	Hendrik Tolman John Cortinas	Final version 1.0
Oct. 2018	1.0.4	Hendrik Tolman	Updated signature page
Feb. 2020	1.0.5	Hendrik Tolman	Minor editorial changes