Organizing Research to Operations Transition

Authors: Unified Forecast System - Steering Committee (UFS - SC) and SIP Working Groups
(Members listed below.)
Contacts: Richard B. Rood (rbrood@umich.edu) and
Hendrik L. Tolman (hendrik.tolman@noaa.gov)
Date of Acceptance: 20181130

Table of Contents (Direct link to Document Summary)

Introduction

The purpose of this document is to describe the transition of research to operations (R2O) within the context of the Unified Forecast System (UFS). For a perspective on the problem see the 2000 National Academy of Science Report, *From Research to Operations in Weather Satellites and Numerical Weather Prediction*[1].

This description is needed to provide the foundation for improving the transition of R2O as well as to define the scope of the activities of the Unified Forecast System - Steering Committee (UFS - SC)[2]. With the definition of the R2O process, it will then be possible to organize, effectively, how operational applications can inform research activities (O2R)[3].

> Definition of the Unified Forecast System: The Unified Forecast System (UFS) is the community-based, coupled comprehensive Earth system model-based analysis and prediction system. The UFS is designed to meet the National Oceanic and Atmospheric Administration's (NOAA) operational forecast mission to protect life and property and improve economic growth. The UFS numerical applications span local to global domains and predictive time scales from sub-hourly analyses to seasonal predictions. It is designed to support the Weather Enterprise and to be the source system for NOAA's operational numerical weather prediction applications. Further description is found here: *https://www.earthsystemcog.org/projects/ufs-sc/definition_ufs*

The challenges of a community-based Unified Forecast System, addressing a portfolio of applications, compels a more formalized, organized, documented, and transparent implementation of the R2O functions.

NOAA and National Centers for Environmental Prediction (NCEP) have successfully made the transition of scientific software from research to operations for decades. Hence, all of the required functions exist in the present culture of building and implementing forecast systems. Currently, documentation and formal processes vary across the functions and organizations. In some cases the processes are more *ad hoc* than managed. It is widely recognized that the current R2O transition is not robustly

[1] https://www.nap.edu/catalog/9948/from-research-to-operations-in-weather-satellites-and-numerical-weather-prediction
[2] https://www.earthsystemcog.org/projects/ufs-sc/
[3] see: https://www.earthsystemcog.org/site_media/projects/ufs-sc/Boukabara_r2o_o2r_Transition_OSSE_BAMS_2016.pdf

resourced. However, only after the R2O process has been described can barriers and gaps be systematically identified and improved.

A number of important overarching issues need to be highlighted.

- The UFS must accommodate far more complexity than previous National Oceanic and Atmospheric Administration forecast systems. Therefore, existing R2O practices and capabilities are unlikely to extend to the requirements of a coupled, community-based system spanning the portfolio of forecast products.
- The evolution of the UFS and the R2O process faces the challenges of maintaining product generation in the short term, with longer-term evolution to the UFS. Hence, the mandate to deliver products in the current fragmented environment challenges the time and resource commitments to develop the protocols and practices of a unified forecast system. There is a need to use short-term activities to advance long-term goals.
- The functions and tasks that are needed in the current R2O process are not wholly defined. There are recognized gaps in the current R2O process. The increased complexity of the UFS amplifies these gaps, and likely, means that there will be new gaps. ***Hence, it is essential to identify the functions and gaps in the end-to-end R2O process prior to allocating resources to improve the R2O process. To spend money in existing tasks and organizations, without definition of the end-to-end R2O process, will support the perpetuation of existing gaps and deficiencies.***

Research and Operations: Overview of the Process

We note that research to operations already occurs; hence, there is a process. That process is documented with different levels of rigor. What is apparent is that the process of moving from research to operations is one of focusing and narrowing research efforts to contribute to specific applications. The selection process, which considers a portfolio of research contributions to be part of a UFS application, however, is not linear. Rather, it is an iterative process that occurs again and again as knowledge is gained from application-based experience.

Figure 1 is a community-level perspective, where community-developed components proceed through evidence-based gateways to become a candidate for operational implementation. Though the process is, ultimately, iterative, there is a general flow from left to right. On the left, the multiple arrows and small boxes represent components that contribute to the unified forecast system. “Component” in this case is a more general term than, for example, land, ocean, atmosphere, etc. of an Earth system model[4]. Components are provided by many individuals, groups, and institutions; that is, the “community;” in fact, many communities.

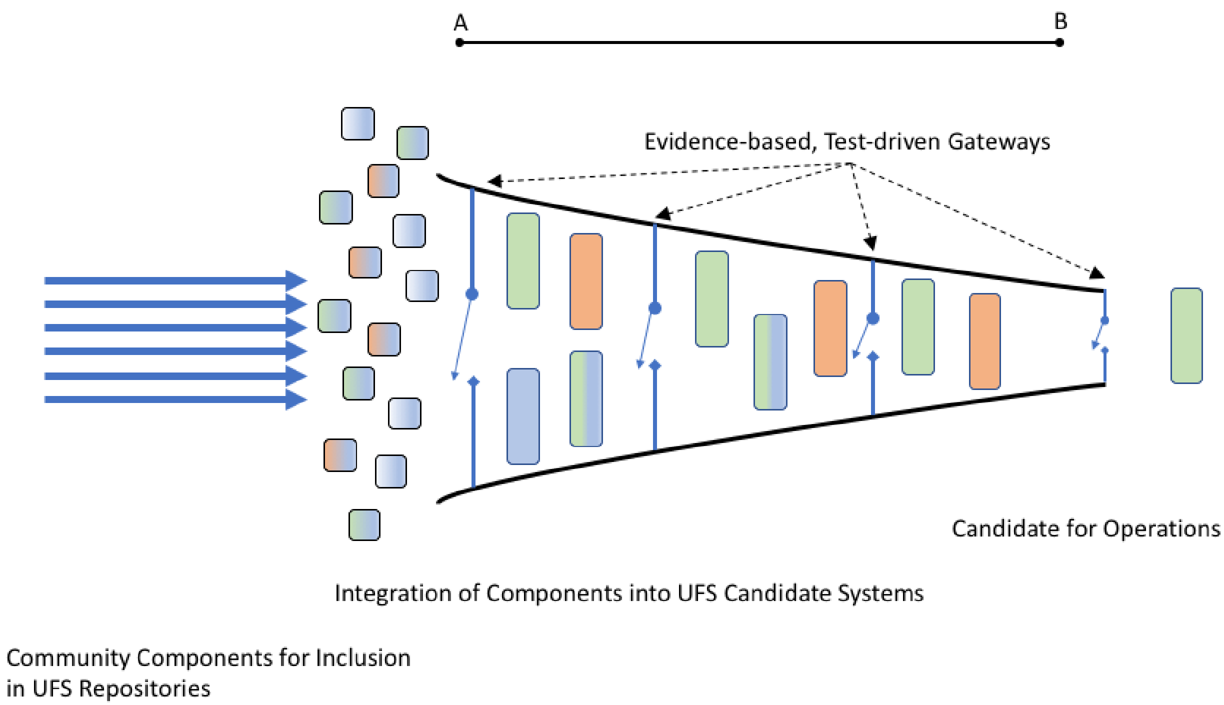

Figure 1: Schematic of UFS System Level research to operations transition process. On the left is a set of community components. There is an evidence-based transition at point A, when components are chosen for Unified Forecast System (UFS) candidate systems. After evaluation the UFS Candidate Systems, are reduced to a Candidate for Operations (Point B).

The segment at the top of the figure, labeled AB, is the primary realm of the UFS - SC governance. The point A is at the interfaces with the community. Tangibly, the interfaces are with the software repositories for community components. The governance of the UFS determines which of those components enter into UFS repositories and receive consideration for integration into UFS candidate systems. Candidate systems enter, then proceed, through the gates that determine viability as an

[4] From System Architecture for Operational Needs and Research Collaborations: Component – “composable” software elements that have a clear function and interface - in coupled models, these are often a portion of the Earth system, e.g., atmosphere, ocean or land surface.
http://www.earthsystemcog.org/site_media/projects/ufs-sawg/System_Architecture_31Mar2017.pdf

operational system. The evidence that is needed to pass through the gates is obtained by execution of a test-driven validation plan. The validation plan includes agreed-to metrics and associated targets for UFS applications. The goal is to provide an application-specific Candidate for Operations at Point B in Figure 1.

At both points A and B there is the need for technical standards and standards of behavior. The components at Point A are provided by communities that are neither managed nor, necessarily, funded by the National Weather Service. Therefore, it is not possible to prescribe or mandate how these components are managed. If those components are to be used in the UFS, it is possible to define standards that need to be met. Therefore, the UFS governance establishes negotiated and informed interfaces at A.

Point B is the interface to NCEP Central Operations. The transition to operations is determined by a process akin to the one described in Figure 1, with the Candidate for Operations being evaluated relative to the current operational system. The procedures and technical standards in the Environmental Equivalence 2 (EE2) Consolidated Document apply to this transition.[5] There are many opportunities for the UFS to be gained by collaborative development and communications at the interface with NCEP Central Operations. For example, if the standards of the EE2 were captured in workflows used in the UFS community, then the operational requirements could be better integrated into systems as they are being developed and tested.

At all interfaces, an essential piece of knowledge is the testing, verification, and validation practices across these interfaces. In as much as testing, verification, and validation do not have to be repeated from one gateway to the next, efficiency is added to the R2O process. That is, a well designed and adhered to validation plan develops trust between members of the community and supports reuse of gathered knowledge.

As suggested above, Point A is a set of interfaces to a large community with many funding sources and missions. This is an example of where the UFS needs to enter, formally, into a larger community. For example, the Earth System Prediction Capability (ESPC) Model Component Liaison Committee[6] has defined a set of minimum guidelines for authoritative component code repositories, and additional guidelines for "community" repositories. The Model Component Liaison Committee is made up of code managers of model component repositories across agencies and includes, but is not limited to,

[5] https://www.earthsystemcog.org/site_media/projects/ufs-sc/EE2-2017.11.29.pdf
[6] https://earthsystemprediction.gov/TechnicalWorkingGroups.aspx#12683254-model-component-liaison-

components in UFS. This is an example of an interagency group necessary for the success of the UFS.

The transition described in Figure 1 is from a collection of community-based components that have been determined suitable for possible integration into the UFS as a Candidate for Operations. This will be defined as a ***UFS System Level*** transition.

The transition of an entire component, say a new ocean model, is rare compared with the transition of smaller change to an existing component, for example, a change to the diffusive characteristics of the atmospheric advection scheme. Figure 2 represents a more narrowed transition than Figure 1. This figure is drawn from examination of the ongoing transition of the Finite Volume version 3 Global Forecast System (FV3GFS) to replace the GFS. The components for a particular forecast application have been chosen and configured as a Candidate for Operations. The Candidate for Operations is, then, tested in a real-time forecast environment with comparisons to the standard metrics of the application.

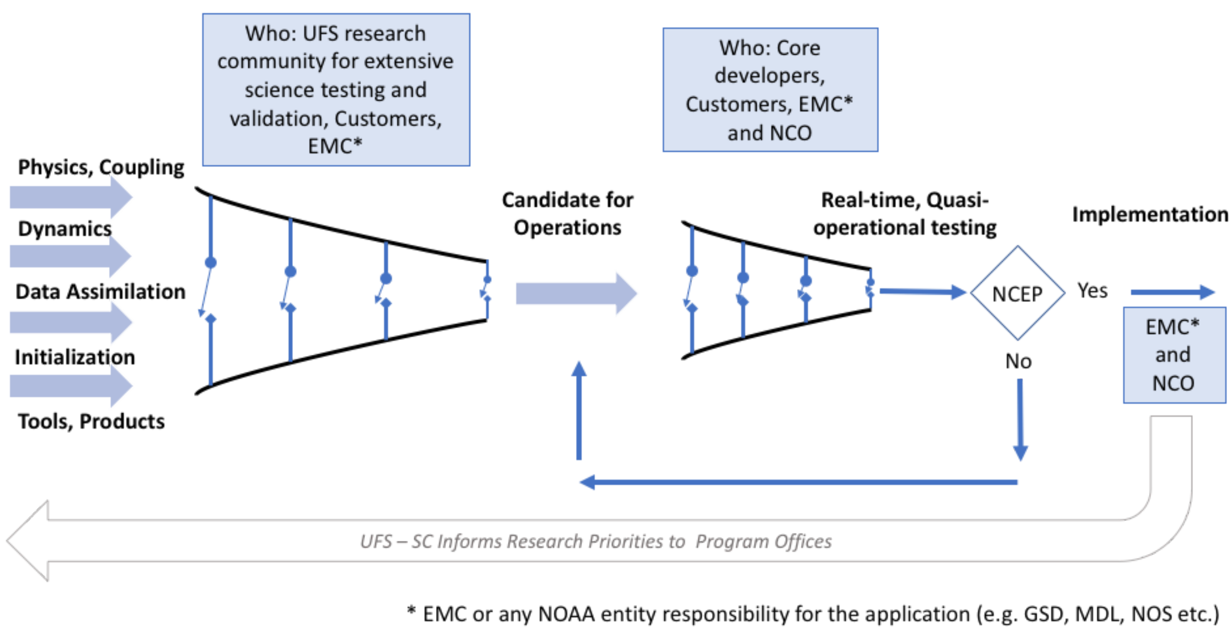

Figure 2: Schematic of UFS Application Level and Incremental Level research to operations transition process. In this case the configuration of an application has been determined. The components of the configuration, the Candidate for Operations, are listed on the left. The Candidate for Operations is tested in a real-time forecast environment. NCEP determines if the model is suitable for operations. If no, then

incremental changes might be made and the testing continues. These shows one aspect of the iterative process of the research to operations transition.

NCEP or other operational NOAA entities that have first-line responsibility for components of the UFS, for example, NOS with respect to ocean models, have the responsibility for determining whether the candidate is suitable for operations. If testing reveals an answer, “no,” then the candidate might be rejected or incremental changes might be made and the testing continues. The incremental changes then proceed through the loop on the right-hand side of Figure 2.

This example demonstrates the iterations in the R2O process as well as the co-development and co-evaluation with the community invested in the UFS. In addition, there is an iterative loop where the outcomes from the operational testing and implementation informs the research topics of the entire community. This loop is shown as the large arrow on the bottom of the figure.

The R2O transition process occurs at different levels of complexity. For the sake of organization, three levels are identified. The ***UFS System Level*** transition (e.g., Figure 1) is an infrequent event that might occur when a new application is brought into the modeling suite or there are imperatives to address basic shortcomings of the current operational system. An example of a UFS Systems Level transition would be community-based evaluation and selection of the FV3 dynamical core for the UFS[7]. (See, Appendix B) The configuration and deployment of the new subseasonal to seasonal capability is an example of new application. A UFS System Level transition will take on the order of 5 years, and they are focused on strategic goals with impacts of more than a decade.

The ***UFS Application Level*** transition (e.g., the left-hand side of Figure 2) considers changes to a component of an existing application’s operational system. An archetypical change might be to the physics of the atmospheric model in the global medium-range product (See, Case Study). The other components in the analysis-forecast system are largely unchanged. The physics packages being tested are drawn from the research community and have been determined through an evidence based process to be a viable candidates for operations. Once the components are chosen and integrated into a candidate system, the transition process is on the order of months to two years. As in the UFS System Level transition, the UFS Application Level transition is a significant investment in resources.

---

[7] https://www.earthsystemcog.org/projects/dycore_test_group/

The ***Incremental Level*** transition (e.g., the right hand side of Figure 2) is for small modifications to an existing operational system of well characterized performance metrics. Such a transition might be to investigate the sensitivity of the forecast to grid-scale mixing parameterizations. Incremental level transitions are common as potential scientific, technical, and engineering improvements are revealed in the operational environment. The cost of an Incremental Level transition is low compared to a UFS System or Application Level transition. (See, Appendix B)

These three levels of change to the UFS are demonstrative, not prescriptive. They are useful for describing and managing the R2O process. Hence, they support improvement of the R2O process.

Role of Computational Resources

Insufficient availability of computational resources is a major gap not only for operations (i.e., which innovation "fits" on the computer), but even more so for research, hierarchical testing, pre-implementation testing, verification, and validation. Given the essential role of testing, verification, and validation in R2O, this gap must be filled to accelerate the transition.

High performance computing is available through NOAA for activities in which there are NOAA collaborators with access to these systems. Additional computing resources offered "in kind" or otherwise external to NOAA systems will be required to fulfill the vision of the UFS as a community modeling system.

Substantial efficiencies can be gained with better test management including design of experiments with verifiable UFS-relevant outcomes. Improved documentation and adherence to validation plans leverages computational resources because tests do not have to be repeated across gateways. There are significant computational benefits that can be realized from simplification and unification of the product suite.

Portability between computational platforms supports community entrainment and increases the UFS usability. The UFS needs to adopt a policy on how to manage portability, which compilers are needed and considered part of the UFS community, and what is a minimal number of platforms that are community resources or commonly used within the community. Likewise new technologies such as containers need to be investigated. Code support functions to allow effective use of computational platforms need to be part of the R2O activities.

Elements of the R2O Transition Process

Glossary

A description of R2O requires a precise approach to describing specific R2O interactions. In order to do this, a common vocabulary is needed for those engaged with the UFS, key processes and events, repository types and locations, and elements of the underlying UFS architecture. A basic UFS vocabulary is captured in a draft glossary.

The following terms are defined and used in this document:

- **Application Level Transition**: See Figure 2, left - An existing analysis-forecast system with changes, primarily, to a component to be evaluated as a Candidate System.
- **Candidate System**: A configured analysis-forecast system for an application that is evaluated relative to other candidates to determine suitability for operations.
- **Candidate for Operations**: A Candidate System that has been been evaluated and selected to enter into evaluation relative to an existing operational system with the goal of replacing the existing operational system.
- **Incremental Level Transition**: See Figure 2, right - a small change, or a limited set of small changes, to an existing analysis-forecast system to be evaluated as a Candidate System.
- **System Level Transition**: See Figure 1 - a major transition with the selection of new components to form Candidate Systems.

Readiness Levels

The R2O overview, above, establishes that the research to operations transition is an iterative process of focusing and selection. The discussion identifies classes of functions that are needed: decision making; code management; systems integration; testing, verification, and validation; and workflow. Implicit also are developer and user support functions. Support is especially important if the operational systems are anticipated as attractive tools for the research community.

The goal of the R2O transition is to move complex scientific software from a loosely managed research community to rigorously defined production software. The production software provides science-evaluated environmental forecasts on a repeating schedule. The R2O transition process requires, therefore, evaluation of software quality, computational performance, and scientific quality.

A managed approach to the R2O transition has been described as a progression through a set of Readiness Levels (RL), systematic metrics that support the assessment of the maturity of research and development projects to provide routine provision of products.[8] (Figure 3, see Appendix A for definitions of the Readiness Levels.) The formal readiness level definitions are useful; however, they are often difficult to apply, directly, to scientific software transition. Note – Readiness Level 1 is basic research. Already, at Readiness Level 2 the research is applied and being integrated into the prediction system with a focus on improved outcomes of operational products. Technical levels 2 through 9 are steps of systems integration and testing.

Notionally, the Readiness Levels can be linked to the gateways introduced in Figure 1. The transition through gateways or Readiness Levels is drawn from the evidence obtained by execution of the test-driven validation plan.

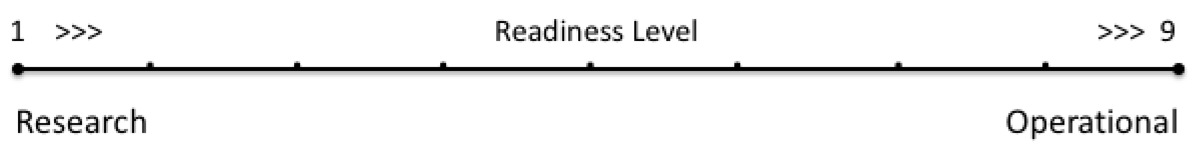

Figure 3: Schematic of NOAA Readiness Levels. The progression from readiness levels 1 to 9 relies on technical and scientific tests and deliberative decision making. The readiness levels based on NOAA's policy are detailed in Appendix A.

The Readiness Levels are useful in evaluating the effort required for transition to operations. With regard to community software posed for the UFS, criteria ranging from addressing priority forecast improvements, to utilizing UFS test plans, to adhering to UFS software management protocols could map a potential contribution from Readiness Level 1 to 5. Considering the UFS System Level, Application Level, and Incremental Level transitions, described above, beneficial incremental transitions often

---

[8] https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-105B.html , http://www.earthsystemcog.org/site_media/projects/communitygovernance/20161017_NOAA_Technical_Readiness_Levels_R2O.pdf

occur when relatively low Readiness Level algorithms are integrated into applications systems of, otherwise, high Readiness Level (7 or 8).

System Architecture

In order to discuss the R2O transition concretely, it is useful to use the system architecture and the terms defined within the systems architecture. The layered architecture and the identification of major components of the UFS, frame the complexity that must be addressed in functions described below. A complete description of the system architecture is found here[9], including requirements and a gap analysis of the R2O process experienced in the development of the systems architecture.

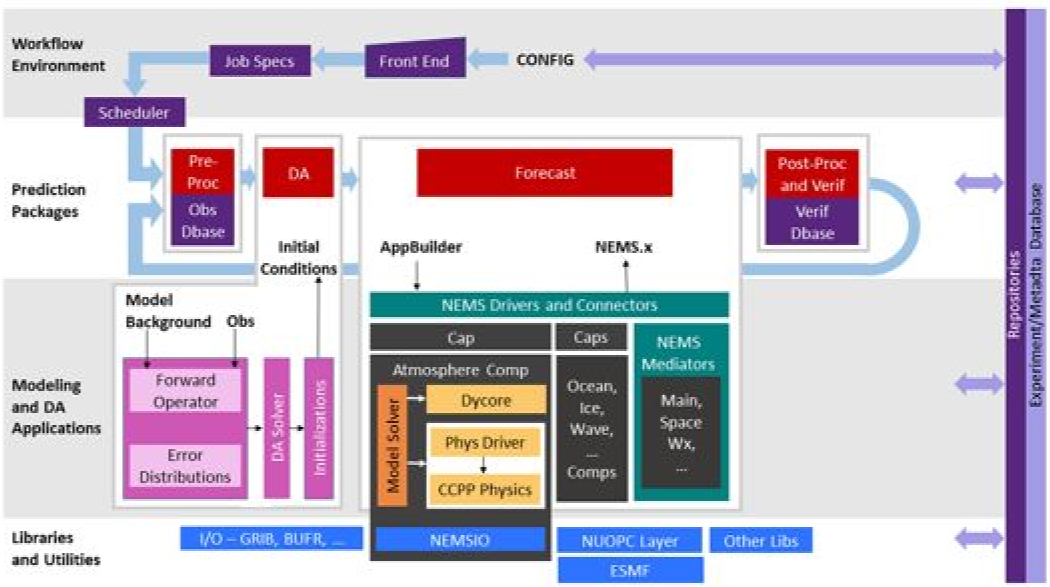

Figure 4: Diagram showing the four main layers in the NEMS system architecture: Libraries and Utilities, Modeling and Data Assimilation Applications, Prediction Packages, and Workflow Environment. Purple boxes indicate parts of the Workflow Environment and databases. Red boxes indicate executables while the thin lines around them represent scripts that invoke the executables. Teal boxes show NEMS infrastructure and model caps. Black boxes represent model and mediator components. Orange boxes show subcomponents of the atmosphere model component. Pink boxes show parts of the data assimilation system. Blue boxes show utilities and libraries. The Prediction Package sequence shown is typical; it may change for different applications.

[9] http://www.earthsystemcog.org/site_media/projects/ufs-sawg/System_Architecture_31Mar2017.pdf

Functions in the R2O Transition

Management and Decision Making

The R2O transition requires a set of management functions. These management functions are charged with making decisions that balance the attributes of science, technical, engineering, cost, and end user. Management functions are required to negotiate interfaces of the UFS with community members.

Management decisions are required for deliberative decision making at transitions/gateways in the R2O process; that is, evidence-based decisions that follow from testing, verification and validation. For the UFS, these decisions need to represent the application suite and the UFS as a whole. With reference to Figure 1, the UFS governance is focused on integration of components that have performed at a level that they are considered viable for operational consideration. This requires a component to not only have proved its potential to lead to an expected forecast outcome, but to have had evaluation of computational viability. This requires the UFS testing, verification, and validation criteria to be defined and executable for entry into the transition to operations.

For research needs we propose a four-step progression that is more intuitive than Readiness Levels (Figure 3).

- Step 1: Ideation
- Step 2: Preliminary Experimentation
- Step 3: Pre-operational Experimentation
- Step 4: Integration and Testing in Prediction Packages

An advantage of this four-step breakdown is that programmatic management roles can be identified. The Ideation step is the step where the research activities of the UFS community are most definitively identified. This is also where the NOAA's research programs in the Office of Oceanic and Atmospheric Research (OAR) and the National Weather Service (NWS) are natural sponsors. It is important to note, that the research in the ideation stage is not limited to predictive natural science, but also includes the technical and computational research required to provide viable product generation.

In the Preliminary Experimentation step, the testing, verification, and validation strategies proposed by the researcher come into contact with the testing required to pass the gateway for consideration to be integrated into the UFS. This is a step where funding by both the research programs and the operational programs is needed. Such a capacity, formally, exists in the R2O process in the NOAA testbeds. A testbed is a working relationship for developmental testing in a quasi-operational framework among researchers and operational scientists/experts. A successful testbed involves physical assets as well as substantial commitments and partnerships[10].

As integration and testing move into Steps 3 and 4, funding requirements move towards the operational interests of the National Weather Service. With regard to the Readiness Levels, the Ideation step aligns with levels 1 and 2, and the Preliminary Experimentation with levels 3 and 4. The Pre-operational Experimentation and Integration and Testing in Prediction Packages align with Readiness Levels 5 through 9.

Management functions will be identified more completely through case studies and use cases. There needs to be care to coordinate the needed management functions with existing governance and management bodies.

Workflow

The workflow management system is software that provides the capability to set up, execute, and monitor the set of tasks required for product generation (top layer of Figure 4). Workflows are needed to address research and operational needs. Having a defined transition between research and operational workflows stands to improve the r2o transition.

The workflow management system executes prediction packages, which include a sequence of tasks including pre-processing, data assimilation, forecasts, and post-processing. Prediction packages include data assimilation and model components coupled and configured for a specific application, e.g., medium-range forecasts, storm surge, subseasonal-to-seasonal, etc.

Analysis of the existing workflow for different prediction packages reveals inefficiencies and barriers in the sequence of tasks, and hence, opportunities to improve the R2O process. Improving tasks that are shared across multiple prediction packages, for example post-processing, stand to have benefits for multiple applications in the NWS suites.

---

[10] https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-105B.html

Code Management

The success of research, development, and implementation of UFS relies on well managed software, code, to assure that researchers and developers are working from a single code base. Throughout the community, there are different approaches to code management, and communities have evolved to practices that work for them. Within the operational weather community, a need for code management and community support was recognized. The Developmental Testbed Center (DTC) has formalized the R2O process in the transition of the Hurricane Weather Research and Forecast Model (HWRF), the Gridpoint Statistical Interpolation (GSI) and Ensemble Kalman Filter (EnKF) data assimilation systems, and the Unified Post Processor (UPP).

Code repository management is a critical element of code management. Repository management requires a management body as well as software designed for code management. Functions of repository management include tracing the history of the code and providing access to researchers and developers in the community. As a specific example, if repositories support both the research and operational developers, then it is possible to incorporate developments in Incremental Level transitions rather than Application Level transitions.

The UFS Infrastructure Working Group developed a Repository Management Plan for the UFS[11]. The report notes “a comprehensive, community-friendly repository strategy for the UFS, which also satisfies operational constraints, is a complex problem. The approach here is to define the elements of the strategy - repository types, locations, and key interaction processes - and use this defined terminology to describe a set of use cases (including actors and events).”

The key principles are:

- Clearly define and communicate the UFS repository structure and practices
- Utilize open repositories to maintain transparency
- Facilitate collaboration between the community and different agencies
- Be flexible enough to support implementation of agency mission deliverables while allowing community contributors to focus on their goals
- Restrict development for each constituent component of the UFS to its own repository

[11] https://drive.google.com/file/d/1dF0DuwH-VC109MrPC_inrAO3i7-_4hD-/view

The report recommends to prototype the plan and to evolve repository management by focusing on two applications, global medium range forecasts, and the subseasonal-to-seasonal forecast. The plan relies on use cases. In addition to the prototypes, advancing the development of the repository governance, protocols, and practices, the prototyping aids in the identification of functions and tasks as well as defining the staff and computational resources to support the activity.

Developer and User Support (Community Support)

Lessons from the research to operations transition of HWRF and GSI inform good practice. In both of these instances, incremental changes to an existing operational system were implemented. Therefore, the full extent required by the UFS was not represented. One of the most essential conclusions from these transitions is the need for community support of code services. These services include the ability to obtain the latest code releases, users' guides, scientific documentation, test datasets, benchmarks, and access to a helpdesk. There are formal training sessions and online support.

The support for the UFS will require community support, but for far more complex systems than in historical R2O examples. Several reviews of NWS capabilities have called for far more resources to be allocated to existing applications; that is, the user support functions that have been developed to date are for only a subset of the NWS applications. The task of extending user support functions across multiple applications with coupled systems is one that requires rigorous planning with the identification of functions and tasks as well as defining the staff and computational resources to support the activity.

It is essential to identify the functions and gaps as well as the scope of the user support to be assumed by the UFS. Services will be key to the UFS system garnering innovations from the community. A work breakdown is needed prior to allocating resources to provide user support. It is essential to consider the role of scientific and application expertise needed to provide effective user support; that is, the role of scientific liaisons. Roles and responsibilities of existing and potentially new organizations need to be defined prior to assigning tasks and allocating resources.

System Integration

System integration brings together the pieces of software that make up the modeling and data assimilation applications, the prediction packages, and the workflow management system. System integration connects software libraries and utilities, with components of the forecast-assimilation model. That is, system integration connects subsystems into larger systems to provide products.

System integration includes verification that the system is working as expected, and therefore requires tests to provide the evidence of successful integration.

Subsystems in the UFS require integration steps to assure that the subsystem functions as expected. When a candidate for operations enters the transition to operations (Figure 1), there is integration of a prediction package into the operational workflow. System integration takes place, repeatedly, throughout the UFS enterprise.

There are system integration activities throughout the *existing* R2O process. These integration activities are associated, largely, with configuring systems for a specific application by application teams. Most of the NWS experience is with uncoupled, atmospheric models. There is limited experience within the NWS on integration of coupled models for some of the applications in the product suite. Systems integration requires definition of the required functions, definition of the human and computational resources needed to address those functions, and funding to provide those resources.

Through comparison with the Geophysical Fluid Dynamics Laboratory (GFDL) and National Center for Atmospheric Research (NCAR), it is safe to say that systems integration for the UFS requires development of organizational protocols and mandates, definition of functions and tasks, and staff and computational resources to support the activity.

Testing, Verification, and Validation

Throughout research, development, and the transition there is evaluation of software. The evaluations span software quality, computational performance, and scientific quality. Transition from one gateway/readiness level to another relies on evidence that comes from systematic testing. Indeed, it is expected that testing, verification, and validation consumes the largest portion of both human and computational resources. Therefore, documented test plans and test results stand to provide information that can be used across applications and across organizations; that is, to reduce redundant testing.

Evaluation is a general term that includes both quantitative measures and qualitative analysis of a model's ability to address its design goals. Across the UFS community the terms verification and validation are likely to be used differently. Within most fields of computational sciences, validation follows from the comparison of model simulations with observations of nature to establish the accuracy of the natural science of the model. Accuracy is informed by quantitative, often statistical, measurement of the suitability to address a specific application. Verification is associated with the computational integrity of the code and might include comparisons with analytic test problems as well as comparisons to high fidelity computations. Testing is defined as part of verification and validation. That is, testing checks the performance, quality, reliability – generically, some attribute in a way that is narrowly defined compared to the model as a whole[12].

Within the field of numerical weather prediction, a primary method of evaluation is the systematic comparison between forecasts and objective analyses of observations. The evaluation is based on a series of weather forecasts taken from subsequent days over a period of time to cover a significant sampling of weather conditions. This process is known as verification, and the use of the term verification to describe this simulation-observation comparison is standard in numerical weather prediction[13].

Within the community of software development of components of the UFS, each community will have an evaluation protocol, which has evolved to serve their needs. As the software system makes the transition to operations, evaluation strategies are expected to converge to a set of narrowly defined technical and scientific performance metrics.

Referring to Figure 1, the UFS governance needs to develop the test plans for the movement of a candidate for operations to the transition to operations. Test strategies need to be planned around specific applications, and scientific and forecast improvements for those applications.

New to UFS activities, test strategies need to be defined across the application suite; that is, multiple applications. Evaluation of coupled models, and the effects of changes in one application to other applications will need to be routinely evaluated. This will

[12] Rood, Richard B. (forthcoming). Validation of Climate Models: An Essential Practice. In: Beisbart, Claus and Nicole J. Saam (Eds.). Computer Simulation Validation. Fundamental Concepts, Methodological Frameworks, Philosophical Perspectives. Cham: Springer International Publishing.

[13] Theis, Susanne & Michael Baldauf (forthcoming). Validation in Weather Forecasting. In: Beisbart, Claus and Nicole J. Saam (Eds.). Computer Simulation Validation. Fundamental Concepts, Methodological Frameworks, Philosophical Perspectives. Cham: Springer International Publishing.

increase the need for management bodies to deliberate the tensions that will arise from the consideration of forecast products at different spatial and temporal scales.

Figure 5 sets out the scope of verification and validation needed for the UFS. The figure makes explicit the need for both computational verification, including meeting performance standards, as well as both scientific verification and validation. The different rows represent levels of systems integration, ranging from parameterizations and algorithms at the bottom to coupled systems in workflows for prediction packages at the top. At each level of integration there are multiple types of tests. These tests use different levels of complexity and make up an ecosystem of interacting tests that inform the accuracy and suitability for a particular application. An efficient R2O process requires standardization of elements in the test plan and that the systems architecture support configurations of varying complexity.

Scientific Verification and Validation

Computational Verification

Coupled Configurations, Applications, Prediction Packages	Idealized Models, Benchmarks, Hindcasts, Process ("Physics"), Forecasts
Components: Atmosphere, Chemistry, Ocean, Land, Ice	Idealized Models, Benchmarks, Hindcasts, Process ("Physics"), Forecasts
Composites, Suites, Sub-components	Process ("Physics"), Field Campaigns, Benchmarks
Algorithms and Parameterizations	"Unit" Tests, Analytic Tests, Synthetic Tests, Process ("Physics")

Figure 5: Elements of computational verification and scientific verification and validation associated with increasing, from bottom to top, of system integration. Topics on the left of the table require testing outlined on the right of the table.

The UFS Verification and Validation Working Group has made significant progress in the development of metrics for the UFS (link). Attention is needed to develop the verification and validation plans for applications and application suites. In addition to these verification and validation plans, there is a need to develop verification and validation criteria at the interface of the UFS with the community, Point A in Figure 1. Documented and published verification and validation criteria at this interface, communicated to the research community, are tactics to bring order to the research efforts that might provide viable components for UFS candidate systems.

Case Study: Advancing Atmospheric Model Physics for FV3GFS

In Appendix B, there is the analysis of R2O transitions that have occurred within the DTC. There is also description of the recent transition of FV3GFS to operations. These analyses describe functions that have proved essential practice and expose gaps in the process. These experiences inform the Functions in the R2O Transition, above.

There are two upcoming transition cycles for improving the physics in the FV3GFS. These planned transitions are an opportunity to further analyze and improve the R2O transition process. This is a UFS Applications Level Transition, where changes to the atmospheric physics parameterizations are being made, primarily, for the global medium-range application (See Figure 2). More details are provided in "Advancing Model Physics in the UFS: Assessing the potential for full-physics-suite replacement in EMC's FV3GFS."

In addition to using the Advancing Atmospheric Model Physics transition as an overarching framework for the R2O transition, we advocate use cases to expose the details of the process. Potential use cases are described in Appendix C.

The Advancing Atmospheric Model Physics transition starts with the Global Forecast System version 15 (GFSv15), which prior to the transition to operations was FV3GFSv1. That is, it is the first version of the GFS that used the Finite Volume version 3 (FV3) dynamical core. From GFSv15, there are two cycles of atmospheric physics advancement that are expected. These will lead to GFSv16 and GFSv17.

GFSv15 uses the atmospheric physics suite that had been in the earlier version of the GFS, with the, primary, exception that the Zhao-Carr microphysics was replaced with the microphysics used in the GFDL Atmospheric Model version 3 (AM3).

One of the goals in this use case is to assess the practice of using atmospheric physics suites that have been highly calibrated in previous testing and applications. This is recognition that the introduction and calibration of the individual parameterizations in the full pre-implementation test suite is impractical. Therefore, the testing of individual parameterizations needs to take place in a more flexible testing environment that includes tests of varying complexity.

Three candidate atmospheric physics suites have been selected for the first cycle of testing, GFSv16. A test plan has been developed for pre-implementation. With regard to Figure 1, each candidate atmospheric physics suite can be viewed as a component provided by the community. The transition, itself, is as in Figure 2, where changes are, primarily, to the atmospheric physics. That is, an atmospheric physics suite will replace the like physics suite in GFSv15, and that will become a candidate for GFSv16.

Referring to Figure 6, there is a calibration phase at Point A, where the physics packages are integrated into the application system. This will provide Candidates for Operation. After integration into candidate systems, there is pre-implementation testing. The outcome of the testing - verification and validation - will be a candidate atmospheric model for use in the medium-range global application. The atmospheric model is, then, also available for integration and testing into the coupled systems required for other applications.

The second cycle of testing for GFSv17, will start from GFSv16. Once there is a set of candidate atmospheric physics suites, the process is analogous to that in the cycle determining GFSv16. Important new aspects of the GFSv17 cycle will be the determination of the candidate atmospheric physics suites; hence, there are characteristics of a UFS Systems Level transition. This will require the development of testing protocols that support effective engagement with the scientific community. Also required is a set of aspirational forecast outcomes and early systems testing to determine the candidate atmospheric physics suites for integration into the atmospheric model of the UFS. (Figure 6)

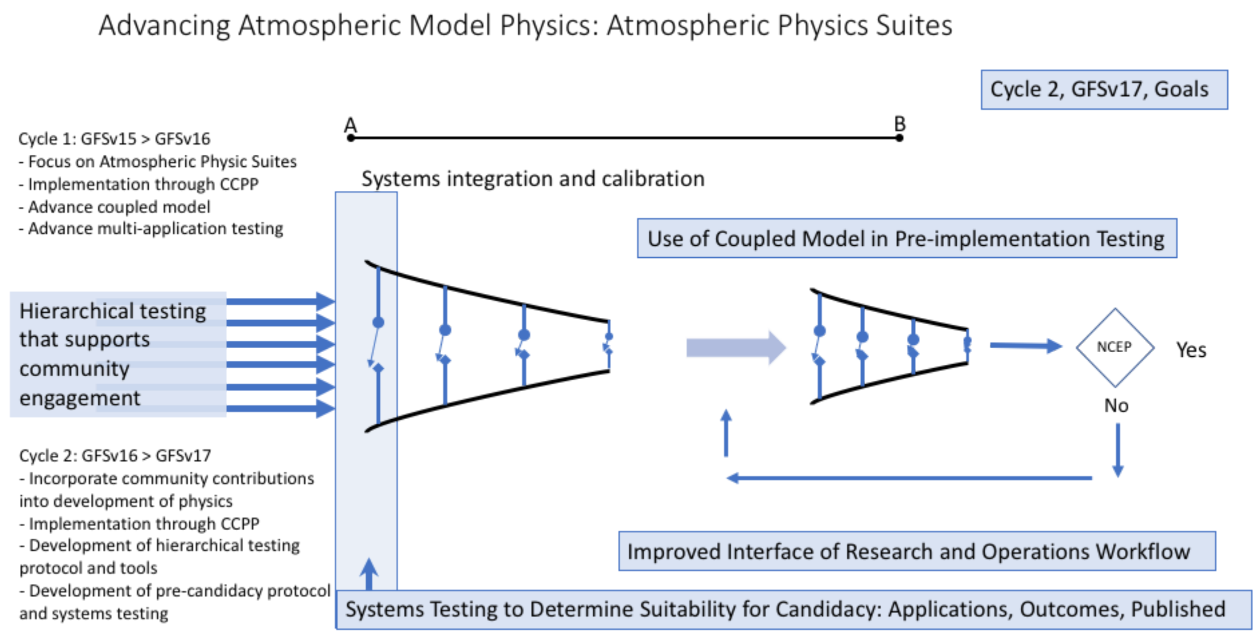

Figure 6 maps the Advancing Atmospheric Model Physics development cycles and UFS R2O goals (blue shaded boxes) to the transition modeled in Figures 1 and 2.

In addition to the scientific and operational goals of the improvements to the physics suite and the global medium-range application, there are numerous UFS-SC goals to improve the R2O transition process.

UFS-SC Goals in Advancing Atmospheric Physics Development Cycle:

- Assess the practice of using physics suites in R20 transition
- Test and evolve Common Community Physics Package
- Develop testing protocol for incorporation of components into atmospheric physics suites
- Develop testing protocol for determining the viability of physics for inclusion into candidate UFS Systems
- Publish testing protocol that informs research program and community of capabilities and outcomes relevant to the UFS applications
- Develop a hierarchy of tests of varying complexity to support scientific and computational verification and validation of components and atmospheric physics suites (Provision of tools?)
- Evolution of verification and validation plan for global medium-range application

- Development of protocols for verification and validation of coupled systems (esp., sub-seasonal to seasonal)
- Perform pre-implementation testing in coupled system (e.g., ocean or data ocean)
- Definition of systems integration steps in coupled system and evolution of hierarchical tests of varying complexity to support coupled applications
- Improve the interface between research and operational workflows

Summary: Organizing Research to Operations Transitions

This document describes the research to operations (R2O) transition process to support NOAA's efforts to develop a Unified Forecast System (UFS). The description relies on policy documents as well as analysis of research to operations transitions that have occurred in the past. To define, better, and to improve research to operations transitions, we advocate using upcoming transitions to identify and manage towards process improvement. We advocate using use cases to develop detailed understanding of the processes and, hence, support improvement.

The role of operations better informing research needs is not as thoroughly discussed. It is recognized that user and developer support functions are absent and needed to facilitate community contributions. This will be developed in future documents. Otherwise, it is maintained that the improvements in the research to operations transition are needed prior to defining, formally, how research is informed by operations. Development of the functions described in this document builds needed capacity for the interface between research and operations.

For the purpose of organization, we identify three types of research to operations transitions. These three types are of different complexity, time spans, and cost. Examples are provided in the text.

1. From the UFS systems perspective, the Systems Level transition requires the selection of system-level components from the community, configuration for a particular application, evaluation of candidate systems, and then transition to operations. This is strategic level transition of order five years in effort with decadal length organizational outcomes.

2. From a UFS application perspective, the Application Level transition considers a set of defined changes to, primarily, a single component in an existing application. This is order of months to two years in efforts.

3. Incremental Level transitions are more frequent and target narrow changes to existing algorithms and functions in application system of high Readiness Level.

We identify the functions that need to exist in a robust, repeatable research to operations transition capacity. These functions are described in the text. They are listed in the table below, along with whether or not the Unified Forecast System - Steering

Committee (UFS-SC) has initiated any meaningful analysis and planning with the Working Groups. Also, included is a qualitative red (major gap), yellow (some existing capacity), green (full capacity) evaluation.

Function	UFS - SC Analysis	Status Evaluation
Management and Decision Making	yes	some existing capacity
Workflow	yes	some existing capacity
Code Management	yes	some existing capacity
System Integration	no	major gap
Developer and User Support	no	major gap
Testing, Verification, and Validation	yes	some existing capacity

Computational resources are not discussed in detail in this document as they have been the subject of many reports on the status of NOAA's research and operational models and forecast systems. If the research to operations transition process is improved, then there is some improvement to be realized in the use of computational resources .

Computational Resources	no	some existing capacity

None of the functions are at full capacity for the current application suite. Given the complexities of the application suite, the software, and the research community, the existing capacity will not scale, effectively, to cover the scope of the Unified Forecast System. Therefore, we summarize the following points in the progressive improvement of the R2O transition.

- The evolution of the UFS and the R2O process faces the challenges of maintaining product generation in the short term, with longer-term evolution to the UFS. There is a need to use short-term activities to advance long-term goals.

- The functions and tasks that are needed in the current R2O process are not wholly defined. ***It is essential to identify the functions and gaps in the end-to-end R2O process prior to allocating resources to improve the R2O process. To spend money in existing tasks and organizations, without definition of the end-to-end R2O process, will support the perpetuation of existing gaps and deficiencies.***

Reference Material

1. References are provided as footnotes in the document.

2. Documents of particular importance to NOAA Policy are:

Environmental Equivalence 2 (EE2) Consolidated Document
(https://www.earthsystemcog.org/site_media/projects/ufs-sc/EE2-2017.11.29.pdf)

NAO 216-105B: Policy on Research and Development Transitions
(https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-105B.html)

3. The Unified Forecast Systems Architecture is described in:

System Architecture for Operational Needs and Research Collaborations: There is a glossary of terms and a R2O gaps analysis.
(http://www.earthsystemcog.org/site_media/projects/ufs-sawg/System_Architecture_31Mar2017.pdf)

4. The Unified Forecast System - Steering Committee has been collecting together documents, information, and commentary on the transition of research to operations. Those can be found here:
(https://docs.google.com/document/d/1M6MfDn2KIy5Ceh830YNaNmHKxd1icKKLsfrD_9gG9dI/)

5. We note the document from the European Centre for Medium-range Weather Forecasts (ECMWF):
The development and evaluation process followed at ECMWF to upgrade the Integrated Forecasting System (IFS)
(https://www.ecmwf.int/en/elibrary/18658-development-and-evaluation-process-followed-ecmwf-upgrade-integrated-forecasting). This describes a detailed process comparable to the Application Level transition described here.

Acronyms

DTC - Developmental Testbed Center
ECMWF - European Centre for Medium-Range Weather Forecasts
EE2 - Environmental Equivalence 2
EMC - Environmental Modeling Center
EnKF - Ensemble Kalman Filter
ESPC - Earth System Prediction Capability
HWRF - Hurricane Weather Research and Forecast Model
FV3 - Finite Volume version 3 (FV3) dynamical core
FV3GFS - Finite Volume version 3 - Global Forecast System
GFDL - Geophysical Fluid Dynamics Laboratory
GFS - Global Forecast System (NWS's Operational global forecast system)
GSD - Global Systems Division
GSI - Gridpoint Statistical Interpolation
HFIP - Hurricane Forecast Improvement Program
IFS - Integrated Forecasting System
MDL - Meteorological Development Laboratory
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
NOAA - National Oceanic and Atmospheric Administration
NOS - National Ocean Service
NWS - National Weather Service
OAR - Office of Oceanic and Atmospheric Research
O2R - Operations to Research
RL - Readiness Levels
R2O - Research to Operations
UFS - Unified Forecast System
UFS-SC - Unified Forecast System - Steering Committee
UPP - Unified Post Processor

Membership of UFS - Steering Committee

All people listed in this section have been invited to Steering Committee Meetings and have had the opportunity to comment on the document. There have been different levels of active participation.

Richard B. Rood* and Hendrik L. Tolman*, Co-Chairs

Program Executive: William Pryor*
Program Support: Karen Keith, Sherrie Morris, Bhavana Rakesh

Whit Anderson, Ligia Bernardet*, Rusty Benson, DaNa Carlis, Adam Clark, Arun Chawla*, Jeffrey Craven*, James Doyle, Georg Grell, Brian Gross*, Tom Hamill*, Tara Jensen*, Daryl Kleist, Shian-Jiann Lin, John Michalakes, William Putman, Tim Schneider*, Ivanka Stajner, Vijay Tallapragada, Gerhard Theurich, Yannick Tremolet, Mariana Vertenstein*, Jeffrey Whitaker, Ming Xue

William Lapenta* (Observer)
Louisa Nance* (Observer)

Provided comments on the document:
Fred Toepfer* and Annarita Mariotti (NGGPS Program Office) and Hui-Ya Chuang* (EMC)
Return to top

Strategic Implementation Plan Working Group Co-Leads

All people listed in this section have been invited, regularly, to Steering Committee Meetings and have had the opportunity to comment on the document. There have been different levels of active participation.

Curtis Alexander, Whit Anderson, Thomas Auligné, Rusty Benson, Lance Bosart, Chris Bretherton, Pat Burke, Arun Chawla, Eric Chassignet, Brian Colle, Jeff Craven*, Cecelia DeLuca*, James Doyle, Mike Ek*, Trey Flowers, Ron Gelaro, Sundararaman Gopalakrishnan, Georg Grell, Robert Hallberg, Lucas Harris, Tom Hamill, Patrick Hogan, Christiane Jablonowski, Susan Jasko, Tara Jensen*, Jack Kain, James Kinter*, Daryl Kleist, Jason Levit, Cheng-Hsuan Lu, Geoff Manikan, Jeff McQueen, Avichal Mehra*, Jason Otkin, Steven Pawson, Richard B. Rood, Tim Schneider*, Arlindo da Silva, Ivanka Stajner, Christina Stan, Ariel Stein, David Stensrud, Vijay Tallapragada, Hendrik Tolman, Ryan Torn, Mariana Vertenstein, Helin Wei, Jeff Whitaker, Zhuo Wang, Yuejian Zhu
Return to top

* Individuals who contributed text or are explicitly logged in the comments

Appendix A: Readiness Levels

NOAA Readiness Levels (RLs) as defined in NOAA Administrative Order 216-105B, Policy on Research and Development Transitions (revised 21 March 2017)

RL 1: Basic research: systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. Basic research, however, may include activities with broad applications in mind.

RL 2: Applied research: systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met; invention and concept formulation.

RL 3: Proof-of-concept for system, process, product, service or tool; this can be considered an early phase of development; feasibility studies may be included.

RL 4: Validation of system, subsystem, process, product, service or tool in laboratory or other experimental environment; this can be considered an intermediate phase of development.

RL 5: Validation of system, subsystem process, product, service or tool in relevant environment through testing and prototyping; this can be considered the final stage of development before demonstration begins.

RL 6: Demonstration of prototype system, subsystem, process, product, service or tool in relevant or test environment (potential demonstrated).

RL 7: Prototype system, process, product, service or tool demonstrated in an operational or other relevant environment (functionality demonstrated in near-real world environment; subsystem components fully integrated into system).

RL 8: Finalized system, process, product, service or tool tested, and shown to operate or function as expected within user's environment; user training and documentation completed; operator or user approval given.

RL 9: System, process, product, service or tool deployed and used routinely.

Appendix B: Analysis of Existing R2O Transition Cases

DTC-supported Operational Systems

To facilitate the transition of research innovations from the broad community into operations, the Developmental Testbed Center (DTC) stood up code management and user support for three NOAA operational software systems that were already being used in operations: HWRF (NOAA's end-to-end tropical storm forecasting system), GSI/EnKF data assimilation systems, and UPP. All of these software management and user support activities are collaborative efforts with the developers, where the exact role of the DTC depends on the software package. The central premise of this effort was to establish a framework based on software systems that are a shared resource with distributed development, where the current operational systems are a subset of the capabilities contained in these software systems. While specific software management plans differ between the various software packages, they all contain the following elements:

- Code repositories maintained under version control software.
- Protocols for proposing modifications to the software, whether the modifications are simply updates to current features, bug fixes or the addition of new features.
- Testing standards proposed software modifications must pass prior to being committed to the code repository.
- Additional testing standards used to more thoroughly check the integrity of the evolving code base.

Given these software packages continue to evolve over time, all testing standards must be updated periodically in order to meet the maintenance requirements of the code base.

The DTC facilitates the engagement of the research community in the code management process by providing developer support. Developer support takes the form of supporting community members' engagement with the various aspects of the code management process. This support ranges from assisting community members with establishing branches/forks in the relevant code repository, running the appropriate tests, and the process for proposing the merge of new capabilities into the master repository. For the most part, the developers the DTC has engaged in this transition process have been funded by a NOAA program (e.g. Hurricane Forecast Improvement

Program (HFIP) and Next Generation Global Prediction System (NGGPS)) and/or the DTC Visitor Program. These engagements have led to a number of innovations being available for consideration of transition to operations. The innovations have touched on a broad spectrum of capabilities: atmospheric physics innovations, a multi-storm configuration, and advances with respect to the ocean component for HWRF, improved forward operator for coastline observations and ability to assimilate new observations types for GSI/EnKF, and new microphysics-specific reflectivity and synthetic satellite output field for UPP.

In addition to the developer's support described above, the DTC also provides support to the general user community. User support centers around periodic releases of the software system that include: 1) the ability for the community to download a snapshot of the code repository that has undergone more extensive testing to address portability and robustness of the code base, 2) access to documentation describing the capabilities included in the code release and how to setup and run the code, 3) an online tutorial, and 4) email help desk support. Over the years, the DTC has also offered resident tutorials that consist of lectures given by system developers covering all aspects of the system, lectures on how to set-up and run the system, and hands-on practical sessions where the participants work through exercises and have the opportunity to ask questions of the instructors. While this support system provides a mechanism to entrain researchers in the development of the operational systems, it is hard to quantify what percentage of this effort supports community members who will never contribute back to the advancement of the operational system.

One potential drawback to the DTC's approach to supporting NOAA's hurricane model is that the support was configured to address the entire end-to-end system for a particular application. This approach led to support for the application of GSI/EnKF and UPP to the hurricane forecast system being handled separately from the other applications of these software systems. This approach impedes communication across applications for the various components and will likely impede work towards unifying the forecast system. In addition, this approach leads to redundancy in the support system for certain software packages since questions related to GSI/EnKF and UPP can be submitted to either their respective helpdesks or the HWRF helpdesk.

Once the innovations are part of the code base that includes the operational system, it is fairly straightforward to conduct testing and evaluation directed at informing the operational community whether an innovation is worth consideration for future operational implementations.

A subset of the innovations for which the DTC provided developer support have been transitioned to operations based on extensive testing following the addition of the innovation to the software system. The DTC's role in this aspect of the R2O process has varied from simply making the innovation available to the core developers for extensive testing to playing an integral role in conducting extensive retrospective tests directed at informing which innovations are considered for the next operational implementation.

FV3GFS Transition to Operations

The FV3 dynamical core (dycore) was developed at NASA and NOAA, where it is being used in coupled modeling activities. NOAA's program to develop the Next Generation Global Prediction System (NGGPS) sought a replacement for the Global Spectral Model dycore currently in use at NCEP for operational weather prediction.

Selecting a non-hydrostatic atmospheric dynamic core (dycore) was the first step in building the NGGPS. Six dycores in development from a variety of institutions were viewed as potential candidates to be evaluated for the new system. Criteria for the selection of a dycore and associated tests to evaluate the dycores were developed. Assessment results were provided to NOAA (NWS) management who made an overall business case decision to select the FV3 dycore for the next operational weather prediction model.

Once this selection was made, the dycore was integrated into the NWS operational workflow, guided by performance constraints and existing infrastructure such as the existing data assimilation system. Constant interaction was required between the authors of the model at NOAA/OAR/GFDL and the development team at NOAA/NWS/NCEP/EMC. When a prototype operational end-to-end system was completed, testing in the operational environment began and the code was released to the public through NOAA's VLab. Operational implementation is planned for Q2 FY 2019. The adoption of the FV3 dycore into other applications, like standalone regional models and fully coupled models, is underway at this time.

Appendix C: Use Cases to Advance the R2O Transition Process

In this document the R2O transition process has been described. The process starts with community-based components with the goal of providing a candidate for operations. A particular goal was to define the classes of functions that are required in the transition.

Examples of past and ongoing R2O exercises have been used to provide concrete examples of the functions in the process. However, none of these past and ongoing activities represent the entire process that will be needed for the UFS. Neither do these past and ongoing activities represent the complexity of the suite of forecast products nor the transition of fully coupled forecast systems. Therefore, strategies are needed to better define and refine the R2O transition in the future.

Going forward, therefore, we will focus on how to improve the R2O process. This will include providing analyses of the R2O process that inform both NOAA and community investments in the evolution of the R2O process. In the near term, we will focus on using ongoing transitions that are imperative to the operational mission to standardize, document, and improve the R2O process.

We will also develop use cases to implement the high-level description. This more precise approach describes specific R2O interactions. In order to do this, a common vocabulary is needed for the actors engaged with the UFS, key processes and events, repository types and locations, and elements of the underlying UFS architecture. The vocabulary can then be used to populate a set of use cases. The advantage of examining the R2O process through use cases is that they are both concrete and integrative - pulling together technical, scientific, and governance aspects.

A basic UFS vocabulary is captured in a draft glossary. Concepts related to actors and events, which are central to R2O, are described in more detail below.

Actors

Actors in this context are divided into three main groups:

1. Non-contributor - People who only want to download and run applications, or expect to make local changes only.

2. People who change the code:
    a. Application developers (or just developers) - People who modify code in order to improve it scientifically or computationally. No distinction is made at this time between EMC and other developers, with the expectation that development processes will be the same for both.
    b. Integrators - People who change application code in order to transition an application into a full operational workflow, typically working on a restricted operational computer (e.g. WCOSS).
    c. Testers - People who test the code.
    d. NCEP Central Operations (NCO) - People who dictate technical requirements for codes running in operations, and may have to invoke emergency fixes working with integrators.
3. People and governance bodies who make decisions about code changes:
    a. Governance bodies of authoritative repositories, who set policies for the repositories.
    b. Gatekeepers - Reviewers of code changes for umbrella repositories.
    c. UFS application leads - Overall leads for UFS application.
    d. UFS code managers - Managers of component repositories.
    e. UFS Working Groups.
    f. Field offices (they approve features coming into operations)

Key Events and Processes

1. Longer term (> year)
    a. Annual or long term planning exercises in which the community participates will be an important coordination element.
2. Shorter term (< year)
    a. Working Group meetings - Working groups are expected to have some authority about code priorities and changes in their respective areas at timescales shorter than one year.
    b. Issue tracking - Issue tracking is expected to occur in authoritative repositories.
    c. Code reviews.

Sample Use Case *(from the Repository WG Report)*

A PI received an NGGPS award to implement a skin temperature parameterization scheme in a UFS application. This scheme was tested in CESM and showed improvements in the sub-seasonal forecast skill. The parameterization will be implemented in the coupled modeling system

- The starting point for this will be the coupled UFS application, which includes FV3GFS and additional components for ocean (MOM6), ice (CICE5) and waves (WAVEWATCH III).
- The developer(s) will provide their development plan to the UFS-SC as well as the code managers of the authoritative repositories to make them aware of their work.
- They will begin with creating a development fork from the master of the appropriate application umbrella repository.
- The developers will then create forks of each relevant authoritative component repository and create new branches in their forked repositories where they will carry out the work associated with their project (in this case the developer would create forks of the Physics repository and probably the ocean and wave repositories for impact on upper ocean mixing). They will then update the connections in their umbrella development fork to point to the appropriate branches/forks of the component repositories where they will be doing work.
- The coupled application will then be tested with their updates in their respective branches.
- The viability of their changes will be shown to UFS-SC and appropriate area-specific working group. If approved, a path will be identified to bring these changes into the master repositories of all the component repos.
- The developers will begin the process of coordinating their updates back into the authoritative repository. They will be responsible to ensure that a) their updates work with the top of the master and b) that they do not break other applications. This is only possible with frequent communication with the code managers of all the repositories that they will be touching and the area-specific working groups evaluating the science.
- Once new features have been added into the master repositories of the respective component repos then they will be automatically available for the next implementation in operations. Use in operations will depend on satisfying implementation requirements which vary from application to application.