Unified Forecast System (UFS) Strategic Plan: 2021 - 2025

Authors: Unified Forecast System - Steering Committee (UFS-SC) and Writing Team

Contacts: Richard B. Rood (rbrood@umich.edu)
Hendrik L. Tolman (hendrik.tolman@noaa.gov)

UFS Acronyms:

Table of Contents

Executive Summary

This document is part of a restructuring of the Unified Forecast System (UFS) planning process, represented previously by the Strategic Implementation Plan[1]. The goal is to separate strategic planning from implementation details, as well as regularly summarizing accomplishments (e.g., an annual report). This document is focused, specifically, on the strategic management of the UFS for the next 5 years. The goal is to support the maturation of the UFS as a sustainable, integrated community organization. There is, also, an effort to bring together and reconcile non-UFS planning documents that influence the evolution of the UFS. This document describes current practice and is pending formal approval by the community-based oversight board envisioned for the UFS (see section 4 of the UFS Organization and Governance v1.0).

The emphases of this plan are Forecast Skill Priorities, Science Goals, and Systems Goals. These have been developed as a community effort, which includes NOAA and non-NOAA participants with contributions from both the research and development community to the operational prediction community. Indeed, NOAA as an integrated part of the community is essential for UFS success and emphasized in this plan. The Forecast Skill Priorities rely on the UFS Application Teams, and the Science Goals are synthesized across the UFS applications. It is recognized that these priorities and goals are but a subset of those needed for the UFS; these guide overarching improvement of the UFS.

The synthesized Science Goals span multiple, in most cases all, applications. They represent long-standing problems requiring applied and basic research. These are the classes of problems, the solutions of which are anticipated to have high benefit to forecast skill. Each application will have specific research and development goals relevant to these overarching goals. The Space Weather goal represents new capacity for a critical application.

The synthesized Science Goals are:

- Reduce surface and near-surface biases
- Incorporate new data types to target specific Forecast Skill Priorities
- Test and implement a coupled component capacity for UFS applications
- Increase physical consistency of global atmospheric dynamics and the coupling of atmospheric physics and dynamics
- Establish ensemble-based methods to describe uncertainty and improve usability by forecasters
- Develop an FV3-based Whole Atmosphere Model with Deep Atmosphere Dynamics

The development and review of this plan has revealed organizational and strategic gaps in the integration of UFS systems and products and those of the hydrological organizations within NOAA. There are direct relationships with component models, infrastructure, and systems architecture. There are hydrological requirements for the UFS that need to be collected. There are tensions with computational

[1] https://www.weather.gov/media/sti/nggps/UFS%20SIP%20FY19-21_20181129.pdf

resources. Better integration of the UFS and its roles in NOAA's hydrological efforts needs to be an organizational imperative.

-

1 Introduction

The vision for the Unified Forecast System is to continuously improve world-class predictions of weather and climate to assure the protection of life and property and the advancement of prosperity. The Unified Forecast System Steering Committee (UFS-SC) strives to balance scientific excellence, end-users' needs for skillful numerical forecast guidance, engagement of and participation by the Nation's researchers, and cost.

The UFS-SC takes a holistic, application-based approach aimed at simplification of the suite of models and forecast systems currently used to meet the operational needs of the organizations responsible for environmental prediction. The goal is to increase the science-based integrity of the application suite and strive for scientific excellence of the organization as a whole. To achieve scientific excellence, the UFS-SC is committed to evidence-based decision-making and the incorporation of innovations that take place across the field of weather and climate research.

The emphases of this document includes Forecast Skill Priorities and Science Goals. These have been developed as a community effort, which includes NOAA and non-NOAA participants with contributions from both the research and development community to the operational prediction community.

The synthesized Science Goals (Section 2.3) are:

- Reduce surface and near-surface biases
- Incorporate new data types to target specific Forecast Skill Priorities
- Test and implement a coupled component capacity for UFS applications
- Increase physical consistency of global atmospheric dynamics and the coupling of atmospheric physics and dynamics
- Establish ensemble-based methods to describe uncertainty and improve usability by forecasters
- Develop an FV3-based Whole Atmosphere Model with Deep Atmosphere Dynamics

The synthesized Science Goals span multiple, in most cases all, applications. They represent long-standing problems requiring applied and basic research. These are the classes of problems, the solutions of which are anticipated to have high benefit to forecast skill. Each application will have specific research and development goals relevant to these overarching goals. The Space Weather goal represents new capacity for a critical application.

These science goals are at the core of UFS activities and part of the foundation of the UFS as an organization. Major organizational goals of the UFS-SC include:

- Engage the research and end-user communities to increase contributions of the US weather research communities to improved forecast skill.
- Develop and sustain a systems-based approach to research, development, and management that links initiation of research with improved forecast outcomes for end-users

- Improve the research and operations interface and transitions: Research to Operations (R2O) and Operations to Research (O2R), or collectively R2O2R and O2R2O
- Simplify and unify the software suite that supports the UFS applications to address scientific goals, cost goals, and end-user needs
- Develop, update, and publish science strategies and forecast skill priorities

At the outset of execution of this plan and to address the above goals, the UFS Steering Committee will focus on the following activities, which are detailed in Section 3.2.

- Continue to develop community engagement and improve cohesion of the UFS organization
- Improve quantification of UFS Forecast Skill Priorities and update UFS Science Goals
- Evolve system architecture to incorporate ensemble-based approaches and post-processing
- Integrate data assimilation into the UFS architecture, applications, and releases
- Develop end-to-end test plans for UFS applications
- Define the stages and gates of the research-operations interface
- Define and publish policy, protocols, and practices for UFS releases

The document has four (4) sections. Section 1 is an introduction, which includes a short description of a realignment of the UFS governance to support the execution of this plan. Section 2 presents science goals and forecast skill priorities. The plan emphasizes that forecast skill is to be achieved through the evolution of the science-based foundations of UFS applications. This is followed, in Section 3, by description of the goals of the UFS as a community-based, scientific organization, and the foundational decisions and community relationships that define the UFS. Finally, Section 4 includes a notional schedule to achieve the goals of the plan.

For a comprehensive description of UFS planning, refer to the complementary documents: UFS Organization and Governance[2], UFS Strategic Plan 2021-2025 (this document), and Organizing Research to Operations Transition[3].

1.1 What is the Unified Forecast System (UFS)?

The Unified Forecast System (UFS) is a community-based, coupled, comprehensive Earth modeling system. It is designed to support the Weather Enterprise[4] and to be the source system for NOAA's operational numerical weather prediction applications.

[2] https://docs.google.com/document/d/1Z2Ut8JZReIfuc0kP_j9ScrcG-HGxbhwcSBpT2uhYCXU/edit?usp=sharing

[3] https://vlab.ncep.noaa.gov/documents/12370130/12994300/20181130_UFS-SC_Describing_the_Research_to_Operations_Interface.pdf/281087f7-cee4-2023-d595-259d28ee3b78?t=1608235633094

[4] https://www.weather.gov/about/weather-enterprise

The Unified Forecast System Steering Committee strives to achieve these goals through an evidence-based process that considers cost, requirements, scientific credibility, and user experience. The UFS aspires to function as a scientific organization, rather than an organization of scientists[5].

The UFS is organized around applications. Each application has a forecast target. The UFS numerical applications span local to global domains and predictive time scales from sub-hourly analyses to seasonal.

The UFS is a unified system because its applications share a set of agreed-upon scientific components (for example, a UFS atmosphere model based on the FV3 dynamical core) and a set of agreed-upon infrastructures. The scientific components and infrastructures are integrated into a consistent system architecture.

1.2 Purpose of this Document

The purpose of the UFS Strategic Plan is to provide a foundation for evolution of the UFS for the next five years. The UFS Strategic Plan builds upon two previous Strategic Implementation Plans (SIP).[6] Compared with the previous Strategic Implementation Plans, this document separates aspects of strategy from those of implementation. Therefore, a comprehensive plan for the UFS is represented by multiple documents: UFS Organization and Governance[7], UFS Strategic Plan 2021-2025 (this document), and Organizing Research to Operations Transition[8]. Foundational information and news for the UFS is found at https://ufscommunity.org .

The UFS Strategic Plan aims to align near-term, less than 2 years, with longer-term, 3-to-5 year activities. The document serves both communication and continuity purposes, as it builds on the previous plans and stands as the primary planning document of the UFS. An important goal is to support better engagement with the community, providing clear points of entry for community members to participate with the UFS.

The UFS Strategic Plan also serves as a bridge to the longer term goals of the UFS Roadmaps, which are intended to provide a 5-to-10 year vision of where the UFS is heading[9]. This vision includes

---

5 https://vlab.ncep.noaa.gov/documents/12370130/12437941/20170914_SIP_Governance_Model__Public__Version_1.pdf/02eb1671-3451-ef57-632d-ffed3e9676bb?t=1604586488603

6 https://www.weather.gov/media/sti/nggps/UFS%20SIP%20FY19-21_20181129.pdf

7 https://docs.google.com/document/d/1Z2Ut8JZReIfuc0kP_j9ScrcG-HGxbhwcSBpT2uhYCXU/edit?usp=sharing

8 https://vlab.ncep.noaa.gov/documents/12370130/12994300/20181130_UFS-SC_Describing_the_Research_to_Operations_Interface.pdf/281087f7-cee4-2023-d595-259d28ee3b78?t=1608235633094

9 https://vlab.ncep.noaa.gov/documents/12370130/12994300/20200416_Strategic_Vision_for_Modeling.pdf/5a072555-5116-8c1b-b73c-c3b033913324?t=1614112863798

improvements of forecast skill, scientific excellence, simplification and unification of the forecast suite, and more effective engagement of the broader research community.

The UFS is a response to external NOAA reviews that called for simplification of the NCEP Production Suite and improvement of scientific excellence. The UFS implementation arose from the Next Generation Global Prediction System (NGGPS) program, and previous SIP plans captured, primarily, contributions from the NGGPS program. This document strives to capture, more broadly, the contributions to the UFS of both NOAA and non-NOAA organizations and individuals. An important strategic programmatic change is the formation of the UFS-R2O Project[10].

The UFS-R2O Project is supported jointly by the NWS, Office of Science and Technology Integration (OSTI) and OAR, Weather Program Office (WPO) to develop UFS global and regional applications planned for FY2024 forecast implementations. The UFS-R2O Project is funded for 2 years towards 3-to-5 year goals. Many of the community-based teams funded by NGGPS in the previous Strategic Implementation Plans are now funded in the UFS-R2O Project.

An important development for the UFS is the genesis of the Earth Prediction Innovation Center (EPIC)[11], which will host UFS community model code on a cloud-based infrastructure platform. EPIC's goal is to accelerate community-developed scientific and technological advancements into operational Numerical Weather Prediction (NWP) applications through its community-focused platform. The UFS Strategic Plan provides information that will support the initiation of EPIC by describing UFS capacity and plans and identifying the most important functional areas to contribute to goals shared by the UFS and EPIC.

The UFS Strategic Plan naturally focuses on two time spans. The shorter time span is about two (2) years, which corresponds to task definition and progress that is aligned with the updates of the NCEP Production Suite[12]. The longer time span is five (5) years, which captures a set of strategic forecast skill priorities and science goals that focus longer term development. We anticipate an evaluation of progress on an annual cadence and revision of five-year goals on a two-year cadence.

1.3 Alignment of UFS Governance with Strategic Goals

This planning document represents an important change with its focus on UFS applications. To support this change, the UFS Governance has been realigned with the Application Teams as a core organizing principle. The complete governance is described in Unified Forecast System Organization and Governance[13].

---

[10] https://vlab.ncep.noaa.gov/documents/12370130/12994300/20181130_UFS-SC_Describing_the_Research_to_Operations_Interface.pdf/281087f7-cee4-2023-d595-259d28ee3b78?t=1608235633094
[11] https://wpo.noaa.gov/Programs/EPIC
[12] https://www.nco.ncep.noaa.gov/pmb/nwprod/prodstat/
[13] https://docs.google.com/document/d/1Z2Ut8JZReIfuc0kP_j9ScrcG-HGxbhwcSBpT2uhYCXU/edit?usp=sharing

Application teams (ATs) ensure that the efforts of UFS-related projects and Component Working Groups are integrated and aligned with the most critical forecast priorities. The UFS Applications are:

- Medium-Range Weather (MRW): Atmospheric behavior out to about two weeks
- Subseasonal-to-Seasonal (S2S): Atmospheric and ocean behavior from about two weeks to about one year
- Hurricane: Hurricane track, intensity, and related effects out to about one week
- Short-Range Weather/Convection Allowing Model (SRW/CAM): Atmospheric behavior from less than an hour to several days
- Space Weather: Upper atmosphere and ionospheric behavior due to solar and geomagnetic activity and forcing from the lower atmosphere from real-time to about ten days
- Coastal: Storm surge and other coastal processes from real-time to multi-decadal
- Air Quality: Aerosol and atmospheric composition out to several days

In addition to the Application Teams, the UFS organization also includes Cross-Cutting Teams and component Working Groups. Cross-Cutting Teams (CCTs) perform essential, integrative, and system-wide functions. The component Working Groups (WGs) are responsible for developing components of the UFS, and engaging the broader community in the process. Work is carried out in each of these organizational units, and members and leadership are shared across the units. These teams span the complexity of the UFS and expose the importance of communication and planning to success. The teams are:

Cross-Cutting Teams (CCTs) perform essential, integrative and system-wide functions.

- System Architecture and Infrastructure
- Verification and Validation
- Communication and Outreach
- Release Preparation

Component Working Groups (WGs) are responsible for developing components of the UFS, and engaging the broader community in the process.

- Aerosols and Atmospheric Composition
- Data Assimilation
- Dynamics and Nesting
- Ensembles
- Land
- Marine
- Physics
- Post-Processing

The UFS Primary Governance Matrix is shown in Figure 1.

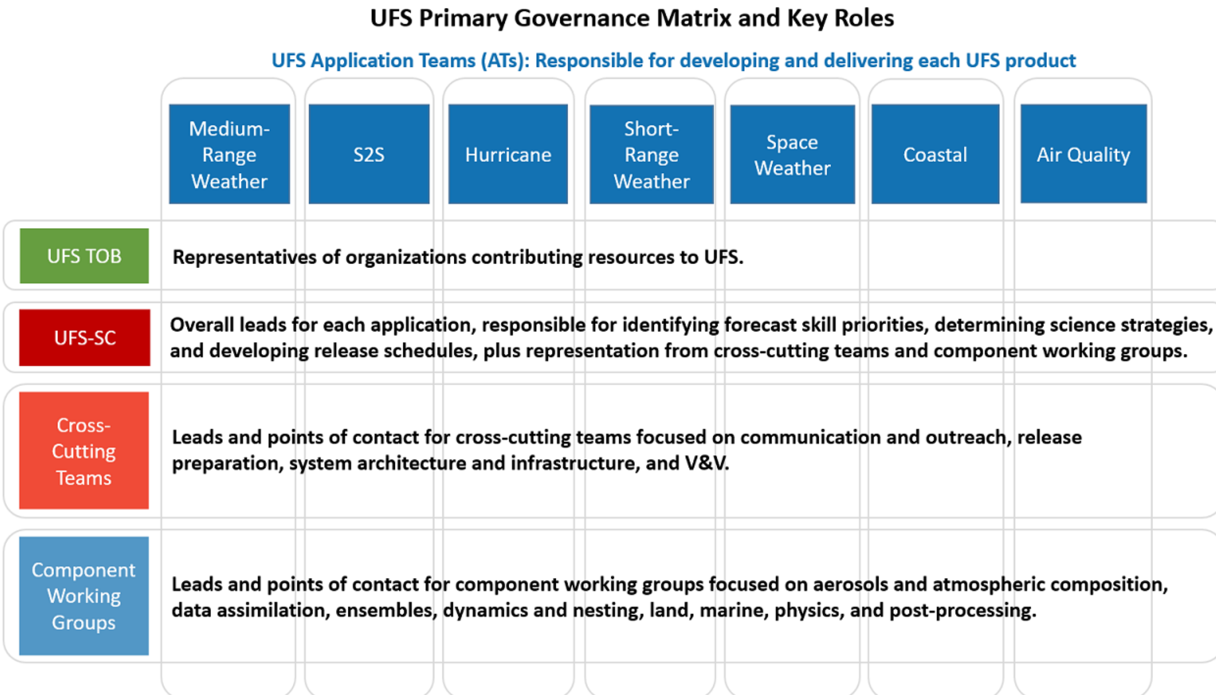

Figure 1: This matrix represents the UFS Governance and its teams.The darker blue boxes represent UFS Application Teams (ATs). The left column boxes show groups that work across the applications: the Technical Oversight Board (TOB), UFS Steering Committee (UFS-SC), Cross-Cutting Teams (CCTs), and component Working Groups (WGs).

2 UFS Forecast Skill Priorities, and Science and Systems Goals

2.1 Introduction

This chapter provides Forecast Skill Priorities, UFS Science Goals, and UFS Systems Goals.

Forecast skill is the primary quantitative measure of an application, and there are metrics of skill for each application. UFS Science Goals are systems-level and relevant to several applications; they represent scientific foci that are expected to contribute to improved forecast skill.

The UFS is committed to achieving improved accuracy of numerical guidance through systematic strengthening of the scientific foundation of the applications guided by operational impact. Therefore, UFS Science Goals and Forecast Skill Priorities are coupled to each other. The UFS Science Goals represent the strategy and the Forecast Skill Priorities represent the verification and validation criteria that are the targeted outcomes of scientific development.

There is also the need to support basic research, whose direct relation to forecast outcomes are, perhaps, unknown. A goal of the plan is to provide information that will help balance the roles of forecast-driven and basic research.

The UFS Systems Goals address continuous improvement of development of all processes associated with the UFS system as a whole. They contribute to the underlying scientific credibility and application of the scientific method, improving usability of the numerical guidance, leveraging investments, and optimization of cost.

The UFS looks, primarily, to the Application Teams (ATs) for the initiation of Forecast Skill Priorities, Science Goals, and Systems Goals. The UFS-SC looks across the sets of priorities from the UFS teams to develop a systems perspective for the UFS.

There is also the need to coordinate with the National Weather Service (NWS), especially the Environmental Modeling Center (EMC), to connect UFS priorities and releases with operational outcomes. Tight coordination is required, especially the case in the present 5-year planning horizon, as the UFS is steering the development of UFS applications from the evolution of the current suite of operational software. Therefore, the UFS strives to achieve longer term goals through incremental development of capacity in the operational cycle. In a 5-to-10 year time horizon, it is desired to loosen the coupling of this coordination to support innovation and, potentially, disruptive evolution.

A UFS-SC priority is to assure that all of the applications advance towards their goals. This requires identifying gaps and removing barriers to systems development.
Currently, the most present priorities of the UFS are related to four applications, Medium-Range Weather (MRW), Subseasonal to Seasonal (S2S), Short-range Weather/Convective Allowing Model

(SRW/CAM), and Hurricane. The MRW application is strongly related to the Global Forecast System (GFS), which is important to all of the other applications. It is, also, a system of high programmatic, end-user, and public priority. The S2S system is a high national and programmatic priority and the first deployments of an S2S application will be a, *de facto*, extension of the MRW application. Likewise, the Hurricane application focuses on severe weather of importance to both national and public interests; it has high programmatic priority. The SRW/CAM application is important to critical severe storm forecasts in the continental U.S. The SRW/CAM Application Team envisions a significant simplification in the software systems used to generate its numerical guidance.

2.2 Forecast Skill and Other Priorities, by Application

We define forecast skill priorities as the most desired improvements to a set of forecast skill metrics, reflecting inputs and requirements from a range of sources including inputs from the UFS Application Teams, the *Weather Research and Forecasting Innovation Act of 2017*, agency metrics prepared in response to the the *Government Performance and Results Act (GPRA)*, the *NWS Strategic Plan 2019-2022*, and activities of the EMC's *Model Evaluation Group (MEG)*.

Other priorities may relate to such aspects as the structure of the application (e.g. a merger of disparate codes to create a smaller code base), the computational performance of the application, and the usability of the application.

The target period is the period of this Strategic Plan, 2021-2025.

2.2.1 Categories

Forecast skill priorities are divided into reach goals, absolute measures, and measures relative to a previous baseline. The *Reach* goals are high level and while substantial progress is expected, they may not be fully met within the target period. The *Absolute measures* are independent of a previous forecast system baseline. *Relative to baseline* forecast skill priorities are also listed, where the forecast skill is measured relative to some previous system performance.

2.2.2 Sources

Several of the *Reach* goals are drawn from the *National Weather Service Strategic Plan 2019-2022,*[14] which outlines a broad and ambitious set of goals.

Many of the *Absolute measures* are derived from the *U.S. Department of Commerce Budget in Brief*[15], which lists performance goals associated with the *Government Performance and Results Act (GPRA) of*

---

[14] NWS Strategic Plan, see for example item 1.7: https://www.weather.gov/media/wrn/NWS_Weather-Ready-Nation_Strategic_Plan_2019-2022.pdf

[15] See, for example, pp 107-109, Objective 3.3: Reduce Extreme Weather Impacts: https://www.commerce.gov/sites/default/files/2020-02/FY_2021_DOC_BiB-021020.pdf

1993.[16] The actual performance versus the goal is documented and reported to Congress. From the *GPRA Agency Performance Plan*,[17] which describes the rationale and use of the goals, "These goals should be as specific as possible, they should drive much of the daily operations of the agency, and they should aim at achieving the long-term general goals of the agency's strategic plan." Forecast skill priorities derived from GPRA performance goals are marked in the table as *GPRA*.

The *Relative to baseline* entries were mainly derived from Application Team inputs, and from the introduction of a set of Benchmark Skill Measures that are widely used to establish forecast skill, marked with *Benchmark* in the table. These capture the basic scientific adequacy of the forecast system, and are similar to those used at other operational weather forecasting centers.[18]

The Benchmark Skill Measures are indicative of the quality of the global dynamics, surface biases, and the representation of weather events. Though they have derived, largely, from efforts of global weather forecasting in the medium range, they are relevant to all of the UFS applications. In addition to their direct measure of quality in global models, they indicate the capacity of global models to provide boundary conditions for regional models. These metrics are also indicative of the ability of the model to provide the information for high-quality data assimilation.

Improvement in the scores of the Benchmark Skill Measures is often slow, especially for medium-range weather applications. This is due in large part to the progress in medium-range weather forecasting having advanced to potential limits of predictability.[19] The Benchmark Skill Measures are required to be sustained or improved over time; declines would need to be addressed prior to deployment in an operational application.

Based on input from the Application Teams, the criteria used by the Model Evaluation Group at EMC[20], and the standards of the field,[21] the following parameters are used to provide the benchmark information: 500 hPa geopotential anomaly correlation, 850 hPa temperature, sea surface temperature, 2 m temperature, 2 m dew point (or relative or specific humidity), 10 m wind, precipitation (especially, equitable threat score (ETS)), hurricane track, hurricane intensity, and significant wave height.

It is recognized that the analysis and skill measures documented here are informed, primarily, by historic focus on deterministic weather prediction. The operational suite is moving rapidly towards probabilistic, ensemble methods as the method of choice for quantifying uncertainty, and for which we already have substantial knowledge. We know, for instance, that ensembles are deficient in their representation of high-impact events. It is, therefore, required that the forecast skill priorities incorporate present measures of ensemble performance. They also need to evolve to support the emerging knowledge of ensemble methods and their use by forecasters. The incorporation of probabilistic priorities and metrics will be a strategic focus of the UFS.

---

[16] An explanation of all GPRA measures, reported to Congress, can be found here - https://www.gao.gov/key_issues/managing_for_results_in_government/issue_summary
[17] https://www.gao.gov/assets/710/703769.pdf
[18] See Headline Scores, https://www.ecmwf.int/en/forecasts/quality-our-forecasts
[19] For example, Hoffman, R. N., et al. 2018: https://journals.ametsoc.org/waf/article/33/6/1661/40348/Progress-in-Forecast-Skill-at-Three-Leading-Global
[20] https://www.emc.ncep.noaa.gov/users/meg/home/index.html
[21] https://www.ecmwf.int/en/elibrary/18873-ifs-upgrade-brings-more-seamless-coupled-forecasts

Multiple measurements of skill are appropriate for the benchmark parameters, depending on the application. The Benchmark Skill Measures, in the tables below, are a chosen subset from a much larger set of forecast skill measures. For any specific application, there are Forecast Skill Priorities that will, likely, indicate definitive improvements in the near term. We emphasize that the priorities and measures documented below will evolve in time and require routine review and revision over the course of this plan. The ultimate determination of improvements in forecast skill will require evidence-based decisions through application-specific scorecards that consider a wide range of skill measures.

2.2.3: Forecast Skill Priorities: Tables

MEDIUM-RANGE WEATHER APPLICATION

FORECAST SKILL PRIORITIES
Reach:

- *(NWS Strategic Plan 2019-2022)* Establish 10-day forecasts as accurate as current 7-day weather forecasts

Absolute measures:

- *(Benchmark)* Improve 500 hPa anomaly correlation coefficient at day 5 (120 hrs) to be above 0.9 in both northern and southern hemispheres
- *(Benchmark)* Reduce 850 hPa temperature bias at day 5 (120 hours) by 0.10 degrees, relative to observations
- *(GPRA)* Global Forecast System (GFS) 500 hPa anomaly correlation coefficient: Length of Forecast Considered Accurate. 2020 - 9.0, 2021 - 9.5
- *(GPRA)* Global Ensemble Forecast System (GEFS) length of forecast considered accurate (days). 2020 - 10.0, 2021 - 10.25
- *(GPRA)* Lead time (hours) and accuracy (%) for winter storm warnings.
  2020 and 2021 - 20 hrs/90%
- *(GPRA)* Accuracy (%) of forecast for marine wind speed / wave height.
  2020 and 2021 - 80% / 83 ht

Relative to baseline: Global Forecast System v16

- *(App Team, Benchmark)* Reduce 2 m temperature bias for the U.S. Bias varies by region, season, and time of day; hence, quantitative goals will vary.
- *(App Team, Benchmark)* Reduce precipitation bias for the U.S. Bias varies by precipitation amount, region, season, and time of day; hence, quantitative goals will vary. Specific goals are to reduce the over-forecast of light precipitation and under-forecast of moderate to heavy precipitation.
- *(App Team, Benchmark)* Improve diurnal cycle of precipitation, especially afternoon onset and night time maxima, of warm season precipitation.
- *(App Team)* Reduce hurricane track and intensity forecast errors, especially cross-track errors.
- *(App Team)* Improve the forecast of temperature and circulation in the stratosphere and mesosphere.

SUBSEASONAL TO SEASONAL (S2S) APPLICATION

FORECAST SKILL PRIORITIES
Reach:

- *(NWS Strategic Plan 2019-2022)* Provide seamless week 3-4 temperature and precipitation forecasts to link information at weather and sub-seasonal timescales.

Absolute measure:

- *(Benchmark)* Reduce CONUS precipitation wet bias
- *(Benchmark)* Reduce sea surface temperature bias in weeks 2 - 4
- *(GPRA)* Subseasonal Temperature Skill Score. 2020 and 2021 - 36%
- *(GPRA)* Global Ensemble Forecast System (GEFS) length of forecast considered accurate (days). 2020 - 10.0, 2021 - 10.25
- *(GPRA)* Percent Extended Range Climate Prediction Center Outlooks exceeding threshold (outlooks) – All Temperature-Precipitation / All Temperature / All Precipitation. 2020 - 78%, 81%, 75%; 2021 - 79%, 82%, 76%
- *(GPRA)* Percent Long Range Climate Prediction Center Outlooks exceeding threshold: – Temperature/Precipitation Outlooks, All Temperature Outlooks, All Precipitation Outlooks 2020 - 48%, 60%, 36%; 2021 - 48%, 60%, 36%
- *(GPRA)* Percent Extended and Long Range Climate Prediction Center Outlooks exceeding threshold (outlooks) – All Temperature-Precipitation / All Temperature / All Precipitation. 2020 - 75%, 80%, 70%; 2021 - 75%, 81%, 71%

Benchmark skill measures:
Relative to baseline: CFSv2 and GEFSv12:

- *(App Team, Benchmark)* Increase 500 hPa geopotential height anomaly correlation coefficient in weeks 2 - 4
- *(App Team, Benchmark)* Increase 2 m temperature anomaly correlation coefficient in weeks 2 - 4)
- *(App Team, Benchmark)* Increase precipitation anomaly correlation coefficient in weeks 2 - 4
- *(App Team, Benchmark)* Increase sea surface temperature anomaly correlation coefficient in weeks 2 - 4 in tropics (20 S - 20 N)
- *(App Team)* Improve initialization and forecast of land states, especially soil moisture, snow cover and depth, and green vegetation fraction.
- *(App Team)* Improve sea-ice prediction through advancing sea-ice thickness initialization and reducing cloud and radiation biases in the warm season.
- *(App Team)* Improve ensemble forecast spread, reduce the over-dispersion of temperature in the tropical lower troposphere and under-dispersion of temperature near the surface over land found in GEFSv12.
- *(App Team)* Improve spatial distribution of ensemble forecast uncertainty through advanced stochastic parameterizations.
- *(App Team)* Reduce systematic errors in the maintenance and propagation of the MJO found in CFSv2. The MJO amplitude in the CFSv2 drops dramatically at the beginning of the prediction and remains weaker than the observed during the target period. The MJO propagation in the CFSv2 is too slow.
- *(App Team)* Reduce systematic biases and improve forecast skill scores of surface temperature and precipitation.

HURRICANE APPLICATION

FORECAST SKILL PRIORITIES
Reach:

- *(NWS Strategic Plan 2019-2022)* Extend current day-2 performance to day-3 for extreme weather events

Absolute measures:

- *(GPRA)* Hurricane forecast track error (48 hour). 2020 - 59 NM, 2021 - 57 NM[22]
- (*GPRA)* Hurricane forecast intensity error (48 hour) 2020 - 12 knots, 2021 - 11 knots

Relative to baseline: 2017 baseline

- *(HFIP 5-Year Plan)* Reduce track, intensity, and structure forecast guidance errors[23] by 50% relative to a 2017 baseline.
- *(HFIP 5-Year Plan)* Reduce intensity forecast guidance errors by 50%, relative to a 2017 baseline, for Rapid Intensification (RI) events.
- *(HFIP 5-Year Plan)* Produce seven-day track and intensity forecast guidance as accurate as a 2017 five-day baseline.
- *(HFIP 5-Year Plan)* Improve forecast guidance on pre-genesis disturbances, for track, intensity, and the timing of genesis, by 20% relative to a 2017 baseline.

A more complete discussion of Hurricane Application priorities can be found in the *Hurricane Forecast Improvement Program Five-Year Plan: 2020-2024*.[24]

SHORT-RANGE WEATHER/CAM APPLICATION

FORECAST SKILL PRIORITIES

Reach:

- *(NWS Strategic Plan 2019-2022)* Extend current day-2 performance to day-3 for extreme weather events

Absolute measures:

- *(App Team, includes Benchmark)* RRFSv1 spread/error ratio near optimality for key forecast variables (temperature and wind at standard levels and near surface)[25]
- *(App Team, includes Benchmark)* Statistically reliable day-1 and day-2 precipitation (0.1", 0.25", 0.5", 1", 2") and radar reflectivity (30dBZ, 40dBZ) forecasts as evaluated through reliability/attributes diagrams.
- *(GPRA)* Accuracy (%) (threat score) of Day 1 precipitation forecasts. 2020 and 2021 - 34%
- *(GPRA)* Severe weather warnings for tornadoes – Storm based lead time (minutes), Accuracy (%), and False Alarm Ratio (FAR) (%) 2020 and 2021 - 13 Min / 72% Accuracy / 71% FAR
- *(GPRA)* Severe weather warnings for flash floods - Lead time (minutes) and Accuracy (%) 2020 and 2021 - 65 MIn, 76% Accuracy
- *(GPRA)* Accuracy (%) and FAR (%) of forecasts of ceiling and visibility (3 miles / 1000 feet) (aviation forecasts) 2020 and 2021 - 65% Accuracy, 38% FAR

Relative to baseline: HRRRv4, NAM Nests (NAMv4), HiRes Windows and HREFv3

- *(App Team)* Match or exceed skill of operational deterministic CAMs (HRRR, NAMnest) with deterministic control RRFS member using upper-air, surface, reflectivity, precipitation, and storm-report type metrics as aggregated via scorecard.[26]

---

[22] NM is nautical mile

[23] Percent improvement is determined by evaluating track, intensity, storm size, and RI error relative to those over the 3-year period 2015-2017.

[24] http://www.hfip.org/documents/HFIP_Strategic_Plan_20190625.pdf

[25] Fortin, V., M. Abaza, F. Anctil, and R. Turcotte, 2014: Why Should Ensemble Spread Match the RMSE of the Ensemble Mean?. *J. Hydrometeor.*, **15**, 1708–1713.

[26] Gallo, B. T., and Coauthors, 2019: Initial Development and Testing of a Convection-Allowing Model Scorecard. *Bull. Amer. Meteor. Soc.*, **100**, ES367–ES384.

- *(App Team)* Objectively measured convective mode characteristics that meet or exceed those of baseline systems.[27] (e.g. storm motion, attributes, etc.)
- *(App Team)* RRFS Match or exceed spread-skill metrics of operational CAM ensemble (HREF) using scorecard and/or reliability diagrams over the range of the forecast (e.g. 48 hrs for HREFv3).
- Assess value of 1-km vs 3-km grid forecasts for WoFS

OTHER PRIORITIES

- *(App Team)* Assess value of sub 3-km grid forecasts for WoFS to investigate resolution-sensitive model forecast scenarios such as lower-CAPE/higher-shear environments that do not sustain isolated surface-based convection in current CAMs.
- *(App Team)* Improve treatment of sub-grid clouds/effects for improvement of surface/PBL diurnal cycle including radiative fluxes/budget which can lead to improvements in forecasts of cold air damming and convective initiation.
- *(App Team)* Improve initialization and forecasts of cloud/precipitation features through improved data assimilation algorithms and better use of a variety of in-situ and remote sensing observations.
- *(App Team)* Reduce high precipitation bias at higher thresholds (1-2"+ in 6 hrs) measured via performance diagram.[28]
- *(App Team)* Improve characterization of winter precipitation.

SPACE WEATHER APPLICATION

FORECAST SKILL PRIORITIES
Reach:

- Provide specification, and short-term and medium-range forecast, of the full spectrum of wave fields driven from the lower atmosphere dynamics that penetrate to the upper thermosphere, to enable prediction of ionospheric irregularities.

Absolute measures:

- *(App Team)* Extend the wavenumber spectrum of mesoscale waves propagating from the middle and lower atmosphere and penetrating to the thermosphere and ionosphere (wave numbers >20-40), to enable waves with horizontal wavelength of 400 km to be resolved, in order to capture small-scale ionospheric disturbances.

Relative to baseline: Enthalpy-based GSMWAM spectral hydrostatic dynamical core at T62 coupled to IPE at the same resolution, as delivered in fall 2020[29]

[27] Potvin, C. K., and Coauthors, 2019: Systematic Comparison of Convection-Allowing Models during the 2017 NOAA HWT Spring Forecasting Experiment. *Wea. Forecasting*, **34**, 1395–1416.
[28] Roebber, P. J., 2009: Visualizing Multiple Measures of Forecast Quality. *Wea. Forecasting*, **24**, 601–608.
[29] Improvements in the Baseline are based on the following: Continued development at EMC of the vertically-extended FV3WAM deep atmosphere, 5 species dycore, variable Cp and R; replacement of the enthalpy-based GSMWAM hydrostatic spectral dynamical core with non-hydrostatic FV3WAM; and enhancement of the horizontal resolution of WAM-IPE from 200 to 50 km. Model improvements will enable development of ionospheric irregularity SW products utilizing the enhanced resolution and wave spectrum of FV3WAM. Other potential improvements to Baseline: Drive WAM-IPE with Geospace operational model output. Extend GSI/JEDI data assimilation into the mesosphere and lower thermosphere (~100 km) with NASA research satellite data. Implement the advanced unified gravity wave physics (UGWP) and eddy mixing to control circulation and turbulence in the E-region dynamo layer.

- *(App Team)* Establish the Baseline metrics based on GSMWAM T62 spectral hydrostatic enthalpy-dycore coupled to an equivalent resolution IPE (~200 km), planned for transition to operations in FY2021.
- *(App Team)* Reduce bias in Total Electron Content (TEC) specification and forecast against Global Navigation Satellite System (GNSS) ground-based and space based radio occultation data by 50%
- *(App Team)* Improve the short-term and medium-range prediction of zonal mean circulation in the 50 to 100 km altitude range by 50% during polar vortex breakups and sudden stratospheric warmings.
- *(App Team)* Improve prediction of tidal amplitudes in the dynamo region 100 to 150 km altitude by 20% during seasonal transitions, polar vortex breakups, and sudden stratospheric warmings
- *(App Team)* Improve specification and short-term forecast of IPE ionospheric TEC day-to-day variability by 20% to enable quantification of quiet geomagnetic and storm response.

A more complete discussion of Space Weather Application priorities can be found in the *Strategic Plan and Requirements for FV3WAM-IPE Development for Space Weather Applications* (in preparation).

COASTAL APPLICATION

FORECAST SKILL PRIORITIES
Reach:

- *(NWS Strategic Plan 2019-2022)* Deliver actionable water resources information from national to street-level and across all time scales; provide minutes-to-months river forecasts that quantify both atmospheric and hydrologic uncertainty; improve forecasts of total water in the coastal zone by linking terrestrial and coastal models in partnership with the National Ocean Service; and deliver forecasts of flood inundation linked with other geospatial information to inform life-saving decisions.
- *(NWS Strategic Plan 2019-2022)* Extend current day-2 performance to day-3 for extreme weather events.
- *(FY21 NOAA Research Council Plan)* Develop ocean modeling strategy that describes how NOAA will support the temporal and spatial scales required to effectively fulfill NOAA's diverse missions in a changing climate.

Absolute measures:

- *(GPRA)* Percentage of U.S. coastal states and territories demonstrating annual improvement in resilience capacity to weather and climate hazards. 2020 and 2021, 77%.

Relative to baseline: (multiple baselines, see individual items)

- *(App Team)* Feasibility study to determine the minimum number of surge model ensemble members required to represent tropical storm surge uncertainty in an operational environment, and method to generate them, irrespective of surge model choice. Metric: Minimum number of members to reach the skill of the current (in 2017) P-Surge 48-hour surge forecast. To inform configuration choices of future UFS systems.
- *(App Team)* Global-ESTOFS (NOS): Initial Operational Capability will be established in 2020. Unification of three former systems - ESTOFS Atlantic, Pacific and Micronesia including higher resolution representation for US Pacific coast, Alaska and some other US Islands (all ADCIRC-based). Incorporates data assimilation based on observed water level anomalies. Maintain RMSE = 0.24 m skill level of individual ESTOFS systems after unification.
- *(App Team)* HSOFS ADCIRC-WW3 (HSUP): Initial Operational Capability to be established by 2025. Unifies tropical storm surge and coastal wave guidance, with 6-member ensemble based on hurricane best track. Skill priority for coastal waves is <10% bias due to coupling with the surge model. Skill priority for surge is to reduce High Water Mark bias to <10% after accounting for wave setup.

- *(App Team)* NWM-ADCIRC-WW3 (HSUP): Initial Operational Capability to be established by 2022. Unifies inland flooding of estuaries with tropical- and extratropical storm surge and coastal wave guidance in a deterministic model, to provide Total Coastal Water Level. Metrics: (i) water level of inundated area, (ii) recession limb of the hydrograph (no baseline/target values available yet).
- *(App Team)* FVCOM-WW3-CICE for the Great Lakes (GLERL): Initial capability of coupled circulation, wave and ice model for the Great Lakes to replace existing stand-alone configuration. Future inclusion of DA & ensembles. Coupled circulation with ecological, biophysical, and water quality models to address navigation, environmental monitoring, and Harmful Algal Blooms (HABS), hypoxia and other ecological issues in the coastal regions.
- NWM-FVCOM-WW3 for Lake Champlain: Initial operational compatibility of a coupled hydrological, hydrodynamic and wave prediction system to address the total water level and flooding potential for Lake Champlain and its watershed (no baseline/target values available yet).
- *(HFIP Strategic Plan 2018, goals 4.1 and 4.2)* For hurricane storm surge (P-Surge): Extend the operational storm surge model forecast guidance to 72 hours (3 days) while maintaining the skill (in 2017) of the current 48 hour (2-day) forecast.
- (*App Team*) ROMS Coupling of Ocean and Rivers (HSUP): Develop an integrated coastal water predictive capability to deliver new water intelligence products and information vital for decision making both during high-impact events, such as hurricanes, nor'easters, and storm surge, and for routine water management, including marine ecosystem health, transportation, and agriculture.
- (App Team) WRF-ROMS-JEDI (HSUP): Compute ocean state estimates using advanced 4-Dimensional Variational (4D-Var) methods for data assimilation (DA) to initialize high-resolution coupled ocean-atmosphere models for hurricane prediction. The project inherits experience from the ROMS developer community with 4D-Var DA, fully 2-way air-sea model coupling using the NUOPC system, and the routine delivery of real-time coastal ocean forecasts. These proven, mature ROMS capabilities will be migrated to the Joint Effort for Data assimilation Integration (JEDI) framework for 4D-Var DA, and the Unified Forecast System (UFS) for model coupling.

OTHER PRIORITIES

- *(App Team)* Following recommendations from external reviews of the Production Suite, the UFS is focusing on next generation models. For coastal inundation and as a part of UFS decision making process, the next-generation storm surge model specification need to be investigated and delineated based on future operational requirements for instance regarding 1) coverage (Local/National/Global), 2) adaptive, flexible, stable and high-fidelity computational domain, 3) optimal performance, 4) architecture agnostic (HPC and cloud support), 5) seamless coupling to other physics (inland hydrology, waves, ice,...), 6) Data assimilation and 8) Strong community support among others. For coastal inundation, the model selected through test bed projects is ADCIRC. In operations, high-resolution ADCIRC is used for Extratropical Surge and Tide Operational Forecast System and SLOSH is used extensively for probabilistic forecasting of tropical storm surge. For the UFS strategy this implies that:
    - ADCIRC needs to be thoroughly optimized for operational use, to be able to make an evidence-based decision on the future of ADCIRC and SLOSH, and
    - if a decision is made that SLOSH will be used long-term in operations, then this model needs to be brought into the UFS.

The unification of coastal applications in operations is complicated, as it is driven by at least 5 authorizations in law, giving individual responsibilities and authority to various parts of NOAA. With that, comprehensive strategies are still under development, and not yet available for reference here.

AIR QUALITY APPLICATION

FORECAST SKILL PRIORITIES
Absolute measure:

- *(App Team)* Extend Air Quality forecasts to 3 days (operational need).

Relative to baseline: CMAQv5, GEFSv12

- *(App Team)* Improve accuracy of location/timing of Air Quality forecasts (higher resolution grids down to 3 km - benefits in complex terrain, coastal areas).
- *(App Team)* Better represent sources of pollution from wildfires.
- *(App Team)* More timely updates of emissions, capturing trends and short-term unplanned events.
- *(App Team)* Evaluate impacts of atmospheric composition forecasts on weather forecast skill.
- *(App Team)* Develop probabilistic prediction.

OTHER PRIORITIES

- *(App Team)* Integrate air quality into UFS.
- *(App Team)* Establish authoritative repositories that are shared and software systems that are integrated.
- *(App Team)* Develop computationally efficient reduced form models.
- *(App Team)* Incorporate information from satellite and in-situ sensors.

2.3 UFS Science Goals

Below is a list of Science Goals that serve as overarching descriptions of scientific research focuses. They span multiple applications. Each application will have specific research and development goals relevant to these overarching goals. The UFS Science Goals are expected to influence a range of Forecast Skill Priorities and to improve the scientific credibility of the underlying modeling systems. Balanced investment is required for all of these goals to assure development of the system as a whole.

2.3.1 Reduce surface and near-surface biases:

Applications at all spatial and temporal scales recognize the importance of reducing surface and near-surface biases. Critical biases include land surface and 2-meter temperatures, sea surface temperature, moisture and the initiation of convection, the temperature profile in the planetary boundary layer, snow cover, ice, and soil moisture. To address the biases require process-based investigation that connect numerous components of the UFS. Viable strategies come from all WGs and require coordination across all WGs, CCTs, and ATs. Improving atmospheric physics, coupling of land and atmosphere, and use of re-forecasts to improve post-processing calibrations and bias correction are recognized as important approaches. Atmospheric physics is recognized as its own class of Science Goals.

2.3.2 Incorporate new data types to target specific Forecast Skill Priorities:

Improved use of data by the data assimilation component of an application is generally accepted as a high priority path to improve forecast skill in all applications. Observation pre-processing, quality control, and consideration of novel observations need to be part of a systems-based approach. Model performance metrics need to consider performance in data assimilation more prominently. and Several Application Teams identify specific data sources hypothesized to improve known deficiencies in the forecasts, including reduction of surface and near-surface biases. For example the Hurricane Application

Team has identified the optimal use of in-situ observations from aircraft reconnaissance and satellites for initializing the vortex structure and intensity in the Hurricane Analysis and Forecast System (HAFS) under the UFS framework is critical to meet the forecast skill priorities and science goals.

2.3.3 Test and implement a coupled component capacity for UFS applications:

There is a scientific imperative to have coupled components in all UFS applications. There is the need to investigate and develop coupled data assimilation methodology. There is the capacity in the UFS for coupling modeling components with the ESMF and NUOPC infrastructure. Priorities are:

2.3.3.1 Enable a flexible design of the land model:

Currently, land-surface processes in the UFS are represented as part of atmospheric physics. The UFS application suite requires a land model that is coupled as an ESMF/NUOPC component. There remain, however, both scientific and hierarchical testing needs that benefit from the in-line coupling with the atmosphere through CCPP. The UFS land component requires, therefore, a design that allows it to be called in line with the atmospheric physics and as a stand-alone component. With the relation to current strategic Science Goals, this is a short-term priority with several downstream outcomes.

2.3.3.2 Test coupled model components in global applications:

There have been experiments with coupled configurations for UFS applications. GEFSv12 was implemented with coupled atmosphere-wave-aerosol interactions. The priority is to focus on the testing to support Medium-range Weather and Subseasonal to Seasonal Applications, and the upgrade of the current Seasonal Forecast System. It is important to evaluate the roles of feedback between model components on forecast skill and estimates of predictability.

2.3.3.3 Initiate and test coupled data assimilation methodology in global applications:

Increased forecast skill is hypothesized to benefit most from improved use of observations in data assimilation. In order to reduce near-surface biases, it is a priority to address coupled land-atmosphere assimilation. Numerous forecast skill priorities in the MRW/S2S are hypothesized to be addressed by coupled atmospheric-land-ocean-aerosol-sea ice assimilation, and these methodologies need to be addressed in the near-term for long-term strategic outcomes.

2.3.3.4 Coupled re-forecast and re-analysis and post-processing calibration

Coupled re-forecast, re-analysis, and post-processing need to be integrated into the development of coupled-component forecast capacity. This requires incorporation into systems architecture, workflow design, and verification and validation.

2.3.4 Increase physical consistency of global-to-regional atmospheric dynamics and the coupling of atmospheric physics and dynamics:

Fidelity of the physical representation of all-scale atmospheric processes influences the accuracy of formation, development, and propagation of weather events and sits at the foundation of increasing forecast skill across a spectrum of phenomena. The physical representation can be improved through improvements of all aspects of the modeling, and in some instances, for example, the Space Weather Application, there are known deficiencies in the dynamical formulation of the underlying algorithms. All UFS applications rely on accuracy in the representation of the global-to-regional atmosphere. Priority focuses include:

2.3.4.1 Establish a cross-application approach to representation of atmospheric physics:

Representation of atmospheric physics is identified by several Application Teams as a known productive path to improve forecast accuracy. Approaches to atmospheric physics vary across the applications, and there has been a historical practice of exchanging atmospheric physics parameterization and evaluating the outcomes on measures of forecast skill. A strategy for a cross-application approach to atmospheric physics would benefit from a process-based approach that focuses on improving the physical relationship between processes and scales that are parameterized. A focus on scale awareness allows use across different resolutions and across applications. As resolution is increased, more processes are resolved which changes the interaction of atmospheric physics with all other processes and scales in UFS components; improved, flexible testing strategies are needed.

2.3.4.2 Improve representation of global-to-regional atmospheric dynamics and physics:

All applications benefit from improved representation of global-to-regional atmospheric dynamics, e.g., Rossby waves, the jet stream, tropical modes of variability, tropospheric-stratospheric interactions. Benefits include, for example, accurate representation of surface fluxes and constituent transport, propagation of energy to the upper atmosphere, and proper representation of storm intensity and path. Standard metrics used to represent global dynamics such as 500 hPa anomaly correlation and 850 hPa temperature are credibility parameters that stand as benchmark criteria. Teleconnections of prominent modes of variability are related to global atmospheric dynamics and hypothesized as essential to predictability beyond the medium-range. Priority items to be addressed include a cold temperature bias in the lower troposphere and measures associated with the Madden-Julian Oscillation.

For the regional scale events, the energy cascade should be accurately depicted on the energy transfer for the whole energy spectrum and spatial and temporal distributions of the precipitation rate in the high-resolution global-to-regional model. The telescopic and moving nesting approaches for UFS are actively developing for resolving the global-to-regional atmospheric dynamics and physical processes.

2.3.4.3 Improve event-based forecast skill:

Public benefit is realized when high impact events are predicted with accuracy. Such events include hurricanes, tornadoes, severe storms, winter storms, heat waves, and cold-air outbreaks. Known weaknesses include hurricane track and intensity, spurious secondary lows, and too fast propagation of mid-latitude cyclones. Process-based studies of these deficiencies are needed to understand science-based and technical solution strategies. Ensembles are potentially useful as a characterization of uncertainty, and in several applications the ensemble spread is a known weakness. Standardized use cases and metrics are needed.

2.3.5 Establish ensemble-based methods to describe uncertainty and improve usability by forecasters:

Most UFS applications are anticipated to be ensemble-based on a 5-year time horizon. This is hypothesized to improve descriptions of uncertainty and to advance the usability of probabilistic forecast guidance. The transition to ensemble-based predictions influences all aspects of the UFS. Strategies need to be physically defensible representations of uncertainties. Direct attention needs to be paid to coupled systems and interactions between components. There are important issues on the roles of atmospheric physics and the dynamics-physics interactions and their relation to ensemble spread. Validation metrics need to guide evidence-based decisions; hence, metrics need to evolve to support the emerging knowledge of ensemble methods and their use by forecasters. With the evolution to ensemble-based systems and the imperative to improve warnings on high-impact events, it is essential for re-analysis, re-forecasting, and post-processing calibration be formally integrated into system planning, program management, system architecture, verification and validation, and workflow.

2.3.7 Develop an FV3-based Whole Atmosphere Model (WAM) with Deep Atmosphere Dynamics (DAD):

The current Space Weather application utilizes the vertically-extended domain to ~600 km of the GSMWAM T62 spectral hydrostatic enthalpy-based dynamical core coupled to an equivalent horizontal resolution (~200km) Ionosphere Plasmasphere and Electrodynamics component (IPE). The development of an extended domain deep-atmosphere FV3WAM non-hydrostatic core with improved horizontal resolution (~50km) and reduced numerical diffusion, will enable a more complete depiction of the spectrum of waves produced in the lower atmosphere that penetrate to the upper thermosphere and ionosphere. The implementation of the advanced unified gravity wave physics (UGWP) and eddy mixing will also improve circulation and turbulence in the E-region dynamo layer. The FV3WAM development will proceed in parallel with enhancement in the IPE component, including increased resolution, transport scheme, and parallel-processing grid decomposition. The model improvement will enable development of ionospheric irregularity space weather products utilizing the enhanced resolution and wave spectrum of FV3WAM.

The development of unified dynamics with data assimilation for this FV3WAM system has the potential to benefit many UFS applications. Weather and climate application are likely to benefit , as well as MER-AT and CAM-AT, due to the complete 3D Coriolis force providing accurate equatorial circulation.

The GSI/JEDI data assimilation will also be extended into the mesosphere and lower thermosphere (~100 km altitude) with NASA research satellite data, to improve the fidelity of tidal and gravity wave propagation into the thermosphere and ionosphere. The initial implementation will be 3DVar-based, and will require a new background error covariance, but with the aim to transition to a hybrid Ensemble Kalman Filter (EnKF) system.

2.4 UFS Systems Goals

It is a goal of the UFS to develop and sustain a systems-based approach to research, development, and management. To achieve that goal, there is a set of priorities focused on system definition and improvement. These system priorities include continuous improvement of development of all processes associated with the UFS system as a whole. UFS Systems Priorities address needs that are: programmatic, capacity building, computational, software engineering, research-operations interface, community building, communication, and cost. These priorities balance improvements of scientific excellence at the organizational level, end-user's needs for numerical forecast guidance, and optimizing cost. In all cases, testing, verification, and validation are required to assure scientific credibility.

2.4.1 Improve the interfaces and engagement of the UFS with the community:

The major organization goals for the UFS (Section 3.1) require attention to communication both internal to UFS activities as well as engagement with individuals and organizations not formally part of the UFS. To support this the UFS will maintain and grow several key communications activities.

2.4.1.1 Develop a meeting schedule and coordinate with meetings of related activities:

As detailed in UFS Organization and Governance[30], the UFS will hold a series of meetings during one week in winter and one week in summer. These meetings will include advancement of technical issues and planning, community engagement, and UFS reviews. Community engagement includes communication from the research, forecaster, and end-users community on performance and usability of the UFS systems and products.

2.4.1.2 Publication of UFS priorities and schedule:

In order to provide better links to the research community the UFS will publish and update Forecast Skill Priorities, UFS Science and Systems Goals, and a schedule of major systems milestones.

[30] https://docs.google.com/document/d/1Z2Ut8JZReIfuc0kP_j9ScrcG-HGxbhwcSBpT2uhYCXU/edit?usp=sharing

2.4.1.3 Improve, centralize, and update UFS public-facing communication services:

The UFS will continue to develop the UFS portal[31] as a hub for accurate and updated information. This will include development of a document repository of key documents as well as glossaries of terms. A UFS Webinar and a Newsletter as primary communication tools. Information on effectiveness of UFS communication services will be based on evidence gathered from users.

2.4.1.4 Support continuous improvement of UFS software and products:

The UFS will support continuous improvement through community surveys of users' experience. An example of this is the Graduate Student Test, which will be expanded to cross UFS applications and to non-academic users. Usability will also be improved by better defining and documenting the transitions between Research to Operations (R2O) and Operations to Research (O2R), through development and publication of test plans and definitions of stages and gates in the R2O process.

2.4.1.5: Development of UFS position papers and organizational interface documents:

In order to provide a structured interface with UFS activities, the UFS will develop documents that provide analysis of key issues; for example, cloud computing needs and opportunities, use of open-source software, and interfaces with partner organizations.

2.4.2 Simplify the Short-range Weather/Convective Allowing Model (SRW/CAM) production suite:

Presently, six separate systems are executed to provide the numerical guidance for SRW/CAM. The goal is to unify these into one system. The first priorities are:

2.4.2.1 Transition of present SRW/CAM capability to FV3-based Limited Area Model (LAM) baseline

2.4.2.2 Release of the FV-based Limited Area Model to research community

2.4.2.3 Replacement of regional mesoscale systems (NAM, RAP, SREF, etc.)

2.4.2.4 Synthesis of convective prediction system physics (hurricane/hazardous wx/severe storms).

2.4.2.5 Development of new ensemble post-processing methods

[31] https://ufscommunity.org/

2.4.3 Develop a systematic approach to applications' workflow:

The NOAA computational environment, including the UFS, is characterized by multiple, divergent workflows, which leads to significant inefficiencies across the entirety of the NOAA modeling effort. Currently application workflows are developed more-or-less independently of each other, leading to significant duplication of effort by developers. The need to learn a new workflow, the primary entry point for any user of an application, is a significant barrier to both scientists and developers moving between applications. It also inhibits the transfer of solutions developed in one application to the other applications within NOAA, and generally acts as a drag upon the entire R2O process.
At the UFS Workflow Workshop (April 29-30) a number of barriers were identified and a sustained effort to reduce these barriers and develop a UFS-centric approach to workflow was initiated.

2.4.4 Develop capacity to support hierarchical systems development (HSD):

Hierarchical system development (HSD) refers to the ability to engage in development and testing at multiple levels of complex application's software, i.e. the ability to test at low resolution or small parts (single physics subroutines) of an Earth system model first in isolation, then progressively connecting the "pieces" with increased coupling between the Earth system model components and HSD steps. HSD includes the necessary (software engineering) infrastructure that allows for all the HSD steps to be connected efficiently. It is critical for research because it enables the research community to have multiple entry points into development that reflect their interests. HSD is, likewise, critical for operations because both localized and integrative, coupled processes must be improved to develop excellence in forecasts. HSD is at the heart of effective interfaces between research and operations, because it ensures that every advance proposed by the research community has a clear development and test path that includes integration into end-to-end applications.

3 UFS Organizational and Management Priorities

3.1 Introduction: Organizational Goals

As a community and a scientific organization, the UFS is driven by balancing scientific excellence, end-user's needs for numerical forecast guidance, and optimizing cost. Major organizational goals of the UFS include:

- Engage the research and end-user communities to connect, better, operational outcomes and the US weather research community
- Develop and sustain a systems-based approach to research, development, and management that links initiation of research with improved outcomes for end-users
- Improve the research and operations interface and transitions: Research to Operations (R2O) and Operations to Research (O2R), or collectively R2O2R and O2R2O
- Simplify and unify the software suite that supports the UFS applications to address scientific goals, cost goals, and end-user needs
- Develop, update, and publish forecast skill priorities and science strategies3.2 UFS Steering Committee Organizational Focuses

The UFS Steering Committee is responsible for executing and adherence to this plan. There is, also, a commitment to updating the plans as research, development, and implementation evolve in an ever-changing Federal landscape.

Essential to the success of the UFS is continuity, as achieved through adherence to UFS plans and commitment to community-based decision making. Therefore, a major part of the Steering Committee's activities include setting agendas, assuring communications within the UFS, and maintaining a focus on the plans and strategic priorities. Through these activities, the Steering Committee strives to develop an organizational culture to sustain community model development for the benefit of U. S. weather research and operations.

The next section details the priority Organizational Focuses for the next 2 years. These will be reviewed and updated on a one-year cadence. This is followed by the Organizing Principles used by the UFS. These principles describe what is at the foundation of all UFS applications: definitions, architecture, components, and infrastructure. This is followed by Strategic Relationships and Agreements which identify the partnerships and community contributing to the UFS.

3.2 UFS Steering Committee Organizational Focuses

3.2.1 Continue to develop community engagement and improve cohesion of the UFS organization:

- Engagement of the forecaster community as a primary UFS customer

- Engagement of hydrological community and coordinate activities with the National Water Center
- Increase engagement of researcher and developer communities
- Represent the UFS with partnering organizations
- Exposure, integration, and publishing of existing NOAA planning documents, including requirements for operational applications
- Update and publish schedules of releases and system developments, including development of release dashboard

3.2.2 Improve quantification of UFS Forecast Skill Priorities and update UFS Science Goals:

UFS Forecast Skill Priorities and update UFS Science Goals are constantly evolving with the improvement of systems and input from end users. Quantification of forecast skill priorities guide the outcomes of the Science Goals and provide the foundation for continuous improvement of numerical guidance. They communicate the operational priorities to the research and developer communities.

3.2.3 Evolve system architecture to incorporate ensemble-based approaches and post-processing:

The systems architecture needs to include, explicitly, ensemble-based approaches. The evolution from deterministic to probabilistic forecasting needs to be elevated and exposed. Re-analysis and re-forecasts functions need to be included. Post-processing calibration needs to be separated from "verification" (Figure 3, below) and included as a separate element. The dependencies of these changes to the end-to-end system and working groups need to be identified. Relationships to verification and validation and workflow need to be incorporated into ongoing activities.

3.2.4 Integration of data assimilation into the UFS architecture, applications, and releases:

Data assimilation is a high-priority path to improve forecast skill in all applications. The UFS has made the decision to rely on Joint Effort for Data assimilation Integration (JEDI). To date, UFS activities have been largely independent of data assimilation. For example, a data assimilation component was not provided in the Medium-range Weather Application release[32], and data assimilation will not be provided with the upcoming Short-term Weather/Convective Allowing Model Release. It is a priority to include data assimilation in future releases. Towards this goal, the Steering Committee will have a focus on integrating JEDI capabilities into the UFS architecture, with definition of the testing that will be required to be a part of the UFS application. Plans, including resourcing, to include data assimilation in future releases will be developed.

3.2.5 Develop end-to-end test plans for UFS applications:

At the foundation of the UFS is testing, verification and validation to support science-based evidence for decision making. In this case, verification and validation are focused on the natural science and forecast accuracy of the application. Testing is a more general term that includes all of the types of testing required in the incremental development of the application software; that is, test is often narrowly defined compared to the application as a whole.

[32] https://ufscommunity.org/news/medrangeweatherapp/

The development of end-to-end test plans for the applications is needed. Aside from the scientific credibility of the software, the test plan allows the more effective engagement of the community of developers and improves organizational efficiency. The UFS community should have access to the test harness, including subsets of the end-to-end testing suite, so that they can evaluate the effectiveness of their innovations. There exists a culture of testing with the Environmental Modeling Center's Model Evaluation Group, which will serve as a foundation for development of end-to-end test plans. It is anticipated that the Medium-Range Weather Application will provide a use-case for the first version of an end-to-end test plan.

3.2.6 Define the stages and gates of the research-operations interface:

In Organizing Research to Operations Transition[33], an iterative stages and gates process was posited to describe the transition from a research effort to use in the operational production stream. The goal of this priority is to define and publish a more precise description of the process, which will follow from the end-to-end test plans for an application. As a high priority, the process for bringing in a new component model will be developed. This is core to the UFS mission both improving the research and operations interface and transitions and engagement of the communities of researchers and developers.

3.2.7 Define and publish policy, protocols, and practices for UFS releases:

The release of the Medium-range Weather Application[34] provided a use case to inform both future releases of the Medium-range Weather Application and other UFS Applications. It identified resource and expertise gaps, and motivated the formation of a standing function in the governance to assure successful releases and community engagement. The priority is to develop a sustainable and persistent approach to UFS Application releases.

3.3 Organizing Principles

3.3.1 Scope of UFS Applications

The Scope of the UFS Applications, listed in Chapter 1, are represented in Figure 2, which show the geographical and temporal spans of the applications. The UFS Applications represent the essential UFS products; that is, the software that provides predictive numerical guidance to be used by forecasters to inform forecasts. The applications have specific forecast targets. The UFS Applications are closely aligned with the operational codes of the National Weather Service.

The development and review of this plan has revealed organizational and strategic gaps in the integration of UFS systems and products and those of the hydrological organizations within NOAA. There

---

[33] https://vlab.ncep.noaa.gov/documents/12370130/12994300/20181130_UFS-SC_Describing_the_Research_to_Operations_Interface.pdf/281087f7-cee4-2023-d595-259d28ee3b78?t=1608235633094

[34] https://ufscommunity.org/news/medrangeweatherapp/

are direct relationships with component models, infrastructure, and systems architecture. There are hydrological requirements for the UFS that need to be collected. There are tensions with computational resources. Better integration of the UFS and its roles in NOAA's hydrological efforts needs to be an organizational priority.

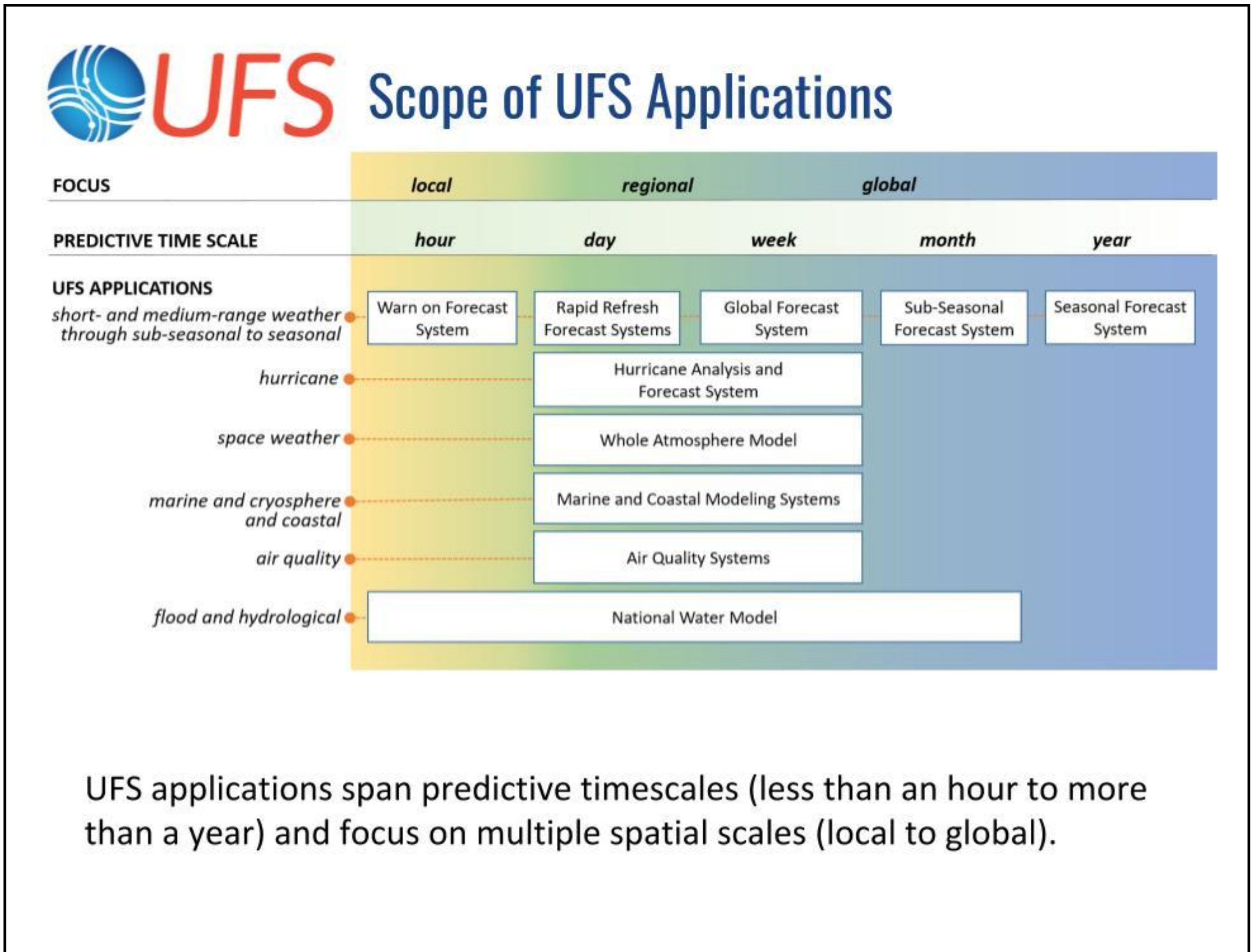

Figure 2: The scope of the UFS applications showing range of the forecast targets and spatial and temporal characteristics (from link)

3.3.2 UFS System Architecture and Components

The UFS is a unified system because its applications share a set of agreed-upon scientific components and a set of agreed-upon infrastructures. The scientific components and infrastructures are integrated into a consistent system architecture. Conforming to these UFS principles is central to UFS planning and success.

Each application combines several software components that represent functions. Each distinct software element of an application is called a component. The components included numerical model forecast, pre-processing, data assimilation, post-processing, verification, and workflow. All components of the UFS Applications are represented in this plan, as well as in the UFS governance. The parts on the UFS applications are represented in Figure 3.

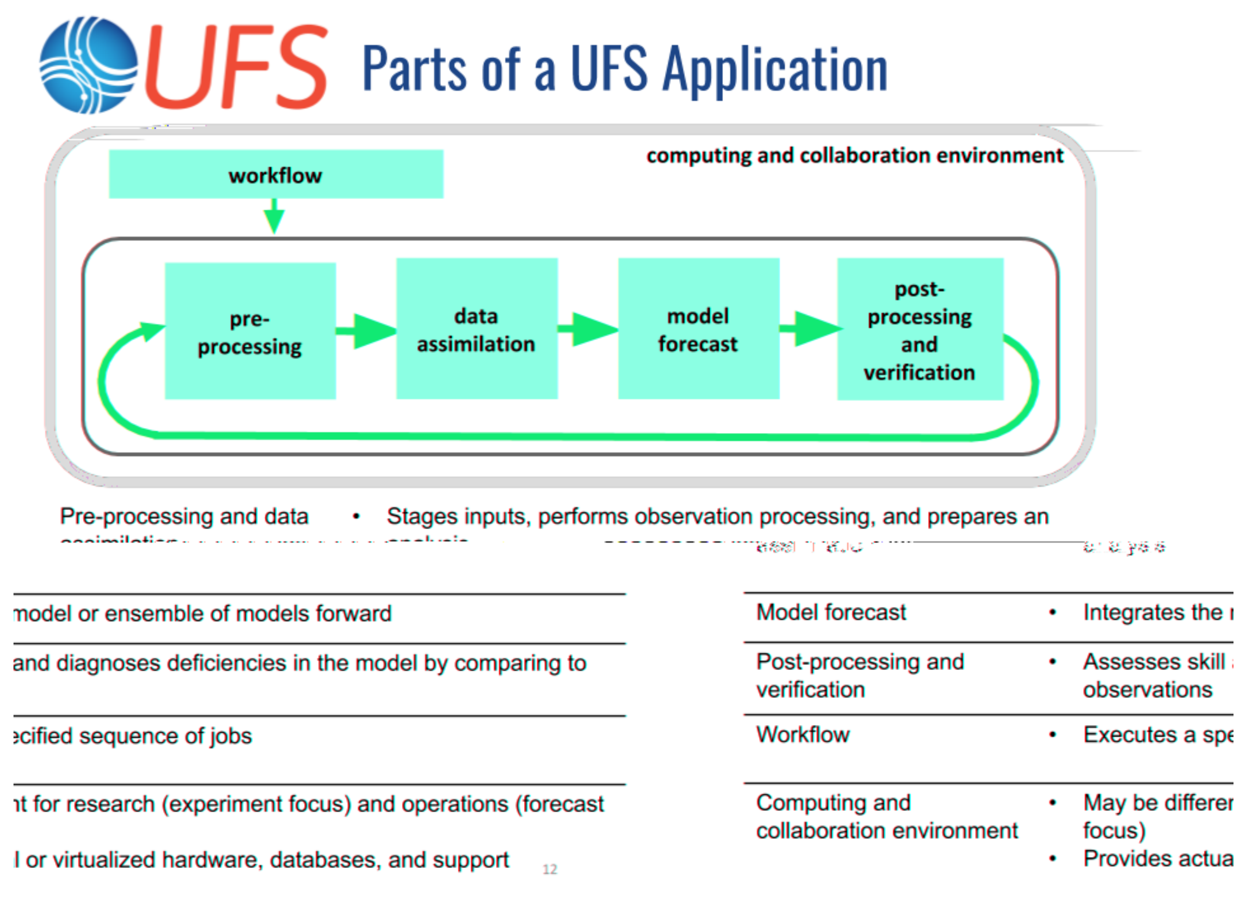

Figure 3: Each application combines software components that represent functions. The components include numerical model forecast, pre-processing, data assimilation, post-processing, verification, and workflow. (from link)

At the foundation of the UFS is the UFS System Architecture, shown in Figure 4. This figure is a more detailed breakdown of the Parts of a UFS Application, shown in Figure 3. The UFS uses a layered architecture and the components of that architecture define related parts of this plan and UFS governance. A complete description of the system architecture is found in System Architecture for Operation Needs and Research Collaborations[35].

UFS Layered Architecture

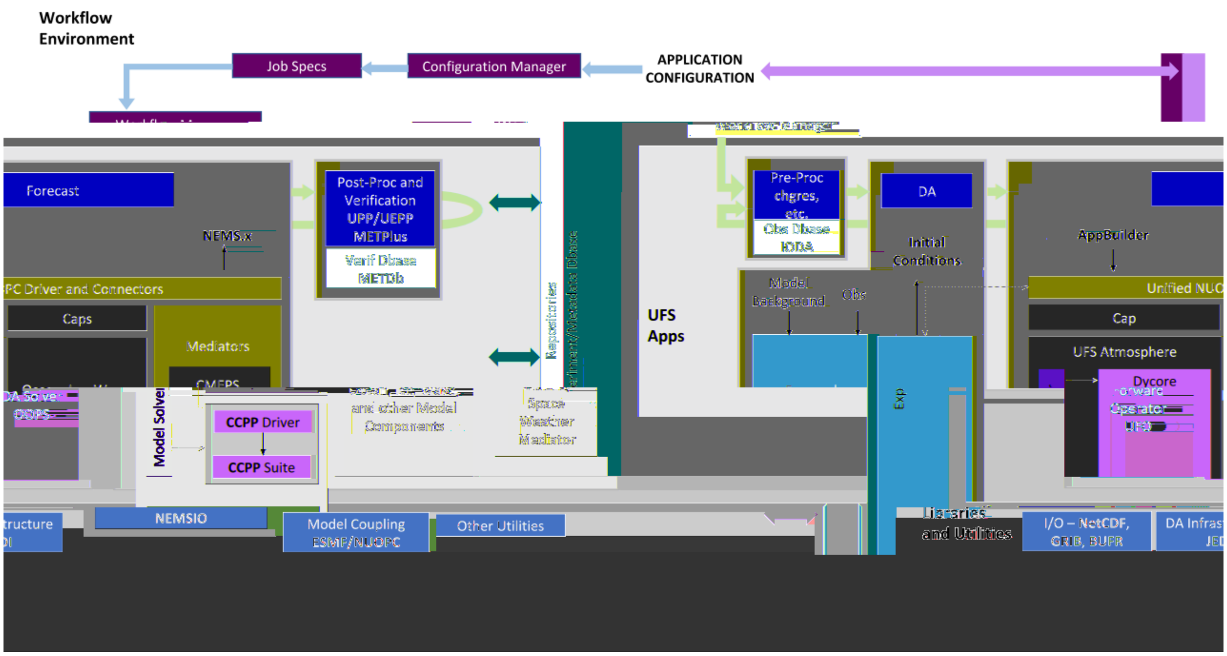

Figure 4: Diagram showing the main layers in the UFS system architecture: Libraries and Utilities, UFS Applications, and Workflow Environment. This is typical for an application, and it may change for different applications (from link)

3.3.3 UFS Foundational Decisions

The foundation of the Unified Forecast System is based on a set of strategic decisions. These are:

1. The selection of the FV3 dynamical core, by the NGGPS Dynamical Core Test Group, as the dynamical core of the Global Forecast System (GFS), and the agreement that FV3-based atmospheric models are a defining characteristic of a UFS application[36].
2. The use of a modular, community-based systems architecture for coupling model components.
3. The choice of the following infrastructure approaches:
    a. For component model coupling:

[35] https://ufscommunity.org/wp-content/uploads/2019/10/20170331_System_Architecture_for_Operational_Needs_and_Research_Collaborations.pdf

[36] https://www.weather.gov/media/sti/nggps/NGGPS%20Dycore%20Phase%202%20Test%20Report%20website.pdf

    i. Earth System Modeling Framework (ESMF)[37]
    ii. National Unified Operational Prediction Capability (NUOPC)[38]
  b. For data assimilation: Joint Effort for Data assimilation Integration (JEDI)[39]
  c. For atmospheric physics: Common Community Physics Package (CCPP)[40]
  d. For forecast verification: Model Evaluation Tools (METplus)[41]
4. The commitment to a sustained planning process.
5. The formalization of a Memorandum of Agreement between NOAA and NCAR[42].

These strategic decisions are expected to persist through the five-year time span of this plan. All of these decisions rely on community-based activities and all of them are evolving based on the needs of their communities, which includes the UFS. To deviate from these decisions would be a strategic decision involving the UFS community and program offices. In the terminology of Organizing Research to Operations Transition[43], a change at this level would be a Systems Level transition and would be expected to take several years, perhaps an entire five-year planning period. The process for making a change at this level has yet to be defined.

3.3.4 UFS Strategic Relationships and Agreements

3.3.4.1 Memorandum of Agreement (MOA) between NCAR, NWS, and OAR

An essential strategic relationship is represented in the Memorandum of Agreement among the National Center for Atmospheric Research (NCAR), the National Weather Service (NWS), and the Office of Oceanic and Atmospheric Research[44]. The Memorandum of Agreement is important for maintenance and evolution of the architecture and infrastructure that are UFS Foundational Decisions. The subject areas of the Memorandum of Agreement include several UFS priorities:

1. Coupling between components
2. Coupling within components
3. Workflow
4. Quality assurance testing in model development
5. Forecast verification
6. Software repository management

[37] https://earthsystemmodeling.org/
[38] https://earthsystemmodeling.org/nuopc/
[39] https://www.jcsda.org/jcsda-project-jedi
[40] https://dtcenter.org/community-code/common-community-physics-package-ccpp
[41] https://dtcenter.org/community-code/metplus
[42] https://www.weather.gov/media/sti/nggps/18-064553_SignedMOU.pdf
[43] https://vlab.ncep.noaa.gov/documents/12370130/12994300/20181130_UFS-SC_Describing_the_Research_to_Operations_Interface.pdf/281087f7-cee4-2023-d595-259d28ee3b78?t=1608235633094

[44] https://www.weather.gov/media/sti/nggps/18-064553_SignedMOU.pdf

7. User and developer support

3.3.4.2 NOAA Program Funding

The UFS-R2O Project represents a coordinated effort in the OSTI and WPO program offices to integrate their contributions to the UFS across programs. This project is focused, specifically, on the 2 year time frame and looks towards a 3-to-5 year time span. Many of the projects funded by NGGPS in the previous Strategic Implementation Plans are now funded in the UFS-R2O Project.

In addition to the UFS-R2O project funding is provided to the UFS community through the following NOAA programs. A portion of these funds are organized towards UFS goals through the Application Teams, Cross-cutting Teams, and component Working Groups. The tasks associated with these programs will be documented in the document, UFS Implementation Tasks.

1. OAR Weather Program Office (WPO), Testbeds and Air Quality Programs
2. OAR Weather Program Office (WPO), Joint Technology Transfer Initiative (JTTI)
3. OAR Weather Program Office (WPO), Subseasonal to Seasonal Funding
4. OAR Weather Program Office (WPO), pre-Earth Prediction Innovation Center (EPIC) Funding
5. NWS, Office of Science and Technology Integration (OSTI) and OAR Weather Program Office (WPO), Hurricane Supplemental, #1
6. NWS, Office of Science and Technology Integration (OSTI) and OAR Weather Program Office (WPO), Hurricane Supplemental, #2
7. NWS, Office of Science and Technology Integration (OSTI), Collaborative Science Technology and Applied Research Program (CSTAR)
8. NWS Office of Science and Technology Integration (OSTI), Hurricane Forecast Improvement Program (HFIP), Notice of Funding Opportunity (NOFO)
9. NWS Office of Science and Technology Integration (OSTI), Next Generation Global Prediction System (NGGPS), Notice of Funding Opportunity (NOFO)
10. NWS Office of Science and Technology Integration (OSTI), Weeks 3-4, Notice of Funding Opportunity (NOFO)

3.3.4.3 Earth Prediction Innovation Center (EPIC)

An important development for the UFS is the genesis of the Earth Prediction Innovation Center (EPIC)[45], which will host UFS community model code on a cloud-based infrastructure platform. EPIC's goal iss are to accelerate community-developed scientific and technological advancements into the operational applications for Numerical Weather Prediction (NWP) applications through its community-focused platformby supporting a UFS community model. As this UFS Strategic Plan is being written, EPIC proposals are being reviewed by NOAA. The UFS Strategic Plan provides informationprovides, therefore, information that will support the initiation of EPIC by describing UFS capacity and plans and identifying the most important functional areas to contribute to goals shared by the UFS and EPIC.

[45] https://wpo.noaa.gov/Programs/EPIC

3.3.4.4 UFS Infrastructure Community

The UFS is a unified system because its applications share a set of agreed-upon scientific components and a set of agreed-upon infrastructures. The UFS has made several foundational decisions regarding its infrastructure. All of these decisions rely on community-based activities and all of them are evolving based on the needs of their communities, which includes the UFS. The agreed-upon infrastructure and the community members represented are:

1. Earth System Modeling Framework (ESMF)
    a. National Aeronautics and Space Administration (NASA)
    b. National Oceanographic and Atmospheric Administration (NOAA)
    c. U. S. Department of Defense (DOD)
    d. National Science Foundation (NSF)
2. National Unified Operational Prediction Capability (NUOPC)
    a. U. S. Navy
    b. U. S. Air Force
    c. National Oceanographic and Atmospheric Administration (NOAA)
3. Joint Effort for Data assimilation Integration (JEDI)
    a. NOAA, National Environmental Satellite, Data, and Information Service (NESDIS)
    b. NOAA, National Weather Service (NWS)
    c. NOAA, Office of Atmospheric Research (OAR)
    d. NOAA, National Ocean Service (NOS)
    e. NASA, Earth Science Division (ESD)
    f. U. S. Navy, Naval Research Laboratory (NRL)
    g. U. S. Navy, Oceanographers of the Navy
    h. U. S. Air Force, Air Force Weather
4. Common Community Physics Package (CCPP)
    a. National Center for Atmospheric Research (NCAR)
    b. NOAA, National Weather Service (NWS)
    c. NOAA, Office of Atmospheric Research (OAR)
    d. U. S. Navy, Naval Research Laboratory (NRL)
5. Model Evaluation Tools (METplus)
    a. U. S. Air Force, 557th Weather Wing
    b. NOAA, National Weather Service (NWS)
    c. Met Office
    d. NOAA, Office of Atmospheric Research (OAR)
    e. National Center for Atmospheric Research (NCAR)
    f. NOAA, National Environmental Satellite, Data, and Information Service (NESDIS)
    g. NASA, Global Modeling and Assimilation Office (GMAO)
    h. Naval Research Laboratory (NRL)
    i. University of Illinois - Urbana/Champaign (UIUC)
    j. State of New York University - Stony Brook (SUNY-SBU)

    k. Embry-Riddle Aeronautical University (ERAU)
    l. George Mason University (GMU)
6. Unified Post Processor (UPP)
    a. NOAA, National Weather Service (NWS)
    b. National Center for Atmospheric Research (NCAR)
    c. NOAA, Office of Atmospheric Research (OAR)

3.3.4.5 Earth System Prediction Capability (ESPC)

The National Earth System Prediction Capability's vision is to develop and implement the next generation integrated physical earth system prediction capability at weather and longer time scales to support hours-to-seasonal global prediction. ESPC focuses on the following items, all of which are important to the UFS.

- Extend predictive capability to decades using multi-model, multi-agency ensembles
- Use ensembles to identify and quantify uncertainty and risk
- Advance computational and environmental numerical prediction science and technology
- Enhance our understanding of complex interactions of the earth environment

ESPC has responsibility for interagency coordination and has brought both planning and monetary resources to the NUOPC infrastructure. The ESPC agencies are:

1. National Aeronautics and Space Administration (NASA)
2. National Oceanographic and Atmospheric Administration (NOAA)
3. National Science Foundation (NSF)
4. Department of the Air Force
5. Department of the Navy
6. Department of Energy (DOE)

3.3.4.6 UFS Community Components

The UFS is a unified system because its applications share a set of agreed-upon scientific components and a set of agreed-upon infrastructures. The agreed-upon physical models and the community members represented are:

1. Medium-Range Weather Application
2. Modular Ocean Model version 6 (MOM6)[46]
    a. NOAA, Geophysical Fluid Dynamics Laboratory (GFDL)
    b. NOAA, National Centers for Environmental Predictions (NCEP)
    c. National Center for Atmospheric Research (NCAR)
    d. Rutgers University
    e. Florida State University
    f. Australian National University
3. WAVEWATCH III® (WW3)[47]
    a. NOAA, Environmental Modeling Center (EMC)

[46] https://www.gfdl.noaa.gov/mom-ocean-model/
[47] https://polar.ncep.noaa.gov/waves/wavewatch/wavewatch.shtml

    b. Office of Naval Research (ONR)
    c. Naval Research Laboratory (Stennis)
    d. Fleet Numerical Meteorology and Oceanography Center (FNMOC)
    e. US Army Corps of Engineers (USACE)
    f. Institut Francais de Recherche pour l'Exploitation de la Mer (IFREMER)
    g. The Met Office
    h. Environment and Climate Change Canada (ECCC)
    i. Bureau of Meteorology (BoM), Australia
4. Los Alamos sea ice model, version 5 (CICE5) and version 6 (CICE6)[48]
    a. Department of Energy (DOE), Los Alamos National Laboratory (LANL)
    b. Danish Meteorological Institute (DMI)
    c. Depart of Defense, Naval Research Laboratory (Stennis)
    d. Environment and Climate Change Canada (ECCC)
    e. Institute of Oceanography, Polish Academy of Sciences (IOPAN)
    f. NOAA, National Weather Service (NWS)
    g. NOAA, Geophysical Fluid Dynamics Laboratory (GFDL)
    h. National Science Foundation (NSF), National Center for Atmospheric Research (NCAR)
5. Goddard Chemistry Aerosol Radiation and Transport Model (GOCART)[49]
    a. NASA, Earth Science Division (ESD)
6. Whole Atmosphere Model Ionosphere Plasmasphere Electrodynamics (WAM-IPE)[50]
7. Advanced CIRCulation Model (ADCIRC)
    a. NOAA, Office of Coast Survey
    b. NOAA, National Geodetic Survey
    c. NOAA, Integrated Ocean Observing System
    d. University of North Carolina - Chapel Hill
    e. University of Notre Dame
    f. US Army Corps of Engineers
8. Finite Volume Community Ocean Model (FVCOM)
    a. NOAA, Office of Coast Survey
    b. NOAA, Center for Operational Oceanographic Products and Services
    c. NOAA, Integrated Ocean Observing System
    d. NOAA, Great Lakes Environmental Research Lab
    e. University of Massachusetts - Dartmouth
    f. Woods Hole Oceanographic Institute
    g. DOE, Pacific Northwest National Laboratory
9. Regional Ocean Modeling System (ROMS)
    a. NOAA, Office of Coast Survey
    b. NOAA, Center for Operational Oceanographic Products and Services
    c. NOAA, Integrated Ocean Observing System
    d. NASA, Jet Propulsion Laboratory

[48] https://github.com/CICE-Consortium/About-Us/wiki/FAQ-(Frequently-Asked-Questions)
[49] https://tropo.gsfc.nasa.gov/gocart/
[50] https://www.swpc.noaa.gov/products/wam-ipe

e. Rutgers University
f. University of California - Santa Cruz
g. North Carolina State University

10. SCHISM/SELFE (Semi-implicit Cross-scale Hydroscience Integrated System Model)
    a. NOAA, Office of Coast Survey
    b. NOAA, Center for Operational Oceanographic Products and Services
    c. Environment Protection Agency (EPA)
    d. Los Alamos National laboratory, Department of Energy
    e. California Dept of Water Resources
    f. Texas Water Development Board
    g. Central Weather Bureau, Taipei, Taiwan
    h. Institute of Coastal Research, Helmholtz Zentrum Geesthacht, Germany
    i. The German Federal Institute of Hydrology (BfG), Germany
    j. European Commission, Joint European Research Centre (JRC)
    k. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia

11. Others? / HYCOM, WRFHydro, ?

3.3.4.7 Joint Center for Satellite Data Assimilation (JCSDA)[51]

1. NOAA, National Environmental Satellite, Data, and Information Service (NESDIS)
2. NOAA, National Weather Service (NWS)
3. NOAA, Office of Atmospheric Research (OAR)
4. NASA, Earth Science Division (ESD)
5. U. S. Navy, Naval Research Laboratory (NRL)
6. U. S. Navy, Oceanographers of the Navy
7. U. S. Air Force, Air Force Weather

[51] https://www.jcsda.org

4 Schedule

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. Therefore, it is required to coordinate with the National Weather Service (NWS), especially the Environmental Modeling Center (EMC), to connect UFS priorities and releases with operational outcomes. Tight coordination is, presently, required, as the UFS is steering the development of UFS applications from the evolution of the current suite of operational software. Therefore, the UFS strives to achieve longer term goals through incremental development of capacity in the operational cycle. In a 5-to-10 year time horizon, it is desired to loosen the coupling of this schedule coordination to support innovation and, potentially, disruptive evolution.

As described in Organizing Research to Operations Transition[52] coordinating UFS releases with operational releases from NOAA, especially EMC, provide the opportunity to analyze and improve the R2O transition process. Therefore the UFS will focus on using ongoing transitions that are imperative to the operational mission to standardize, document, and improve the R2O process, as well as to remain true to the primary UFS commitment to operational outcomes.

Detailed scheduling requires specific consideration of implementation tasks and resources, which are beyond the scope of this document. Therefore, what is provided outlines the transition from the current production suite to a production suite that is consistent with the tenets of this plan.

From 2014 - 2020, NCEP has made many upgrades to the production suite. A disruptive-technology upgrade, initiating the transition to the UFS, was selecting the non-hydrostatic atmospheric dynamic core (dycore), FV3. 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. GFSv15 moved to operations in 2019. GEFSv12 is expected to move to operations in Fall 2020. Both of these upgrades represent substantial improvements in forecast skill, and provide part of the foundation for the future development of the UFS.

The Environmental Modeling Center has set an ambitious vision to transition the NCEP Production Suite to the UFS in the next five years. This vision aims to reduce the current 24 modeling systems in the NCEP Production Suite to the eight UFS applications, plus two related applications for the Great Lakes and Regional Hydrology. The primary simplification comes from the reduction of the number of systems being run to provide the SRW/CAM forecast guidance, and unification of global systems to be run in

52 https://vlab.ncep.noaa.gov/documents/12370130/12994300/20181130_UFS-SC_Describing_the_Research_to_Operations_Interface.pdf/281087f7-cee4-2023-d595-259d28ee3b78?t=1608235633094

coupled configurations. This notional schedule was presented at the 2020 AMS meeting, and an updated version is reproduced here in Figure 5.

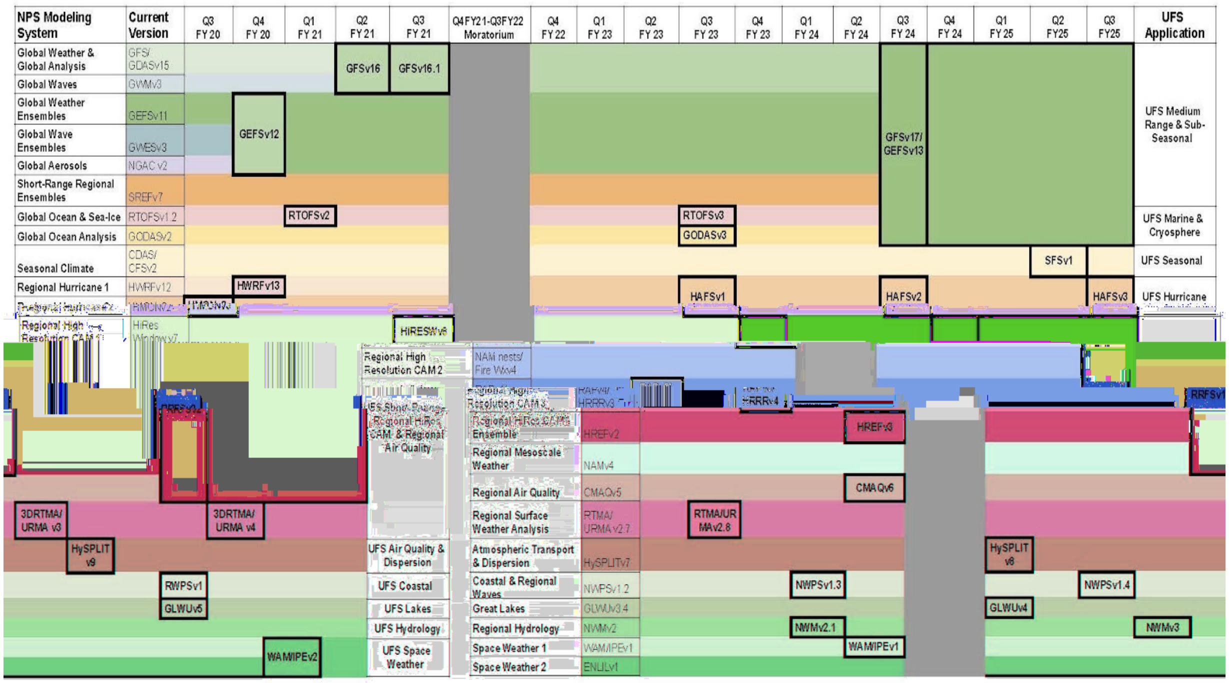

Figure 5: Plan to transition the NCEP Production Suite (NPS) to the Unified Forecast System. Note the major simplifications associated with the Short-Range Weather/Convection Allowing Model and Air Quality applications. (from link)

Of special notes in this schedule are

- In Fiscal Year 23, unification of existing Convective Allowing Models and the Mesoscale Systems into one system, Short Range Weather/ Convection Allowing Model. This is followed in FY 24 by incorporating Regional Air Quality into this system.
- In Fiscal Year 24, unification of GFSv17 and GEFS v13

The visionary schedule of Figure 5 is complemented by more concrete near-term schedules provided by the National Weather Service and documented on the R2O Project site.

- Medium-range Weather (MRW) App 1.0.0, March 2020 (FV3 based, Interoperable atmospheric physics and land surface supported with Common Community Physics Package (CCPP))
- GEFSv12.0, September 2020 (FV3 based, coupled waves, aerosols)

- Medium-range Weather (MRW) App 1.1.0, October 2020 (updates from graduate student test responses, build systems, documentation, chgres)
- Short-range Weather (SRW) App 1.0, February 2021 (FV3 Limited Area Model)
- GFSv16, March 2021 (updated atmospheric physics)

The Short-range Weather release will be a research model for the community, and the first UFS release that is not linked to an operational release.

Membership of the UFS - Steering Committee

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

Richard B. Rood and Hendrik L. Tolman, Co-Chairs
Program Support: Karen Keith

Henrique Alves, Thomas Auligne, Jian-Wen Bao, Michael Barlage, Ligia Bernardet, Jacob Carley, Rocky Dunlap, Gregory Frost, Brian Gross, Tom Hamill, Lucas Harris, Tara Jensen, Henry Juang, James Kinter, Dorothy Koch, Geoffrey Manikin, Avichal Mehra, Louisa Nance, Shackak Peeri, Russell Schneider, Ivanka Stajner, Cristiana Stan, Vijay Tallapragada, Mariana Vertenstein, Jeffrey Whitaker, Xuejin Zhang

Writing Team

Cecelia DeLuca, Brian Gross, Karen Keith, Daniel Meléndez, William Pryor, Richard Rood, Hendrik Tolman