



R20 Initiative:

**Next Generation Global Prediction
System**

(NGGPS)

Implementation

Plan

DRAFT as of October 10, 2014 v 1.0

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REVISION HISTORY

Rev.	Date	Author	Description of Change

DRAFT

1 R20 Initiative: Next Generation Global Prediction System

1.1 Background

The National Oceanic and Atmospheric (NOAA) National Weather Service (NWS) has the responsibility to provide weather, water, and climate information to protect life and property, and enhance the national economy. The NWS mission is to provide the best possible guidance to a wide variety of customers, including emergency managers, forecasters, and the aviation community. Fundamental to this mission, the global numerical weather prediction system provides initial condition data and initial states for regional atmospheric and ocean models, space weather applications, air quality forecasters, and the National Centers for Environmental Prediction (NCEP) service centers. To properly service the customers, the forecasts must be available reliably and at the appropriate time within available resources.

NWS supplies information to support and protect the Nation's social and economic development by ensuring society is prepared to respond to environmental events, resulting in a weather-ready nation. In order to build a weather-ready nation, NWS must have access to cutting edge weather prediction techniques and develop them for operations.

In 2012, after Hurricane Sandy hit the east coast of the United States, causing extensive damage, flooding, and deaths, an accelerated research to operations project to produce a more accurate and timely prediction of storms was presented to Congress. Congress then appropriated an increase in \$14.8 million in base funding for a Research to Operations (R20) Initiative to produce a state-of-the-art prediction model system, along with a \$15 million increase in the operational computing budget to increase high performance computing (HPC) architecture to enhance the new modeling capability. This initiative was coordinated with both NWS and the Office of Oceanic and Atmospheric Research (OAR), and language in the FY14 President's Budget and Appropriation was agreed to by NOAA/NWS, the Department of Commerce (DOC), and the Office of Management and Budget (OMB). The overarching initiative objective is to build a Next Generation Global Prediction System (NGGPS).

Over the next five years, design, develop, and implement the Next Generation Global Prediction System and maintain world-class forecast capability for the protection of life and property and economic growth and prosperity.

1.2 Goals

The R2O Initiative will expand and accelerate critical weather forecasting research to operation to address growing service demands and increase the accuracy of weather forecasts. For the next five years, NOAA NWS will design, develop, and implement a global prediction system that extends weather forecasting skill to 30 days. The design of this weather forecasting system will be accomplished through the development and implementation of global weather prediction model, improved data assimilation techniques, and improved software architecture and system engineering. This R2O Initiative will deliver:

- A next generation global prediction system that meet the evolving national prediction requirements
- Effective assimilation for environmental observations at global and regional scales
- A software architecture and engineered system that maximizes the benefit from HPC enabling quicker transition of internal and external research to operations
- Hurricane forecast models that meet societal requirements to effectively mitigate economic disruption

To achieve these goals the major work areas will include:

- Selecting an atmospheric dynamic core from existing research and operational models
- Improving model physics packages to better describe weather phenomenon at global and regional scales
- Developing multiple, interacting, high resolution nested grids within the global model to accurately account for the evolution of severe weather systems including hurricanes
- Accelerating development and implementation of weather prediction model components, such as ocean, wave, sea ice, land surface and aerosol models; and improve coupling between the component model systems
- Developing advanced data assimilation methods at global and regional scales and for specific storms such as hurricanes
- Incorporating all system components into the NOAA Environmental Modeling System (NEMS) framework
- Improving software architecture and systems engineering through:
 - Building a high-performance, flexible software infrastructure to increase ease of use, performance, and interoperability

- Investigating effective use of emerging HPC technologies; simplifying of software structure; and implementing a community-based model infrastructure which will streamline the incorporation of proven research advances into operations.
- Increasing the resolution of key environmental models to improve the specificity of forecasts (target 3-10 km for the global models, 0.5-2 km for the interior nests)
- Enhancing probabilistic forecast systems by including more ensemble members at higher resolution
- Conducting data impact studies of future observing systems such as the next-generation satellites to enable both rapid incorporation of future observing systems data and guide observing systems strategies and requirements

This initiative will serve as a “transition to operations” project for current and future research and development efforts both inside and outside the NWS, and will include NWS participation with university research community and partnership efforts, such as the National Earth System Prediction Capability (ESPC) and the Earth System Modeling Framework (ESMF) support within NEMS. Proposal driven support will be considered for other on-going initiatives and projects such as: Hurricane Sandy Supplemental, including the High Impact Weather Prediction Project (HIWPP); Gap Mitigation; Hurricane Forecast Improvement Project (HFIP); U.S. Weather Research Program (USWRP); and Testbeds, including the Development Testbed Center (DTC).

1.3 Five Year Schedule

This five year effort will incorporate all aspects of weather prediction models.

- FY 2014
 - Define Prototype Next Generation Global Prediction System
- FY 2015
 - Extend NEMS infrastructure to include ice, ocean, near shore water level (storm surge), and land surface prediction models
 - Define model re-architecture requirements for next-generation heterogeneous fine-grain computing platforms
- FY 2016
 - Demonstrate increased skill (7-day skill extended to 14 days) for coupled global ocean-atmosphere-ice-wave system
- FY 2017
 - Redesign architecture and re-engineer component models for efficient transfer to fine grain computing platforms
- FY 2018
 - Implement Next Generation Global Prediction System

1.4 Overall Deliverables

In general, the NGGPS overall deliverables are:

- Annual upgrades to operational Data Assimilation System
- Upgrades to NEMS infrastructure
- Upgrades to component models (ocean, atmosphere, ice, land surface, wave, aerosols) for a coupled system
- Coupled global system using re-engineered system component models
- Improved utilization of HPC resources and cost effective implementation of science
- Agile HPC environment with quicker operational transition of research and development efforts

2 The NGGPS Model

NOAA's Next Generation Global Prediction System will be the foundation for the operating forecast guidance system for the next several decades. The system will include a single atmospheric dynamic core; a suite of atmospheric physics; numerical ocean, wave, ice, aerosol, and land surface models; supporting functions including data assimilation systems, ensemble design and initialization, post-processing; and guidance products. Developing a global prediction system based on the best operational and research models available entails identifying candidate components that have the potential to contribute to the complete system, identifying any scientific gaps therein, and modifying/customizing the components to incorporate them into the new system.

The new prediction system will be weather focused with forecast skill from 0-30 days, with the fully coupled ocean, wave, aerosol, land surface, and ice models at 3-10km resolution. It will incorporate telescoping moving convective resolving nests for severe weather and hurricanes, (one or two for a nested region and an ability to include several of these nests simultaneously over individual hurricanes), state-of-the science data assimilation, and probabilistic forecasts using ensembles.

The increase in computational capacity needed for greater accuracy and detail achieved by the new prediction system will be addressed with next generation computing technology. NWS will take advantage of the most cutting edge information technology by continuing to adapt and optimize codes for increased performance in multi-cores, participating in co-design to improve suitability hardware, and exploring new algorithms.

All aspects of observation processing, data assimilation, numerical modeling, ensemble forecasting, post-processing and verification, along with increased HPC, together will produce the best possible prediction.

The next generation global system will be:

- Non-hydrostatic
- Applicable and stable for all NWS applications currently using Global Spectral Model (GSM)
 - Global high resolution weather prediction
 - Whole Atmosphere Model
 - Multiple high resolution nests with moving capability for hurricane and severe weather forecasting
 - Aerosol forecasting
 - Seasonal climate modeling
 - Ensemble forecasting
 - Atmospheric composition forecasting (currently only ozone)
- Usable in NEMS infrastructure
- Usable within NWS data assimilation system

2.1 Fully Coupled Model Components

NEMS is a shared, portable, high performance software superstructure used by NCEP to streamline operational modeling suites into a common modeling framework. The foundation for NEMS is the Earth System Modeling Framework (ESMF), a community software infrastructure system that enables different model components to operate together. The model components for the new global prediction model will be included in this NEMS framework. Individual models will be run both as stand-alone and coupled. Multiple storm-scale phenomena will be modeled on movable grids nested within the global domain.

The global atmospheric model contains two components: a dynamic core and a physics package. The atmospheric model dynamic core is the basic numerical model of the governing equations (equations of motion, thermodynamic energy equation, equation of state, mass conservation and usually an equation for advection of various atmospheric species like water vapor). The physics packages are subsystems used by the model to simulate various other atmospheric processes such as cloud microphysics, radiation, surface fluxes, etc. Given a reasonable dynamic core and initialization system for that core, the quality of the physics package will largely determine the quality of the forecasts.

Development and upgrades to individual model components: land surface, ocean, wave, sea ice and aerosol, will be accelerated for coupling within NEMS. All components have a certain amount of interaction with other components and the work must be closely coordinated. Coupling space weather models that forecast solar and geophysical events (which impact satellites, power grids, communications, navigation, and many other technological systems) is considered a long term goal of this initiative.

One of the early NGGPS milestones is to develop a prototype coupled prediction system within the NEMS framework by the end of FY15. As of the beginning of FY15, NEMS included Global Forecast System (GFS), its dynamic core, the GSM and two global ocean models: the Modular Ocean Model, release 5 (MOM5), and the Hybrid Coordinate Ocean Model (HYCOM). The goal is to include the GFS physics driver, the Wave Watch III wave model; and the Los Alamos sea ice model (CICE) in FY15. By the end of FY15, the components will be coupled in a test-ready system. The eventual coupled structure including initial component models is shown in Figure 1.

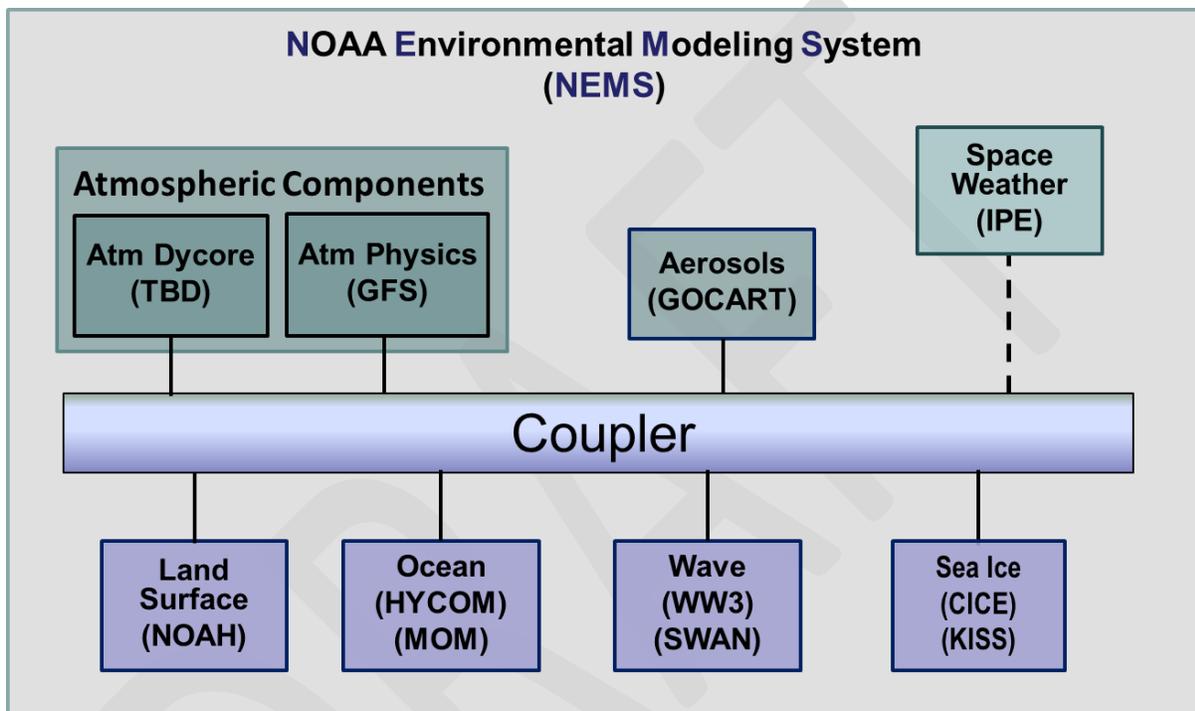


Figure 1. NGGPS Model Components

Component models will be continually upgraded, tested, improved further, and coupled through the NEMS framework. Each newly-coupled system then goes through further testing and validation resulting in tweaking, or tuning, before the new or enhanced model is operational.

2.2 Support Functions

Supporting the model components, data assimilation will be addressed to provide the best possible initial conditions for the forecast model by integrating data observations into the system. Due to the diverse nature of the initial data types, a variety of data formats will be evaluated, used and integrated into the system, as well as modified as needed. The data assimilation, ensemble predictions, and post-processing components of the system will take this initial data, the model uncertainty and supporting data sets, to reduce the forecast error as much as possible; with specific goals to make the forecast guidance more skillful, reliable and detailed. To fully

evaluate the individual components and coupled systems of NGGPS, NOAA Testbeds and Proving Grounds (TBPG) will test, evaluate/develop, and demonstrate operational readiness to deploy the operational NGGPS.

Infrastructure items, such as documentation of scientific and algorithmic aspects of the model, including documentation within the code, as well as an online science reference guide, and training will be addressed and can expand as the system comes into operation. Training will be focused on the model bias, strengths and weaknesses with respect to various skill metrics and typical forecasting situations.

NWS will depend on HPC for the comprehensive numerical modeling. The prediction systems are computationally very expensive due to the complex interactions of the different model components as they are integrated into a single system to provide the forecast data. Increased numerical resolution, increasingly complex models and the use of ensembles to better quantify uncertainty require significantly enhanced HPC capabilities, as well as new evaluation of data management, transmission, and storage.

2.3 Production Suite Compatibility

The specific effort for NGGPS must integrate with and add to the NCEP's Environmental Modeling Center (EMC) work plan. To run properly within the NWS production suite, all models in the system along with any changes/upgrades must satisfy certain requirements. These requirements are applicable to groups both internal and external to NWS:

- The components and modifications must be compatible with input/output and architecture through inclusion in NEMS.
- Models and changes must satisfy all current downstream requirements and uses of the system, (i.e., no reduction in downstream capability for users).
- The computational resources required for any changes or component modification should not exceed the available computational resources. Available resources are defined by NCEP to be the resources (time, number of processors, disk space) that can be used by that particular component of the operational suite. Generally, a change that uses the same or reduces the amount of resources satisfies this requirement. Additional resources may be available, but must be approved by NWS/NCEP management with consideration given to cost versus benefit, balance between systems and future planning.
- Modifications must be maintainable and sustainable, allowing quick diagnosis and repair of problems and upgrades by other groups. This can be achieved with any combination of sufficient documentation, and long term external support.

- Modifications must be introduced into NCEP's EMC code management system following the established code management procedures.
- Testing must convince NWS developers and downstream users that the changes are valid and will not result in degradation or failure of the system. Final validation will be done as part of the implementation process at NCEP.
- All modifications will become property of the government and restrictions on the distribution or use of the modifications will not be allowed.

2.4 Strategy for the Implementation of NGGPS

Performing a cycle of research-upgrade-testing-operational implementation to continuously improve the guidance offered by the system will result in a state-of-the-art weather prediction system, accelerated due to a research-to-operations pathway.

The plan is to have an operational-ready fully coupled system by the end of fiscal year 2018 (FY18). In FY16, a single dynamic core will be selected and the existing models and system components inventoried, with components integrated within the NEMS framework by the end of FY17. Inventory includes existing and next generation components, and ongoing upgrades including enhancements pursued through parallel initiatives.

Figure 2 shows the NGGPS development schedule. At the onset, the prototype NGGPS is defined, including performance, design and architecture requirements, the latter making the system easily adaptable to advanced computer technologies (e.g., next generation heterogeneous fine-grain computing platforms). While candidate dynamic cores are evaluated and existing components are incorporated into NEMS, the development infrastructure will be established with code restructuring and memory management optimization; developing a verification system; establishing and standardizing performance measures; establishing a testbed capability and testing program; and preparing documentation and training programs. The testing program will likely require new testbed capabilities.

The dynamic core should be established in the second quarter FY16. Over the following two years, the selected core will undergo pre-implementation development and testing and, when deemed ready at NCEP, enter a year of testing parallel to the current (FY18) operational system. As shown on Figure 2, improvements to the operational GFS will continue throughout the selection, development and testing of the NGGPS dynamic core. Those improvements include the Semi-Lagrangian version to be implemented in the present upgrade cycle (November 2014) and the non-hydrostatic version with an increase in vertical levels, not yet scheduled.

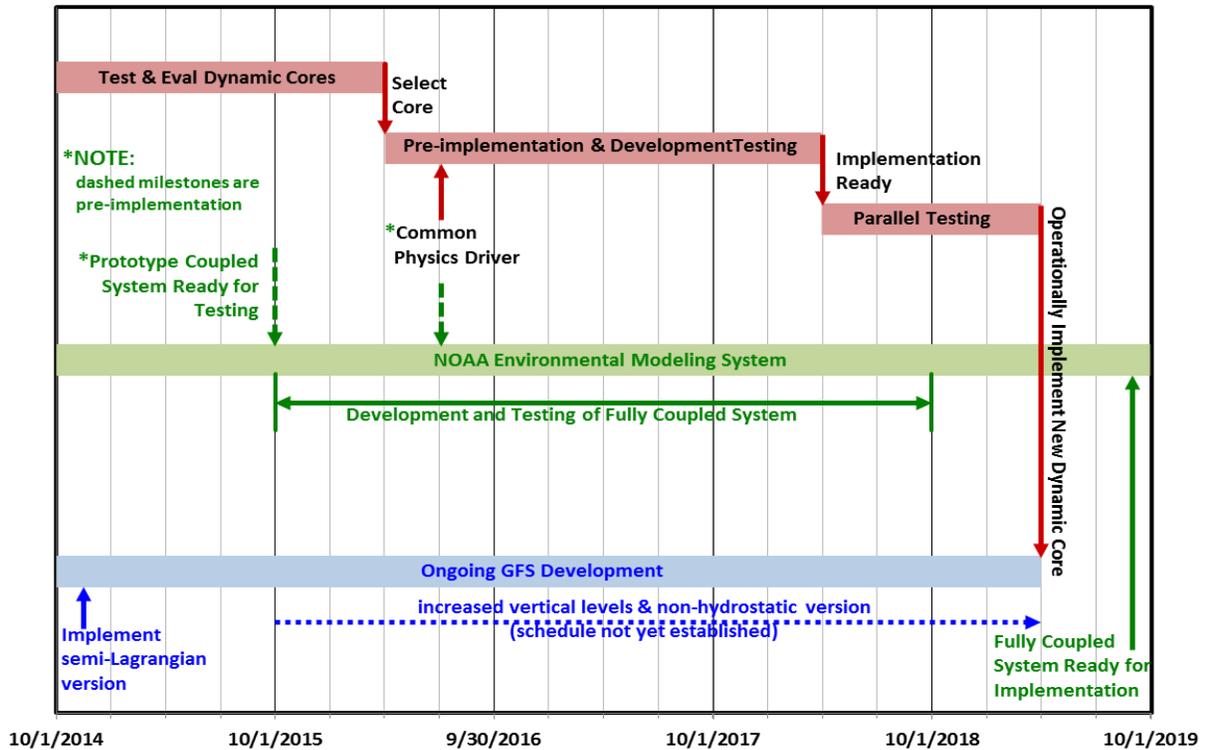


Figure 2. NGGPS Implementation

NGGPS will not become operational until it has been demonstrated to provide forecasts equal to or better than the operational system during parallel testing. Forecasts are evaluated through the implementation process at NCEP. The new model prediction system must demonstrate forecast accuracy, and do so reliably and within the computational time and resource constraints of the operational system. Once NGGPS becomes operational, further upgrades must meet the same standards. The fully coupled NGGPS should be implementation ready by FY2019.

3 Performance Goals and Metrics

Specific metrics have not yet been established for NGGPS performance. To focus on creating a weather prediction model out to 30 days, the system must not only meet the accuracy of the current operational system, but have the capability to go beyond. The new system will have capability, scalability, and upgrade potential beyond that of the current system. As component models are integrated and nested, these goals will be developed over time for this initiative. A small team will be identified to define a limited number of performance goals which will be reviewed by the management team, and presented to the EOB. Each performance goal established for this project will address goals of NOAA’s Government Performance and Result Act (GPRA) and each of the NGGPS objectives. Quantifying (i.e. x percent improvement within y years) the list below is the initial set of proposed goals to track the project’s progress.

- Increase rate of improvement of skill for global numerical weather prediction
- Extend forecast skill of numerical weather prediction out to 30 days
- Improve overall accuracy and reliability of probabilistic forecasts

More detailed tracking of performance at the project level will entail a larger set of criteria. Some ongoing projects have goals in place that will continue to be tracked as part of the R2O Initiative. For example, HFIP’s ten-year goals associated with mean hurricane track and intensity errors will apply as five year goals to this effort. In addition, the teams will determine a common set of standard metrics from a list of already established at NCEP for evaluating improvements in model performance. Additional measures not yet defined may be evaluated as the capabilities of the prediction system increases. This common set of metrics will be measured and reported on a recurring basis.

4 Management

The NGGPS Project is a collaborative effort between OAR and NWS, with NWS having the overall responsibility to implement an operational prediction system. The goals and deliverables will be implemented through a management structure comprised of expertise from both operations and research communities. The cross-community partnership requires open communication and a clear definition of responsibilities and authority for each organization. The management structure and lines of communication are shown on Figure 3.

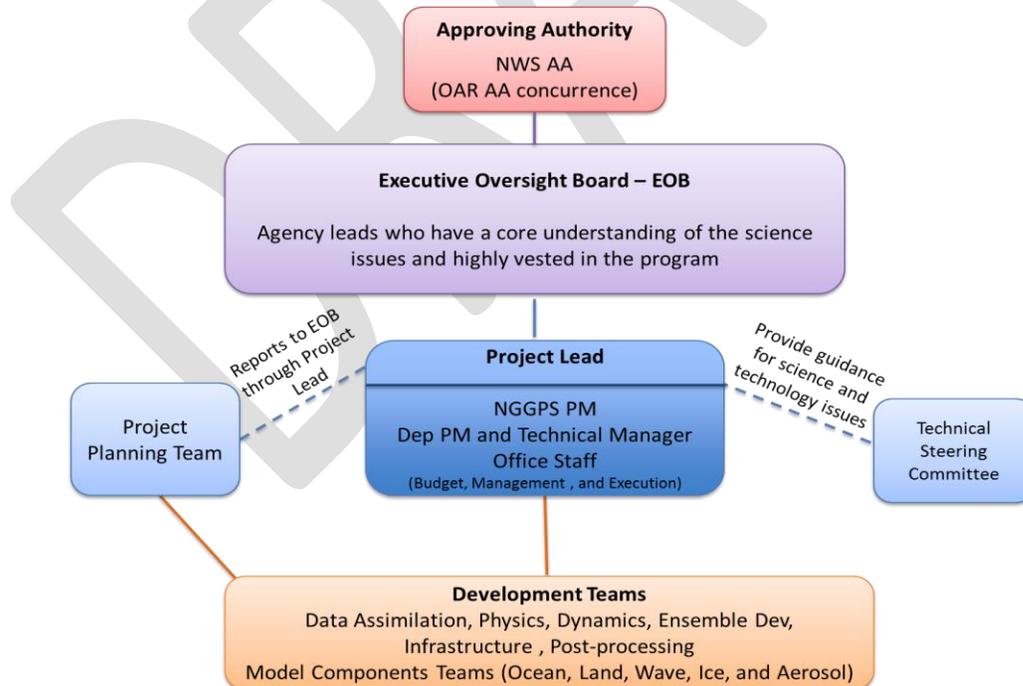


Figure 3. Management Structure

The roles and responsibilities within that management structure are described below and summarized in Table 1.

Table 1. Roles and Responsibilities

Position	Role
Approving Authority	
NWS Assistant Administrator	Final approval of plans, priorities, and goals
OAR Assistant Administrator	Concurrence of plans, priorities, and goals
Executive Oversight Board Members	
NCEP Director	Decision authority on selection of identified next generation dynamical core
NWS Office of Science and Technology Director	Responsibility of implementation of NGGPS
NWS Science and Technology Integrations Director	Recommends approval of plans, priorities, goals and execution of spend plans to AA; strive for consensus on every issue; ensure formation of partnerships and broad multi-agency participation; ensure congressionally mandated milestones and deliverables are met
NESDIS/STAR Director	
NWS Central Processing Portfolio Director	
OAR Office of Policy Planning and Evaluation Director	
OAR ESRL Global Systems Division Director	
OAR ESRL Physical Sciences Division Director	
Project Lead (NWS/OST)	
NGGPS Management Team	
NWS/OST Project Lead (appointed by EOB)	Single focal point for the effort in NWS. Oversees and coordinates entire project
Technical Manager (appointed by Project Lead)	Single focal point for the research and development activities. Oversees that coordination is across NOAA collaboration
Project Management Office Staff (NWS/OST)	Staff directly supports the Project Lead. Manages and track all programmatic activities; provide administrative support
Technical Steering Committee	Monitor technical progress and provide guidance on science and technical issues
Project Planning Team (Subject Matter Experts)	Deliver a multi-year project <i>plan, plan</i> ; define detailed technical scope of activities. Chairs and manages development team
Development Teams	Submit proposals for activities and deliver milestones; reports status and progress of deliverables

4.1 Approving Authority

National Weather Service Assistant Administrator (NWS AA) and Office of Oceanic and Atmospheric Research Assistant Administrator (OAR AA)

The NWS AA with concurrence from the OAR AA approves plans, priorities and goals recommended by the Executive Oversight Board (EOB). The EOB will report and recommend

approvals based on general consensus. In cases where consensus cannot be achieved, the NWS AA has the final decision authority.

4.2 Executive Oversight Board

The Executive Oversight Board provides oversight of the project including reviewing and recommending annual operating plans and budgets for approval. The EOB is comprised of Division Directors from NWS, OAR, and National Environmental Satellite, Data, and Information Service (NESDIS), and the Project Lead as an Ex-Officio member. The primary role is to recommend approval of plans, priorities and goals. The board ensures a solid transition to operations; and that both short-term and long-term objectives, particularly congressionally mandated milestones and deliverables, are met through proper prioritization and allocation of resources. The EOB ensures the formation and development of internal and external partnerships resulting in broad multi-agency participation.

Director, National Centers for Environmental Prediction

As a member of the EOB, the Director of NCEP has input in approving priorities, plans and goals and recommendation to the NWS AA. The NWS/NCEP Director oversees the development of and improvements to numerical prediction and, therefore, has the final decision authority on the selection of the model that will transition from research into the NOAA Operational Production Suite. Within NGGPS project, the NCEP Director will approve the testing plan for selecting the next dynamic core.

Director, NWS Office of Science and Technology (OST)

The NWS/OST Director manages the implementation of NGGPS and oversees the NGGPS Project Office, including implementation of the program within the approved scope, cost, and schedule, and management of top level planning, acquisition, development, and transition to operations of the fully coupled global modeling system. The NWS/OST Director jointly coordinates transition to operations with the NWS/NCEP Director.

Director, NWS Science and Technology Integration Portfolio

In addition to the role and responsibility of an EOB member, when the pending NWS reorganization commences, the role and responsibility of the NWS/OST Director regarding the EOB transfers to NWS/STI Portfolio Director. That responsibility includes coordinating transitions to operations with the NWS/NCEP Director.

NESDIS and OAR Members

The remaining EOB members are Division Directors and key members in coordinating jointly funded activities. They ensure broad multi-Agency participation. The NESDIS and OAR members will serve as the focal point for their respective organizations. They form and develop internal and external partnerships.

NWS/OST Program Manager or Project Lead

The Project Lead serves as the single focus for the effort within the NWS and has execution oversight authority for project plan elements endorsed by the EOB and approved by the AA.

4.3 Project Lead and Project Office

The Project Office, managed by the Project Lead oversees and coordinates the entire project. The Project Lead, along with supporting contractor staff, develops annual operating plans, annual budgets, annual reports, and facilitate all aspects of the program including regular communication with and between all parts of the project, maintaining a webpage, facilitating workshops and other meetings. The Project Lead leads the Project Planning Team in organizing applicable research and development activities, coordinating project efforts internal and external to the NWS and NOAA, and presenting plans and reports to the EOB for approval. The Technical Manager position is within the project office. The Technical Manager designs and manages the developmental and scientific strategies. The Technical Manager aligns collaborative activities submitted by the developmental teams. The Technical Manager is a member of the Technical Steering Committee and co-leads the Planning Team along with the Project Lead.

4.4 Technical Steering Committee

The Technical Steering Committee (TSC) will oversee the design and development activities of the project, monitor technical progress, and ensure cross-collaboration. This committee is charged with chartering task-oriented working groups/tiger teams and chooses internal or external experts to address specific elements of the NGGPS development and deployment. Working groups include independent review panels and evaluation teams that provide guidance on science and technical issues.

4.5 Project Planning Team

The Planning Team defines and develops the approach and process for building the next generation system. The team determined the Development Teams, their memberships and leads (many of whom are Planning Team members). The Planning Team is comprised of subject matter experts for each of the major development areas. The team will propose partition of activities between directed development and competitively awarded grants and define the detailed technical scope of activities.

4.5.1 Development Teams

The Development Teams were established to work on various aspects of the NGGPS development. Each team drafted a plan identifying gaps in the state-of-the-science, opportunities to leverage other ongoing programs and projects, and near- and long-term objectives associated with their particular focus. They meet periodically and, when needed, conduct technical workshops to gather information from the community on aspects of the global model system development. The Development Teams report progress and results to the Project Office, and

recommend funding priorities and changes in emphasis within the project. In addition to developing and enhancing the predictive capabilities and efficiencies, the teams are responsible for considering developments from and establishing requirements for the general research and development community (NOAA and other US Government agencies and laboratories, cooperative institutions, universities, the international operational numerical weather prediction community, etc.). The teams and their charges are listed in Table 2.

Table 2. Development Teams

Team	Charge
Data Assimilation	Formulate strategy and identify gaps for data assimilation components for atmosphere, ocean, sea ice, and land, at various scales; plan future requirements
Atmospheric Prediction, Dynamics	Assess dynamic cores for use as NGGPS core; upgrade and enhance dynamic core
Atmospheric Prediction, Physics	Define NGGPS physical parameterization suite; assess impacts of additional environmental parameterizations (e.g., aerosols); upgrade physics packages to accommodate increases in resolution
Ocean Prediction	Plan the updating, incorporation, and coupling of ocean model components, including ocean, waves, and sea ice; identify gaps; form strategies to increase resolutions
Land Prediction	Formulate strategy and identify gaps for the land surface system, including links to hydrologic forecasts
Hurricanes and Tropical Storms	Plan the development of hurricane and tropical storm data assimilation and forecasts
Nested Subsystem for Storm-scale, Fire Weather and Severe Convective Weather Prediction	Ensure NGGPS architecture and software can address storm-scale data assimilation and forecasts in operations
Ensemble Development	Plan future development of NGGPS ensemble prediction system including data assimilation and forecast applications
Post-processing	Develop strategy and next-steps for evolution of post-processed products from NGGPS, including atmospheric, marine, and land-hydrologic products
Infrastructure	Define supporting infrastructure requirements; plan upgrades enabling testing, verification, documentation, and training of and for NGGPS
Testing/Testbeds	Develop and test coupled system; conduct feasibility studies with current software
HPC Configuration	Define software architecture and engineered systems; assess and plan scalability

5 Development Team Plans

Each Development Team produced a technical plan with proposed objectives towards creating a global model prediction system in five years. The Teams reviewed the current status of their part of the R2O Initiative, identified gaps in the state-of-the-science, opportunities to leverage other ongoing programs and projects, and near- and long-term objectives. The sections that follow are a consolidation of their proposed activities.

5.1 Dynamical Cores

5.1.1 Background

The first step in building a next generation global prediction system starts with a non-hydrostatic atmospheric dynamic core. Since the equations for the dynamics are well known and can be solved to a high degree of accuracy in many different ways, the choice of dynamics is driven more by the computational efficiency than the accuracy and skill of forecast. Specific selection criteria and/or attributes will be defined to select a dynamic core for the next model. Attributes such as numerical accuracy, scalability/computational efficiency, positive definite advection, and minimal grid imprinting, among others, will be considered.

Six dynamic cores currently being developed and modified from a variety of institutions are viewed as potential candidates to be evaluated for the new system. These cores include:

- NIM - ESRL's Non-hydrostatic Icosahedral Model
- MPAS - National Center for Atmospheric Research (NCAR)'s Model for Prediction Across Scales an unstructured grid with C-grid discretization
- NUMA - Navy's NEPTUNE (Navy's Environmental Prediction System Using the Non-hydrostatic Unified Model (NUMA) of the Atmosphere core), flexible grid with adaptive mesh refinement
- HIRAM - Geophysical Fluid Dynamics Laboratory (GFDL)'s coupled general Circulation Model (CM3) – cubed sphere, finite volume
- NMMB – EMC's Non-hydrostatic Multi-scale Model on B-grid, finite difference, Cartesian grid, global extension of regional model
- GFS-NH – EMC's non-hydrostatic extension of Semi-Lagrangian Spectral model

To determine the best path forward in the selection of a single dynamic core for the new model, the R2O project planning team will work with the candidate core model developers to create a testing and evaluation procedure to be applied to potential dynamic cores. Although a similar endeavor as part of HIWPP's project plan is to complete an inter-comparison dynamic core evaluation for the production of a severe weather prediction system, the evaluation is between non-hydrostatic models. The criteria and the weighting of the criteria of the R2O project differ somewhat from the HIWPP project since the focus of the R2O project is operational implementation of a global model in an operational computer infrastructure.

Five of the six cores considered for NGGPS are currently under evaluation through HIWPP; the GFS non-hydrostatic core is still being developed. Leveraging activities and results from the HIWPP independent dynamical core evaluation process may help determine the preferred technical aspects to be evaluated for the NGGPS core selection. Per approval of both HIWPP leadership and R2O EOB, modelers may modify their experimental protocols to provide more objective feedback for NGGPS dynamic core requirements. Every effort is being made to coordinate the two projects to minimize unnecessary duplication of effort.

5.1.2 Short Term Goals

Evaluation of the dynamic cores response to a variety of criteria may include idealized tests, scaling tests, simple physics and full GFS physics. The evaluation and testing of the cores will consider the attributes listed below, among others:

- Conservation
- Advection
- Minimal grid imprinting
- Minimize computational modes
- Stability
- Performance and scalability
- Non-hydrodynamics switchable
- Regional nesting
- Deep atmosphere
- Bit reproducibility
- Portability/extensibility/flexibility
- Adaptable to NEMS/ESMF
- Grid interpolation tools availability

Model developers participated in a Dynamic Core Evaluation workshop to discuss and define the various technical aspects desired in a dynamic core and continue to vet out the preferred criteria/attributes discussed during the workshop. Once the preferred criteria are defined and tests are determined, institutions developing the six dynamic cores will be invited to submit proposals for participation in a dynamic core evaluation.

A committee, called the Advanced Computing Evaluation Committee (AVEC) will be organized to address the details of testing parameters and procedures. Once the optimal technical aspects are determined, the cores will be put through a series of test runs and evaluated against agreed upon metrics. Tests will be performed on each of the six dynamic cores, and results of each technical requirement will be reviewed against the evaluation protocol by a committee. Once this first level of testing is complete, a review of test results will be used to reduce the pool to two or three optimal performing cores. Level two testing of the cores will involve another level of tests determined by the AVEC committee. Again, the results will be weighed and evaluated. Based on the assessment of the results, a recommendation will be submitted to selection officials and a core selected. Please see Figure 4 below for a proposed draft schedule.

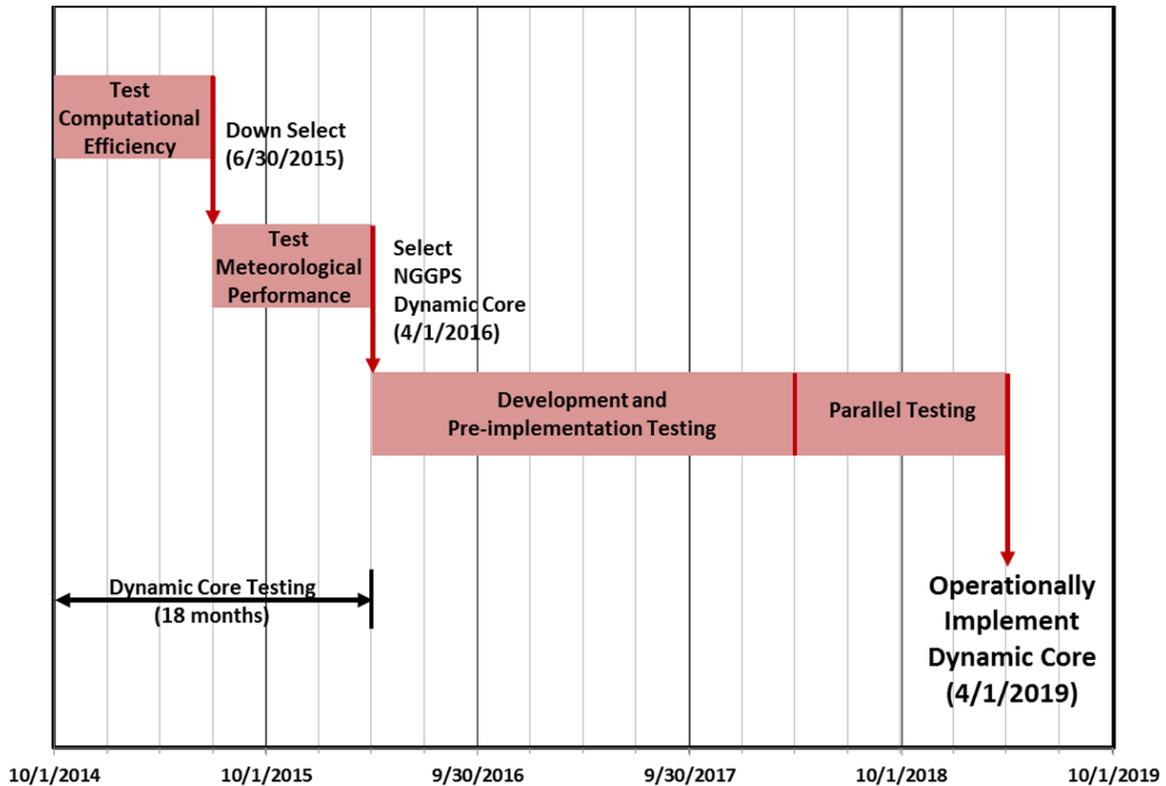


Figure 4. Draft Dynamic Core Selection Schedule

5.1.3 Long Term Goals

Once the dynamic core is selected, major efforts will focus on testing the core with the designated physics package, and various models to which it will be coupled to in the weather prediction model. These tests will be performed in parallel to the prediction system currently running. There is a five year timeline for the implementation of the core with the physics package and coupled model components.

5.2 Physical Parameterization Development

5.2.1 Background

The overall physics parameterization objective is to develop and transition to NWS operations accurate and efficient representations of atmospheric physical processes, such as clouds, radiation, turbulence, and chemistry across applications that span a wide range of spatial scales from cloud and convective permitting resolutions (~1 km) to horizontal resolutions used in climate applications (~100 km). The R2O advanced physical parameterization suite should significantly improve the deterministic and probabilistic forecast guidance using the traditional and new metrics (e.g., scorecards, downstream model performance, etc.) established by EMC.

The “correct” equations for the physics at the scales of Numerical Weather Prediction (NWP) models are not known and therefore are represented by simplified equations with a number of assignable parameters. Thus there is considerable uncertainty in the formulation of the physics packages. Even though there can be significant interaction between the individual physics parameterizations, the physics are generally divided into specific physical processes. These processes are updated individually with the interaction accounted for when constructing (tuning) a physics “package” that includes the various components. This is done by a careful evaluation of the performance of the package with the dynamic core and then the various controlling parameters in the various physics components are adjusted to improve forecasts. The basic physical processes and expected areas of research on those physical processes are listed in Table 3. Note that some components will also interact more strongly with other component models besides the atmospheric dynamic.

5.2.2 Short Term Goals

To design an optimum physics package, short term goals include:

- A physical parameterization workshop hosted by NCEP, with logistical support from DTC, will be convened to formulate a technical plan.
- The current state-of-the-science with regard to physical parameterizations will be assessed and a report drafted.
- The current state-of-the-science of aerosol predictions and their impact on NWP will be assessed and a report drafted. How much complexity might be needed for accurate aerosol predictions and estimated impact on computational resources will be determined.
- The new (for GFS) microphysics parameterization will be incorporated, tested, and evaluated for level of improvement.
- The physics will be modified based on increased vertical resolution planned in FY16.
- Leverage the collaborative development with NUOPC/National ESPC for the physical parameterization driver interface with 1-D physics capability.
- Fund external efforts to modernize spectroscopy in reference radiation models used to develop and update operational parameterizations.

5.2.3 Long Term Goals

The development of a physics package is an ongoing effort; these evaluations will lead to suggested changes in various constants within the various physics components. After these changes are rigorously tested, implementation of these changes in the operational system should lead to improved forecasts. This process of evaluation and suggesting changes in the physics packages will greatly benefit from close collaboration between EMC and outside researchers who can do a lot of the preliminary evaluations and testing of changes. Final implementation testing will be done by EMC. As stated previously, Table 3 outlines planned development emphasis for each of the various physics components.

Table 3. The 5 Year Physical Parameterization Development Technical Plan

Physical Parameterization Development Technical Plan (5 year)	
<p>1. Radiation</p> <ul style="list-style-type: none"> a) Enhanced spectral resolution b) Improved line-by-line modeling c) Cloud/aerosol/trace gas radiation interaction d) Improved surface reflectivity/emissivity estimation e) Improved line-by-line modeling as a basis for radiation band modeling f) Cloud overlap g) Improve computational efficiency <p>2. Turbulent transport and interactions with the surface</p> <ul style="list-style-type: none"> a) Moist Eddy-Diffusivity Mass-Flux or higher-order turbulence parameterization which can include shallow cumulus convection b) Turbulent kinetic energy dissipative heating parameterization c) Vertical diffusion in clouds and cumulus convection d) Improved surface flux parameterizations and surface energy balance equations e) Flux parameterization for high wind speeds over sea (e.g., limited drag and sea spray effects on surface flux calculations) f) Advanced turbulent orographic form drag parameterization g) Diagnostic computations for 2m T,q and 10m winds, wind gusts, and planetary boundary layer depth h) Improve computational efficiency <p>3. Improved cloud and precipitation estimation/prediction</p> <ul style="list-style-type: none"> a) Non-resolved shallow convection b) Non-resolved deep convection. Scale-adaptability will need to be treated (e.g. with unified convection parameterizations) as model resolutions approach the “grey zone” at which convection is not fully resolved nor fully sub-grid-scale. Aerosol dependence will also need to be evaluated. c) Convective initiation as a function of scale for shallow and deep convection d) Microphysics schemes accounting for cloud distribution (partial cloudiness, distribution moments) on rates including precipitation e) Additional predictive variables (second moment schemes, suspended precipitation, etc.) f) Aerosol/cloud condensation nuclei interaction g) Precipitation type at surface (ice, snow, rain, etc.) h) Improve computational efficiency <p>4. Orographic and non-orographic drag</p> <ul style="list-style-type: none"> a) Stationary and non-stationary orographic gravity wave drag b) Stationary and non-stationary non-orographic gravity waves <p>5. Prediction of natural and anthropogenic aerosols</p> <ul style="list-style-type: none"> a) Sources and sinks b) Transport, sedimentation, scavenging, and removal by precipitation c) Particle size, composition and transformations (e.g. nucleation, condensation, coagulation, chemical reactions) d) Volcanic ash e) Interaction with other physics (e.g., radiation, clouds) f) Impact on computational resources <p>6. Atmospheric composition/trace gas prediction</p> <ul style="list-style-type: none"> a) Sources and sinks b) Ozone chemistry c) Interaction with other physics d) Impact on computational resources 	

Physical Parameterization Development Technical Plan (5 year)

7. **NEMS infrastructure**
 - a) Continue development of NEMS software to facilitate interoperability within NWS and NOAA community. All models need to be compatible with NEMS.
8. **Develop/utilize physics driver to facilitate more interoperability for operational physics suites**
 - a) Single column physics that seamlessly operates within and outside of NEMS
 - b) GEWEX Cloud System Study and GASS test cases for physical parameterizations testing in single column mode utilizing DOE Atmospheric Radiation Measurement and other field observations
9. **Future developments should aim to explicitly account for uncertainty in their formulation and in sub-grid scale quantities, and therefore produce easily adaptable to ensemble prediction systems.**

5.3 Atmospheric Data Assimilation

5.3.1 Background

The primary goal of data assimilation is to produce the best possible initial conditions for the forecast model. Here the emphasis will be on the data assimilation in the atmospheric component of the global system. The data assimilation system will be the HYbrid system that has been under development for several years at EMC, where the background error are defined from an ensemble system and at least initially these will be introduced into the Gridpoint Statistical Interpolation (GSI) data assimilation system, a 3-D variational (3DVAR) format that has been the data assimilation system used by the global model up until 2012. This type of a hybrid system has been shown to be superior to either the GSI system or an Ensemble Kalman Filter system used individually. In the longer term, the GSI component may evolve to a 4DVAR system. The primary foci of the data assimilation development are shown in Table 4. Data assimilation specific to ocean and wave models are described in the ocean and wave model sections below.

Table 4. Data Assimilation Development Plan

Data Assimilation Development Plan

1. The enhancement of the ensemble forecasts. This work will be done in coordination with the ensemble group, other divisions in NCEP and ESRL/PSD. Improving the ensemble forecasts will allow an improved analysis through the hybrid system. The primary direction for improving the ensembles for data assimilation will be directed towards estimation of the forecast error. Much of this work will be directed towards developing appropriate representations of model uncertainty (i.e. stochastic physics parameterizations).
2. Production of reanalyses to support reforecast calibration. Ongoing production of reanalyses is needed to initialize reforecasts as the operation assimilation and forecast system evolves.
3. The data assimilation will continue to improve the use of current observations
 - a. Improved specification of observation and representativeness error
 - b. Improved quality control (including the use of ensemble information)
 - c. Improved forward models
 - d. Inclusion of additional channels (especially water vapor) from currently used instruments

Data Assimilation Development Plan

- e. Use of aerosol and trace gas information in radiative transfer when available
- f. Bias correction of conventional observations
- g. Correlated errors
4. Incorporation of additional data types in the global assimilation system
 - a. Inclusion of surface observations over land (can be done more appropriately with hybrid system than with earlier systems). This may include coupled assimilation of the land surface and atmospheric states.
 - b. Inclusion of new satellite instruments such as: GOES-R, METOP-C, Joint Polar Satellite System (JPSS) instruments, Imager observations, COSMIC-2, Chinese and Russian satellites, GPM satellites, and others
 - c. Radar data
 - d. Lightning data
 - e. Ground based cloud observations
 - f. Aircraft moisture
 - g. MLS real time (and other) ozone profile information
 - h. Wind observations from turbine hubs from wind energy sector
 - i. Others
5. Inclusion of cloudy radiances and cloud observations such as microwave observations, IR observations, and visible observations
6. Improved assimilation techniques
 - a. 4-D ensemble-var hybrid and EVIL (variational ensemble update)
 - b. Improved static background-error term
 - c. Inclusion of improved (Purser) variational quality control
 - d. Field alignment to deal with displacement errors in the background
7. Improved data and assimilation monitoring - flexible diagnostic file structure
8. Increased resolution consistent with forecast model
9. Reduction in model spin-up from analysis (improved balance, in both the model dynamics and the hydrologic cycle)
10. Improved minimization techniques (faster convergence)
11. Refactoring of the assimilation code to improve modularity/extensibility as well as scalability/efficiency

5.3.2 Short Term Goals

Currently, the R2O effort milestones involve potential compute resources such as including the field alignment scheme in GSI, convening a planning committee to discuss the GSI code refactor, and producing a plan that defines the physics interfaces and requirements. The first phase of refactoring will begin, as well as developing the capability for ongoing reanalysis production. An agreement with Global Systems Division (GSD) involving support for the use of Global Positioning System-Radio Occultation (GPS-RO) observations is an additional goal.

5.3.3 Long Term Goals

The list in Table 4 above is a multi-year plan though most of the components will be worked on simultaneously. It is expected that all these development paths will be completed by 2019.

5.4 Ocean Model

EMC presently has two different ocean modeling approaches, the first via the Modular Ocean Model (MOM) series models and the corresponding Global Ocean Data Assimilation System (GODAS) data assimilation approach, and the second is based on the HYbrid Coordinate Ocean Model (HYCOM) and is intended to include the Navy Coupled Ocean Data Assimilation (NCODA) data assimilation systems, both developed (mostly) at U.S. Naval Research Laboratory (NRL). Normally, EMC would not want to support two different modeling systems for similar purposes (ocean modeling in this case). However, MOM presently targets seasonal time scales and receives support from GFDL, whereas HYCOM/NCODA targets weather time scales and receives support from the Navy and academia. MOM and GODAS support has traditionally been associated with the Climate Forecast System (CFS) models, have in-house base support, and are expected to obtain continued support for CFS-v3 development. The R2O Initiative can target HYCOM/NCODA to fill in the gap for support, as well as operational and pre-operational capabilities of these models at EMC. Deliverables are directly linked to operational implementations including some operational implementation of initial capabilities, and fine tuning of model products based on evolving user requests. Below are tentative deliverables per system, organized per year. Actual implementation (delivery) dates will be worked out in collaboration with NCEP Central Operations (NCO) in the context of a holistic sustainable implementation schedule.

5.4.1 Ocean Model Deliverables

The Real-Time Ocean Forecast System (RTOFS)-Global Model transition to Navy GOFS 3.1, is a year 1 milestone and will occur in lockstep with Navy's upgrade. Although the upgrade is scheduled for year 1, it is dependent upon the timing of the upgrade at the Navy. Additional Year 1 milestones include:

- Operational upgrades of RTOFS-Global and –Atlantic. RTOFS-Atlantic will be fully nested in RTOFS-Global for the first time.
- Upgrades to the real-time data in the existing data assimilation schemes as new data sources emerge and old data sources expire.
- Upgrades to products as requested by users such as adding GRIB2 (GRIdded Binary data) fields for use in NOAA's Advanced Weather Interactive Processing System (AWIPS).

Year 2 ROFS-Global milestones include:

- Science and Input/Output upgrades will continue as determined at the end of Year 1.
- Transition of operational codes to Weather and Climate Operational Supercomputer System (WCOSS) phase II (deposing on delivery of system) will occur.

The RTOFS-NEMS Model milestones in Year 1 will include:

- Finalize the development of 0.25° global RTOFS-NEMS model for coupled HYCOM-GSM model runs.
- Evaluate ice modeling in this system (NEMS GFDL version of the Los Alamos sea ice model (CICE) or EMC KISS models).

Year 2 milestones for RTOF-NEMS will encompass:

- Perform initial experiment with HYCOM-GFS or HYCOM-GEFS (Global Ensemble Forecast System) coupled model, and assess the impact on traditional forecasts skills. Note that ice modeling will be critical here, and may be leveraged from Arctic coupled modeling projects.

The RTOFS-HWRF (Hurricane Weather Research and Forecast System) Model goals will include:

- The first operational implementation of an HYCOM-HWRF coupled model system is tentatively schedule for FY15.
- The first upgrade of the HYCOM-HWRF system, potentially adding wave model coupling, would occur the following fiscal year.

5.4.2 Ocean Data Assimilation

The initial data assimilation capability for the RTOFS (HYCOM) models needs to be addressed. In 2013, EMC signed a Memorandum of Understanding (MOU) with NRL to port NCODA to EMC, thus avoiding the need for a daily data feed from NRL to EMC, as well as the need to EMC to remain in lockstep with NAVO/NRL with respect to model development. A second need is in transferring data assimilation (DA) approaches for the coupled HWRF-HYCOM model from HFIP to the R2O Initiative. The two main goals for the first two years under R2O is to 1) Implement NCODA at EMC, and 2) Provide ocean DA for coupled HWRF-HYCOM model. As NCODA reaches implementation at EMC, development and research priorities will be addressed.

The NCODA Deliverables for first 24 months would address work that has started, but with limited support, and will be increased incrementally. The 0 month point for this plan is effectively the start of FY14Q4, as the code was delivered to EMC late FY14Q3. The six month goal is to:

- Port NCODA code to WCOSS for compilation, running and profiling, and run with canned data sets provided by the Navy.
- Prepare a plan for converting Navy data streams to NCO data tank standards, procedures and data.
- Provide NCO with a request for data used by NCODA but not yet in NCO data tanks.

Twelve months out, 35% of the data streams will be converted from Navy protocols to NCO protocols. The design and prototype of diagnostics, along with prototype scripts for data handling in preparation for low-resolution assimilation experiments, will be prepared.

Within 18 months, 70% of data streams will be converted from Navy protocols to NCO protocols. The prototype setup for low resolution assimilation experiments will be completed with initial results reported.

By 24 months, the goal is to finish data stream conversion to NCO protocols, and have real-time low-resolution hindcast Nowcast running in real time. Experiments with full resolution assimilation will be started. Note that full resolution assimilation requires Phase II WCOSS to be in place at expected petaflop capability. The deliverables include planning conservatively for the availability of Phase II, but it may be possible to do stratified high-resolution runs earlier if Phase II is available, and if data stream conversion to NCO standards allows this.

The schedule by 30 months expects the system is ready for the operational implementation of NCODA for RTOFS-Global, with actual operational implementation dependent on NCO implementation schedule.

The HYCOM-HWRF deliverables for first 24 months include ongoing work that can be transitioned from HFIP to the R2O Initiative. The tentative first operational implementation of HYCOM-HWRF system with ocean DA of Sea Surface Temperature (SST) and Salinity will take place by May 2015. By May 2016, the first upgrade of HYCOM-HWRF system adding Sea Surface Height (SSH), and Temperature-Salinity profiles to assimilation will occur.

5.5 Wave Model

Three gaps have been identified for modification for the wave models to be incorporated into the new NCGPS.

1. Enable wave-coupling in all EMC/NCEP models. This requires finishing the NEMS / ESMF / NUOPC wrapper for the WAVEWATCH III model. This project has just started and will need additional support to bring to full fruition.
2. Although wave requirements have shifted to coastal modeling, where coastal wave modeling is reasonably covered with the Nearshore Wave Prediction System (NWPS), NWPS needs to become a fully coupled wave-surge capability on unstructured grids. This will require WAVEWATCH III to be coupled to 2 and 3D ocean circulation models,

ADCIR (ADvanced CIRCulation model) and FVCOM (Finite Volume Coastal Ocean Model). The unstructured-grid wave-surge coupling needs additional resources to bring this to operations in the NWS and inside NWPS. Note that NWPS also supports SWAN (Simulating WAVes Nearshore) as a wave model, for which the coupling is already available. Long term Operation and Management (O & M) considerations may move towards a full WAVEWATCH III based system rather than supporting multiple wave models.

3. WAVEWATCH III is a community model, where research may be leveraged with partners in the Federal Government and academia, as has been proven in a recent National Oceanographic Partnership Program (NOPP) project, resulting in an overhaul of most wave model physics. To gain the maximum benefit from this community modeling effort, EMC would need a full time WW3 code manager, dedicated to supporting community modeling.

The three identified gaps result in three separate projects, with three separate sets of deliverables for NEMS, NWPS and code management.

1) Deliverables for NEMS would include:

- The wrapper will be ready as well as a “solo coupler” in NEMS by six months.
- By 12 months, there will be a demonstration of a multi_1 wave model one-way coupled with GFS or GEFS, avoiding the need for coupling in near-real-time through the file system, and the hand-over to O&M for operational implementation.
- The focus for Year 2 will depend on progress in other projects. Actual projects and deliverables will be determined at the end of year 1, with the potential projects and deliverables selecting one of the four listed below:
 1. Focus on GFS: Experiment with two-way coupling to see if it can improve both weather and wave forecasting.
 2. Focus on Arctic modeling: Add waves to prototype coupled Arctic model.
 3. Start wave-ocean coupling to improve ocean mixed-layer forecast by adding Langmuir and Stokes-Coriolis mixing to ocean model.
 4. Improve wave forecast by adding wave-current interactions.
- Beyond year 2, HWRF is scheduled to be tentatively converted to NEMS by early FY16. Once this capability is available, the next high-priority wave coupling effort will be with the HWRF. This is potentially high-impact for operations, as an “all-storm-in-one” HWRF allows NWS to have the hurricane wave model directly included in HWRF, instead of running it downstream as is done now.

2) Deliverables for NWPS are:

- Within the next six months, a prototype WW3-Adcirc coupling to demonstrate the quality of the model and estimate future resource needs.
- By 12 months, the coupled model will be included in NWPS baseline software.
- Within 24 months, six Weather Forecast Offices (WFO) will be set up with an unstructured grid coupled WW3-Adcirc (or SWAN-Adcirc) model.

3) Every three months, deliverables for code management will include the implementation of three contributions (internal or external) to the WAVEWATCH III trunk model, full regression testing on these upgrades, and documentation in the manual. Target upgrades will be identified for the next six month.

5.5.1 Wave Data Assimilation

The wind wave model is different from most major models at NWS as it represents a forced and damped problem, rather than an initial value problem such as short time scale weather, and ocean models. For this reason DA in wave modeling is not as critical as in weather modeling. Wave DA was operational in the late 1990s and early 2000s, but became defunct as the system did not keep up with new altimeter data streams, and was ultimately not ported to new operational computers. Adding wave DA back into the operational systems is important for three reasons:

1. Improving short-term forecasts, i.e., wind seas in general for 6-12 hour forecast, depending on spatial scale of problem, and swells for potentially up to 2 weeks for long swells on the Pacific Ocean.
2. Justification for satellite observations (altimeter waves, Synthetic Aperture Radar (SAR) spectra). These observations are critical for off-line wave model validation and development, but only seem to receive attention if used in real time. Hence, adding data assimilation to wave models is politically important to protect critical sources of observations.
3. Initial experiments with assessing coupled errors in wind and waves using EnKF methods indicate a strong relation between the two. This implies that future coupled ocean-wave-weather assimilation (starting with wave-wind) can potentially improve each system more than traditional decoupled assimilation. Wave DA could this potentially help weather DA directly.

Presently, wave DA is being re-established into NCEP operations through Joint Center for Satellite Data Assimilation (JCSDA) funding for altimeter wave data quality control (QC), as well as preparation to assimilate wave height data through the GSI. This project is funded for initial development of the QC and GSI approaches, but not for full implementation. Hence, the first step is to re-introduce wave DA into the operational global model, tentatively using the GSI and the new QC algorithms. After this, the following expansions can be considered in the Global

Hurricane wave model, which is a high priority, with minimal effort as the model is very similar to regular global model. The Global wave ensemble expansion can be considered a high priority as well, but more complex effort is involved as the model requires consideration of generating / maintaining ensemble spread. The Great Lakes model, is a low priority, as short residence time of wave in GL will result in quickly losing impact of DA, and hence impact only for short-term forecasts (expected < 6-12h).

After this, technical improvements are needed for the simple initial DA techniques. The following improvements are expected to all yield significant benefits for the wave models, as well as for future coupled systems.

- Develop wave-system based DA (Initial DA only considers overall wave height of all wave systems combined).
- Consider assimilation of spectral wave data from buoys or from SAR. Presently, only overall wave height is assimilated.
- Develop a hybrid DA system similar to that used in the GODAS. Initial work on this has already been started by our partners in academia.

The wave DA deliverables for first 24 months are initiated after funding is available at EMC and contractor/visiting scientists are available. The selection of possible subjects from above is partially determined by the possible availability of a visiting scientist with a strong background in EnKF and hybrid approaches.

- Six month deliverables include having the parallel wave DA system up and running and ready for implementation. At this stage, the implementation will be done by existing O&M wave support. DA intended for multi_1 global wave model will be in place and possibly also adopted for multi_2 global hurricane wave model.
- The proof of concept for hybrid wave DA system for overall significant wave heights will be delivered by 18 months.
- By 24 months, it is expected to have a full pre-operational prototype for the hybrid system, and there will be a hand-over to wave O&M support.

5.6 Ice Model

Ice guidance with a fully coupled ice model is described in detail in the Arctic plan below. For collaboration within NOAA, the Great Lakes Environmental Research Laboratory (GLERL) Ice modeling and GFDL climate ice modeling are natural points of collaborations. As collaboration with GLERL is already funded on the short time scales through NOAA's National Ocean Service Coastal Storms, and has a request for long lead time ice funding through OAR ESPC funding, GFDL appears the best candidate to work with on (Arctic) ice modeling, particularly with their existing ice models. Focusing on potential work that can help EMC operations, the following work can be by GFDL:

- In Year 1, use the GFDL climate model for “short term” runs to assess ice predictability for 5-7, 16 and 30 day forecasts and 6 week and 6 month forecasts. GFDL could work with EMC on developing sensible ice concentration metrics.
- In Year 2, as the NCEP Ice model (KISS) becomes fully available in NEMS, test out this model (including flux bias treatments) in one or more GFDL models for longer lead-time climate runs. This will be helpful with respect to assessing the KISS capabilities at longer time scales, as well as with respect to necessary bias corrections for KISS in general.

5.7 Arctic Model

With the increased size of ice-free zones in the Arctic summer, the NWS has expanded forecast responsibilities in these areas. However, present advanced models such as the Navy Arctic Cap Nowcast Forecast System (ACNFS) have been shown to have no skill over ice persistence beyond a 3 day forecast. A review of literature and local experience shows that ice predictability is strongly linked to the accuracy of heat fluxes into the ice/ocean. Biases as little as 10 W/m^2 result in an annual growth or melting of up to 1m of ice thickness. Our experience with simple drift models show that such models also provide more predictability of the location of the ice edge than a full dynamical model like the ACNFS. Furthermore considering that the ice has a major impact on air-sea fluxes, an accurate representation of dominant processes for ice modeling requires a coupled atmosphere-ocean model with a common ice representation (i.e., coupled atmosphere-ocean-ice model), with an explicit control of flux biases. Furthermore, the dependence on flux errors suggests that suppression of random flux errors due to ensemble averaging is expected to also increase predictability of ice coverage. From a pure ice modeling perspective, this implies that a simple ice model using thermodynamics and simple ice drift approaches is sufficient for creating predictability, and is much easier to control than full physical model. Such a model is under development at EMC (KISS). There is also concern that conventional validation techniques for ice concentrations do not adequately address with accuracy the movement of the ice edge, which for most users is the most critical aspect of an ice forecast. Hence, development of proper metrics for validating ice concentrations and/or ice edge location should be an integral part of the development of a modeling systems focusing on Arctic ice.

The above considerations would lead to a modeling system that is unique compared to existing modeling systems in five ways:

1. It is fully coupled (atmosphere-ice-ocean).
2. It applies bias corrections to the heat fluxes.
3. It includes a simple ice model focusing on predictability rather than full physics.
4. It is an ensemble to minimize random flux errors.
5. It includes new skill metrics, particularly designed for ice products and their users.

The economy of such a model, in light of limited compute resources at NOAA, suggests a regional approach with modest resolution. Operational sustainability suggests the use of existing

modeling tools within NEMS, implying a regional Nonhydrostatic Multiscale Model on B-grid (NMMB) mesoscale weather model coupled to a regional HYCOM ocean model. This also suggests a modest initial forecast range of 5-7 days, allowing an assessment of this modeling approach compared to the present ACNFS, as well as persistence with respect to ice concentration of ice edge forecasting. Such a model could initially be implemented as a stand-alone new model at NCEP, but has a clear path of integration into existing modeling systems such as the GEFS and GFS as it uses common building blocks in NEMS. Note that the Navy followed a similar path with ACNFS, by first developing this as a separate model with a focus on upgrading the ice model, and is now merging this model back into their operational Global Ocean Forecast System (GOFS 3.1).

An additional option, pending available resources, includes considering coupling a wave model into this system, both for experimenting with wave coupling, and evaluating whether wave momentum has a direct impact on ice drift in the marginal ice zone. As this is not a critical element of the arctic work plan, wave coupling will not be considered in detail in the work plan described below.

The key to efficiently building this experimental coupled model is the use of existing building blocks in NEMS. For the ocean model, an Arctic subset of the grid of RTOFS-global will be used, with the latter model providing the lateral boundary conditions. For the atmosphere, a regional NMMB model will be used, nested in the GFS for the initial deterministic setup, and in the GEFS for the final ensemble setup. The two models will use the same ice concentration data from the KISS model, which will be initialized using the daily high-resolution ice concentration analysis from NCEP (the latter analysis is used also in the ACNFS, but this system does not use a coupled ocean-atmosphere approach). Considering the present skill of the ACNFS, it is sufficient to initially run this system with a 5-7 day forecast range. This range is somewhat relevant to offshore operations, although there are needs for forecast products in the 1-2 week, 6 week and 6 month ranges. The initial setup of this model allows up to 8 days forecasting with dynamic ocean boundary data from RTOFS-Global, and up to 16 days with weather boundary data from GFS or GEFS (and constant ocean boundary data beyond day 8). After the initial setup of the model at the 5-7 day forecast range, it will be trivial to expand the validation up to day 16, assuming significantly improved compute resources at the end of FY 2015. Deliverables for the arctic model include:

- Have a stand-alone NMMB and HYCOM regional model running independently (“solo coupler”) in NEMS environment in four months, along with the first estimate of heat-flux biases based on archived model data, while targeting 5-7 day forecast for initial model testing.
- Within six months of funding, a KISS v1 model would be running with solo coupler in NEMS.

- At eight months, a prototype of new metrics for validating Arctic ice model would be provided.
- Within a year, a demonstration version of a coupled deterministic model will be ready, including KISS v2 with an initial static bias correction.
- By 16 months, a prototype ensemble model based on the above deterministic model, and with NMMB nested in GEFS, will be finished.
- At 24 months, the ensemble will be fully tested and ready for operational implementation, with a reasonable forecast range base on predictability of ice, and availability of GEFS boundary data for NMMB (16 days maximum) established.

5.8 Land Surface Model

The Noah Land Surface Model (LSM) provides boundary conditions as well as land-atmosphere interactions and is currently coupled with the following NCEP models: North American Mesoscale model (NAM: short-range), GFS: medium-range, CFS: seasonal, and other NCEP modeling systems (i.e. NLDAS & GLDAS). An NCEP-NCAR unified Noah land model provides boundary conditions for NCEP operational weather and climate models. Land model validation using (near-) surface observations, i.e. air temp, RH, wind, soil moisture, surface fluxes, (and upper-air, precipitation scores, etc.) are used to suggest model physics upgrades, e.g. Noah-MP upgrades. Complex land surface variability including soil moisture/type/temperature, land use, land coverage/vegetation type/cover/density, canopy water, and snow pack are all components of the community Noah LSM. The NGGPS will include a more fully coupled land modeling system taking into account the surface energy budgets and development will continue as the component is integrated into the new NGGPS.

5.9 Aerosols Model

The NEMS GFS Aerosol Component (NGAC) is a global in-line aerosol forecast system. The atmospheric forecast model component of the NGAC is the GFS, and the aerosol component model is the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model. Funded mainly by NASA Earth Science programs, the GOCART model was developed to simulate atmospheric aerosols including sulfate, black carbon, organic carbon, dust, and sea-salt aerosols. The implementation of GSFCs GOCART module into NEMS GFS at NCEP was funded by NOAA-NASA-DOD JCSDA and NASA Applied Sciences Program.

The initial operational implementation of NGAC was to produce 120-hour global dust forecasts. The system runs once daily within the NCEP Production Job Suite. Output is posted to a 1x1 degree equally longitude/latitude grid with 3-h forecast interval to 120-h, cycled once per day. This model will continue to be expanded and developed under the R2O Initiative for coupling to the NGGPS.

5.10 Ensemble Development

5.10.1 State of the Science

Ensemble predictions are increasingly being used for providing situational awareness of high-impact weather forecast events and informing the forecaster of the range of possible weather scenarios. Ensembles are now also commonly used to provide estimates of forecast-error covariances in data assimilation methods. There are two sources of forecast uncertainty in ensemble system models: the first is initial-condition uncertainty. An ensemble should be initialized with samples from the distribution of plausible analysis states. The second is model uncertainty, which can bias the mean forecast and limit the spread of simulations, resulting in an overconfident ensemble especially for surface-related variables (e.g., surface temperature and precipitation) and tropical forecasts such as hurricane tracks. These contributions to forecast error come from model deficiencies as well as from deterministic assumptions built into the forecast models' components, such as parameterizations.

Addressing the former challenge, initial-condition uncertainty, has progressed in recent years more than the latter, model uncertainty. With ensemble Kalman filters and hybrid methods, there is now a direct method for sampling analysis uncertainty, though the accuracy of such methods depends critically on ensemble size, the treatment of model uncertainty, the extent of non-linearity, and dealing with position errors of coherent features. Model uncertainty treatments are less advanced. Researchers are seeking ways of ameliorating forecast bias and increasing forecast spread that are physically realistic. Lacking these, they also seek appropriate methods of post-processing the forecast guidance to ensure that it is as bias-free, skillful, and reliable as possible.

Improved methods for ensemble initialization (part of data assimilation), improved post-processing, and addressing model uncertainty are needed to dramatically improve the probabilistic forecast guidance of high-impact weather elements that can be provided directly from raw ensembles, making the forecast guidance much more skillful, reliable, and detailed. Model uncertainty will be discussed here.

5.10.2 Short Term Goals

Many of the physically based methods of treating model uncertainty can be improved and initial goals are listed below.

1. Improve the numerical methods used for treating model uncertainty in global ensemble prediction systems in collaboration with Federal agencies and universities by:
 - Developing, testing, and implementing physically based stochastic parameterization methods. Efforts are likely to center on developing physically based stochastic parameterizations for deep convection, microphysics, and land- and ocean-surface interactions.
 - Understanding the characteristics of the uncertainty of dry dynamical forecasts, and developing physically based methods for estimating this uncertainty during the conduct of ensemble forecasts.
 - Drafting and submitting a journal article describing the research and pre-operational testing of physically based stochastic parameterization of deep convection.

- Describing a methodology for physically based stochastic parameterizations of microphysics that can be used in advanced testing.
 - Describing a methodology for physically based stochastic parameterization of dry dynamical forecast uncertainty that can be used in advanced testing.
 - Collaborating with other Federal agencies and universities on the development of stochastic convective parameterizations.
2. Develop and implement improved methods of modeling the forecast uncertainty that can be attributed to the interactions with the land, ocean, and ice by:
 - Continuing with the implementation of methods for stimulating realistic variability of near-surface variables over land, in collaboration with the land project.
 - Further developing and implementing methods for stimulating realistic variability of near-surface variables over water and ice.
 - Beginning pre-operational testing of a physically based method for generating near-surface variability over land and water, applied to a prototype monthly GEFS forecast system.
 - Beginning pre-operational testing of a physically based method for generating near-surface variability over water, applied to a prototype monthly GEFS forecast system.
 3. Develop and implement adjustments to the GEFS system to make its forecasts suitable for the full 0-30 day prediction period by.
 - Developing, testing, and evaluating methods for modeling ocean-atmosphere interactivity at the intra-seasonal time scale.
 - Determining which candidate approach is to be recommended for 30-day ocean modeling in the GEFS. Produce a report outlining aspects such as the relative benefits of mixed layer vs. coupled in the GEFS, and approaches for maintaining consistency of ocean initialization with atmospheric initialization.
 - Developing methods for pre-operational testing in collaboration with EMC and ESRL/PSD, via Sandy Supplemental funds.
 4. Conduct a workshop to recommend ensemble development plans for the 1.5 to 5-year period of the R2O Initiative.

5.10.3 Long Term Goals

The workshop proposed in the short-term objectives above will determine details through 2019. Generally, there will be a continuation for stochastic physics development at levels commensurate with those in the first 1.5 years, and the development of a 30-day GEFS system, with somewhat more funding to allow for transition to operations of ideas developed under the Sandy Supplemental and early stages of R2O's Initiative.

Additional goals such as advancing the prediction capability of the operational medium-range global ensemble system to include weeks 3 and 4, modeling the interactions with the ocean, land and ice that can occur at these time scales, will involve the concurrence of management.

5.11 Post-Processing

5.11.1 State of the science

Statistical post-processing methods have been successfully applied for many decades now to weather predictions, helping to ameliorate forecast bias and to produce reliable, skillful probabilistic forecasts of weather events (e.g., surface temperatures and winds, sky cover, rainfall probability and amount) that are of direct importance to the user. Statistical post-processing works most smoothly when there is a relatively large sample of past forecasts that are statistically consistent in accuracy and bias with the current forecast. If such forecasts as well as high-quality analysis and/or observational data are available, then it is relatively straightforward to develop and apply statistical corrections that produce dramatically improved forecast accuracy, skill, and reliability.

Recently, the NWS embarked on a new project, known as the “Blender” project, with the goal of yielding centrally produced, high-resolution, nationally consistent, statistically post-processed and blended forecast guidance. Forecast inputs will initially come from a variety of global models, including the NCEP GFS and GEFS, the Navy global prediction systems, and deterministic and ensemble predictions from both the Canadian Meteorological Centre and the European Centre for Medium Range Weather Forecast (EDMWF). Novel aspects of this project include: (a) the production of reliable guidance for a wide range of forecast variables, (b) it will be suitable for use in the National Digital Forecast Database at high spatial and temporal resolution, and (c) the desire to blend guidance from a variety of modeling systems in a way that preserves spatial specificity while not compromising on accuracy or reliability. The initial stages of this project are funded by the NWS Sandy Supplemental project. Continuing this project through to completion will require supplemental funds, which will hopefully continue through this R2O initiative.

The longer-term success of the Blender project is dependent on the quality of supporting databases, including reanalysis and reforecasts necessary to support the post-processing of NWS model guidance. The existing Blender project does not provide any funding for the development of these data sets. Given the broad needs for reanalyses funding from a variety of sources is needed to jumpstart the process. A team of approximately nine people for reanalysis research, generation, and quality control is recommended, and extensive computational resources (>> 100M CPUh) are also needed. Additional funds would be needed to complete the reanalyses and to set up a regular production of reforecasts to continue the project for through Year 5.

As stated, the goal of NGGPS is to produce usable forecast guidance, especially on high-impact weather events, to +30 days lead time. There may be statistical post-processing issues that are specific to these longer leads, where the initial-condition related signal has waned and where what marginal predictable signal there is will be linked to low-frequency variability El Niño –

Southern Oscillation (ENSO), Madden-Julian Oscillation, Arctic Oscillation, quasi-biennial oscillation, and such). Post-processing goals will be completed by:

- Generating the supporting data sets (global reanalysis and reforecasts) necessary to support highly accurate post-processing.
- Enhancing the (Sandy-Supplemental funded) Blender project's post-processing for ensemble and deterministic prediction, including: (a) improving the post-processing and blending methods, allowing them to fully exploit the information in the improved ensembles, and (b) extending the post-processing and blending methods to include extra forecast variables and a wider range of forecast lead times.
- Extending the post-processing to provide probabilistic guidance for high-impact events and improved decision support, e.g., heavy precipitation and precipitation type, severe weather potential, etc.
- Developing post-processing techniques specific to the forecast problems of longer-lead forecasts (weeks 2-4).
- Developing methods appropriate for the post-processing of significant weather and hazardous events, with a primary focus ensembles and probabilistic guidance.

5.11.2 Short Term Goals

Reanalysis, organization and production for post-processing include organizing and determining the configuration for NOAA's next-generation modern-era global reanalysis (together with data assimilation team). Proposed activities include:

- Setting up a weather reanalysis task force, including members supported by other OAR and NWS initiatives.
- Deciding on which model configuration, analysis methodology, and specific observational data sets are to be used in this reanalysis.
- Setting up a common observation data archive that can be used for multiple current and future worldwide reanalysis efforts, perhaps in conjunction with ECMWF and Japan Meteorological Agency (JMA) who also do reanalysis.
- Determining the computational and storage resources needed to conduct the complete reanalysis.
- Conducting tests (and leveraging tests of others) to determine how to preserve reanalysis continuity during periods when the observation data set changes, e.g., with the advent of AMSU-A radiance assimilation.
- Determining appropriate methodologies for accounting for interactions between the land surface, ocean surface, and atmosphere, e.g., how to cycle the land state analysis in conjunction with the reanalysis.
- Producing a report that describes the anticipated reanalysis project: the length of the weather reanalysis, the model configuration, analysis methodology, numerical methods for dealing with data non-stationary, methods for ocean/land/atmosphere interactions, etc.
- Delivering the common observation data archive.

Week 2-4 product development proposed activities include:

- Developing and applying new post-processing methodologies, such as those that leverage modes of low-frequency variability (ENSO)
- Developing new products at week +2 forecast leads such as for severe weather and flash drought (currently, longer leads must wait for extended-range GEFS and reforecasts to become available)
- Delivering experimental post-processing methods for 1-2 week-range severe weather forecasts and flash drought that can be applied to weeks 3 and 4, pending their availability at a later date
- Verifying the skill of forecast products
- Evaluating and documenting the products and drafting journal article(s)

Additional short term efforts will be to develop methods for adjusting to changes in analysis bias prior to reforecast initialization. The assumption here is that reanalyses are challenging and computationally expensive to perform too frequently, therefore in the future, reanalyses will be generated roughly every 5 years or so. However, the real-time assimilation and forecast model will change more frequently, leading to changes in the systematic errors of the initial condition. Prior to running real-time reforecasts, the reanalysis of initial conditions used for reforecast initialization will be adjusted so that they have similar error characteristics to the updated analysis. Proposed activities include:

- Developing new methods for statistically adjusting the reanalysis initial conditions to be consistent with newer analyses
- Comparing forecast statistics with and without this error correction
- Evaluating and documenting the method in a journal article(s)

5.11.3 Long Term Goals

Long term goals for post-processing emphasize four main topics, with these activities producing a deliverable of the most recent 5 years of reanalyses by 30 June 2016, and the full reanalysis data set by 30 June 2017.

- 1) Produce NOAA's next-generation modern-era global reanalyses with the following activities:
 - Generating the reanalyses on NOAA supercomputers
 - Archiving the data
 - Producing an interface for users to access the data; examining and documenting the reanalysis quality and characteristics in a journal article
 - Setting up procedures for the regular archival of observations in order to support future reanalyses
 - Conducting preparatory activities for the follow-on reanalysis, with the expectation that NOAA will regenerate its reanalyses every few years.
- 2) Produce reforecasts initialized from the new global reanalyses with the following activities (delivering reforecasts starts six months after completion of the reanalysis data set).

- Setting up the scripts for generating reforecasts automatically on NCEP's production supercomputer, including applying the corrections for systematic differences between reanalyses and real-time analyses developed in the short-term activities
- Conducting the reforecasts
- Archiving the most relevant data on disk, with tape storage for the full reforecast
- Producing an interface for users to access to the data
- Examining and documenting the reforecast in a journal article

(3) Long term efforts include refine the Blender project's post-processing methods for ensemble and deterministic prediction over Years 2-5. During this time, it is anticipated that annual updates with improved quality and expanded suite of weather variables, timed to coincide with global model upgrades will occur. Proposed activities will include:

- Extending the post-processing and blending methods to include extra forecast variables and a wider range of forecast lead times
- Improving the post-processing and blending methods, allowing them to fully exploit the information in the improved ensembles
- Maintaining training forecast and observation data sets and the utilizing new data sets, including high-resolution precipitation analyses, lightning data from geostationary satellite, and sky cover products from cooperative institutes like the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS)
- Refinement of first-generation post-processing and blending techniques (expected feedback from the field after this product becomes operational, will produce a need to refine products to address this feedback)

(4) Throughout Years 2-5, weeks 2-4 product development will include the following proposed activities:

- Validating the quality of reanalyses and reforecasts
- Testing post-processing methods on weeks 3-4 forecasts from upgraded GEFS, when they are available
- Implementing these methods, and generating operational weeks 3-4 post-processed guidance
- Subsequent deliverables will result from the above activities:
 - A journal article on reanalysis/reforecast quality by one year after completion of reanalysis/reforecast data sets
 - Operational weeks 3-4 forecast products

5.12 Testbeds

The overall objective to engage the NOAA Testbeds and Proving Grounds (TBPG) is to tap into their capability and capacity to test and evaluate the developmental progress and the operational readiness of NGGPS. NOAA TBPG have consistent guidelines for governance, function and execution of testing activities, and have traditionally conducted independent testing. Many of the facilities have at least some base support and infrastructure (e.g. IT workstations) and some have programmatically sponsored testing and even supercomputing resources (e.g. DTC).

Leveraging coordinated and collaborative testing activities will be key to the success and smooth transition of the model and coupled components. Testing projects for components and coupled system prototypes of the NGGPS, and testing/evaluation of forecast service impacts will involve a diverse range of subject matter experts, forecasters and stakeholders.

Testbeds and proving grounds will focus on generalized phases of transition to operations as illustrated in the transition Table 5 below. Developmental testing will be followed by experimental testing to demonstrate the project components' readiness to progress to the operations phase, and ultimately deployment into NWS operations.

Table 5. Phased Implementation into NWS Operations

Phase	Key Q	Key Metric	Facility
R & D	Does it work?	Peer-reviewed publication	Universities, government labs, private industry
Developmental Testing	Does it work with operational systems?	Feasibility/ Engineering analysis successful	Testbed with operations-like environment
Experimental Testing	Does it meet operational performance criteria?	Go/No Go based on: <ul style="list-style-type: none"> Objective performance (e.g. accuracy) Subjective feedback Production readiness 	Operational proving ground for clinical tests and full "dress rehearsal"
Operational	Does it maintain required performance?	Objective criteria: <ul style="list-style-type: none"> Accuracy Reliability 	Operations

Working with the NGGPS team, test criteria will be established in three general categories, for both developmental and experimental testing:

1. Objective performance (e.g. specific NWP skill metrics), reliability, run-time, latency, etc.
2. Subjective performance (e.g. utility to forecasters, workforce/workflow impacts, user feedback (forecasters, external partners including decision-makers))

3. Production readiness (e.g. engineering criteria including H/W S/W protocols, back-up and data retention capabilities, ongoing near-real time verification)

5.12.1 Short Term Goals

The short term objective is to establish performance targets, refine testing infrastructure and testing approach. Performance criteria and targets will be used to solicit and competitively review proposed test plans for conducting developmental testing and evaluation, and experimental testing and evaluation at NOAA TBPG. Prospective investigators will include additional specific test metrics in proposed test plans, which if accepted would be finalized in consultation with the appropriate TBPG and NGGPS managers. Once approved, phased testing for individual components and couples system prototypes will occur. The longer-term objective is to refine and test overarching performance targets for NGGPS as well as phased testing of advanced system prototypes.

During the first 18 months of the project, the following activities will occur:

- Presenting high-level testing criteria and performance targets for testing, identifying any critical gaps in metrics, and documenting metrics targets and gaps to be submitted to the R2O Initiative lead. Generalized criteria and performance targets for which to base the high-level performance criteria are shown in Table 6.
- Refining the testing infrastructure and testing approach by adjusting the basic structure shown in Table 7 and delivering the procedural guidelines for testing to the R2O Initiative lead.
- Preparing an announcement of opportunity, reviewing proposed test plans, and tracking and monitoring competitively selected tests.
- Launching testing projects, conducting, analyzing, and reporting on projects.
- Completing initial testing conducted on components, and compiling results in a report.
- Completing annual announcement of opportunity for 2nd cycle of test projects, launch 2nd-cycle test projects.

5.12.2 Long Term Goals

The long term goals for Years 3-5 include refining and testing overarching performance targets as well as conducting phased testing for advanced system prototypes for NGGPS. The work will continue supporting collaborative phased transition testing for both internal and external investigators, covering progression of component, system, and forecast service testing progressing toward operational readiness testing with increasing emphasis on forecast service impacts testing.

Table 6. Generalized Test Criteria and Performance Targets for NGGPS Testing

Generalized Test Criteria and Performance Targets
<p>Based on following upgrade schedule for GFS, GEFS: FY14Q4: GFS goes to ~13 km resolution with numerous physics and data assimilation changes FY15Q2: GEFS upgrades resolution and configuration FY15Q4: GFS data assimilation goes to 4Dvar-like FY16Q2: Another GFS upgrade.</p> <p>Objective Targets QPF Objective Skill Goal: Current Day 2 threat score for 1" threshold is attained at Day 3 by 2018</p> <p>Aviation weather skill goal: Improve the numerical prediction of instrument meteorological conditions (IMC) for the NGGPS by 25% over the baseline skill (to be determined) of GFS upgrade targeted for Q4FY14: T1534L4</p> <p>Severe Convection: Extend current severe weather forecast service skill by 24 hours (Goal FY18; e.g. current Day 1 skill at Day 2; Day 3 skill at Day 4)</p> <p>Fire Weather: Extend current fire weather forecast service skill by 24 hours (Goal FY18; e.g. current Day 1 skill at Day 2; Day 3 skill at Day 4)</p> <p>Service Targets and Subjective Targets</p> <p>QPF Service Goal: Improving extreme event prediction from Day 0 to Day 10. For inclusion in AO: This entails improvements in warm season mesoscale prediction in the short range, as well as extending skill out in time (day 6, 7, ...10)</p> <p>QPF Effective, novel ways to synthesize information for the forecaster to communicate forecast impacts.</p> <p>Sample Performance Measure: Decision managers using week 2 QPF information for planning.</p> <p>Winter weather Objective Skill: For inclusion in AO:</p> <p>Examine alternative objective skill goals, based on analysis of reforecast and soon-to-be available gridded snowfall analysis, and develop recommended forecast skill target, Q4 FY15</p> <p>Winter weather: Achieve Winter Storm Warning lead time of 24 hours while maintaining POD of 0.90 by 2018. This lead time is 4 hours longer than the current GPRA goal. For inclusion in AO: This entails improved prediction of explosive cyclogenesis, improved snowfall algorithms, extending skill out in time (day 6-10), and finally novel ways to synthesize information for the forecaster.</p> <p>Aviation weather: Advance the spatial and temporal consistency of NWS products and decision support services provided to the aviation community based on increasing global model resolution (e.g. 13km, T1534L64 projected in Q4FY14) and future higher-resolution windows. A mesoscale global model with higher-resolution windows is a major step toward meeting NTSB Safety Recommendation A-14-17 on achieving consistency across NWS aviation and non-aviation specific statements, forecasts, advisories, and warnings that provide information on hazards important to aviation safety such as low clouds, ceilings, visibility, wind, convection, and precipitation.</p>

Generalized Test Criteria and Performance Targets

Aviation weather: Improve the basis for decision support services re instrument meteorological conditions, with numerical prediction guidance of clouds and visibility, and particularly hydrometeors

Severe Convection: Develop effective objective measures of severe weather forecast skill appropriate for both initial NGGPS (evolved GFS) and future convection-allowing nests through work with forecast specialists and numerical modelers. Baseline current global forecast system and Storm Prediction Center objective severe weather forecast skill, and refine objective goals for NGGPS project and associated Hazardous Weather Testbed testing (Goal: 4QFY15).

Severe Convection: Improve Day 2-10 national severe weather and convection sensitive services exploiting service-oriented objective and subjective metrics and iterative testbed experiments, through a focus on NGGPS forecasts of severe storm supporting mesoscale environments, boundary layer thermodynamic structures, and convective precipitation (object metrics established in FY15).

Severe Convection: Develop specialized NGGPS information extraction to support severe weather service improvement goals, and approaches for effective communication and use of improved NGGPS predictive skill by NWS forecasters and community decision makers

Fire Weather: Develop effective objective measures of fire weather forecast skill appropriate for both initial NGGPS (evolved GFS) and future convection-allowing nests through work with forecast specialists and numerical modelers. Baseline current global forecast system and Storm Prediction Center objective fire weather forecast skill, and refine objective goals for NGGPS project and associated Hazardous Weather Testbed testing (Goal: 4QFY15).

Fire Weather: Improve Day 2-10 national fire weather services exploiting service-oriented objective and subjective metrics and iterative testbed experiments with a focus on implied fuels, large-scale fire weather conditions, and implicit or explicit forecasts of convection and potential new fire starts by associated lightning (object metrics established in FY15).

Fire Weather: Develop specialized NGGPS information extraction to support fire weather service improvement goals, and approaches for effective communication and use of improved NGGPS predictive skill by NWS forecasters and fire weather decision makers

Table 7. Testing Infrastructure for NNGPS Testing

TBPG coordination structure	
<p>Potential contributions of NOAA TBPG in R2O coupled model initiative:</p> <p>CODE testing:</p> <ol style="list-style-type: none"> Global components COMT, JCSDA, SWPT, CTB, GRPG collaborative NWP testing approach³ Regional & Storm-scale components: 	
<p>Forecaster and service impacts (including Post-processing and forecaster apps):</p> <p>Service centers</p>	<p>JHT HMT/WPC HWT AWT</p>
<p>Local offices</p>	<p>OPG (for WFOs, RFCs)</p>
<p>Notes:</p> <ol style="list-style-type: none"> DTC in partnership with OAR & NCEP serves as/ becomes testing environment for NNGPS- generating tests output for model components, and (eventually) integrated system. Interface for external R&D partners to test selected potential component upgrades. NCEP is partner or lead for additional O2R functions, e.g. maintaining code repository for current operational codes, supporting user requests for downloads, helpdesk etc. COMT, JCSDA, SWPT, CTB, GRPG potential roles would grow in Yrs2-5, with additional resources for testing special model components: coastal/ocean components (COMT); week 2-4 testing in conjunction with IS/IA timeframes; and (CTB) high-altitude extension (SWPT). Additional work on testing expanded satellite data assimilation during years 2-5 would be expected, depending on whether analyses (of early developmental testing of the NNGPS) show critical observational gaps. Collaborative NWP testing could involve sharing (real-time) predictions generated in DTC for global coupled to additional regional or storm-scale components 	

5.13 Infrastructure

Development of documentation to provide user guidance for both NWS and the research community will cover the scientific and algorithmic aspects of the prediction system, documentation within the code, and an online science reference guide, to build on and complement existing GSM documentation. Training materials to be developed will also provide guidance on model strength, bias and weaknesses with respect to various skill metrics, and typical forecasting situations. This will provide the forecaster with assistance in the optimal use of the prediction guidance put forth by the new system.

5.13.1 Model Verification

The current model verification system already includes many skill metrics, however, as the development of the next generation model increases in resolution, the list of capabilities which are desirable to add, especially as the resolution of the global model increases. The R2O Initiative will accelerate the development of the global model verification package, as it is expected that new gaps will be identified as part of the initial 18 month effort and will be added to the list of desired capabilities for the 3 to 5 year plan. Further, it is recognized that the longer-term plan will look to find synergies with other verification software development efforts such as that being funded under HIWPP.

5.13.1.1 Short Term Goals

The new model capabilities will be added to the verification package for EMC global model over the next 18 months. The new capabilities will include the following:

- Using Real-Time Mesoscale Analysis (RTMA)/Un-Restricted Mesoscale Analysis (URMA) for verifying surface forecasts of T2m, RH2m and 10-m winds, etc. over the Continental United States. Both two-dimensional maps and scatter plots will be developed.
- Adding object-oriented/neighborhood methods for precipitation verification.
- Adding grid-to-grid precipitation verification against precipitation analyses including the Climatology-Calibrated Precipitation Analysis (CCPA), and Stage-V data sets.
 - Adding verification of cloud cover and cloud optical depth against satellite observations, including CloudSat, CLAVR-x, International Satellite Cloud Climatology Project (ISCCP), and GOES Surface and Insolation Product (GSIP).
- Using ARM Best Estimate Data Products for verifying cloud, radiation, and atmospheric quantities. This product is especially useful for developing and validating model physics processes.
- Adding significance test to the verifications of hurricane track error and intensity error.

These new capabilities will be added to the operational verification package as they are finished. Additional milestones include:

- Ramping up current verification package and developing a prioritized plan for adding new capabilities to the global model verification package.
- Adding verification capability of surface forecasts against RTMA/URMA.
- Adding object-oriented/neighborhood methods for precipitation verification and grid-to-grid precipitation verification against CCPA and Stage-V data sets.
- Adding cloud verification against satellite products and DOE/ARM cloud observations. Modifying the plan for highest priority capabilities to add as needed, and beginning the implementation of remaining features as outlined above.

- Producing a global model verification package supporting the new capabilities as outlined above. It should be noted that the list of new capabilities to add will likely evolve over the course of the project.

5.13.2 Model Documentation and Libraries

Maintenance and support of the libraries for the NCEP operational models is currently tasked to EMC staff members. Given the critical nature of library support for running and developing the NCEP production suite, and the continually evolving HPC environment, it is desirable to dedicate full-time support to the library maintenance and development tasks outlined below. This need will be further compounded by expansion of the number of external (university-based) researchers using and developing the operational models (potentially on non-NOAA HPC platforms) as planned for in the R2O Initiative. The tasks for improving the software library at NCEO include:

- Weekly synchronization of selected NCEP libraries on selected NOAA platforms
- Communicating with users and development of a uses wiki page.
- Developing unit tests and stress tests for the libraries.
- Performing minor upgrades such as adding parameters to the libraries.
- Porting libraries supported by NCEP NCO on the WCOSS to other platforms.
- Providing the first line of support for library users.
- Serving as the code manager for library repository releases.
- Leading the implementation of libraries onto WCOSS through NCO.
- Submitting EMC code fixes for NCO supported libraries.
- Participating in the general development of NCEP operational model libraries.
- Participating in NCEPLIBS group meetings and mailings.
- Establishing and providing similar support for NCEP utilities such as wgrib2 and copygb.

5.13.2.1 Short Term Goals

Milestones for the model software library task include developing a prioritized work plan for library maintenance and development, and annual review of continuing library maintenance and development, and refining priorities as warranted.

Acronym List

3-DVAR	3-D variational
ACNFS	Navy’s Arctic Cap Nowcast Forecast System
AA	Assistant Administrator
AVEC	Advanced Computing Evaluation Committee
AWIPS	Advanced Weather Interactive Processing System
CCPA	Climatology-Calibrated Precipitation Analysis
CFS	Climate Forecast System
CICE	Los Alamos sea ice model
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies
COMT	Coastal and Ocean Modeling Testbed
DA	Data Assimilation
DOC	Department of Congress
DTC	Development Testbed Center
ECMWF	European Center for Medium Range Weather Forecasting
EMC	NCEP’s Environmental Modeling Center
ENSO	El Niño – Southern Oscillation
EOB	Executive Oversight Board
ESMF	Earth System Modeling Framework
ESPC	Earth System Prediction Capability
ESRL	Earth System Research Laboratory
GEFS	Global Ensemble Forecast System
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast System
GFS-NH	EMC’s non-hydrostatic extension of Semi-Lagrangian Spectral model

GOCART	Goddard Chemistry Aerosol Radiation and Transport Model
GODAS	Global Ocean Data Assimilation System
GLERL	Great Lakes Environmental Research Laboratory
GPRA	Government Performance and Result Act
GPS-RO	Global Positioning System-Radio Occultation
GSD	Global Systems Division
GSI	Gridpoint Statistical Interpolation (system)
GSIP	GOES Surface and Insolation Product
GSM	Global Spectral Model
HPC	High Performance Computing
HFIP	hurricane forecast improvement project
HIRAM	GFDL's coupled general Circulation Model (CM3) – cubed sphere, finite volume
HIWPP	High Impact Weather Prediction Project
HWRF	Hurricane Weather Research and Forecast System
HWT	Hazardous Weather Testbed
HYCOM	Hybrid Coordinate Ocean Model
ISCCP	International Satellite Cloud Climatology Project
JMA	Japan Meteorological Agency
JCSDA	Joint Center for Satellite Data Assimilation
LSM	Land Surface Model
MOM	Modular Ocean Model
MOA	Memorandum of Understanding
MPAS	National Center for Atmospheric Research (NCAR)'s Model for Prediction Across Scales an unstructured grid with C-grid discretization
NCAR	National Center for Atmospheric Research

NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NCODA	Navy Coupled Ocean Data Assimilation
NEMS	Environmental Modeling System
NEPTUNE	Navy's Environmental Prediction System Using the NUMA corE
NESDIS	National Environmental Satellite, Data, and Information Service
NGAC	NEMS GFS Aerosol Component
NIM	ESRL's Non-hydrostatic Icosahedral Model
NGGPS	Next generation global prediction system
NMMB	Non-hydrostatic Multi-scale Model on B-grid
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Oceanographic Partnership Program
NRL	Naval Research Laboratory
NUMA	Non-hydrostatic Unified Model
NUOPC	National Unified Operational Prediction Capability
NWP	Numerical Weather Prediction
NWPS	Nearshore Wave Prediction System
NWS	NOAA's National Weather Service
O & M	Operations and Management
OAR	Office of Oceanic & Atmospheric Research
OMB	Office of Management and Budget
OST	Office of Science and Technology
QC	quality control
R2O	Research to Operations
RTMA	Real-Time Mesoscale Analysis

RTOFS	Real-Time Ocean Forecast System
SAR	Synthetic Aperture Radar
SSH	Sea Surface Height
SST	Sea Surface Temperature
SWAN	Simulating WAVes Nearshore
TBPG	NOAA testbeds and proving grounds
TSC	Technical Steering Committee
URMA	Un-Restricted Mesoscale Analysis
USWRP	United States Weather Research Program
WCOSS	Weather and Climate Operational Supercomputing system
WFO	Weather Forecast Offices
WW3	WAVEWATCHIII